POLITECNICO DI TORINO

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Urban noise: effects on human health and regulation framework; overview of rules for measuring the noise level on building façade and simulation about influence of receivers position.

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Acknowledgments

Thank you...

To mom, dad, grandma Piera and grandpa Teresio,
grandma Lucia and grandpa Geppe,
the “good old beast” Max and the newcomers,
the wild Loki and my little sparrow Cippì.

To my girlfriend Paola and her family with my newly sister Roberta,
mom Franca and dad Beppe and uncles,
my cousin Lucia,
cousins and grandparents all.

To Anna and to her mother and sister.

To Marina.

To all those, friends or simple acquaintances,
with whom I shared dark and happy days
in simple and sincere cooperation.

Abstract

Noise pollution in urban areas is today, an internationally recognized problem, while in the past this type of pollution has generally been underestimated, downgrading it to a disturbance phenomenon of public peace or work activity. This, because its acute manifestations remained limited to areas destined to manufacturing or industrial premises or were limited to portions of the urban fabric such as the market areas or zones near transport infrastructures.

Only in the last decades of the last century the collective and individual sensitivity to noise pollution increased considerably, following the spread of this phenomenon in many urban areas and the publication of medical researches which highlighted its link with serious phenomena of physical and psychological diseases.

In this general framework, the present thesis project intends to analyse the legislation on noise pollution in the urban contexts, to verify the applicability of relevant regulations and the contribution provided by the building façades design in improving the acoustic quality of urban environments.

As case-study, an existing building in the city of Turin (Italy) has been chosen which was already used to investigate the acoustic effects due to the variation of a series of façade geometric features and the properties of its materials, with the purpose to reduce the noise reflection towards the facing street.

The different façade shape are the current existing façade of the building, a completely flat façade, a façade with balconies, a façade with loggias and a façade with balconies and loggias, all that positioned in the 3D model where the real case-study building is located, including the street and the façade of the opposite facing building.

In each of these models, four lines of receivers were positioned on the façade at different height and the reference microphone was moved perpendicularly varying its distances from the façade itself.

The purpose of the simulation is to evaluate the behaviour of the Sound pressure Level (SPL) varying the refence microphone position, the “correction factor“ (c.f.) mentioned by the ISO 1996-2, the ΔL_{fs} according to ISO 12354-3, the SPL (A)

verification according to Regulation 318 of Turin. Al linear sound source and a punctual sound source were used the simulation done with the Odeon 13 acoustic software.

On the basis of the results obtained, a series of considerations were elaborated concerning the application and the compliance with current norms and regulations, to support designers in the design of new buildings facades or in the renovation of existing ones, in particular if located in critical zones such as a street canyons.

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1 NOISE, HEALTH AND COSTS

1.1 Introduction

The aim of this chapter is to give an overview of the impact of noise on human health, starting from the considerations of international organizations and agencies, such as the World Health Organization (WHO) and the European Environment Agency (EEA) which have analyzed this issue.

In the chapter, the effect of noise on human health are briefly described, not only taking into account the direct effect on the auditory system, but also considering the non-auditory effects such as sleep disturbance, cardiovascular and physiological effects, mental health effects, annoyance and cognitive impairment. The economic impact and the effects on wild life are also taken into account.

1.2 Health impacts from exposure to environmental noise

Environmental noise is an important public health issue, featuring among the top environmental risks to health. It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe as stated by the recent “WHO Environmental Guideline for the European Region 2018” (WHO 2018).

The WHO highlighted the importance of keeping up-to-date noise guidelines therefore, the WHO Regional Office for Europe has developed this new environmental noise guidelines, proposing an updated set of public health recommendations on exposure to environmental noise.

The effects of noise on human health have been previously assessed by the WHO with the publication of the “Guidelines for Community Noise” GCN, (WHO GCN, 1999) and successively the WHO has issued the “Night noise guidelines for Europe” NNG (WHO NNG, 2009) and the “Burden of disease from environmental noise” report (WHO Burden, 2011).

This last estimated that at least one million healthy life years are lost every year in western Europe due to health effects arising from noise exposure to road traffic alone, further, it categorizes noise as being the second-worst environmental cause of ill health, behind only ultra-fine particulate matter ($PM_{2.5}$) air pollution.

The environmental issue has been also assessed by the European Environment Agency (EEA), through the technical guideline "Good practice guide on noise exposure and potential health effects" (EEA, 2010) and through the "Noise in Europe 2014 - EEA Report No 10/2014" (EEA 2014) following the requirements of the European Union "Environmental Noise Directive" 2002/49/EC (END, 2002) related to the assessment and management of environmental noise.

The EEA Report is the first noise assessment report performed by the European Environment Agency (EEA, 2014). Its purpose was to present an overview and analysis of environmental noise based upon information reported to EEA by its member countries.

The report affirms that noise pollution has long been recognized as affecting quality of life and well-being and over past decades it has, in addition, increasingly been acknowledged as an important public health issue.

The key messages from EEA Report are summarized here following:

a) noise pollution is a major environmental health problem in Europe;
b) road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 decibels (dB) L_{den} (day-evening-night level);
c) environmental noise causes at least 10 000 cases of premature death in Europe each year;
d) almost 20 million adults are annoyed and a further 8 million suffer sleep disturbance due to environmental noise;
e) over 900 000 cases of hypertension are caused by environmental noise each year;
f) noise pollution causes 43 000 hospital admissions in Europe per year;
g) effects of noise upon the wider soundscape, including wildlife and quiet areas, need further assessment;
h) political ambitions are high with the European Union's (EU) Seventh Environment Action Programme (7th EAP) containing the objective that

noise pollution in the EU has significantly decreased by 2020, moving closer to World Health Organization (WHO) recommended levels;

i) a complete assessment and future outlook are hindered by the fact that exposure estimates reported by countries are not complete, with as little as 44 % of the expected amount of data, depending on source, being delivered in the latest reporting round;

j) lack of comparable and common assessment methods often causes significant inconsistencies in exposure estimates, between different countries and even within a single country.

According to Rylander (2004) conceptually sounds serve as a means for contact with the environment and a primary role of the hearing system is to serve as a warning system against dangers to ensure survival.

This task takes place in the Central Nervous System (CNS) by processing the intensities and the frequencies in the sound, comparing them to previous experience and initiating a number of reactions. The meaning and the predictability of the sounds and, to a lesser extent, the sound level, are important parameters that determine the ensuing reactions.

These characteristics determine if the sound will be experienced as a noise (a negative component of the environment) or a normal, acceptable component. There is a large variation between individuals in the induction of the above reactions by noise (EEA, 2014).

The reasons for these differences are largely unknown although it is clear that genetic factors, previous experience and the simultaneous presence of other environmental stimuli play a role for noise sensitivity.

A number of adverse health impacts, both direct and indirect, have been linked to exposure to persistent or high levels of noise.

Night-time effects can differ significantly from daytime impacts and the WHO recommends to reduce noise levels produced by road traffic below 53 decibels (dB) L_{den} because this type of noise above this level is associated with different adverse health effects, while for night-time exposure, it is recommended to reduce the level below 45 dB L_{night} do not cause disturbance on sleep (WHO 2018).

Equivalent recommendations are done for the railways noise to reduce the levels below 54 dB L_{den} and 44 dB L_{night} and for aircraft noise, below 45 dB L_{den} and 40 dB L_{night}.

Figure 1-1 shows qualitatively how exposure to noise affects health and wellbeing. Within a part of a population exposed to elevated levels of noise, stress reactions, sleep-stage changes, and other biological and biophysical effects may occur. These may in turn lead to a worsening of various health risk factors such as blood pressure. For a relatively small part of the population, the subsequent changes may then develop into clinical symptoms like insomnia and cardiovascular diseases that, as a consequence, can increase rates of premature mortality.

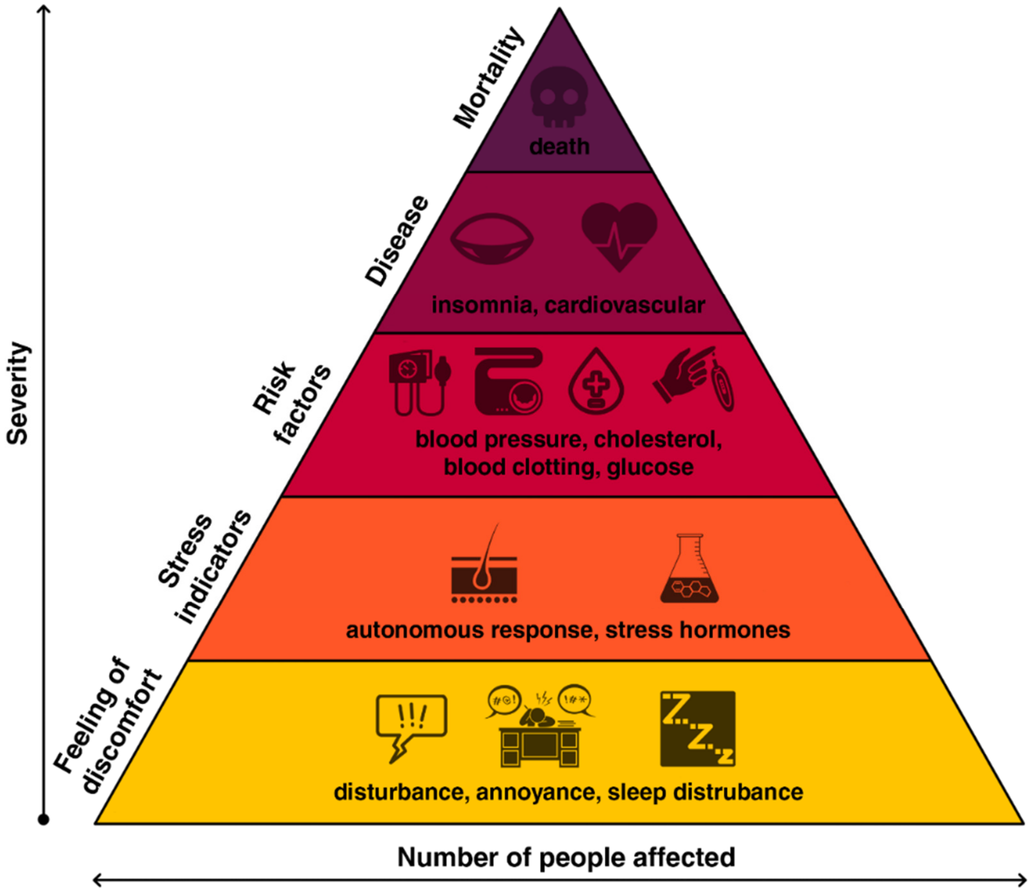

Figure 1-1– Pyramids of noise effect (reworked image)
(Babisch, 2002, based on WHO, 1972)

The effects of the noise depend on its intensity and duration of exposure, and it is usual to distinguish them in auditory and extra auditory effects (Basner et al. 2014).

The most significant auditory effect is the hearing loss which consists in a progressive decrease of the auditory capacity up to the loss of the almost total of it, due to a prolonged exposure to the noise.

Noise-induced hearing loss remains highly prevalent in occupational ambient and is increasingly caused by social noise exposure (e.g. through personal music players).

Evidence of the non-auditory effects of environmental noise exposure on public health is growing. Observational and experimental studies have shown that noise exposure leads to annoyance, disturbs sleep and causes daytime sleepiness, affects patient outcomes and staff performance in hospitals, increases the occurrence of hypertension and cardiovascular disease, and impairs cognitive performance in schoolchildren (Basner M. et al. 2014).

With reference to such guidelines, the major effects and disturbances on human health generated by the exposure to noise pollution can be summarized as follows:

- Noise effect on auditory system
- Sleep disturbance
- Cardiovascular and physiological effects
- Human fertility effects
- Mental health effects
- Annoyance
- Cognitive impairment

To such effects, the following issues, not related to human health, should be also added:

- Impacts on wildlife (Dutilleux, 2012)
- Economic impacts (EU Commission 1996, EEA 2014)

1.2.1 Effect of noise on auditory system

Every day, people experience sound in the environment, such as the sounds from television and radio, household appliances, and traffic. Normally, these sounds are at safe levels that don't damage hearing.

But sounds can be harmful when they are too loud even for a brief time, or long lasting even not so loud, or when they are both loud and long-lasting. These sounds can damage sensitive structures in the inner ear and cause the so-called Noise-Induced Hearing Loss (NIHL) leading to partial or complete deafness (https://www.nidcd.nih.gov/health)NIHL can be immediate or it can take a long time to be noticeable. It can be temporary or permanent, and it can affect one ear or both ears.

Noise exposures are a combination of the intensity and the duration of the noise exposure (https://www.tinnitus.org.uk).

The 'dosage' of noise exposure is dependent on two main factors:

- the 'volume' or intensity of the noise
- the time or duration of the exposure to that noise

Most international regulations for noise exposure at work state that the loudest noise someone should be exposed to for an 8-hour working day is 85dB - roughly equivalent to a blender, or a milling machine.

A 88dB sound is twice as intense as a 85 dB sound, so it follows that the maximum exposure duration should be half as much, so 4 hours. This rule of halving the maximum exposure duration for every 3dB increase (so doubling) in sound intensity is true for noises up to around 110 -120dB. Above this, even a very short exposure time can be damaging.

Hearing depends on a series of events that change sound waves in the air into electrical signals. The auditory nerve then carries these signals to the brain through a complex series of steps [https://www.nidcd.nih.gov/health].

- Sound waves enter the outer ear and travel through a narrow passageway called the ear canal, which leads to the eardrum.

- The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear. These bones are called the malleus, incus, and stapes.
- The bones in the middle ear couple the sound vibrations from the air to fluid vibrations in the cochlea of the inner ear, which is shaped like a snail and filled with fluid. An elastic partition runs from the beginning to the end of the cochlea, splitting it into an upper and lower part. This partition is called the basilar membrane because it serves as the base, or ground floor, on which key hearing structures sit.
- Once the vibrations cause the fluid inside the cochlea to ripple, a traveling wave forms along the basilar membrane. Hair cells (sensory cells sitting on top of the basilar membrane) ride the wave.
- As the hair cells move up and down, microscopic hair-like projections (known as stereocilia) that perch on top of the hair cells bump against an overlying structure and bend. Bending causes pore-like channels, which are at the tips of the stereocilia, to open up. When that happens, chemicals rush into the cell, creating an electrical signal.
- The auditory nerve carries this electrical signal to the brain, which translates it into a sound that we recognize and understand.

Exposure to intense sound or noise can result in purely temporary threshold shift (TTS) or leave a residual permanent threshold shift (PTS) along with alterations in growth functions of auditory nerve output (Kurabi A. et al. 2017).

Recent research has revealed several mechanisms that contribute to noise-induced hearing loss (NIHL). The principle cause is damage to cochlear hair cells and associated synaptopathy.

Contributions to TTS include reversible damage to hair cell (HC) stereocilia or synapses, while moderate TTS reflects protective purinergic hearing adaptation. PTS represents permanent damage to or loss of HCs and synapses. While the substrates of HC damage are complex, they include the accumulation of reactive oxygen species and the active stimulation of intracellular stress pathways,

leading to programmed and/or necrotic cell death. Permanent damage to cochlear neurons can also contribute to the effects of NIHL, in
addition to HC damage. These mechanisms have translational potential for pharmacological intervention and provide multiple opportunities to prevent HC damage or to rescue HCs and spiral ganglion neurons that have suffered injury.
“Unlike bird and amphibian hair cells, human hair cells don’t grow back” [https://www.nidcd.nih.gov/health]

1.2.2 Sleep disturbance

Sleep disturbance is thought to be the most deleterious non-auditory effect of environmental noise exposure, because undisturbed sleep of a sufficient length is needed for daytime alertness and performance, quality of life, and health. Human beings perceive, evaluate, and react to environmental sounds, even while asleep. Maximum sound pressure levels as low as L_{Amax} 33 dB can induce physiological reactions during sleep including autonomic, motor, and cortical arousals (eg, tachycardia, body movements, and awakenings) (Basner M. et al. 2014).

Uninterrupted sleep is known to be a prerequisite for good physiological and mental functioning of healthy persons (WHO, GCN 1999, quoted by EEA 2010); however, sleep disturbance is considered to be one of the effects arising from exposure to environmental noise.

Noise can cause difficulty in falling asleep, awakening and alterations to the depth of sleep, especially a reduction in the proportion of healthy rapid eye movement sleep. Other primary physiological effects induced by noise during sleep can include increased blood pressure, increased heart rate, vasoconstriction, changes in respiration and increased body movements (WHO, GCN 1999 quoted by EEA 2010).

Exposure to night-time noise also may induce secondary effects, or so-called after-effects. These are effects that can be measured the day following exposure, while the individual is awake, and include increased fatigue, depression and reduced performance (Pearsons, 1998 quoted by EEA 2010)

In 2009, as written before, WHO published the Night Noise Guidelines for Europe (WHO NNG 2009), an expert consensus mapping four noise exposure groups to negative health outcomes ranging from no substantial biological effects to increased risk of cardiovascular disease. WHO regards average nocturnal noise levels of less than $L_{Aeq,outside}$ 55 dB to be an interim goal and 40 dB a long-term goal for the prevention of noise-induced health effects (Basner M. et al. 2014).

1.2.3 Cardiovascular and physiological effects

As anticipated according to (WHO GCN, 1999) noise exposure can increase blood pressure and vasoconstriction. After prolonged exposure, susceptible individuals may develop more permanent effects such as hypertension and heart disease.

Ischaemic heart disease (including myocardial infarction) and hypertension (high blood pressure) have been much investigated with respect to noise.

The hypothesis that chronic noise affects cardiovascular health is due to the following facts (biological plausibility):

a. Laboratory studies in humans have shown that exposure to acute noise affects the sympathetic and endocrine system, resulting in nonspecific physiological responses (e.g. heart rate, blood pressure, vasoconstriction, stress hormones).
b. Noise-induced instantaneous autonomic responses do not only occur in waking hours but also in sleeping subjects. They do not fully adapt on a long-term basis although a clear subjective habituation occurs after a few nights.
c. Animal studies have shown that long-term exposure to high noise levels leads to manifest health disorders, including high blood pressure and 'ageing of the heart'.
d. Although effects tend to be diluted in occupational studies due to the 'healthy worker effect', epidemiological studies carried out in the occupational field have shown that employees working in high noise

> environments are at a higher risk of high blood pressure and myocardial infarction.

The objective noise exposure (sound level) and the subjective noise exposure (annoyance) may both be interacting predictors in the relationship between noise and health endpoints.

Short-term changes in circulation including blood pressure, heart rate, cardiac output and vasoconstriction as well as the release of stress hormones, including adrenaline and noradrenalin and cortisol have been studied in experimental settings. Classical biological risk factors have been shown to be elevated in subjects who were exposed to high levels of noise.

Acute noise effects do not only occur at high sound levels in occupational settings, but also at relatively low environmental sound levels when certain activities such as concentration, relaxation or sleep are disturbed (EEA, 2010).

Cardiocerebrovascular disease is significantly affected by genetic factors, as shown by its ties to family history, however, in terms of management and prevention measures, external environmental factors are important as the noise pollution; the traffic noise in certain conditions and decibel levels is correlated with increased myocardial infarction and hypertension incidence. (Lee et al., 2002, 2012 quoted by Myoungjin Oh et al. 2018)

The study of W. Babish et al. (2013) investigated 4861 subjects in the frame of the HYENA activity (Hypertension and exposure to noise near airports) analyzing the effect modifying impact of annoyance due to aircraft noise and road traffic noise on the relationships between the aircraft noise level and road traffic noise level on the prevalence of hypertension.

Different models were investigated either including the noise level and noise annoyance variables separately, or simultaneously, or together with an interaction term referring to the same noise source for the noise level and the noise annoyance.

The results obtained showed that significant effect modification was found with respect to the association between aircraft noise and hypertension. The association was stronger in more annoyed subjects. No clear interaction was found with respect to road traffic noise. The comparison of the magnitude of the main effects of noise level and noise annoyance variables revealed stronger associations with hypertension for the noise levels.

Main conclusion of this study shows that there is some indication that the noise level has a stronger predictive meaning for the relationship between noise exposure and hypertension than the reported noise annoyance (main effects). The results from the Hyena study support the hypothesis that noise annoyance acts as an effect modifier of the relationship between the noise level and hypertension.

In principal, the noise level (objective exposure) as well as the noise annoyance (subjective exposure) may serve as explanatory variables for the assessment of cardiovascular diseases due to chronic noise exposure.

There was some indication from the HYENA study that the noise level might have a stronger predictive meaning for the relationship between noise exposure and hypertension than the reported noise annoyance. However, no general conclusion can be drawn of whether 1 of the two exposures (noise level and noise annoyance) is a “better” predictor of cardiovascular risk than the other.

The recent paper of Myoungjin Oh et al. (2018) investigate health impact for noise exposure on a large scale in South Korea by combining health data from the National Health Insurance Service and noise data from the National Noise Information System. A dedicated additive model was utilized to reduce the sampling problem caused by the big amount of data.

The results obtained confirmed that a high noise level significantly affects cerebrovascular disease, hypertension, and heart disease. When the noise increases by 1 dB(A), the number of hospitalizations increases by 0.66% in cerebrovascular disease, 0.17% in hypertension, and 0.38% in heart disease.

Based on the estimation results, a scenario was investigated, assuming that the noise levels in 19 of the 37 regions examined would decrease to the regulated level. Under that scenario, in the 19 regions, local populations showed a diseases diminution, and the incidence declined by 2077 cases of cerebrovascular disease, 5705 cases of hypertension, and 1151 cases of heart disease per 1 million people

Results provide supporting evidence for why noise reduction policies need to be extended.

1.2.4 Mental health effects

According to EEA Report (EEA 2014) an exact causal relationship between noise and mental illness remains ill-defined, and it may well be that noise is just one of many factors affecting mental health. The WHO has suggested that environmental noise intensifies the development of latent mental disorder. Symptoms cited include anxiety, stress, nervousness, nausea, headaches, instability, argumentativeness, sexual impotency and mood changes. Studies on the use of drugs such as tranquillisers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates, however suggest links between environmental noise and adverse effects on mental health (WHO, CGN 1999, quoted by EAA 2010)

An investigation carried out in Plovdiv (Bulgaria) on a significant number of young people (399 students aged 15-25 years old) showed that higher noise exposure was associated with worse mental health only indirectly (Dzhambov A. et al. 2017). Noise annoyance, perceived restorative quality of the living environment, commuting and leisure time physical activity, and neighbourhood social cohesion were assessed using validated questionnaires. Analyses were based on linear regression mediation models and a structural equation modelling (SEM) to account for the hypothesized interdependencies between candidate mediators.

1.2.5 Human infertility

Some authors have investigated the effect of noise pollution on human infertility. In particular, the study of Min K. B. et al. 2017 examined an association between daytime and nocturnal noise exposures over four years

(2002 - 2005) and subsequent male infertility.

They used the Korean National Health Insurance Service-National Sample Cohort (2002 - 2013), a population-wide health insurance claim data-set. A total of 206.492 males of reproductive age (20 – 59 years) with no history of congenital malformations were followed up for an 8-year period (2006 - 2013).

Data on noise exposure was obtained from the National Noise Information System.

Exposure levels of daytime and night time noise were extrapolated using geographic information systems and collated with the subjects' administrative district code, and individual exposure levels assigned.

During the study period, the 1.6% of male sample had a diagnosis of infertility. Although there was no association of infertility with 1dB increments in noise exposure, a non-linear dose-response relationship was observed between infertility and quartiles of daytime and night time noise after adjustment for confounding variables (i.e., age, income, residential area, exercise, smoking, alcohol drinking, blood sugar, body mass index, medical histories, and particulate pollution). Based on WHO criteria, adjusted odds for infertility were significantly increased in males exposed to night time noise ≥ 55 dB.

Concerning the equivalent problem of female infertility the investigation done by Talamanca I. F. 2006 took into account the effect of noise in the frame of occupational risk factors reporting that although the evidence is not complete, and there are no recent well-designed studies on occupational noise and reproductive outcome in women, the possible negative effect on reproduction is biologically plausible, as well as amenable to prevention.

1.2.6 Annoyance

Annoyance has been defined as a feeling of displeasure associated with any agent or condition known or believed by an individual or group to adversely affect them (Koelega, 1987 quoted by EEA 2014).

Annoyance is the most prevalent community response in a population exposed to environmental noise. Noise annoyance can result from noise interfering with daily activities, feelings, thoughts, sleep, or rest, and might be accompanied by negative responses, such as anger, displeasure, exhaustion, and by stress-related symptoms (Basner M. et al. 2014).

In severe forms, it could be thought to affect wellbeing and health, and because of the high number of people affected, annoyance substantially contributes to the burden of disease from environmental noise.

1.2.7 Cognitive impairment

The detrimental effects of environmental noise on the learning abilities of children have also been demonstrated by various studies. In particular, it has been found that noise from airports in the vicinity of schools has adversely affected the reading ability of the pupils (Hygge et al., 2002 quoted by [1]). Similarly, the effect of road traffic and aircraft noise has exhibited a detrimental impact on both the health and cognitive abilities of children (Stansfeld et al., 2005 quoted by EEA 2014).

Postulated mechanisms for noise effects on children's cognition include communication difficulties, impaired attention, increased arousal, learned helplessness, frustration, noise annoyance, and consequences of sleep disturbance on performance. Investigators have also suggested psychological stress responses as a mechanism because children are poor at appraising threats from stressors and have less well-developed coping strategies than do adults (Basner M. et al. 2014).

More than 20 studies have shown environmental noise exposure has a negative effect on children's learning outcomes and cognitive performance,57 and that children with chronic aircraft, road traffic, or rail noise exposure at school have poorer reading ability, memory, and performance on national standardised tests than do children who are not exposed to noise at school.

The RANCH study of 2844 children aged 9–10 years attending 89 schools around Heathrow (London, UK), Schiphol (Amsterdam, the Netherlands), and Madrid-Barajas (Spain) airports showed a linear exposure–effect relation between aircraft noise exposure at school and a child's reading comprehension and recognition memory after adjusting for a range of socio-economic factors. A L_{Aeq} 5 dB increase in aircraft noise exposure was associated with a 2 months delay in reading age in children in the UK and a month delay in those in the Netherlands.

These linear associations suggest that there is no threshold for effects and any reduction in noise level at school should improve a child’s cognition (Basner M. et al. 2014).

1.3 Impacts on wildlife

There is increasing scientific evidence regarding the harmful effects of noise on wildlife (Dutilleux, 2012)

Whether in the terrestrial or marine environment, many species rely on acoustic communication for important aspects of life, such as finding food or locating a mate. Anthropogenic noise sources can potentially interfere with these functions and thus adversely affect species richness, reproductive success, population size and distribution. Noise pollution is also known to widely affect behaviour in some species. (EEA 2014).

1.4 Economic impact

When the European Commission presented its Green Paper on Future Noise Policy in 1996 (EC 1996) estimated the annual economic damage to the European Union due to environmental noise as potentially ranging from EUR 13 million to EUR 30 billion.

The Green Paper considered that the key elements contributing to these external costs were a reduction of house prices, reduced possibilities of land use, increased medical costs and the cost of lost productivity in the workplace due to illness caused by the effects of noise pollution.

Subsequently, in its 2011 report on the implementation of the END (European Noise Directive), the European Commission estimated the social cost of rail and road traffic noise in the EU as being 40 billion Euro per year, of which 90% was related to passenger cars and goods vehicles (EEA 2014).

A number of Member States have made their own analyses of the costs associated with exposure to noise.

There are presently two main methods employed to estimate the economic benefit associated with projects that reduce noise levels: contingent valuation and hedonic pricing.

Concerning the former approach, a European Commission working group earlier developed a position paper 'Valuation of noise' (EC, 2004) quoted by EEA 2014 based on the willingness-to-pay principle, drawing upon data from the work of Navrud S. (2002).

The paper recommends the use of a benefit of EUR 25 per household per decibel per year above noise levels of L_{den} = 50 ÷ 55 dB. Even though this figure has been criticized by some as being too low, it appears that most noise-abatement measures do deliver a positive cost/benefit ratio (EEA, 2010).

Hedonic pricing data come from studies of real estate markets, for which it is found that properties exposed to higher noise levels will typically have a lower value on the market than similar buildings exposed to lower noise levels.

This relationship is well documented for residential houses (for which there is extensive literature) and probably may be similar for commercial office buildings. A best estimate is that house prices lose 0.5 % of their value per decibel over 50–55 dB Lden. The range of research results is between 0.2 % and 1.5 %, with a tendency for higher values for aircraft noise (EEA, 2010).

1.4.1 Economical effect of “movida” noise pollution

In Italy some urban areas are plagued by a particular type of noise pollution defined as "recreational noise" usually generated by the phenomenon of "nightlife" or “movida”, as well as by the most known types of urban noise but this last is covered by law and regulations.

This aspect is not linked to the issue of sound insulation building in accordance with the D.P.C.M. 5/12/1997, whose non-compliance is considered a "serious defect" as is the art. 1669 "*Rovina e difetti di cose immobili* " from the Italian Civil Code.

Recreational noise refers to the disturbing noise coming from recreational activities such as bars, pubs, disco-pubs, bistros, restaurants, pizzerias, etc. and more generally from public and private venues for receptive or recreational purposes.

Concerning this recreational noise is possible to identify typical paths of transmission in a building: directly through the façade, the noise transmitted through the building structure due to bad sound insulation of entertainment venues, the poor sound system limitation and noise from the back of the building, where service equipment is often installed.

Many factors contribute to the phenomenon as the building geometry, local generated noise, type and age of the building. Low frequency diffusion through the building structure is particularly serious when discos or late-night pubs are located in the building itself.

The noise from “movida” has been also worsened by the ban on smoking inside the venues.

The "movida" is a very complex phenomenon that brings high potentials in terms of social and economic benefits, but also problems related to the impact of alcohol abuse, drugs consumption and other crime related disorders, in synergy with the public annoyance caused by noise pollution generated.

The urban areas affected by the phenomenon of the "movida" are the beating heart of the night economy not only for the urban area concerned, but also for the city in general and have very important positive economic effects on the territory. However, these areas suffer negative effects on the quality of life of the residents due to shouting, loud music and various disturbances with consequent and correlated negative economic effects, such as the depreciation of property values and the expenses that private individuals must support to mitigate the effects of noise generated by the presence of hundreds of rejoicing people (Ottoz e. at al, 2018).

Despite the disturbing effects, this type of noise pollution has so far been poorly studied; in fact the recreational noise has not been mentioned in the EEA Report, (EEA 2014) in which environmental noise is limited to "unwanted or harmful external sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic and industrial activity sites".

The study conducted by Ottoz E. et al. (2018) on the phenomenon of recreational noise conducted in the urban areas of Navigli, Città Studi and Brera in Milan and San Salvario, Piazza Vittorio and Vanchiglia in Turin, pointed out that 84% of respondents, through a suitable online questionnaire, are afflicted by the negative effects of this form of noise pollution.

The European Commission states that the effects of exposure to noise have an acoustic impact on the EU economies as they lead to a loss of productivity of workers whose health and well-being are affected by noise, constitute an increase in costs for the maintenance of care systems and cause a depreciation of the real estate value.

The adverse environment for an apartment located in a "movida" area causes, in fact, a decrease of market value compared to an apartment with similar characteristics, in a quieter area. This happens because the potential buyers reduce their demand, due to eventual nuisance, loss of tranquility and possible health effects.

An indicator of noise-induced damage is the difference between the values determined by the market of the two apartments (Ottoz E. et al. 2018).

Patrigest (www.patrigest.it) an Italian company specializing in real estate valuation and consultancy, conducted a search in 2011 in the cities of Rome and Milan, concluding that excessive noise, in particular due to the proximity of pubs and discos, it depreciates the value of the real estate assets by 10 and 20%.

On the contrary, some argue, instead, that the price of properties increases after the development of the "movida", at least in urban areas previously in decline.

The two statements are not necessarily contradictory, in fact, situations were encountered where people have a different feeling about the noise in general and in particular, when the position of the bed rooms is not exposed to the street noise; the ambient is reasonably quiet and the inhabitants enjoy the lively atmosphere without environmental costs.

In any case, 82% of respondents in Milan and 85% in Turin think that noise is responsible for a depreciation of their apartment.

To improve the soundproofing of the apartments the owners have carried out specific interventions where double glazing accounts for the highest percentage of the global cost (44.7% in Milan and 50.4% in Turin), followed by soundproofing (20, 3% and 19.8%, respectively)

A complete renovation is less common because rather expensive (5.7% and 8.3% respectively). Other costs are represented by sound level appraisal, legal expenses and weekend spent outside home to avoid noise (22.7% and 33.8%, respectively).

The 45.7% of respondents in Milan and the 56.2% in Turin incurred costs between €2100 and €15,000 while the 25.7% in Milan and 20.9% in Turin faced costs greater than 25,000 Euros.

The average cost to improve the soundproofing of the apartments is around 5000 Euros in Milan and 6400 in Turin.

[Table 1-1] – Reported households' expenditure (rework)

	Milan % of Reporting expenditure	Mean (Euro)	Median (Euro)	Turin % of reporting expenditure	Mean (Euro)	Median (Euro)
Sound proofing	20,3 %	6193,64	2500,00	19,8 %	3906,62	1750,00
Double glazing	44,7 %	6979,00	4000,00	50,4 %	5591,06	4000,00
House Renovation	5,7 %	6600,71	2000,00	8,3 %	8030,00	3400,00
Forced weekends	22,7 %	3335,96	2000,00	33,8 %	1797,93	800,00
Legal actions	11,3 %	3357,36	1000,00	14,4 %	2182,94	500,00
Sound level measures	9,3 %	945,13	945,00	6,6 %	1631,25	750,00

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2 NOISE REGULATIONS

2.1 Introduction

This chapter takes into consideration the rather complex panorama of regulations and laws on environmental noise and noise mitigation, starting from the European Environmental Noise Directive and continuing through the examination of national, regional and local regulations, with specific focus on the municipality of Turin.

Due to the aims of this work, the frameworks of the regulations is examined with specific focus on the aspects related to noise mitigation policies that can affect the development of built areas, without entering into the merits of the individual Laws and regulations dedicated to specific activities and means of transport.

Some information is provided also on the laws of the United Kingdom and Germany, because both these countries have a political and economic relevance in Europe and are traditionally attentive to environmental problems and to the well-being of their citizens.

2.2 Environmental Noise Directive (END)

The "Environmental Noise Directive" commonly referred to as the END, (Directive 2002/49/EC of 25 June 2002) relating to the assessment and management of environmental noise, is the main EU instrument to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level.

(http://ec.europa.eu/environment/noise/directive_en.htm) [x]

The END main tasks consist on the determination of exposure to environmental noise, on the diffusion of information about environmental noise and its effects, on prevention and reduction of the noise where necessary, on preservation of environmental noise quality where it is good.

The directive applies to the noise to which humans are exposed, in particular in inhabited areas, in public parks or in other quiet areas of urban agglomeration, near schools, hospitals and other sensitive to noise buildings and areas, even in quiet areas in open countryside

The directive does not apply to noise that is caused directly by the persons themselves, domestic activities, neighbours, noise at work places or inside transport means.

The Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for the agglomerations with more than 100,000 inhabitants, for the major roads, railway and airports.

Member States' authorities are required to consult the concerned public about the noise management action plans; both noise maps and plans can also be consulted in the European Environment Agency's Report-Net system.

It is important to note, that the Directive does not set limit or target values, nor does it prescribe the measures to be included in the action plans, leaving those issues at the discretion of the competent Member State authorities (http://ec.europa.eu/environment/noise/directive_en.htm)

2.2.1 Noise indicators in the END

The WHO describes the environmental noise generically as that emitted by all sources except for noise in the industrial workplace (WHO, 1999), while the “Environmental noise directive” defines more precisely the environmental noise as the unwanted or harmful outdoor sound created by human activities, as reported in the previous paragraph.

Some of the areas not covered by the END, such as those related to indoor noise, are covered by other policy instruments both at national and EU level, such as those related to health and occupational safety.

Harmful effects are further defined as meaning negative effects on human health.

The END defines the noise indicators to be applied in noise mapping and action planning. These indicators represent a physical scale for the description of environmental noise, which has a relationship with its harmful effects.

The two most important indicators are:

a) L_{den}: the day-evening-night–level indicator expressed in decibel (dB) is designed to assess annoyance;

where:

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods of a year,

- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a years,

- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night period of a years;

in which:

- the day is 12 hours, the evening four hours and the night eight hours.

The Member States may shorten the evening period by one or two hours and lengthen the day and/or the night period accordingly, provided that this choice is the same for all the sources and that they provide the Commission with information on any systematic difference from the default option,

- the start of the day (and consequently the start of the evening and the start of the might) shall be chosen by the Member State (that choice shall be the same for noise from all sources); the default values are 07.00 to 19.00, 19.00 to 23.00 and 23.00 to 07.00 local time,

- a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances.

b) L_{night}: the night-level indicator designed to assess sleep disturbance;

where:

- the night-time noise indicator Lnight is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year.

Annex I of the END gives technical definitions for Lden and Lnight, as well as supplementary noise indicators, which might be useful for monitoring special noise situations.

The END reports that until the use of common assessment methods for the determination of L_{den} and L_{night} is made obligatory, existing national noise indicators and related data may be used by Member States for this purpose and should be converted into the indicators mentioned above. These data must not be more than three years old.

2.3 Italian legislation on urban noise mitigation and building acoustics

The first references of Italian legislation dealing with issues related to acoustics and noise pollution are contained in the Codice Penale (Criminal Code) of 1930 and in the Codice Civile (Civil Code) of 1942 and are articles that punish the disturbance of public environment.

It is necessary to wait the 90s of the last century, to find a dedicated legislation at national level. In particular the Law 26 October No 447 dated 1995 “Legge quadro sull’inquinamento acustico” (Framework law on noise pollution) became the reference point for all subsequent laws and decree (Romano G. 2016).

2.3.1 L. 447/1995 “the framework law on noise pollution”

In 1995, the L. 447/1995 was promulgated, known as the “Legge quadro sull’inquinamento acustico” (Framework law on noise pollution) which establishes the fundamental principles regarding the protection of the external environment and the living environment from noise pollution, in accordance with the article 117 of the Italian Constitution

This law establishes a series of provisions that shall be implemented and that constitute the references for the various regional laws such as those adopted by the Piedmont Region.

This law defines the fundamental principles regarding the protection of the external environment and the living environment from noise pollution, but in substance, it does not indicate the limits to be respected only defining who is in charge of the actions and what are these actions." (Romano G. 2016).

The law analyses all the issues concerning noise, the subjects aimed at analysing them and the competences of the State, Regions, Provinces and Municipalities.
[https://www.anit.it/norma/l-447-1995-legge-quadro-sullinquinamento-acustico/]

The L. 447/1995 establishes the obligation to draw up the planimetry of the area subject of the acoustic analysis and the description of the methodology used for its identification.

In particular, as regards the planimetry, it must be oriented, updated and on an adequate scale and must indicate the location of the project, its perimeter, the receptors and the main pre-existing sound sources, with the indication of the elevation profile.

Furthermore for the investigated area shall be indicated the approved acoustic classification pursuant to art. 6 of the L.R. n.52 / 2000 “Disposizioni per la tutela dell’ambiente in materia di inquinamento acustico” (Provisions for the protection of the environment regarding noise pollution) as described further on.

If the classification has not yet been approved, the proposer (the subject interested in the classification), taking into account the current urban masterplan, the end use of the area and the regional guidelines (as for instance those contained in the Piedmont D.G.R. n.85 - 3802/2001), can hypothesize it, by assigning it to each receiver present in the study area, paying particular attention to those who fall into the classes I “particularly protected areas” and II “predominantly residential areas” as reported by another regulation i.e. the D.P.C.M. 14/11/1997, as described below. (Romano G. 2016).

For a better understanding of the problems related to sound pollution, the competences of the various subjects in charge (national, regional and local authorities) are summarized.

The article 3, L. 447/1995 establishes that the Italian State has the duty to:

- determine the noise emission limit values, the noise input limit values, attention values, quality values;
- coordinate the activity and the definition of the general technical legislation with the purpose of containment and noise abatement;
- determine the techniques of detection and measurement of noise pollution, taking into account the peculiar characteristics of the noise emitted by transport infrastructures;
- coordinate research, technical-scientific experimentation, data collection, processing and dissemination activities;
- determine the acoustic requirements of the sound sources and the passive acoustic requirements of the buildings and their components;

- indicate the criteria for the design, execution and renovation of building constructions and infrastructure of buildings and transport infrastructures;
- determine the acoustic requirements of alarm systems, sound sources in places for public entertainment;
- adopt long-term plans for the containment of noise emissions produced for the performance of essential public services such as railway lines, undergrounds, motorways and state roads within the limits established for each specific transport system, without prejudice to the jurisdiction of the regions, provinces and common;
- determine the criteria for measuring the noise emitted by boats and aircraft
- plan consumer information and school educational campaigns.

The article 4 of L. 447/1995 indicates the competences of the regions to issue the normative acts for defining criteria, methods and procedure as summarized below (Romano G. 2016):

- the criteria according to which the municipalities must classify their territory and the rules to apply in the event of municipalities inaction;
- the procedures for checking the compliance with the regulations for the protection of noise pollution when issuing building permits for new plants and infrastructures and manufacturing activites;
- the procedures and criteria for the identification, preparation, adoption by the municipalities of acoustic redevelopment plans including areas of significant landscape, environmental and tourism interest.
- the criteria and conditions for the identification, by the municipalities whose territory has a significant landscape-environmental and tourism interest of values lower than those referred to in article 3, paragraph 1, lett. a) of the L. 447/1995 (the framework law)
- the procedures for issuing municipal authorizations for performing potentially noisy public temporary activities
- the competences of the provinces with regard to noise pollution pursuant to Law 8 June 1990, no.142 "Set of rules of local autonomies;
- the criteria for scheduling of the acoustic interventions plans of the territory.

The provincial administration shall perform the functions assigned to them by the Regional Laws, i.e. to perform all those functions of control and supervision designed to guarantee their implementation in the territorial areas falling within the territory of several Municipalities included in the provincial district through the use of the structures by the Agencies Regional for the Protection of the Environment (Agenzie Regionali per la Protezione dell'Ambiente) (Romano G. 2016)

The municipalities shall classify their territory according to the criteria defined at regional level, coordinate their urban planning instruments and adopt acoustic recovery plans.

Under municipal responsibility there is the control of compliance with the regulations for the protection of noise pollution when issuing building permits for new plants and infrastructures for manufacturing, sport and leisure activities, provisions enabling use of the same buildings and infrastructures, as well as licensing or authorization to carry out productive activities.

The municipalities shall also adopt the rules for the implementation of state and regional regulations about the protection of noise pollution; carry out the measurement of the noise emissions produced by vehicles, and verify their compliance with the noise containment requirements.

The prerogative of the Municipality is also the granting or refusal of permits, even in derogation to limit values, for the performance of temporary activities in a public place for shows, building sites, roads and similar, in compliance with the provisions indicated by the municipality itself (Romano G. 2016).

Following the promulgation of the L. 447/1995 (Framework law) have been issued many legislative regulations, in particular have a great importance the following:

- D.P.C.M. 14/11/1997 - Determinazione dei valori limite delle sorgenti sonore (Determination of the sound sources limit values)

This decree, which entered into force on 1 January 1998, determines the limit values of the sound sources as explained more in detail in next paragraph 2.5

- D.M. 16/03/1998 - Tecniche di rilevamento e di misurazione dell'inquinamento acustico (Detection and measurement techniques of noise pollution)

This decree integrates the previous D.P.C.M. 14/11/97 and specifies the techniques for detecting and measuring the noise pollution, implementing the requirements the L. 447/1995. It describes the characteristics which the measuring instruments shall comply and the technical standards for the execution of general and specific measures both in external and internal environment. More details are reported in next paragraph Errore. L'origine riferimento non è stata trovata.

- D.P.R. March 30, 2004, no. 142 - Disposizioni per il contenimento e la prevenzione dell'inquinamento acustico derivante dal traffico veicolare, a norma dell'articolo 11 della L. 26 ottobre 1995, n. 447. (Provisions for the containment and prevention of noise pollution)

This D.P.R. establishes the rules for the prevention and containment of noise pollution originating from the operation of road infrastructure as defined by article 2 of legislative decree n. 285 of 1992, and subsequent amendments, as well as by attachment 1 of the same decree.

The aforementioned different law and decree are implemented by the "Regione Piemonte" through the L.R. 52/2000 "Disposizioni per la tutela dell'ambiente in materia di inquinamento acustico " (Provisions for environmental protection regarding noise pollution) and other minor regional resolutions.

The L.R. 52/2000 reorganizes the administrative competences regarding noise pollution pursuant to Law n. 142/1990 and subsequent amendments and the provisions given by the Legislative Decree 112/1998 which confers functions and administrative tasks of the State to the regions and local authorities.

This law gives dispositions finalized to the prevention, to the protection, to the planning and the redevelopment of the external and housing environment, as well as to the safeguard of the public health from alterations consequent to the acoustic pollution deriving from anthropic activities.

The City of Turin implements the laws and regulations in force (i.e. the L. 447/1995 and the L.R. 52/2000) expressing them in "Regolamento comunale per la tutela dall'inquinamento acustico N. 318" (Municipal regulation for the protection from noise pollution no. 318)

It is important to mention also the P.C.C.A. Piano Comunale di Classificazione Acustica (Municipal Acoustic Classification Plan) commonly called “zonizzazione acustica” (acoustic zoning) which is a technical-political act that plans the environmental objectives of an area in relation to the existing sound sources for which limits are set (Luvrano G. et al 2005)

The acoustic classification consists of the subdivision of the municipal territory into acoustically homogeneous areas following a careful urban planning analysis. The aim of the classification is to prevent the deterioration of acoustically unpolluted areas and to provide an indispensable planning tool for urban, commercial, handcraft and industrial development.

It is an act that the political body of the municipality, not only sets the limits for existing sound sources, but plans the environmental objectives of an area, so that the municipal planning instruments (general plan, urban traffic plan and structural plan) must comply with the acoustic classification plan of the municipal area.

The municipality of Turin has its own P.C.C.A. released in May 2010.

2.4 Italian and Piedmont Region legislation timeline

The following diagrams present in synthetic form the chronological evolution of the main Italian Laws and the Piedmont Regional Laws.

The purpose of the schemes is to show the global legislative framework for building acoustics by differentiating the type of legislative provision and the existing relationships with the previous ones and those following their enactment.

The diagrams do not present a complete and exhaustive picture, but are to be understood as a time map for orienting oneself in the legislation on building acoustics.

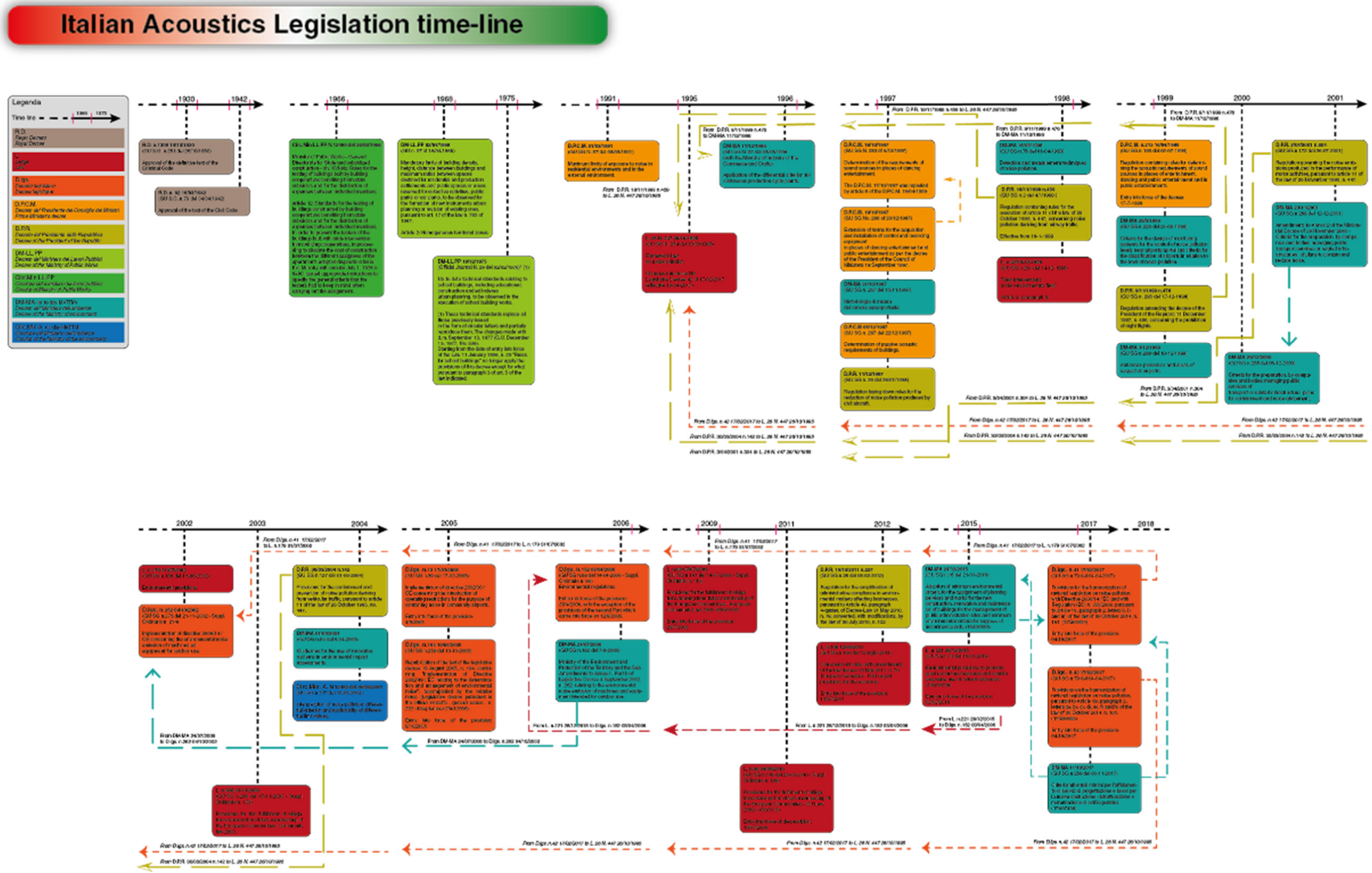
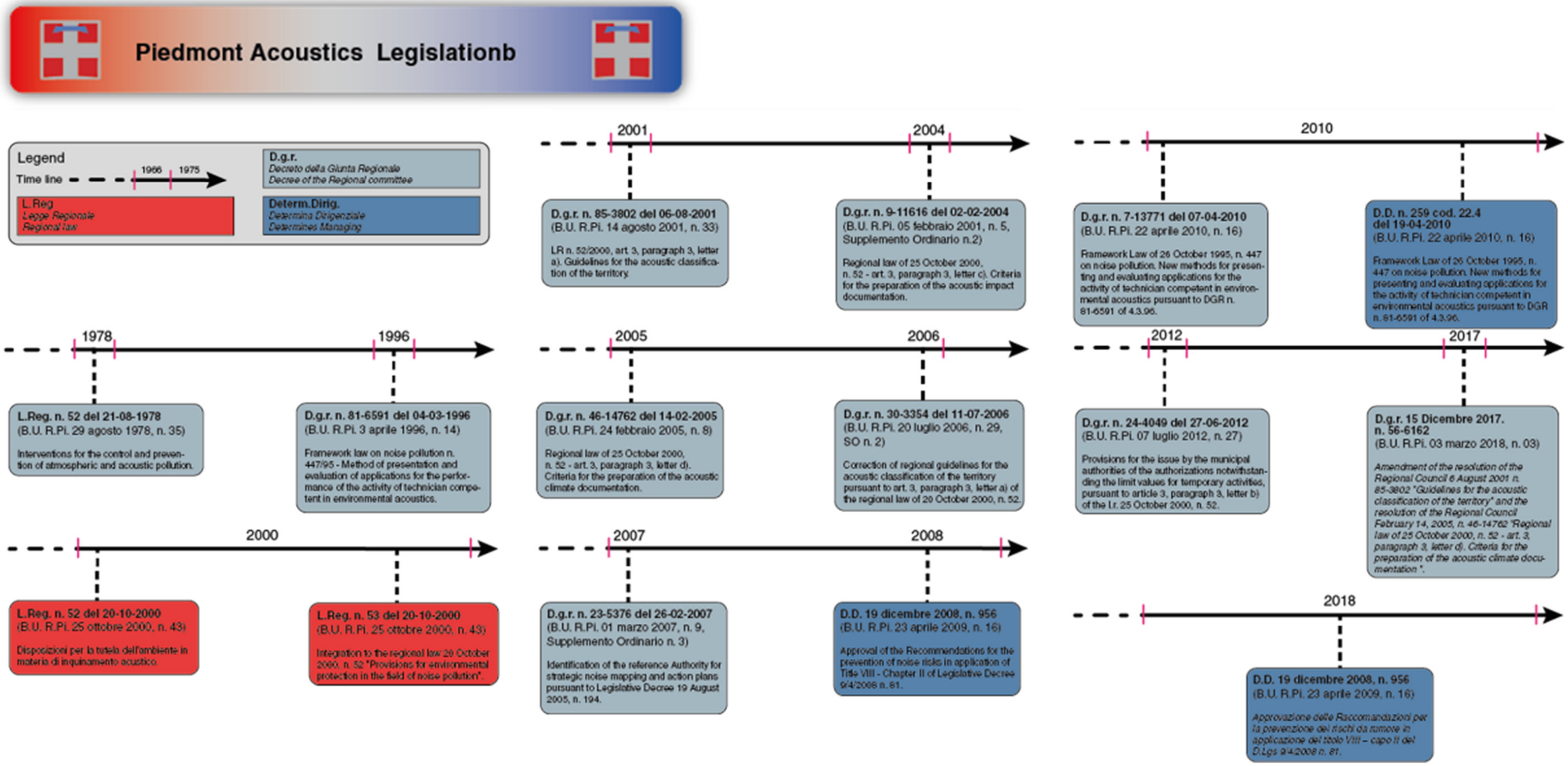


Figure 2-1- Italian Legislation 1930-2017



L.Reg. n. 52 del 21-08-1978
(B.U. R.Pi. 29 agosto 1978, n. 35)

Interventions for the control and prevention of atmospheric and acoustic pollution.

D.g.r. n. 81-6591 del 04-03-1996
(B.U. R.Pi. 3 aprile 1996, n. 14)

Framework law on noise pollution n. 447/95 - Method of presentation and evaluation of applications for the performance of the activity of technician competent in environmental acoustics.

L.Reg. n. 52 del 20-10-2000
(B.U. R.Pi. 25 ottobre 2000, n. 43)

Disposizioni per la tutela dell'ambiente in materia di inquinamento acustico.

L.Reg. n. 53 del 20-10-2000
(B.U. R.Pi. 25 ottobre 2000, n. 43)

Integration to the regional law 20 October 2000, n. 52 "Provisions for environmental protection in the field of noise pollution".

D.g.r. n. 85-3802 del 06-08-2001
(B.U. R.Pi. 14 agosto 2001, n. 33)

LR n. 52/2000, art. 3, paragraph 3, letter a). Guidelines for the acoustic classification of the territory.

D.g.r. n. 9-11616 del 02-02-2004
(B.U. R.Pi. 05 febbraio 2001, n. 5, Supplemento Ordinario n.2)

Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter c). Criteria for the preparation of the acoustic impact documentation.

D.g.r. n. 46-14762 del 14-02-2005
(B.U. R.Pi. 24 febbraio 2005, n. 8)

Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter d). Criteria for the preparation of the acoustic climate documentation.

D.g.r. n. 30-3354 del 11-07-2006
(B.U. R.Pi. 20 luglio 2006, n. 29, SO n. 2)

Correction of regional guidelines for the acoustic classification of the territory pursuant to art. 3, paragraph 3, letter a) of the regional law of 20 October 2000, n. 52.

D.g.r. n. 23-5376 del 26-02-2007
(B.U. R.Pi. 01 marzo 2007, n. 9, Supplemento Ordinario n. 3)

Identification of the reference Authority for strategic noise mapping and action plans pursuant to Legislative Decree 19 August 2005, n. 194.

D.D. 19 dicembre 2008, n. 956
(B.U. R.Pi. 23 aprile 2009, n. 16)

Approval of the Recommendations for the prevention of noise risks in application of Title VIII - Chapter II of Legislative Decree 9/4/2008 n. 81.

D.g.r. n. 7-13771 del 07-04-2010
(B.U. R.Pi. 22 aprile 2010, n. 16)

Framework Law of 26 October 1995, n. 447 on noise pollution. New methods for presenting and evaluating applications for the activity of technician competent in environmental acoustics pursuant to DGR n. 81-6591 of 4.3.96.

D.D. n. 259 cod. 22.4 del 19-04-2010
(B.U. R.Pi. 22 aprile 2010, n. 16)

Framework Law of 26 October 1995, n. 447 on noise pollution. New methods for presenting and evaluating applications for the activity of technician competent in environmental acoustics pursuant to DGR n. 81-6591 of 4.3.96.

D.g.r. n. 24-4049 del 27-06-2012
(B.U. R.Pi. 07 luglio 2012, n. 27)

Provisions for the issue by the municipal authorities of the authorizations notwithstanding the limit values for temporary activities, pursuant to article 3, paragraph 3, letter b) of the l.r. 25 October 2000, n. 52.

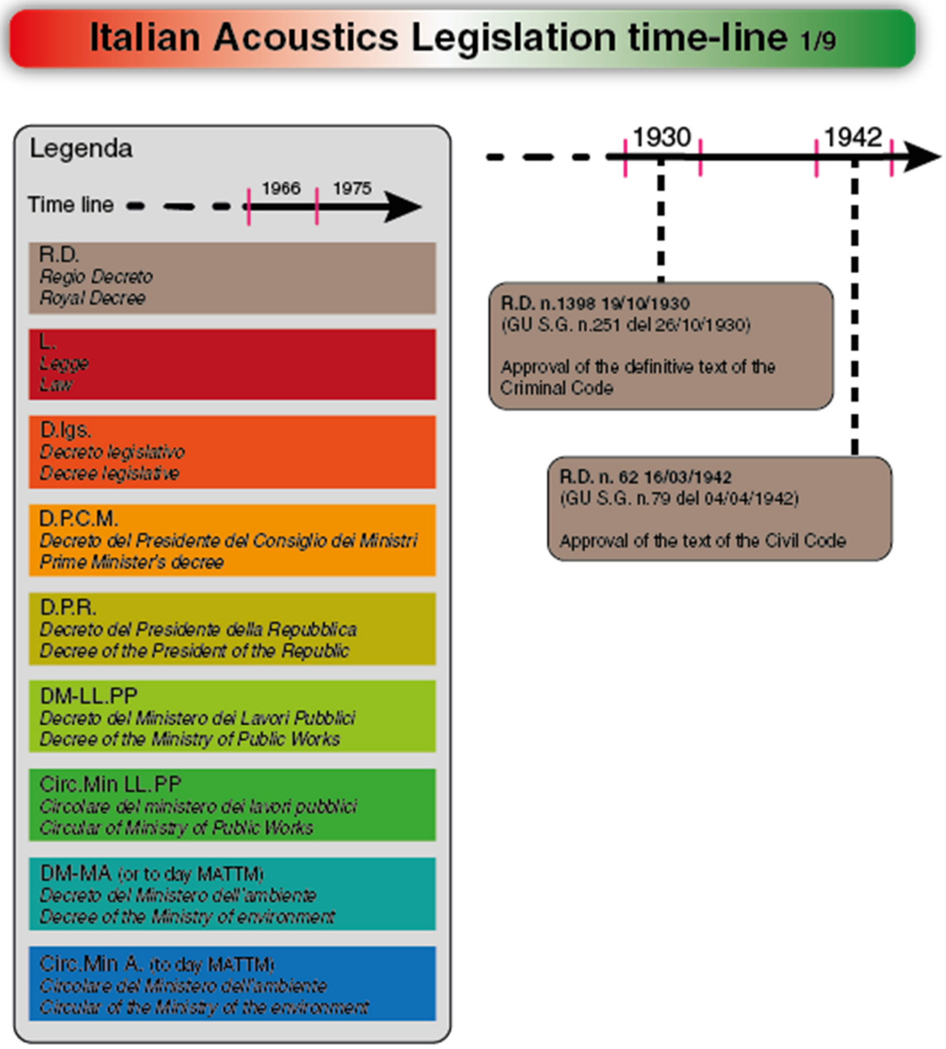
D.g.r. 15 Dicembre 2017. n. 56-6162
(B.U. R.Pi. 03 marzo 2018, n. 03)

Amendment of the resolution of the Regional Council 6 August 2001 n. 85-3802 "Guidelines for the acoustic classification of the territory" and the resolution of the Regional Council February 14, 2005, n. 46-14762 "Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter d). Criteria for the preparation of the acoustic climate documentation ".

D.D. 19 dicembre 2008, n. 956
(B.U. R.Pi. 23 aprile 2009, n. 16)

Approvazione delle Raccomandazioni per la prevenzione dei rischi da rumore in applicazione del titolo VIII – capo II del D.Lgs 9/4/2008 n. 81.

Figure 2-2- Regional Legislation 1978-2018 (Regione Piemonte)



Italian Acoustics Legislation time-line 1/9

Legenda

R.D.
Regio Decreto
Royal Decree

L.
Legge
Law

D.lgs.
Decreto legislativo
Decree legislative

D.P.C.M.
Decreto del Presidente del Consiglio dei Ministri
Prime Minister's decree

D.P.R.
Decreto del Presidente della Repubblica
Decree of the President of the Republic

DM-LL.PP
Decreto del Ministero dei Lavori Pubblici
Decree of the Ministry of Public Works

Circ.Min LL.PP
Circolare del ministero dei lavori pubblici
Circular of Ministry of Public Works

DM-MA (or to day MATTM)
Decreto del Ministero dell'ambiente
Decree of the Ministry of environment

Circ.Min A. (to day MATTM)
Circolare del Ministero dell'ambiente
Circular of the Ministry of the environment

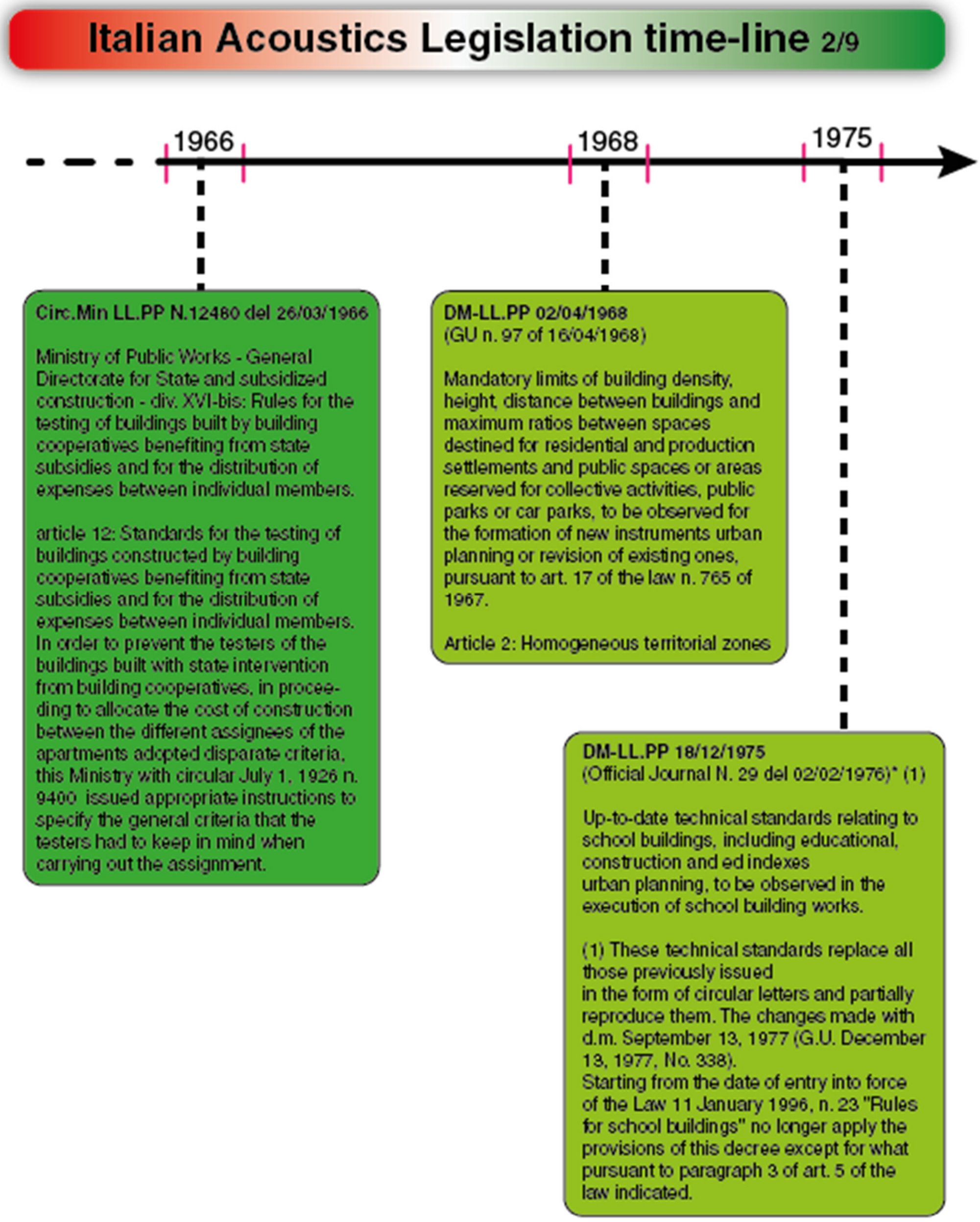
R.D. n.1398 19/10/1930
(GU S.G. n.251 del 26/10/1930)

Approval of the definitive text of the Criminal Code

R.D. n. 62 16/03/1942
(GU S.G. n.79 del 04/04/1942)

Approval of the text of the Civil Code

Figure 2-3- Italian Legislation 1930-1942



Circ.Min LL.PP N.12480 del 26/03/1966

Ministry of Public Works - General Directorate for State and subsidized construction - div. XVI-bis: Rules for the testing of buildings built by building cooperatives benefiting from state subsidies and for the distribution of expenses between individual members.

article 12: Standards for the testing of buildings constructed by building cooperatives benefiting from state subsidies and for the distribution of expenses between individual members. In order to prevent the testers of the buildings built with state intervention from building cooperatives, in proceeding to allocate the cost of construction between the different assignees of the apartments adopted disparate criteria, this Ministry with circular July 1, 1926 n. 9400 issued appropriate instructions to specify the general criteria that the testers had to keep in mind when carrying out the assignment.

DM-LL.PP 02/04/1968
(GU n. 97 of 16/04/1968)

Mandatory limits of building density, height, distance between buildings and maximum ratios between spaces destined for residential and production settlements and public spaces or areas reserved for collective activities, public parks or car parks, to be observed for the formation of new instruments urban planning or revision of existing ones, pursuant to art. 17 of the law n. 765 of 1967.

Article 2: Homogeneous territorial zones

DM-LL.PP 18/12/1975
(Official Journal N. 29 del 02/02/1976)* (1)

Up-to-date technical standards relating to school buildings, including educational, construction and ed indexes
urban planning, to be observed in the execution of school building works.

(1) These technical standards replace all those previously issued
in the form of circular letters and partially reproduce them. The changes made with d.m. September 13, 1977 (G.U. December 13, 1977, No. 338).
Starting from the date of entry into force of the Law 11 January 1996, n. 23 "Rules for school buildings" no longer apply the provisions of this decree except for what pursuant to paragraph 3 of art. 5 of the law indicated.

Figure 2-4- Italian Legislation 1966-1975

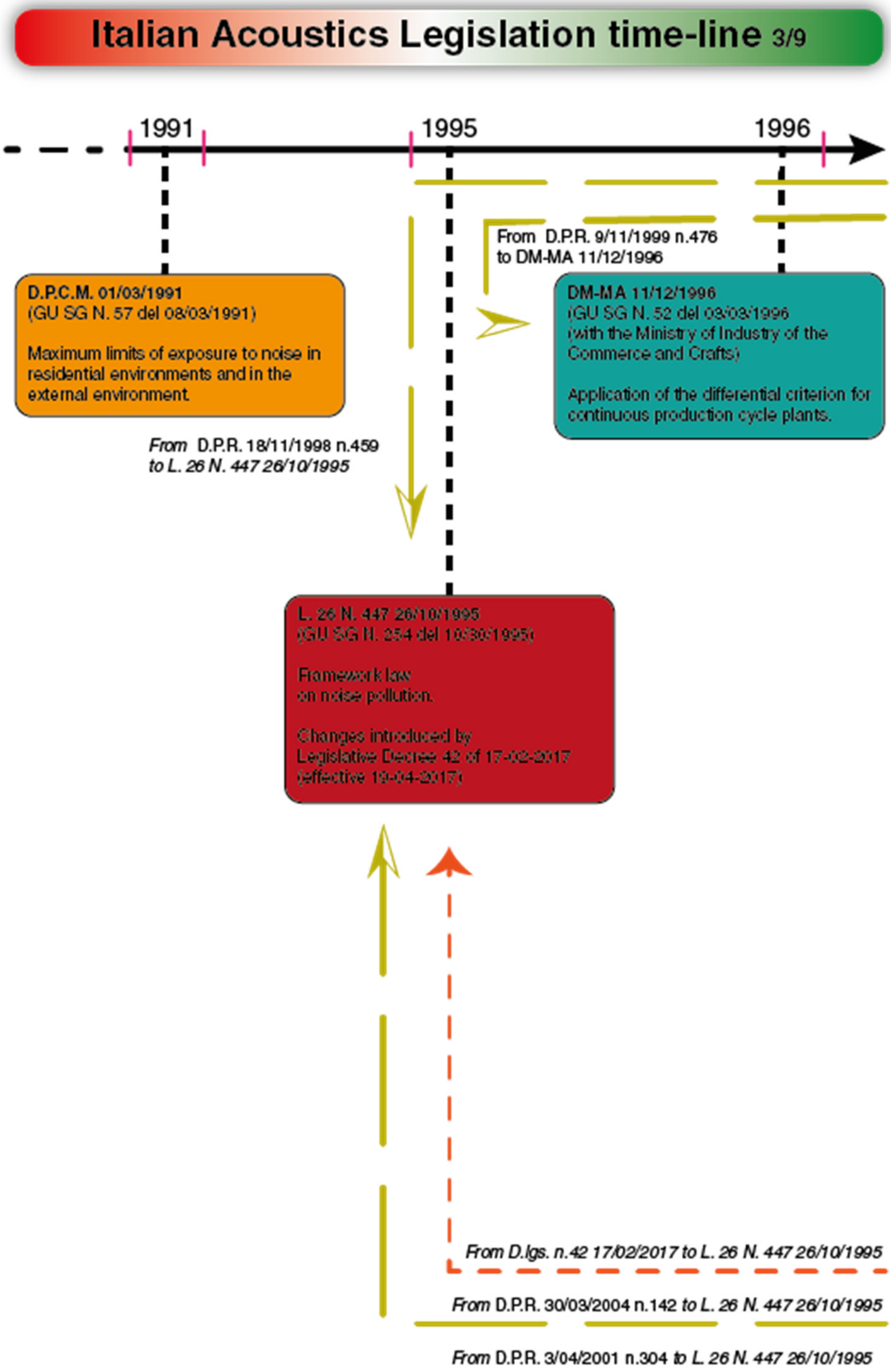


Figure 2-5- Italian Legislation 1991-1996

D.P.C.M. 18/10/1997
(GU SG N. 233 of 6/12/1997)

Determination of the requirements of sound sources in places of dancing entertainment.

The D.P.C.M. 17/10/1997 was repealed by article 8 of the D.P.C.M. 16/04/1999

D.P.C.M. 19/10/1997
(GU SG No. 296 of 20/12/1997)

Extension of terms for the acquisition and installation of control and recording equipment
in places of dancing entertainment and public entertainment as per the decree of the President of the Council of Ministers 18 September 1997.

DM-MA 31/10/1997
(GU SG n. 267 del 15/11/1997)

Metodologia di misura del rumore aereoportuale.

D.P.C.M 05/12/1997
(GU SG n. 297 del 22/12/1997)

Determination of passive acoustic requirements of buildings.

D.P.R. 11/12/1997
(GU SG n. 20 del 26/01/1998)

Regulation laying down rules for the reduction of noise pollution produced by civil aircraft.

DM-MA 16/03/1998
(GU SG n.76 del 01-04-1998)

Detection and measurement techniques of noise pollution.

D.P.R. 18/11/1998 n.459
(GU SG n.2 del 4/1/1999)

Regulation containing rules for the execution of article 11 of the law of 26 October 1995, n. 447, concerning noise pollution deriving from railway traffic.

Effective from 19-1-1999

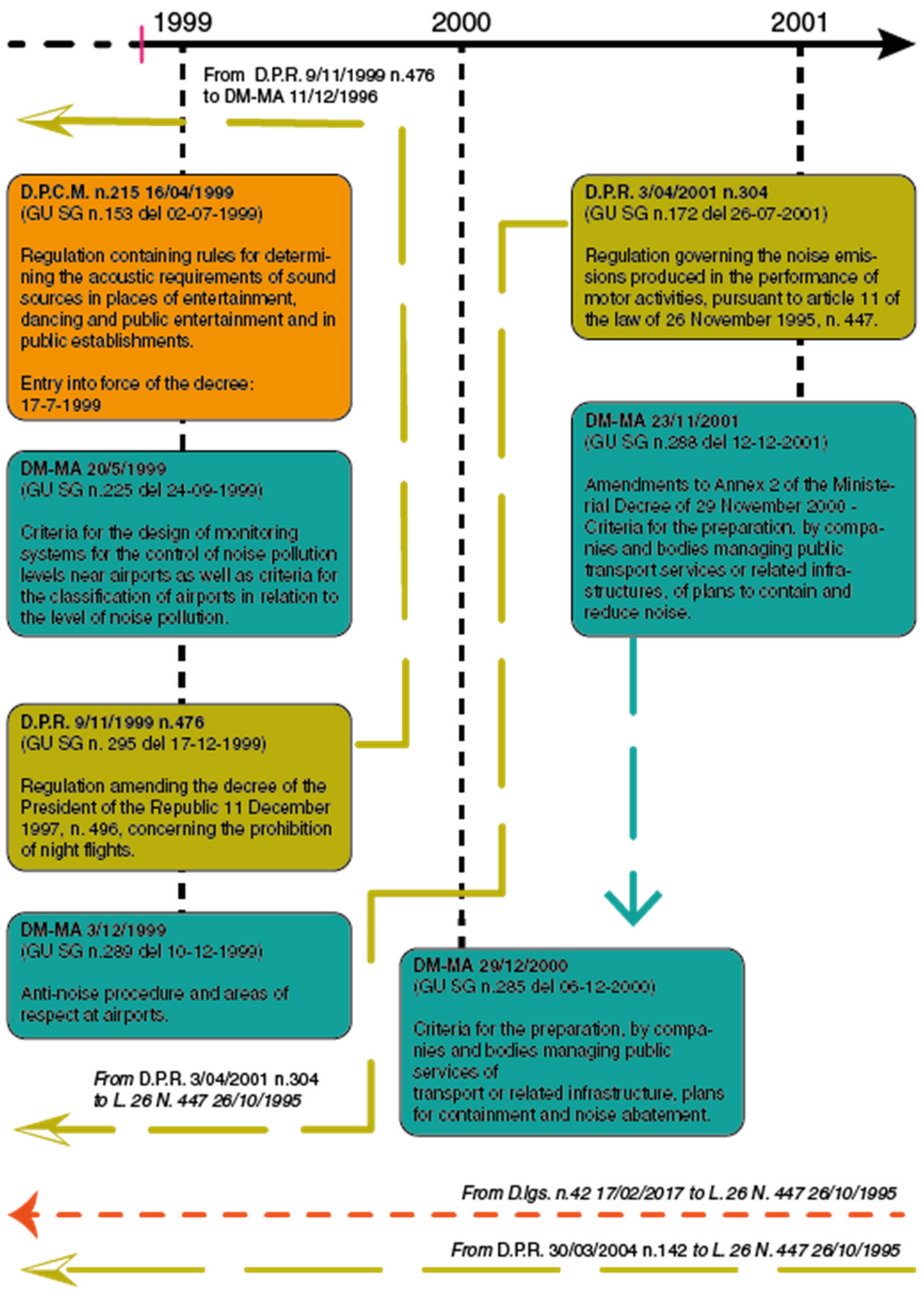
L. n.426 9/12/1998
(GU SG n.291 del 14-12-1998)

"New interventions in the environmental field"

Article 4, paragraph 3)

Figure 2-6 - Italian Legislation 1997-1998

Italian Acoustics Legislation time-line 5/9



From D.P.R. 9/11/1999 n.476 to DM-MA 11/12/1996

D.P.C.M. n.215 16/04/1999
(GU SG n.153 del 02-07-1999)

Regulation containing rules for determining the acoustic requirements of sound sources in places of entertainment, dancing and public entertainment and in public establishments.

Entry into force of the decree: 17-7-1999

DM-MA 20/5/1999
(GU SG n.225 del 24-09-1999)

Criteria for the design of monitoring systems for the control of noise pollution levels near airports as well as criteria for the classification of airports in relation to the level of noise pollution.

D.P.R. 9/11/1999 n.476
(GU SG n. 295 del 17-12-1999)

Regulation amending the decree of the President of the Republic 11 December 1997, n. 496, concerning the prohibition of night flights.

DM-MA 3/12/1999
(GU SG n.289 del 10-12-1999)

Anti-noise procedure and areas of respect at airports.

From D.P.R. 3/04/2001 n.304 to L 26 N. 447 26/10/1995

D.P.R. 3/04/2001 n.304
(GU SG n.172 del 26-07-2001)

Regulation governing the noise emissions produced in the performance of motor activities, pursuant to article 11 of the law of 26 November 1995, n. 447.

DM-MA 23/11/2001
(GU SG n.288 del 12-12-2001)

Amendments to Annex 2 of the Ministerial Decree of 29 November 2000 - Criteria for the preparation, by companies and bodies managing public transport services or related infrastructures, of plans to contain and reduce noise.

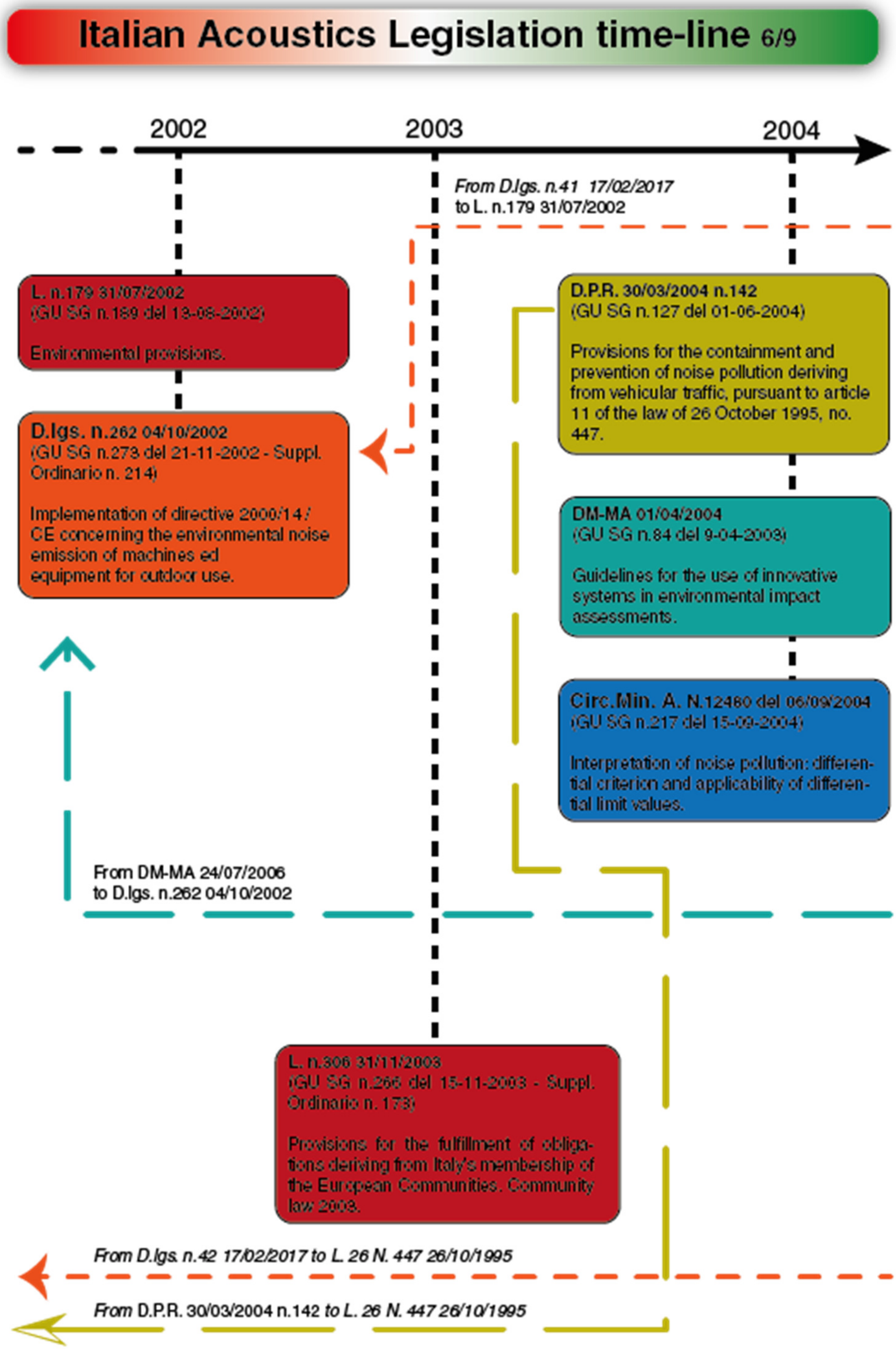
DM-MA 29/12/2000
(GU SG n.285 del 06-12-2000)

Criteria for the preparation, by companies and bodies managing public services of transport or related infrastructure, plans for containment and noise abatement.

From D.lgs. n.42 17/02/2017 to L 26 N. 447 26/10/1995

From D.P.R. 30/03/2004 n.142 to L 26 N. 447 26/10/1995

Figure 2-7 - Italian Legislation 1999-2001



L. n.179 31/07/2002
(GU SG n.189 del 13-08-2002)

Environmental provisions.

D.lgs. n.262 04/10/2002
(GU SG n.273 del 21-11-2002 - Suppl. Ordinario n. 214)

Implementation of directive 2000/14/CE concerning the environmental noise emission of machines ed equipment for outdoor use.

D.P.R. 30/03/2004 n.142
(GU SG n.127 del 01-06-2004)

Provisions for the containment and prevention of noise pollution deriving from vehicular traffic, pursuant to article 11 of the law of 26 October 1995, no. 447.

DM-MA 01/04/2004
(GU SG n.84 del 9-04-2003)

Guidelines for the use of innovative systems in environmental impact assessments.

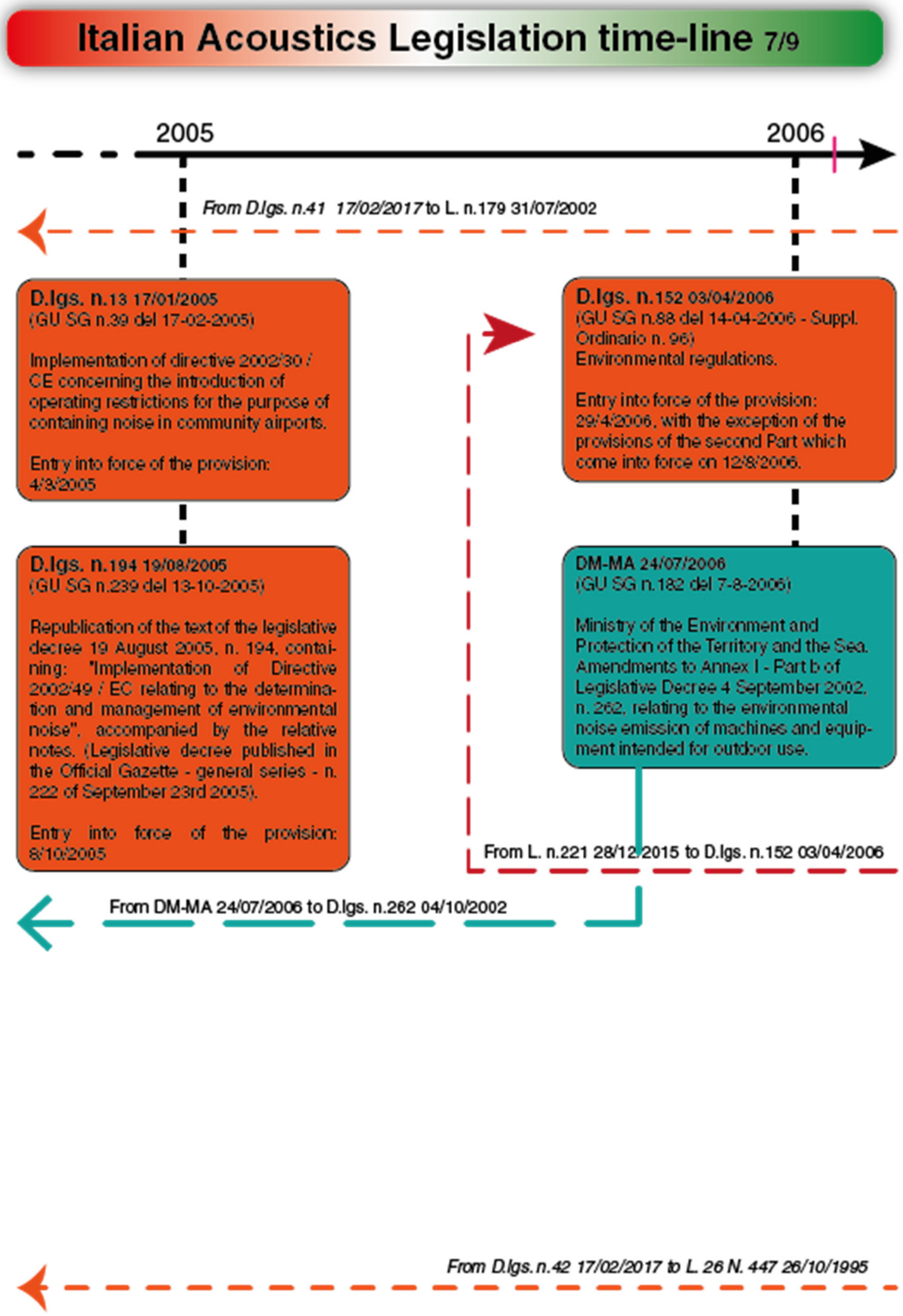
Circ.Min. A. N.12480 del 06/09/2004
(GU SG n.217 del 15-09-2004)

Interpretation of noise pollution: differential criterion and applicability of differential limit values.

L. n.306 31/11/2003
(GU SG n.266 del 15-11-2003 - Suppl. Ordinario n. 173)

Provisions for the fulfillment of obligations deriving from Italy's membership of the European Communities. Community law 2003.

Figure 2-8 - Italian Legislation 2002-2004



D.lgs. n.13 17/01/2005
(GU SG n.39 del 17-02-2005)

Implementation of directive 2002/30 / CE concerning the introduction of operating restrictions for the purpose of containing noise in community airports.

Entry into force of the provision: 4/3/2005

D.lgs. n.194 19/08/2005
(GU SG n.239 del 13-10-2005)

Republication of the text of the legislative decree 19 August 2005, n. 194, containing: "Implementation of Directive 2002/49 / EC relating to the determination and management of environmental noise", accompanied by the relative notes. (Legislative decree published in the Official Gazette - general series - n. 222 of September 23rd 2005).

Entry into force of the provision: 8/10/2005

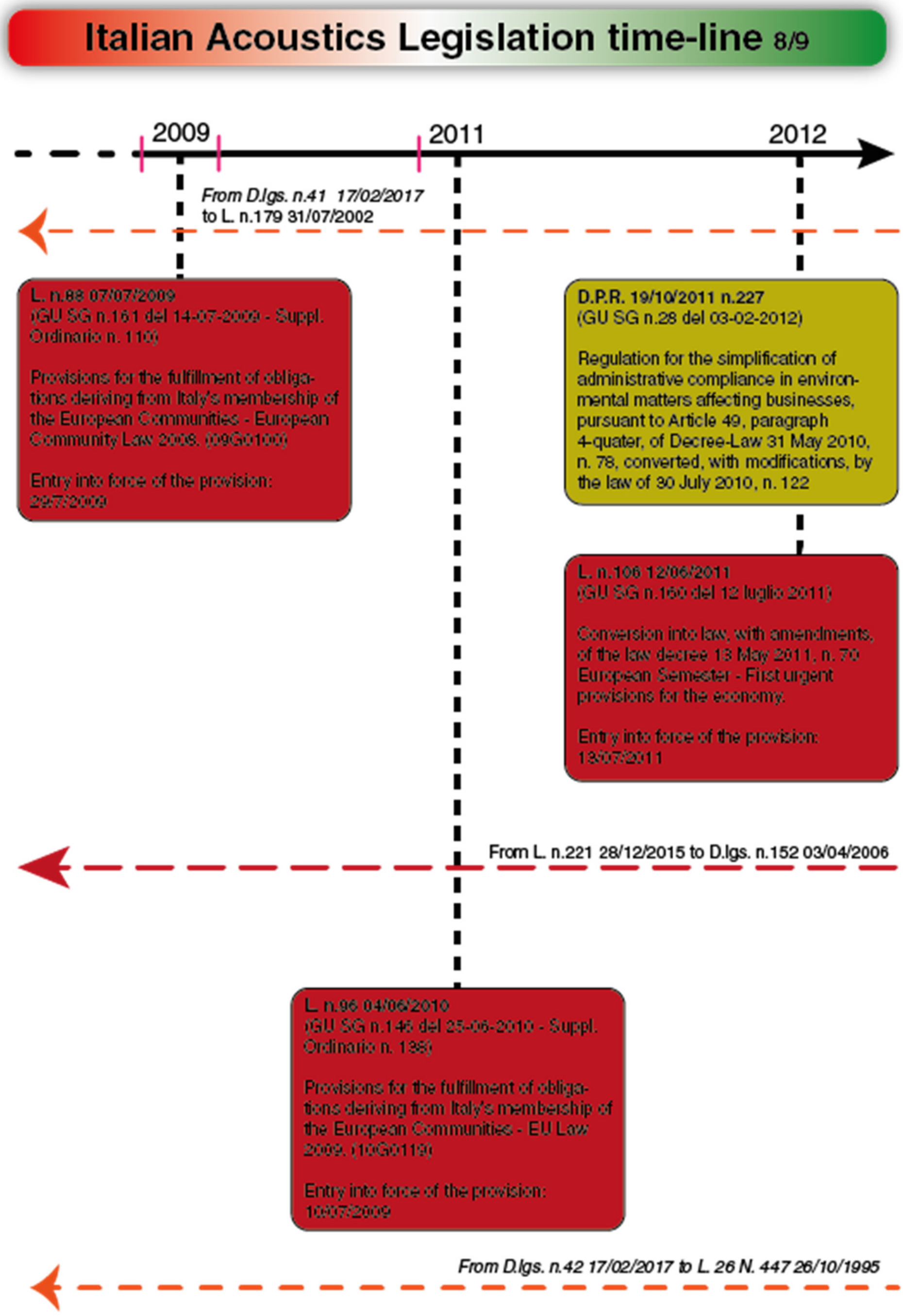
D.lgs. n.152 03/04/2006
(GU SG n.88 del 14-04-2006 - Suppl. Ordinario n. 96)
Environmental regulations.

Entry into force of the provision: 29/4/2006, with the exception of the provisions of the second Part which come into force on 12/8/2006.

DM-MA 24/07/2006
(GU SG n.182 del 7-8-2006)

Ministry of the Environment and Protection of the Territory and the Sea. Amendments to Annex I - Part b of Legislative Decree 4 September 2002, n. 262, relating to the environmental noise emission of machines and equipment intended for outdoor use.

Figure 2-9 - Italian Legislation 2005-2006



L. n.88 07/07/2009
(GU SG n.161 del 14-07-2009 - Suppl. Ordinario n. 110)

Provisions for the fulfillment of obligations deriving from Italy's membership of the European Communities - European Community Law 2008. (09G0100)

Entry into force of the provision: 29/7/2009

D.P.R. 19/10/2011 n.227
(GU SG n.28 del 03-02-2012)

Regulation for the simplification of administrative compliance in environmental matters affecting businesses, pursuant to Article 49, paragraph 4-quater, of Decree-Law 31 May 2010, n. 78, converted, with modifications, by the law of 30 July 2010, n. 122

L. n.106 12/06/2011
(GU SG n.160 del 12 luglio 2011)

Conversion into law, with amendments, of the law decree 13 May 2011, n. 70 European Semester - First urgent provisions for the economy.

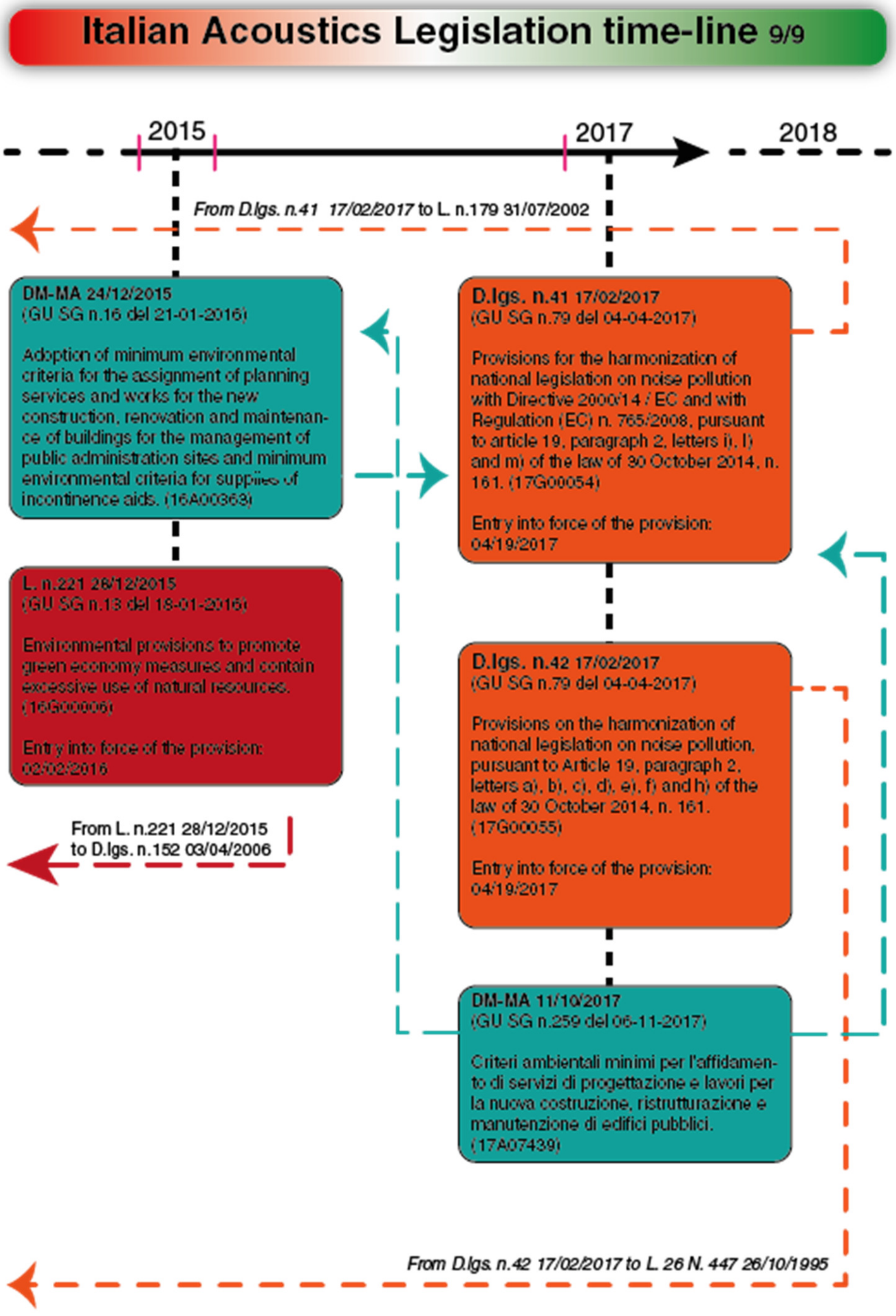
Entry into force of the provision: 13/07/2011

L. n.96 04/06/2010
(GU SG n.146 del 25-06-2010 - Suppl. Ordinario n. 138)

Provisions for the fulfillment of obligations deriving from Italy's membership of the European Communities - EU Law 2009. (10G0119)

Entry into force of the provision: 10/07/2009

Figure 2-10 - Italian Legislation 2009-2012.



DM-MA 24/12/2015
(GU SG n.16 del 21-01-2016)

Adoption of minimum environmental criteria for the assignment of planning services and works for the new construction, renovation and maintenance of buildings for the management of public administration sites and minimum environmental criteria for suppiies of incontinence aids. (16A00363)

L. n.221 28/12/2015
(GU SG n.13 del 18-01-2016)

Environmental provisions to promote green economy measures and contain excessive use of natural resources. (16G00006)

Entry into force of the provision: 02/02/2016

D.lgs. n.41 17/02/2017
(GU SG n.79 del 04-04-2017)

Provisions for the harmonization of national legislation on noise pollution with Directive 2000/14 / EC and with Regulation (EC) n. 765/2008, pursuant to article 19, paragraph 2, letters i), l) and m) of the law of 30 October 2014, n. 161. (17G00054)

Entry into force of the provision: 04/19/2017

D.lgs. n.42 17/02/2017
(GU SG n.79 del 04-04-2017)

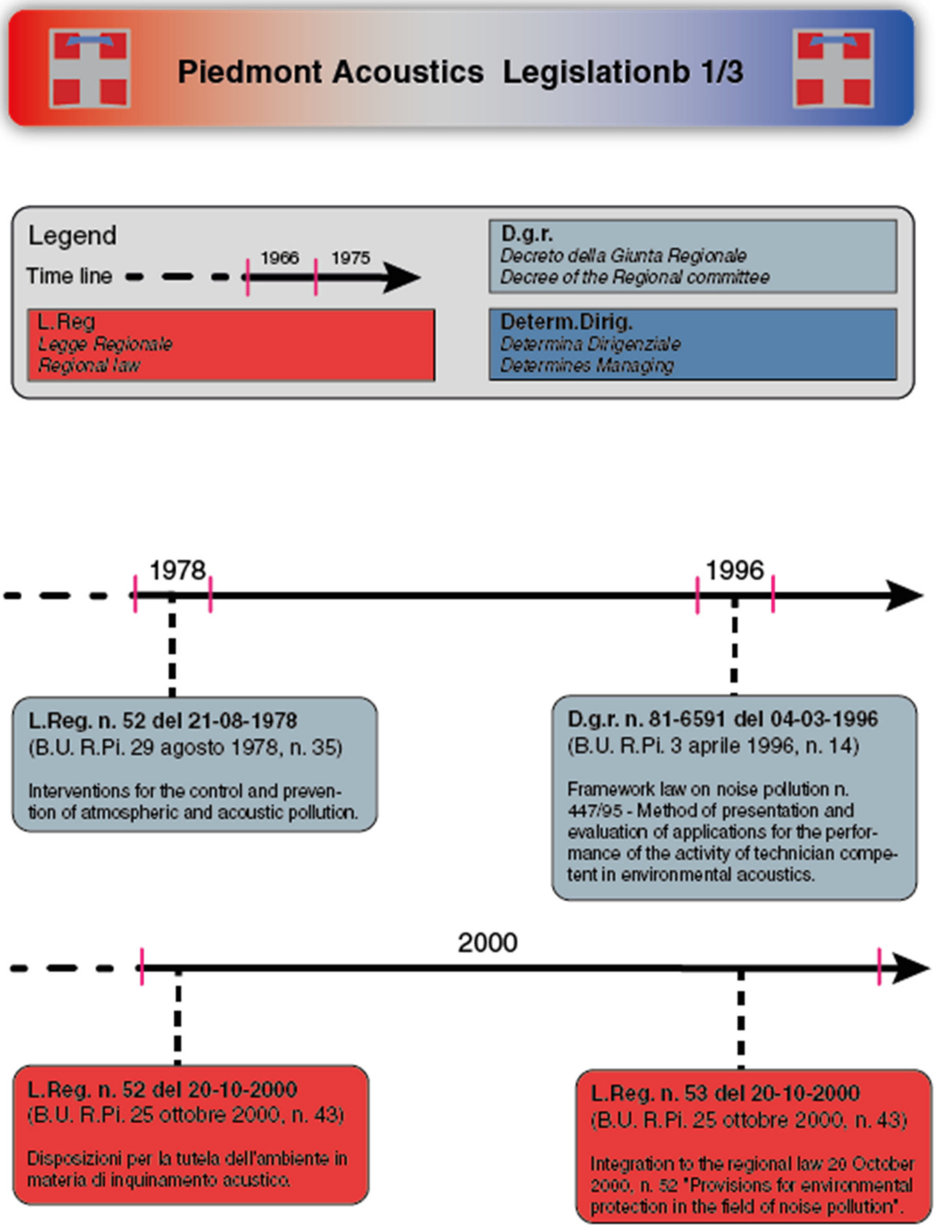
Provisions on the harmonization of national legislation on noise pollution, pursuant to Article 19, paragraph 2, letters a), b), c), d), e), f) and h) of the law of 30 October 2014, n. 161. (17G00055)

Entry into force of the provision: 04/19/2017

DM-MA 11/10/2017
(GU SG n.259 del 06-11-2017)

Criteri ambientali minimi per l'affidamento di servizi di progettazione e lavori per la nuova costruzione, ristrutturazione e manutenzione di edifici pubblici. (17A07439)

Figure 2-11 - Italian Legislation 2015-2018



Piedmont Acoustics Legislationb 1/3

Legend

L.Reg
Legge Regionale
Regional law

D.g.r.
Decreto della Giunta Regionale
Decree of the Regional committee

Determ.Dirig.
Determina Dirigenziale
Determines Managing

L.Reg. n. 52 del 21-08-1978
(B.U. R.Pi. 29 agosto 1978, n. 35)

Interventions for the control and prevention of atmospheric and acoustic pollution.

D.g.r. n. 81-6591 del 04-03-1996
(B.U. R.Pi. 3 aprile 1996, n. 14)

Framework law on noise pollution n. 447/95 - Method of presentation and evaluation of applications for the performance of the activity of technician competent in environmental acoustics.

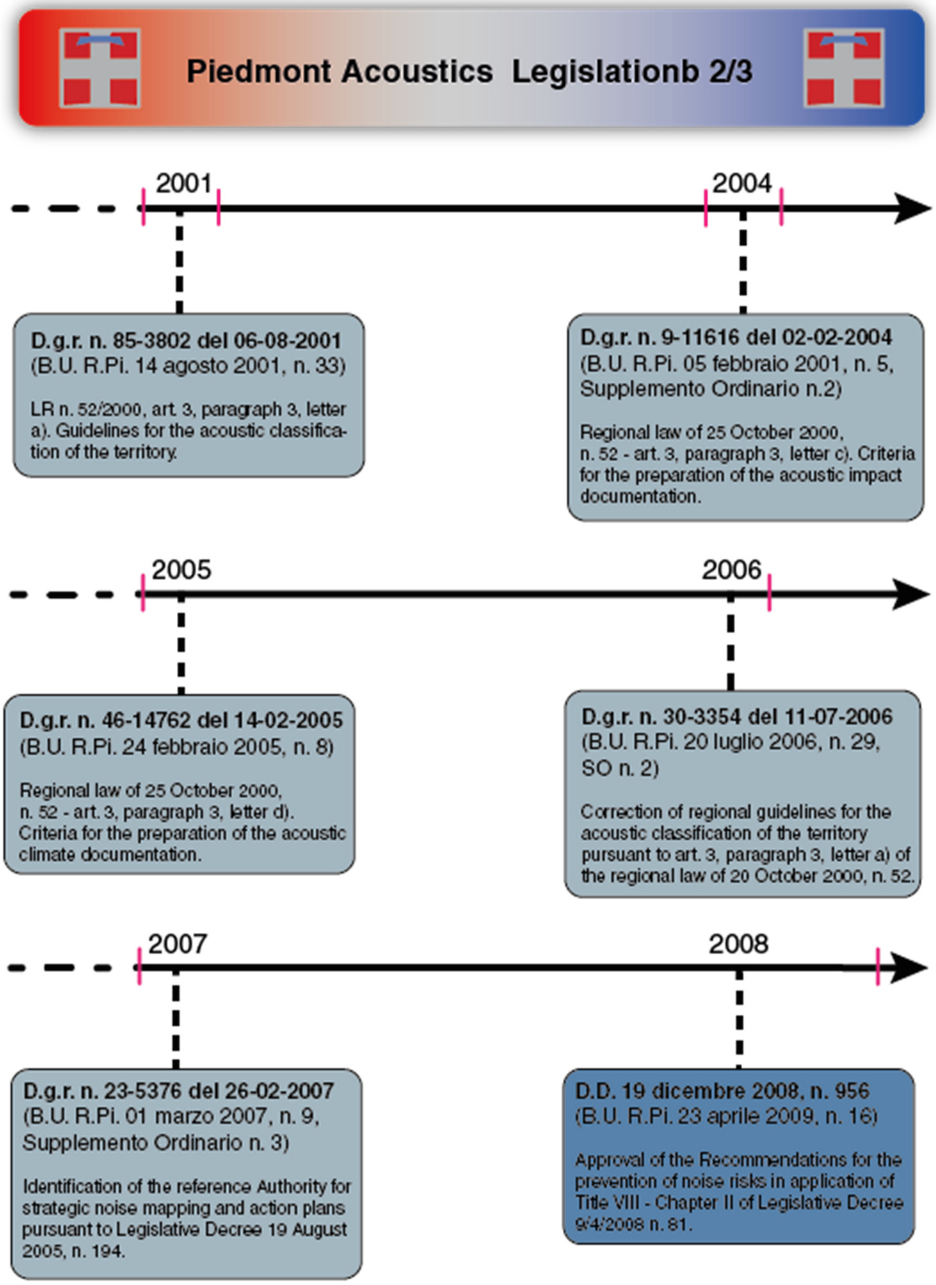
L.Reg. n. 52 del 20-10-2000
(B.U. R.Pi. 25 ottobre 2000, n. 43)

Disposizioni per la tutela dell'ambiente in materia di inquinamento acustico.

L.Reg. n. 53 del 20-10-2000
(B.U. R.Pi. 25 ottobre 2000, n. 43)

Integration to the regional law 20 October 2000, n. 52 "Provisions for environmental protection in the field of noise pollution".

Figure 2-12 - Regional Legislation 1978-1996 (Regione Piemonte)



D.g.r. n. 85-3802 del 06-08-2001
(B.U. R.Pi. 14 agosto 2001, n. 33)

LR n. 52/2000, art. 3, paragraph 3, letter a). Guidelines for the acoustic classification of the territory.

D.g.r. n. 9-11616 del 02-02-2004
(B.U. R.Pi. 05 febbraio 2001, n. 5, Supplemento Ordinario n.2)

Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter c). Criteria for the preparation of the acoustic impact documentation.

D.g.r. n. 46-14762 del 14-02-2005
(B.U. R.Pi. 24 febbraio 2005, n. 8)

Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter d). Criteria for the preparation of the acoustic climate documentation.

D.g.r. n. 30-3354 del 11-07-2006
(B.U. R.Pi. 20 luglio 2006, n. 29, SO n. 2)

Correction of regional guidelines for the acoustic classification of the territory pursuant to art. 3, paragraph 3, letter a) of the regional law of 20 October 2000, n. 52.

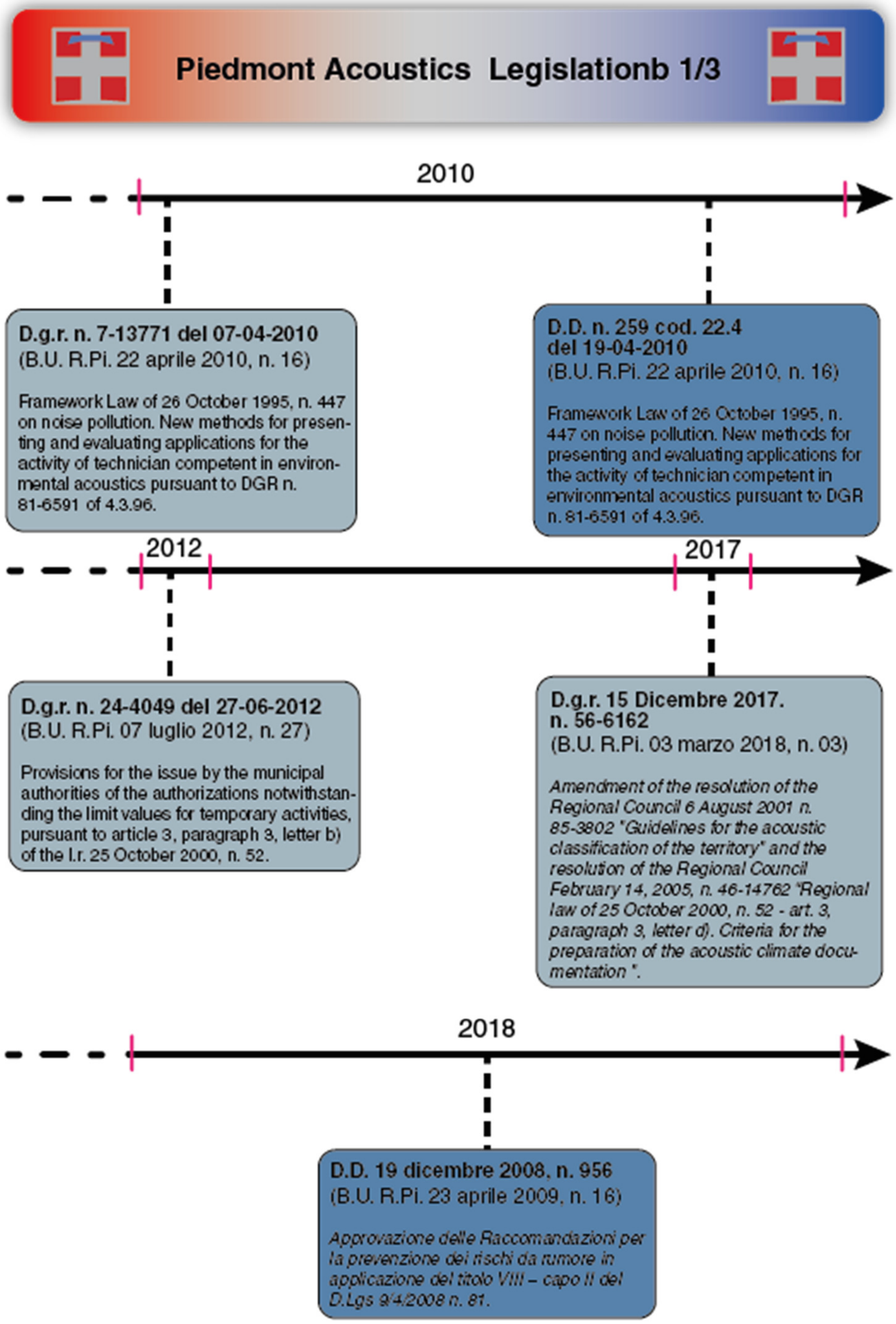
D.g.r. n. 23-5376 del 26-02-2007
(B.U. R.Pi. 01 marzo 2007, n. 9, Supplemento Ordinario n. 3)

Identification of the reference Authority for strategic noise mapping and action plans pursuant to Legislative Decree 19 August 2005, n. 194.

D.D. 19 dicembre 2008, n. 956
(B.U. R.Pi. 23 aprile 2009, n. 16)

Approval of the Recommendations for the prevention of noise risks in application of Title VIII - Chapter II of Legislative Decree 9/4/2008 n. 81.

Figure 2-13 - Regional Legislation 1978-1996 (Regione Piemonte)



D.g.r. n. 7-13771 del 07-04-2010
(B.U. R.Pi. 22 aprile 2010, n. 16)

Framework Law of 26 October 1995, n. 447 on noise pollution. New methods for presenting and evaluating applications for the activity of technician competent in environmental acoustics pursuant to DGR n. 81-6591 of 4.3.96.

D.D. n. 259 cod. 22.4 del 19-04-2010
(B.U. R.Pi. 22 aprile 2010, n. 16)

Framework Law of 26 October 1995, n. 447 on noise pollution. New methods for presenting and evaluating applications for the activity of technician competent in environmental acoustics pursuant to DGR n. 81-6591 of 4.3.96.

D.g.r. n. 24-4049 del 27-06-2012
(B.U. R.Pi. 07 luglio 2012, n. 27)

Provisions for the issue by the municipal authorities of the authorizations notwithstanding the limit values for temporary activities, pursuant to article 3, paragraph 3, letter b) of the l.r. 25 October 2000, n. 52.

D.g.r. 15 Dicembre 2017. n. 56-6162
(B.U. R.Pi. 03 marzo 2018, n. 03)

Amendment of the resolution of the Regional Council 6 August 2001 n. 85-3802 "Guidelines for the acoustic classification of the territory" and the resolution of the Regional Council February 14, 2005, n. 46-14762 "Regional law of 25 October 2000, n. 52 - art. 3, paragraph 3, letter d). Criteria for the preparation of the acoustic climate documentation ".

D.D. 19 dicembre 2008, n. 956
(B.U. R.Pi. 23 aprile 2009, n. 16)

Approvazione delle Raccomandazioni per la prevenzione dei rischi da rumore in applicazione del titolo VIII – capo II del D.Lgs 9/4/2008 n. 81.

Figure 2-14 - Regional Legislation 2007-2017 (Regione Piemonte)

2.5 Emission noise limits

The D.P.C.M. decree 14/11/97, which entered into force on 1 January 1998, determines the limit values of the sound sources, in particular sets:

- the maximum noise emission limit values that can be emitted from a source (table B of the decree);
- the maximum noise input limit values that can be entered by one or more sound sources in the home or external environment, divided into absolute and differential figures (table C of the decree);
- noise warning values that indicate the presence of a potential risk to health or the environment (based on table C of the decree);
- noise quality values to be achieved as a goal in the short, medium and long term (table C of the decree).

The limit values are set by dividing the territory into six acoustical classes (table A of the decree)

The D.P.C.M. 14/11/97 sets the absolute input limits for the external environment for all types of sources.

Ths decree also defines the emission limit values to be understood as the "emission levels relative to a specific source evaluated at the receiver". These values, with the exclusion of transport infrastructures, must be respected by all sound sources.

The climate and noise impact assessments, required by the L. 447/1995, shall be prepared based on these limits,

Table 2-1 – Annexes to the D.P.C.M. 14/11/97, Tables A, B, C, D

Table A: classification of the municipal area (Article 1)
CLASS I - particularly protected areas: This class includes areas where the quiet represents a basic element for their use: hospital areas, schools, areas for rest and leisure, rural residential areas, areas of particular urban interest, public parks, etc.
CLASS II - Predominantly residential areas. This class includes urban areas mainly affected by local vehicular traffic, with low population density, with limited presence of commercial activities and the absence of industrial and handcraft activities.
CLASS III - Mixed type areas. This class includes urban areas affected by local or crossing vehicular traffic, with an average population density, with commercial activities, offices, with limited presence of artisanal activities and without industrial activities, rural areas affected by activities employing operating machines.
CLASS IV - Areas of intense human activity. This class includes urban areas affected by intense vehicular traffic, with a high population density, a high presence of commercial activities and offices, with the presence of handcraft activities, areas close to major roads and railway lines, port areas, areas with limited presence of small industries.
CLASS V - Mainly industrial areas. This class includes areas affected by industrial settlements and few housing.
CLASS VI - Exclusively industrial areas. This class includes areas exclusively occupied by industrial activities and without housing settlements.

Table B: emission limit values - L_{eq} in dB (A) (Article 2)

classes of intended use	reference times of the territory	
	daytime (06:00 to 22:00)	Night (22:00 to 6:00)
I	45	35
II	50	40
III	55	45
IV	60	50
V	65	55
VI	65	65

Table C: absolute input limit values - L_{eq} in dB (A) (Article 3)

classes of intended use	reference times of the territory	
	daytime (06:00 to 22:00)	Night (22:00 to 6:00)
I	50	40
II	55	45
III	60	50
IV	65	55
V	70	70
VI	70	70

Table D: quality values - L_{eq} in dB (A) (Article 7)

classes of intended use	reference times of the territory	
	daytime (06:00 to 22:00)	Night (22:00 to 6:00)
I	47	37
II	52	42
III	57	47
IV	62	52
V	67	57
VI	70	70

The DM 14/11/1997 states that the absolute limit values of introduction in ambient as defined in the art. 2, of L. 447/1995, referring to the noise introduced into the external environment by the set of all the sources are those indicated in table C attached to the decree.

Within the relevant zones, the individual sound sources different from those indicated must respect the limits set out in table B.

Sound sources other than those referred to in paragraph 2 above must comply, as a whole, with the limits set out in table C attached to this decree, according to the classification that is assigned to that zone.

As anticipated the City of Turin implements the laws and regulations in force (i.e. the L. 447/1995 and the L.R. 52/2000) expressing them in “Regolamento comunale per la tutela dall'inquinamento acustico N. 318” (Municipal regulation for the protection from noise pollution no. 318)

In the following tables are reported the sound emission levels and the relevant applicable derogation.

Table 2-2 – Municipality of Turin, Regulation 318 (rework) (I)

Timetables and limits of sound input, Municipality of Turin, Regulation 318

Table A: absolute limit values - articles 2 and 3, D.P.C.M. November 14, 1997:

Destination classes land use		Entry limits Leq in dB (A)	
		diurnal (06: 00-22: 00)	night (22: 00-06: 00)
I	Particularly protected areas	50	40
II	Predominantly residential areas	55	45
III	Mixed type areas	60	50
IV	Areas of intense human activity	65	55
V	Mainly industrial areas	70	60
VI	Exclusively industrial areas	70	70

The maximum allowable sound input limit is 70 dB (A), referred to the equivalent level measured over a 30-minute observation time, to be verified on the façade to the most exposed receiver according to the procedures described in the D.M. 16 March 1998. In the event that the propagation of noise occurs mainly internally, specific limitations will also be imposed on the internal input levels.
For events, the maximum entry limit can be raised up to a maximum of:
73 dB (A) over 30 minutes
if the application for authorization in derogation is accompanied by technical documentation based on which they can be foreseen at the receivers exposed, background noise levels due to vehicular traffic exceeding 65 dB (A) over 1 hour.
Compliance with the limits in force cannot be waived for entries at school facilities (limited to the time the educational activity is carried out) and hospitals, or other sensitive receptors (eg retirement homes), except in cases where these structures are themselves promoters of the activity causing the exceeding.
The limits can be raised up to:
80 dB (A) over 30 minutes for a maximum of 5 days for each site, even non-consecutive, during the calendar year, subject to a resolution by the City Council that expresses a favorable opinion based on documented motivations of an artistic and socio-cultural nature or in any case of public interest.
The maximum permissible sound emission limits for construction activities referred to in Article 17 of this regulation, to be verified on the façade to the most exposed receiver according to the procedures described in Annex C of the Ministerial Decree March 16, 1998, are indicated according to the time slot in the following diagram.

Note: Pursuant to Article 6 of Law 447/1995 and Article 9 of Regional Law 52/2000, the performance of the activities referred to in Article 17 of this regulation may be the subject of municipal authorizations to waive compliance with the limits in force for the sound sources; these documents authorize the exceeding of the limits in force for sound sources, but they do not exempt from the possession of other authorizations that may be necessary to carry out the activities. Construction sites of less than 3 working days, operating in the time period between 8.00 and 19.00, are exempt from the requirement of having the authorization in derogation, and whose noise emissions on the façade to the exposed receivers do not exceed the limit of 70 dB (A), intended as an equivalent level measured over any 1 hour interval according to the methods described in Annex D of the DM 16 March 1998.

Table 2-3 – Municipality of Turin, Regulation 318 (rework) (II)

working days:

- Leq = 75 dB (A)
  on any interval of 1 hour in the time slots 8: 00-12: 00
  and 14: 00-20: 00
- Leq = 70 dB (A)
  on any 1 hour interval in the 12: 00-14: 00 time slot
- Leq = 70 dB (A)
  averaged over the entire time slot 8:00 - 20:00
- Leq = 65 dB (A)
  on any interval of 15 minutes in the time slot
  between 08.00 and 08.00
- Leq = 60 dB (A) averaged over the entire time slot 20:00 - 8:00

Note: the differential limits referred to in article 4 of the D.P.C.M. 14 November 1997 (table C in the appendix to this regulation) days before holidays.

Public holidays:

- Leq = 75 dB (A)
  on any interval of 1 hour in the time slot 8: 00-12: 00
- Leq = 70 dB (A)
  on any 1 hour interval in the 12: 00-14: 00 time slot

Note: the differential limits referred to in article 4 of the D.P.C.M. 14 November 1997

With regard to school facilities (limited to the time the educational activity is being carried out) and hospitals, or other sensitive receptors (eg retirement homes), the above limits are reduced by 5 dB (A). If noise propagation occurs mainly internally, specific limitations will also be imposed on the internal input levels.

The P.C.C.A. Piano Comunale di Classificazione Acustica (Municipal Acoustic Classification Plan) of the municipal area divides the territory according to six classes of destination of use defined in Table A of the D.P.C.M. 11/14/1997 "Determination of the limit values of sound sources", pursuant to Article 6 of L. 447/1995 "Framework law on noise pollution" and Article 5 of Regional Law No. 52 of 20 October 2000 "Provisions for environmental protection in the field of noise pollution".

The Acoustical Classification Plan integrates the current urban planning instruments, in order to harmonize the needs of protection of the environment and housing from noise pollution, keeping into consideration their use and the development methods of the territory.

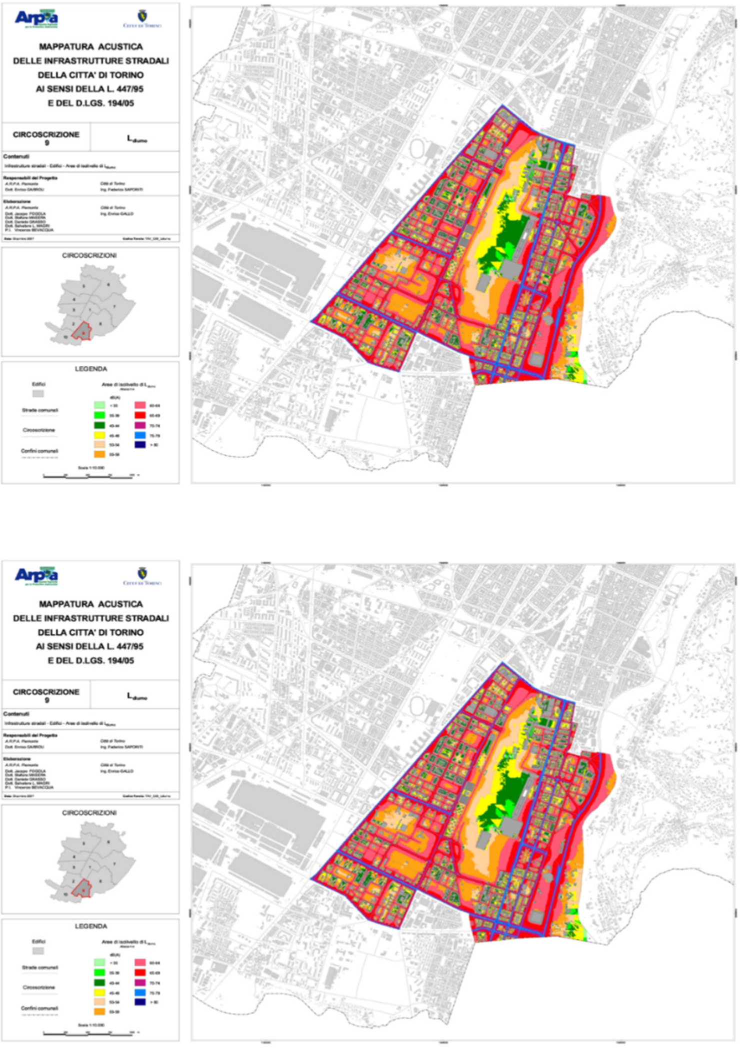
This plan is governed by "homogeneous zones", "buffer zones", "areas to be transformed" and "particular zones" differently classified according to the regulations in force, the settlement features and the directions dictated by the municipal territorial planning instruments

For the purpose of correct identification of the boundaries of the zones, the reference is represented by the perimeters defined by P.R.G.C. (Town Plan)

The homogeneous areas are classified according to the same ranking for the end use reported in the previous Table 2-1.

Following the D.P.C.M. 11/14/97, for each acoustic class into which the territory is divided, the emission limit values are defined, the input limit values, the attention values and the quality values, distinguished for the day periods (06 hours, 00-22.00) and night (22.00 to 06.00 hours).

Table 2-4 – Municipality of Turin, P.C.C.A.



Aree di asolivello di L_{diurno} ed $L_{notturno}$

Altezza 4 m

	dB (A)		dB (A)		dB (A)
🟩	< 35	🟧	50 - 45	🟪	70 - 74
🟩	35 - 39	🟧	55 - 59	🟦	75 - 79
🟩	40 - 44	🟥	60 - 64	🟦	> 80
🟨	45 - 49	🟥	65 - 69		

The acoustic mapping of the City of Turin is the cartographic representation of the noise levels produced by the infrastructures considering the contribution of private traffic and that of public transport.

Acoustic mapping is achieved through the use of a calibrated mathematical model with instrumental measurements; the estimates are particularly reliable for the noisiest areas, while overestimates are possible for roads with less traffic.

The mapping is prepared every five years by the ARPA Piemonte (Regional Agency for Environmental Protection) in collaboration with the Municipality

The mapping shows, for each constituency, the estimated noise levels expressed according to the national indicators.

2.6 Road adjacent zone and noise limit values

The existing buildings or those being planned which are noise receptors in an urban environment are almost entirely located adjacent to at least three of the six different types of roads classified in D.L. No. 285 dated 30/04/92 “Nuovo codice della strada” (New road traffic code)

Each type of road should respect input limits that are greater than the limits set by D.P.C.M. 14/11/97 for all building types not considered particular sensitive to noise, as for instance schools, hospitals etc.

The D.P.R. 142/04 “Disposizioni per il contenimento e la prevenzione dell'inquinamento acustico derivante dal traffico veicolare, art. 11 legge 447/1995” completes the regulatory framework relating to noise pollution due to the operation of road infrastructures.

This decree establishes the limit values and the zones relevant to the roads through a specific division into classes.

For extra-urban infrastructures, named A, B and C according to the classification established by the highway code, and for the main urban ones (Da and Db), noise limits are determined at national level.

With regard to secondary urban roads (E - urban areas, F - local), the definition of the maximum permitted levels is delegated to the individual municipalities in accordance with the acoustic zoning of the territory.

Therefore, for the purposes of preparing the “Piano di Contenimento e Abbattimento del Rumore” (Noise containment and reduction plan) for municipal roads, the classification of the "minor" roads and the assignment of the relative limit values becomes fundamental.

In general, the classification of roads, following the D.P.R. 142/04, shall be carried out according to the typologies defined by the Legislative Decree DL 285/1992, as well as according to the criteria foreseen in the D.M. 11/05/01 “Norme funzionali e geometriche per la costruzione delle strade” (Functional and geometric rules for road construction) for newly built infrastructures and for existing ones, according to the CNR Regulations 1980 and the applicable PUT “Piano Urbano del Traffico” (Traffic Urban Plan)

However, the interpretation of these rules is not so easy and immediate and the road classification results in several cases of difficult implementation.

In urban areas, for example, the type of "interquartiere" road (streets in the neighbourhood) is considered by the D.P.R. n.142/04 in the subtype “Da” with maximum noise limit values equal to those of motorway infrastructures.

In the PUT directives, the same typology of infrastructures is however considered intermediate "between those defined as minor roads and those as urban neighbourhood type". (Fogola J, at al, 2006).

Table 2-5 – Allegato 1, Tabella 2,

Strade esistenti ed assimilabili, DPR 142/2004 (rework)

Tipo di strada (secondo codice della strada	Sottotipi a fini acustici (secondo Norme CNR 1980 e direttive PUT)	Ampiezza fascia di pertinenza acustica (m)	Scuole, ospedali, case di cura e di riposo		Altri ricettori	
			Diurno dB(A)	Notturno dB(A)	Diurno dB(A)	Notturno dB(A)
A - autostrada		100 (Fascia A)	50	40	70	60
		150 (Fascia B)			65	55
B- extra urbana principale		100 (Fascia A)	50	40	70	60
		150 (Fascia B)			65	55
C – Extraurbana secondaria	Ca (Strade a carreggiate separate e tipo IV CNR 1980)	100 (Fascia A)	50	40	70	60
		150 (Fascia B)			65	55
	Cb (Tutte le altre strade extra urbane secondarie)	100 (Fascia A)	50	40	70	60
		150 (Fascia B)			65	55
D – urbana a scorrimento	Da (strade a carreggiate separate e interquartiere)	100	50	40	70	60
	Db (tutte le altre strade urbane di scorrimento)	100	50	40	65	55
E – urbana di quartiere		30	Definiti dai comuni, nel rispetto dei valori riportati in Tabella C allegata al D.P.C.M. in data 14 novembre 1997 e comunque in modo conforme alla zonizzazione acustica delle aree urbane, come prevista dall'art. 6, comma 1, lettara a), della L. 447/1995.			
F - locale		30				

Another critical aspect concerns with the assignment of limit values for type E (urban neighbourhood) and type F (local) roads.

The Municipalities shall establish the limit levels in compliance with the values reported in the D.P.C.M. 11/14/97 and in compliance with the acoustic zoning of urban areas. (Municipality of Turin, regulation n.318)

Interpreting this provision in a rigorous and literal way, each street should be assigned the limit value of the acoustic class of the area it crosses.

In the case of the Piedmont Region this interpretation is difficult to apply. In fact, the Regional Guidelines for the acoustic classification establish that the way for the zone classification does not take into account the presence of transport infrastructures".

Consequently, the acoustic classifications in Piedmont were carried out considering only the presence of residential, sensitive and productive settlements in the territory. For this reason, the classification of an area can be, in several cases, fragmented and not correlated with the types of road infrastructures which cross it (Fogola J, at al, 2006).

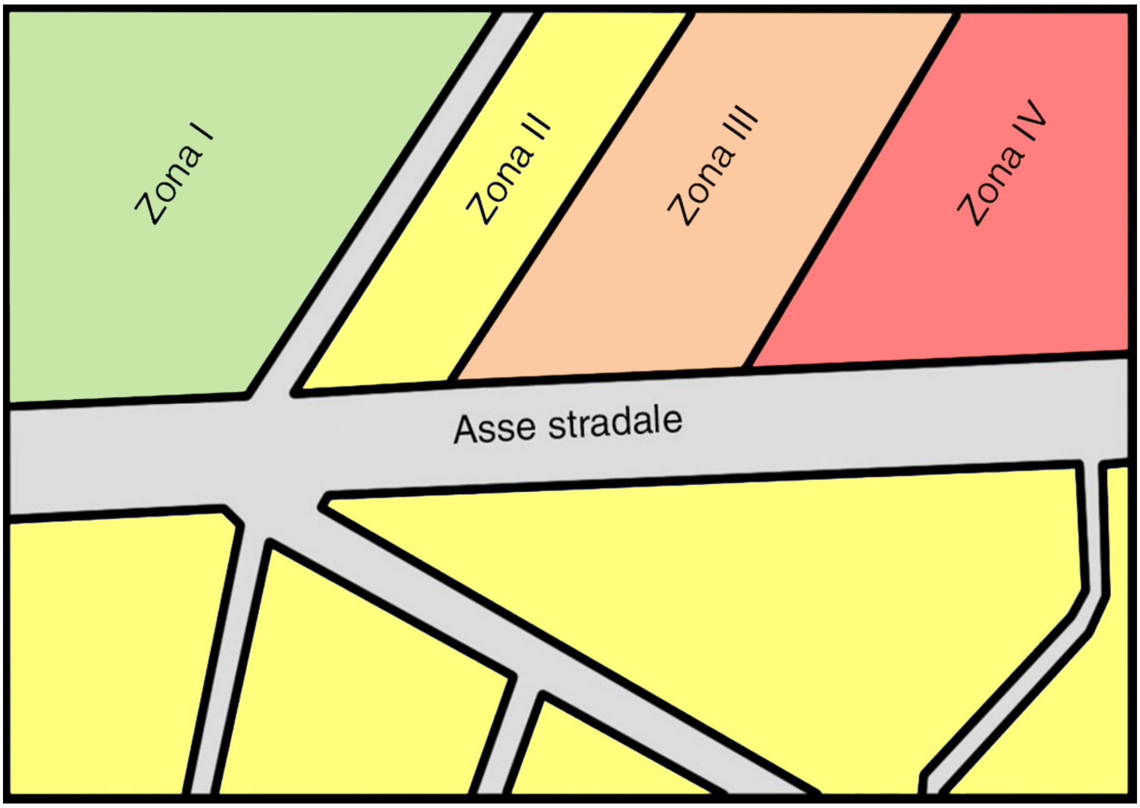


Figure 2-15 – Acoustic zoning near urban road infrastructures.

In the example shown Figure 2-15 the same road infrastructure crosses areas included in classes I, II, III and IV over a distance of about 500 meters: assigning a limit value in accordance with acoustic zoning becomes almost impossible, unless you create paradoxical situations in which the same road must respect different 15 dB limits within a few meters. (Fogola J, at al, 2006)

In application of the D.P.R. 142/2004, the P.C.C.A. Piano Comunale di Classificazione Acustica (Municipal Acoustic Classification Plan) define the absolute sound emission limit values to be applied within the relevance zones of existing road infrastructures and their variants, new infrastructures alongside existing roads and newly built infrastructures as reported in the following Table 2-6 and Table 2-7 respectivrely

Table 2-6 – Absolute limits existing infrastructure (P.C.C.A.)

TYPE OF ROAD	UNDER ACOUSTIC TYPE	ABSOLUTE INPUT LIMIT VALUES dB(A)			
		Hospitals, nursing, homes and rest homes*		other recipe book	
		Daytime period	Night period	Daytime period	Night period
A		50	40	70 (Band A)	60 (Band A)
				65 (Band B)	55 (Band B)
B		50	40	70 (Band A)	60 (Band A)
				65 (Band B)	55 (Band B)
C	Ca	50	40	70 (Band A)	60 (Band A)
				65 (Band B)	55 (Band B)
	Cb	50	40	70 (Band A)	60 (Band A)
				65 (Band B)	55 (Band B)
D	Da	50	40	70	60
	Db	50	40	65	55
E		50	40	65	55
F		50	40	65	55

* only daytime fees apply to schools

Table 2-7 – Absolute limits new infrastructure (P.C.C.A.)

TYPE OF ROAD	UNDER ACOUSTIC TYPE	ABSOLUTE INPUT LIMIT VALUES dB(A)			
		Hospitals, nursing, homes and rest homes*		other recipe book	
		Daytime period	Night period	Daytime period	Night period
A		50	40	65	55
B		50	40	65	55
C	C1	50	40	65	55
	C2	50	40	65	55
D		50	40	65	55
E		50	40	65	55
F		50	40	65	55

* only daytime fees apply to schools

If the values referred to Art. 8, outside the relevant band, and the values indicated in Art. 7 of these regulations are not technically achievable, or if on the basis of technical, economic or environmental assessments the opportunity to proceed with direct interventions on the receptors is highlighted, respect for the following limits must be ensured:

- 35 dB (A) Night L_{eq} for hospitals, nursing homes and rest homes;
- 40 dB (A) Night L_{eq} for all the other living receptors;
- 45 dB (A) Daytime L_{eq} for schools.

In this regard, Title VI of the Regulation 318 of the City of Turin states that the Municipality competences are exercised as a priority through Urban Traffic Plan "and the" Acoustic Recovery Plans "referred to in DM November 29, 2000 containing the "Criteria for the preparation, by companies and bodies managing public transport services or related infrastructures, of plans to contain and reduce noise".

In the design of new roads, in fact, compliance with the limits set by the D.P.R. must be guaranteed 142/2004 and the tools for implementing the P.R.G. they must include an "Acoustic Impact Assessment" of the new road network they provide.

In the case of new building constructions in the vicinity of existing roads, compliance with the current limits set out in the D.P.R. 142/2004, is the responsibility of the creator of the work itself and this respect must be reported in the VPCA.

Table 2-8– Limits comparison table (I)

Destination class of use of the territory [Tabella A, D.P.M 14/11/1997]			Turin Type of road (according to the highway code, CNR rules and PUT directives)							
			Urban scrolling, Type D, Amplitude band of acoustic relevance 30 m							
			Separate roadways and independent Typology From Amplitude band of acoustic relevance 100 m				All other urban roads scroll Type D_b Amplitude band of acoustic relevance 100 m			
			Schools, hospitals, houses of care and rest		Other receptors		Schools, hospitals, houses of care and rest		Other receptors	
	Diurnal dB(A) (22.00 – 06.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)
II predominantly residential areas	55	45	50 (50 < 55)	40 (40 < 45)	65 (70 > 55)	55 (60 > 45)	50 (50 < 55)	40 (40 < 45)	65 (65 > 55)	55 (55 > 45)
III mixed type areas	60	50	50 (50 < 60Z	40 (40 < 50)	65 (70 > 60)	55 (60 > 50)	40 (50 < 60)	40 (40 < 50)	65 (65 > 60)	55 (55 > 50)

Agreement between laws and regulations	🟩	Discordance between laws and regulations	🟥

Table 2-9 – Limits comparison table (II)

Destination class of use of the territory [Tabella A, D.P.M 14/11/1997]			Turin Type of road (according to the highway code, CNR rules and PUT directives)							
			Urban neighborhood Type E Amplitude band of acoustic relevance 30 m				Local Type F Amplitude band of acoustic relevance 30 m			
			Schools, hospitals, houses of care and rest		Other receptors		Schools, hospitals, houses of care and rest		Other receptors	
	Diurnal dB(A) (22.00 – 06.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)	Diurnal dB(A) (06.00 – 22.00)	Night dB(A) (22.00 – 06.00)
II predominantly residential areas	55	45	50 50 < *55*	40 40 < *45*	65 70 > *55*	55 60 > *45*	50 50 < *55*	40 40 < *45*	65 70 > *55*	55 R. 60 > *45*
III mixed type areas	60	50	50 50 < *60*	50 40 < *50*	65 65 > *60*	55 55 > *50*	50 50 < *60*	50 50 < *50*	65 65 > *60*	55 55 > *50*

Agreement between laws and regulations	🟩	Discordance between laws and regulations	🟥

2.7 Detection and measurement techniques of noise pollution

The measurements of the L_{eq} input limits in dB(A) must be performed in accordance with the provisions of the Decree of 16 March 1998, that define the techniques for detecting and measuring noise pollution established by the L. 447/1995.

The decree states that in the case of external measurements, with the building façade flush with roadway, the microphone shall be located 1 m from the same façade

In the case of buildings with separation from the road or free spaces, the microphone must be placed within the space usable by people or communities and, in any case, not less than 1 m from the façade of the building.

The height of the microphone both for measurements in built-up areas and for measurements in other sites must be chosen in accordance with the real or assumed position of the receiver.

The influence of the shape and characteristics of the façade of the building on the measurement of the sound level (ΔL_{fs}) in this decree and in the laws and regulations is not considered in determining the sound level on the façade even if it has a very important function. (Novo M., at al, 2005)

It is important to remember that the Tribunale Amministrativo Regionale TAR (Regional Administrative Court) of Puglia with sentence n. 1329 of 5 June 2013, in reference to the recreational activity of a nightclub in Lecce, stated that the verification of the ARPA (Agenzia Regionale per la Protezione dell'Ambiente), made on the basis of the configuration of the sound system and of the operating conditions declared by the applicant, is insufficient to prove compliance with the legal limits regarding the level of sound inputs, as the measurement of noise input in ambient shall be based on data that can be derived from the actual performance of the activity and not on a simulation. (Santucci E., 2013).

The objective of acoustic mitigation to be achieved if a new construction to be built in an area falling within the boundary zone of a linear transport infrastructure and in an acoustic class with restrictive limits such as class II, are to be diversified and to be applied separately, depending on the source that generates the noise. One is the established limit for the transport infrastructure, as far as the noise produced by the same is concerned, the other is the limit established by the acoustic class for the part of noise generated by all the other sound sources.

It is important to note that if the mitigation objective is technically and economically difficult to achieve, the cost necessary for the realization of the mitigation works constitutes an disincentive to the realization of housing units or other sensitive receptors too close to the strongly noise sources as reported by a communication from the “Direzione Tutela e Risanamento Ambientale Programmazione e Gestione Rifiuti della Regione Piemonte, 2006.

2.8 Predictive Acoustic Climate Assessment

As already written, the absolute limits of sound input per acoustic zone in the City of Turin, to be measured on the facade of the receiving buildings are the same of the D.P.C.M. 14/11/97.

Therefore, for every acoustic class into which the territory is divided, are defined the input limits, the warning and quality values, distinguished for the diurnal and night periods 06.00 ÷ 22.00 and 22.00 ÷ 06.00 respectively.

The limits are verified by means of the documentation of the “Predictive Acoustic Climate Assessment” which must be attached to the documentation for the issuance of the “permission to build”, concerning the construction of new buildings such as new residential settlements, schools and kindergartens, hospitals, nursing homes and rest centres, urban and suburban public parks, where the quiet constitutes a basic element for their use, including also urban and suburban public parks.

If the absolute limits of sound input per zone are not respected in the verification phase the Municipality shall deny both the “permesso di costruire" (Building Permit) and the “certificato di agibilità" (Certificate of Occupancy). (Municipality of Turin, Regulation n.318)

The Predictive Evaluation of Acoustic Climate is a documentation that must be written by a licensed professional in Environmental Acoustics following the criteria for the preparation of the documentation in accordance with the Regional Law 25 October 2000 n. 52.

The Municipality reserves the right to request further information and additions in cases of particular criticality or complexity.

If the Predictive Evaluation of Acoustic Climate shows a situation of possible overcoming of the established limits, it is mandatory to add a description of design and construction arrangements to be adopted in order to contain this inconvenience inside the living areas, taking into account the provisions of the city Regulation n.318 if applicable.

The Predictive Evaluation of Acoustic Climate is requested according to the art. 8 of the Law 447/95 and the report includes a study with phono-metric measurements that analyses the sound climate in the investigated area; in practice, by mean of this study it is requires to check that the environment of the area is not acoustically polluted,

The missed redaction of the Predictive Evaluation of Acoustic Climate is considered as a serious lack of documentation and it results in the not acceptance of SCIA (Segnalazione certificato di inizio attività), the impediment for not releasing the “Certificato di agibilità” (Certificate of occupancy) and the authorization to carry out any kind of activity.

The issuing of permits or authorizations can be subordinated to the implementation of specific interventions or to the presentation of an acoustic test report “collaudo acustico” signed by a licensed professional in acoustic, after the realization of the work or the beginning of the activity.

It is important to underline that from 1942 to 1997, for every new building work, no documentation was required attesting to compliance with the acoustic requirements even in the very rare cases where these were envisaged, in terms of regional and in particular municipal hygiene regulations.

Only with the entry into force of the D.P.C.M. of 5/12/1997 for the first time in Italy the requirements of sound insulation of new buildings have been prescribed by law.

The more recent D.P.R. 380/2001 "Testo unico delle disposizioni legislative e regolamentari in materia edilizia." (Consolidated text of the legislative and regulatory provisions on building matters) does not introduced the acoustic requirements prescribed by the D.P.C.M. of 5/12/1997 already in force.

The D.P.R. 380/2001, in fact, in art. 24 does not require compliance with the acoustic requirements, but is limited to checking the hygiene conditions that include phenomena related to noise pollution assessed according to the regulations in force on the subject. (Bosio D. 2014).

According to the D.P.C.M. of 5/12/1997, the municipal building regulations shall require the verification of the acoustic requirements, by a licensed professional in the field of environmental acoustics, since the first design phase and issue the "building permit" only following the evidence of their respect in the design documentation.

According to the same decree, moreover, the municipal building regulations shall require the verification of the acoustic requirements to be carried out on the completed building, by a licensed professional, in order to obtain the “Certificate of occupancy” that will be released only if the building passes the acoustic test in place.

In such a way the Municipality guarantees the users or the buyers of new buildings that these meet the established requirements with the relative acoustic quality.

The decree, in itself, does not oblige to draw up reports or carry out acoustic tests, but assigns these activities to the municipalities.

In the event of missed compliance with the acoustic requirements of the new buildings out, the municipality always has the right to revoke the “Certificate of occupancy” of the house due to sound insulation defects (Borsoi D. 2014).

The municipal building regulations, in any case, can always be even more restrictive than the limits set by the D.P.C.M. 5/12/1997 and in the case they does not mention limits, those of the decree shall be considered implicitly applicable, because the decree is a hierarchical source of law superior to a municipal regulation.

The municipal administration, with the support of A.R.P.A., upon receipt of complaints or by samples investigation, may do checks relating to the congruence between the works carried out and what is stated in the documentation presented. In case of discrepancies from what is stated in the documentation, the Municipality can order the regularization of the work or activity, setting a deadline limit.

From what has been analysed, to obtain the issue of the “Building Permit” or the “Certificate of Occupancy”, for example, to Class II (areas destined mainly for residential use) and Class III (mixed type areas) for the City of Turin and in an Italian Municipality in general, it is necessary that the level of noise introduced by the environment and measured in the facade of the receiving building, for which one of the aforementioned authorizations is required, is not higher than the values as indicated in Table C of the D.P.C.M. 14/11/97.

2.9 UK and German regulations on urban noise mitigation

2.9.1 UK (United Kingdom)

In the United Kingdom the main attention is devoted to reduce the noise level inside dwellings and houses in accordance with the Regulations established for each of the country forming the United Kingdom i.e. England, Wales, North Ireland and Scotland.

The content of these Regulations very similar and the noise level admitted inside the buildings are the same in England, Wales, North Ireland and more relaxed in Scotland in respect of noise from outdoor (Approved Document E for England & Wales - 2000; Section 5 Noise of Scottish Government Technical Handbook – 2017; Building Regulation – Technical Booklet G - Norther Ireland – 2012).

There’s no legal limit to traffic noise and it is important to remark that the façade sound insulation is only treated indirectly, in the frame of global sound insulation of the walls and floors. Only generic indication has been reported in a document in Scotland edited by the Napier University specifically dedicated to Scotland “Housing and sound insulation” (Smith S., at al., 2006) where there is a small section dedicated to façade sound insulation.

This section is limited to general information how sound can be transmitted due to acoustic flanking problems when new, lightweight curtain walling (or curtain glazing) is fixed onto the outside of the building and tied back to the floors. No indication in terms of sound level are reported.

The information how the noise pollution is treated in UK are released directly by the governmental site dedicated to “Safety and the environment in your community” from the UK governmental website (www.gov.uk).

There are strategic noise maps for England provided by the Department for Environment, Food and Rural Affairs (Defra).

These estimate noise from:

- major roads - those with more than 6 million vehicle passages annually.
- major railways - those with more than 60,000 train passages annually.
- major airports - those with more than 50,000 aircraft movements annually (except for training on light aircraft).

As already reported, there’s no legal limit to traffic noise; when planning a new road, the local authorities assess how the noise at private properties will change after the road opens. If noise from a new road exceeds certain levels, the inhabitants can require and get an adequate road sound insulation (www.gov.uk)

There are limits to the amount of noise that vehicles can make on public roads. This applies to all types of vehicles. There are noise limits on tires and since November 2012 all new tires are graded and labelled to show how noisy they are, similarly there are rules concerning modified exhaust systems (www.gov.uk).

There are no legal limits to noise from existing railways. If inhabitants think that noise levels are affecting their health, they can contact the local council who will investigate on their behalf.

Similarly, to the road noise, if noise from a new railway exceeds certain levels, the inhabitants can require and get an adequate road sound insulation (www.gov.uk).

2.9.2 Germany

The German policy about noise pollution is well controlled by many norms and regulations, different national standards as well as the definition of noise limits imposed to the potential sources outside dwellings. Nevertheless, the sound façade insulation is not explicitly treated, and it is limited to specific intervention on the windows characteristic. In Germany the basic rule consists in do not generate noise exceeding the imposed limits.

The road traffic has long been the dominant source of noise in Germany; more than half of the German population feels disturbed or bothered by road traffic noise as the result of a dedicated investigation "Environmental Awareness in Germany 2016". (www.umweltbundesamt.de)

According to rough calculations, about half of the German population is exposed to road traffic noise at averaging levels of at least 55 dB (A) during the day and 45 dB (A) at night; about 15 percent are even burdened with levels of at least 65 dB(A) or 55 dB(A) at night. (www.umweltbundesamt.de)

In the case of new construction or a significant modification of a road, emission limits for traffic noise prevention is regulated by the Traffic Noise Ordinance (16th Federal Immission Control Ordinance). (16 - Straßenverkehrsordnung StVO)

The following emission limits apply:

- ✓ at hospitals, schools, spas and retirement homes
  - by day: 57 dB (A)
  - at night: 47 dB (A)
- ✓ in pure and general residential areas and small settlement areas
  - by day: 59 dB (A)
  - at night: 49 dB (A)
- ✓ in core areas, village areas and mixed areas
  - by day: 64 dB (A)
  - at night: 54 dB (A)
- ✓ in industrial areas
  - by day: 69 dB (A)
  - at night: 59 dB (A)

The Traffic Noise Ordinance also contains the formulas and rules how to assess the noise level coming from road (and railway) and are specifically dedicated to measurements done for them to keep into consideration their characteristics. About roads, correction factors to be applied to the measured medium levels (day and night) are tabulated considering type of street, vehicle speed, type of road surface, topographic and meteorological conditions. There is no particular indication how to perform the noise measurement in front of buildings, because the scope of this Ordinance is to correctly evaluate the noise emitted by the source i.e. the road. If the noise exceeds the defined emission limits, a proper soundproofing must be done or improved along the road.

Main references to German regulations are the requirements of the European Union Directives first, the Federal Constitutional Law (Articles 2, 12, 14, 20a, 74 Basic Law) and some sections of the Civil Code. The standards on sound insulation in buildings in Germany have a long tradition starting in 1938. The first standard DIN 4109 "Sound insulation in building" was published in 1959. In July 2016 a new version of DIN 4109 was published as a consequence of developments in building materials and construction methods as well as changed expectations on sound insulation in the society during the past years. (Kornadt, O., at al., 2016)

Additionally, to the DIN 4109 there are further standards in Germany defining requirements on enhanced sound insulation in buildings if higher comfort is requested. The requirements according to VDI 4100 are classified in 3 quality levels from smooth enhanced to high enhanced sound insulation in buildings (but the characteristic parameters used for defining them are different in DIN 4109 (R'w and L'n,w) and VDI 4100 (DnT,w and L'nT,w) while the VDI guideline 2719 specifies sound insulation classes 1 to 6 for windows and their additional equipment. A further improvement and intensification of requirements is reported by the new DIN SPEC 91314:2017-01 "Sound insulation in buildings - Requirements for increased sound insulation in dwellings" and by the "DEGA (German society for Acoustics) Recommendation 103: Soundproofing in housing - sound insulation. (DEGA-Empfehlung 103).In few words it seems that in Germany there is no specific and punctual requirements concerning sound insulation of building facades, but concentrating the attention to two main aspects i.e. the regulations to control the external sources which generate noise and the insulation property of the windows.

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3 STREET CANYON EFFECT

3.1 Introduction

Until few years ago the main attention was dedicated to housing and dwelling insulation in order to contain the sound pollution effect by limiting the transmission inside, disregarding other aspects as those linked to urban configuration and street geometry (Vardoulakis, at al. 2003)

Architects and urbanists take decisions that define the shape of streets and buildings construction not considering the environmental noise pollution; furthermore there is little information about the influence of urban geometry on traffic noise exposure in streets (Echevarria S. et al. 2015)

In central city areas, where realizations of new buildings or renovations of existing ones have to fit into the compact historical urban fabric (Douglas et al. 2013), the noise pollution effects are worsened by the so-called canyon effect where continuous building fronts along narrow streets reflect the sound multiple times, hence increasing the sound pressure level within the urban environment.

This issue has been investigated by many authors simulating the effect of diffuse reflections (Can A. et al. 2015), studying the noise propagation (Li K. M. et al. 2009), evaluating the contribution of street canyon geometry and of the building shape (Echevarria S. et al. 2015).

One of the aspects less investigated is the contribution of the façade characteristics to limit the sound reflection that contribute to increase noise levels in the street.

The noise pollution determined by road traffic depends by many factors as its volume, the noise emission of vehicles, the combination of tire and roadway characteristic as well as the geometric conditions during sound propagation (Nunez, M., at al. 1977).

Taking into account the issues raised by above authors the elements that can help in noise reduction, buy also increasing the sound adsorption and in limiting the sound reflection are:

- the street configuration (aspect ratio) and their general design

- the shape of the façade
- the presence of balcony, terraces, bow-windows
- the presence of windows and protrusions
- the façade materials and type of plaster
- the presence of incidental or built barriers in the street in front of the buildings

3.2 Influence of aspect ratio

The most important geometrical detail about a street canyon is the ratio of the canyon height (H) to canyon width (W), H/W, which is defined as the “aspect ratio” (Vardoulakis, at al. 2003)

A sub-classification of each of the different aspect ratio can be done depending on the distance between two major intersections along the street, defined as the length (L) of the street canyon.

Another classification is based on the symmetry of the canyon.

The different classifications are reported in the following Table 3-1

Table 3-1 - Canyon street classification (Vardoulakis, at al. 2003)

Main classification	Aspect ratio H/W
Regular canyon	~ 1
Avenue canyon	< 0.5
Deep canyon	~ 2
Sub classification (I)	Length ratio L/H
Short canyon	~ 3
Medium canyon	~ 5
Long canyon	~ 7
Sub classification (II)	Symmetry
Symmetric (or even) canyon	The buildings that make the canyon have approximately the same height
Asymmetric canyon	The buildings that make the canyon have significant height differences
“Step-up” canyon	The height of the upwind building is less than the height of the downwind building.

Urban canyons affect various local conditions, including temperature, wind, air quality, and radio reception, including satellite navigation signals.

3.3 Influence of facade design

In the study done by Echevarria S. et al. (2015) the effect of detailed urban canyon geometry on the distribution of sound pressure level is investigated with the aim of compiling an architectural guidance to reduce the overall noise levels for pedestrians and along façades.

According to the authors the current approach to this problem is mainly based on corrective methods applied when the problem already exists, while noise pollution in the city should preferably be dealt in advance in urban design.

The equivalent power spectra according to the “Common Noise Assessment Methods in Europe” (Cnossos 2012) were used to approach road traffic noise sources along two traffic lanes.

Different canyon shapes were numerically studied and their design influence was assessed by means of a detailed full-wave numerical simulation technique through namely the finite difference time-domain (FDTD) method. The calculation model was validated by using real street reverberation measurements with a setup was mounted on the roof of a car consisting in an omnidirectional dodecahedron loudspeaker and two free field microphones placed at 2.48 m distance from the source at either side.

Different street designs were considered, departing from a basic canyon section of 20 m wide and 26 m high corresponding to an 8 floors building, i.e. ground floor + 7 as shown Figure 3-1 (which aspect ratio corresponds to 1,3 and it can be classified as a “regular canyon”].

Two incoherent line sources are symmetrically placed at 1.5 m from the canyon centre, modelling a 7 m wide road located 20 cm below walkways.

A horizontal line of receivers, separated each 0.06 m, is positioned along the street width at pedestrian ear height (1.5 m). Vertical lines of receivers are distributed along the façade at 0.01m distance (pressure values are calculated in the centres of the cells).

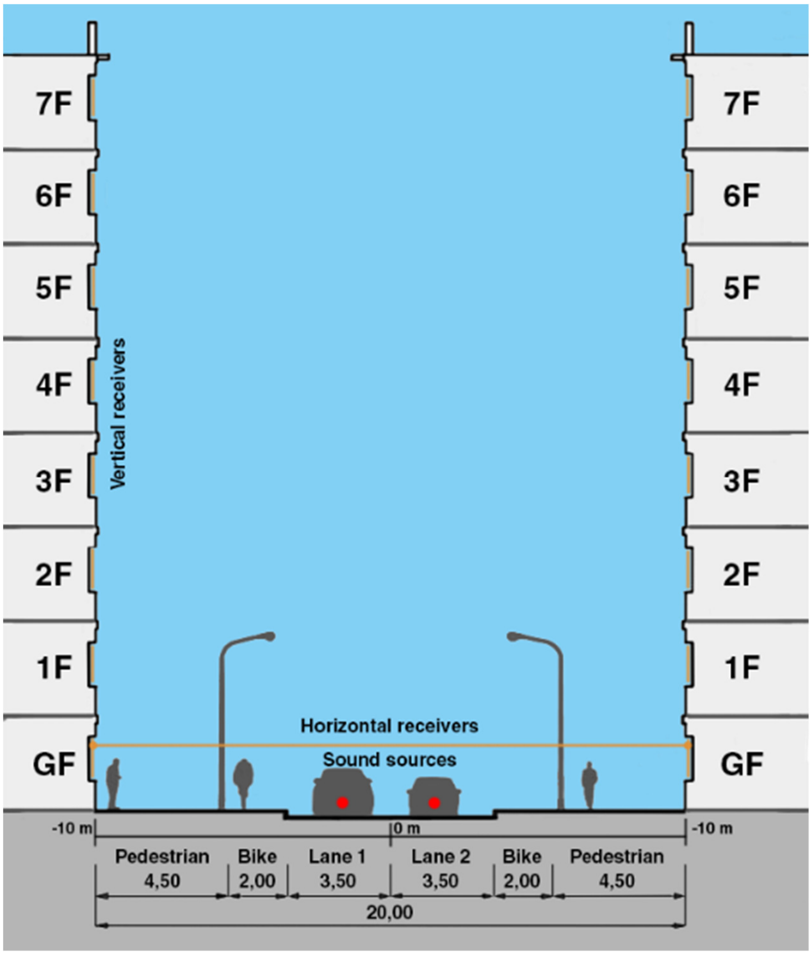

Figure 3-1- Street canyon setup (Echevarria S. et al. 2015)

The study considers 42 different cases including building shape whit different inclinations, the setback of the lower storeys. the balcony geometry, the introduction of triangular prominences on façade and shielded inclined windows. Concerning the street, have been considered low barrier of different shape with/without sound absorption, a depressed road and a two-level street.

The numerical results obtained indicate that canyon shape has an important influence on traffic noise levels for directly exposed receivers.

The building geometry mainly influences noise levels along the façades whereas geometrical changes next to the noise source have a higher relevance for pedestrians and at the windows of the lower floors.

The building shape (sequence F1 of Figure 3-2) may reduce the noise at pedestrians level, as a flat upwardly inclined and concave façades redirect the first noise reflections towards the ceiling of the canyon, reducing the reverberation, while flat downwardly inclined façades do not contribute to this effect.

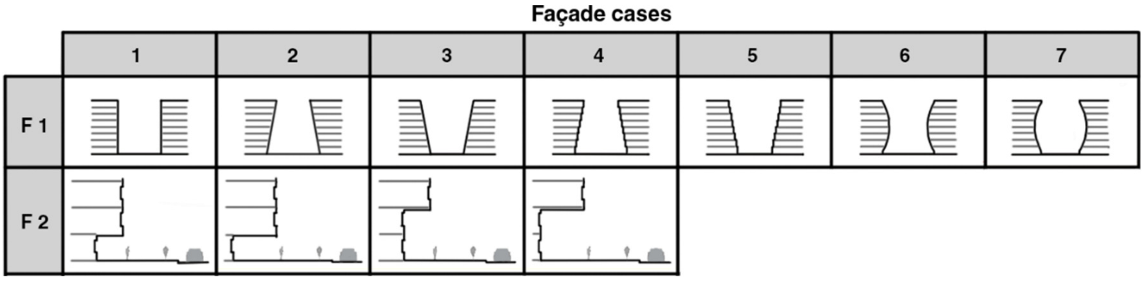

Figure 3-2- Façade inclination and building setback (Echevarria S. et al. 2015)

Taking the flat façade case F1.1 has as reference the maximum difference on pedestrian exposure in the unfavourable case F1.2 (downward inclined) is 6,1 dB(A) for glass facades while adopting brick materials reduced difference in noticed in all the examined cases.

Also the setback of the first floors of a building (sequence F2 of Figure 3-2) has a positive influence along façades less for the pedestrians, because they are exposed directly to the noise source. A maximum reduction of 4,2 dB(A) as average value is obtained in the ground-floor window, 2.4dB(A) in the first floor, and around 1.5 dB(A) at the other floor's windows. The setback height has a higher influence on the façade than on pedestrians.

In the same paper, Echevarria S. et al. (2015) investigated also the effect done by the balconies concluding that their design has a great influence on the façade noise levels.

A combination of measures is most advantageous: inclining the balcony ceiling and ledge in upper storeys and adding ceilings absorption up to the 3rd floor, significantly reduces the average noise levels along windows in upper floors up to 12.7 dBA (sequence F3 of Figure 3-3). Additionally, 6dB(A) reduction can be achieved by optimizing balcony shape and the inclination of the ledge (F3.2) slightly reduces the average exposure at windows.

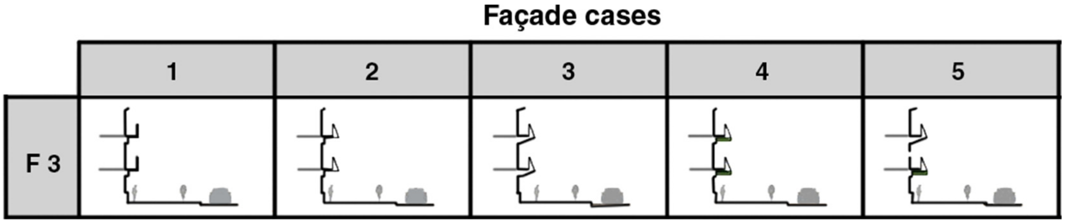

Figure 3-3- Balcony design variation (Echevarria S. et al. 2015)

The inclination of the balcony ceilings (F3.3) has a great influence on the façade exposure, reducing average noise levels along windows with more than 12 dB(A), especially in upper floors. F3.3 is the most advantageous case within the sequence. The addition of absorption on the ceiling of each balcony (F3.4) also results in an important reduction of façade noise level

A reduction up to 8.4 dB(A) is predicted with the addition of triangular prominences on the façade, which have a strong influence on its exposure, especially at the upper floors (sequence F4 of Figure 3-4)

Also the self-shielded windows provide a reduction up to 7.6 dB(A) in the upper floors; this reduction is proportional to the angle of inclination (sequence F5 of Figure 3-3).

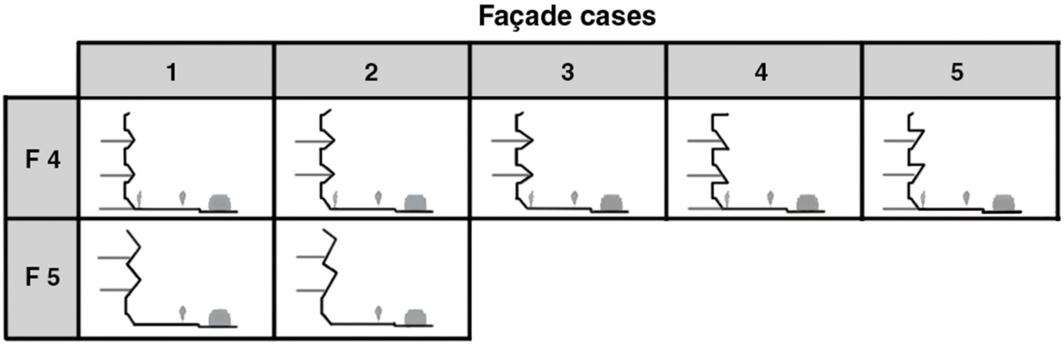

Figure 3-4- Prominences and self-shielded windows (Echevarria S. et al. 2015)

Regarding the effects the balcony design on the reduction of exterior noise, an interesting investigation has been performed by Lee P. J. et al. (2007).

The study has been performed by doing measurements in loco and in laboratory with a 1:50 scale model; then simulations have been done to identify how the introduction of some configuration modification could improve the noise reduction.

The object of investigation was a 15-storey apartment building with balconies exposed to the traffic noise from an adjacent road and surrounded by other similar constructions in an urban environment. These balconies were completely open to sound because they are closed by a simple railing.

To study the effect of potential improvement, the simulation introduced six different balcony configurations, each with one or more added elements.

In the first configuration a shield-plate was added horizontally to the balcony floor; in the second a solid parapet; in the third an inclined ceiling.

Then more elements were changed together: a deadening surface was added to the inclined ceiling; subsequently a parapet was added to the inclined deadening ceiling configuration. Finally, a new deadening surface has been placed on the parapet maintaining the inclined sound-absorbing surface (Figure 3-5).

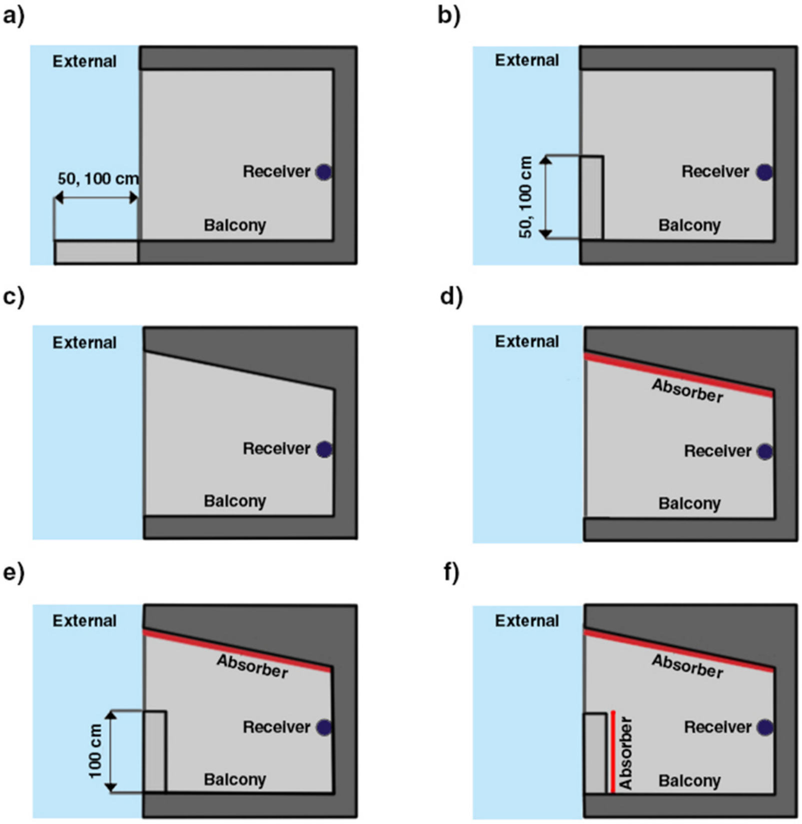

Figure 3-5- Balcony sound improvement (Lee P. J. et al. 2007).

The road noise measurement, conducted at different storey levels, showed that the sound pressure was more severe at upper storeys being they more exposed. The efficiency of different balcony forms for reducing exterior noise was determined using a 1:50 scale model and a single spark source and the results of the simulation were compared with those of the scale model test.
It was found that parapets were more effective in reducing exterior noise than the horizontal plates.
Based on the measurements of the parapet used for this study and the absorptive materials in the scale model, a maximum noise reduction of 23 dB was obtained.

A detailed study was done by Secchi S. et al. (2010). starting from the consideration that the façade sound insulation can be improved by using high performance components or by modifying the shape of the façade, but in many cases the use of high-performance components cannot be sufficient for technical reasons or for the cost.
The European standard EN 12354-3 gives a simplified method to estimate the influence of the façade shape in the reduction of sound pressure level at the outside of the building envelope.
The influence of the façade was evaluated for a number of building typologies as a function of the incoming sound general direction and of the surface acoustic absorption coefficient of the balcony underside.
The study has been carried out by means of a prediction software based on the modified theory of the ray tracing (pyramid tracing), and some of the configurations analysed have been tested also in a scale model.
With reference to a typical urban configuration, results are expressed as level difference between the simple plane façade and the façade with different kind of shielding as the example reported in Figure 3-6

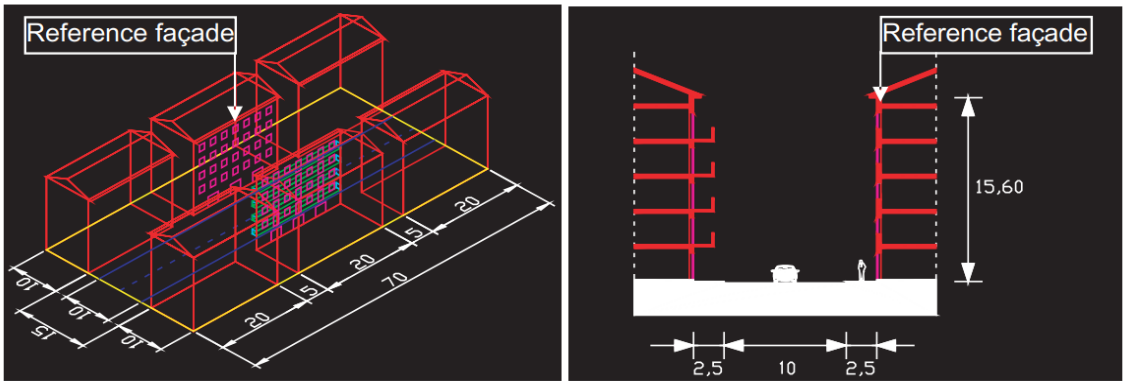

Figure 3-6 - Case study schemes (Secchi et al. 2010)

The conclusions show that the effect of the balcony depth is relevant (positive) only for the higher floors while the balcony length (gallery) greater than 4 m is not relevant in general.

The Figure 3-7 shows the results of balconies 1.5 m (left) and 3 m (right) deep and 4 m wide.

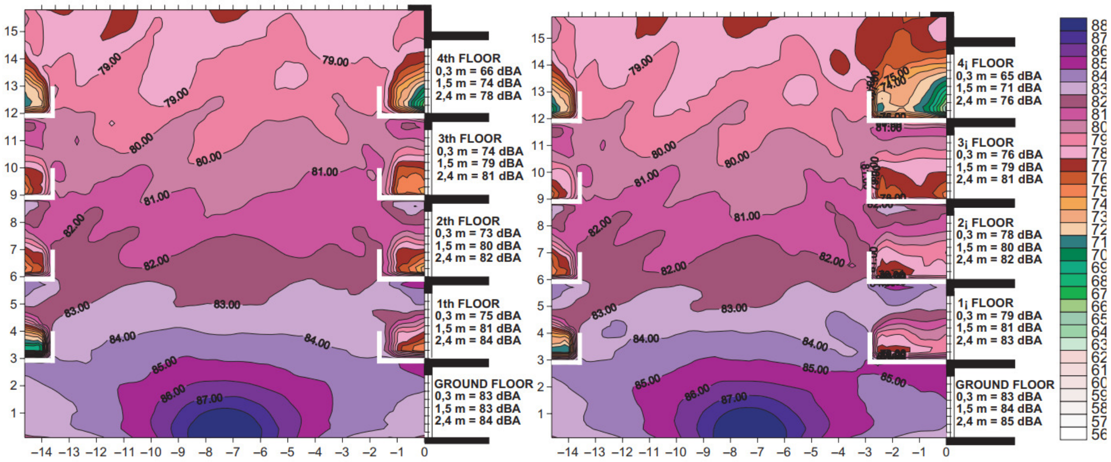

Figure 3-7 – SPL curves of 1,5 m. and 3 m. balconies (Secchi et al. 2010)

The structure of the window sill (parapet) creates a greater reduction of about 1÷3 dB if compared with an open banister; this positive effect increases at higher floors.

The inclination of the window sill of 10° forward produces a positive effect of 1 dB at every floor, as a consequence of the reduction of sound transmission for diffraction over the upper side of the window sill itself, while the inclination of the balcony ceiling surface produces no relevant effect on sound propagation.

Concerning shelves installed on the windows they have a positive effect for inclinations greater than 30°upward; the level difference may increase of 2 ÷ 3 dB at higher floors, in comparison to horizontal light shelves.

The case of staggered façades with full window sills, produce a great positive effect on noise level difference; with staggers of at least 3 m, the noise level difference may be greater than 10 dB, but this effect is partially due to the increased distance between the façade plane and the traffic line.

S. Secchi S. et al. (2010) in their study considered also the case with façades partially or totally covered with the absorbing material concluding that at ground floor, the effect of absorbing linings is relevant only with complete covering of façade surfaces and this positive effect of lining increases at higher floors;

In general, the better solution, which minimises the use of absorbing material (and also better protects this material from weather effects) is when the absorbing material is positioned on the ceiling balcony and on the internal side of the window sill (that is in accordance with the study of Lee P. J., at al., (2007).

The paper of Calleri C. et al. (2018) explored the possibility of integrating optimized façades design for outdoor noise mitigation into the preliminary building design phases through performance-based design, taking into consideration the contribution of materials.

Analysis have been conducted on a case-study building located in Turin through Rhinoceros 3D models, Grasshopper algorithms and Pachyderm Acoustic Simulation plug-in.

Different layers were used in the model for possible material changes i.e. the ceilings and the floors of the loggias, the parapets of loggias and balconies, the floors of balconies and the plaster of the whole façade.

The utilised algorithm allowed to test 3600 different combinations to maximize the environmental noise mitigation.

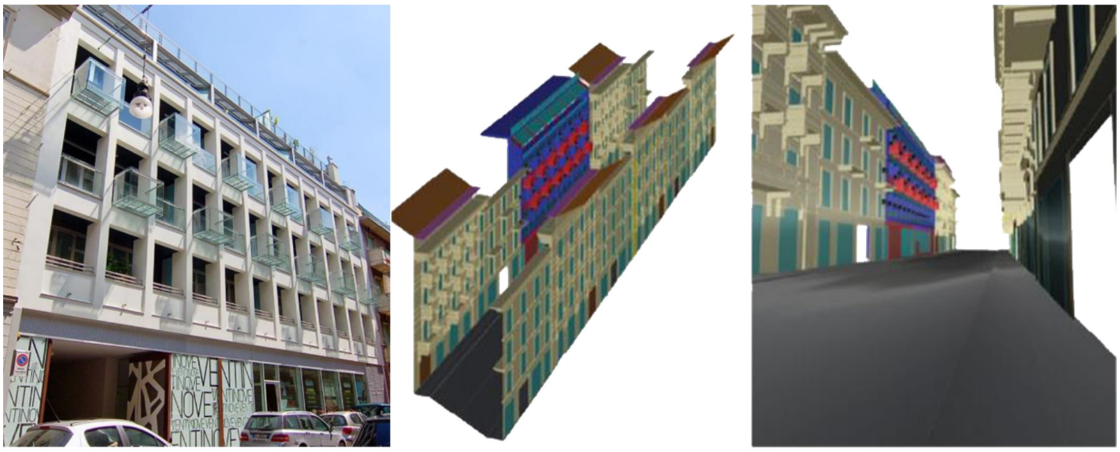

Figure 3-8- Real façade and models (Calleri C. et al., 2018)

A reduction of 1.2 dB was obtained by the optimization of materials keeping into account the realistic constraints which are present when designing a building façade.

Results of further simulations shows that sound absorbing materials on the street pavement and at the ground floor of the building have negligible effects for receivers placed above the ground floor, while variations in balconies geometries have a significant effect.

A very recent paper of Badino E. et al (2019) continuing the research of previous mentioned work of Calleri C. et al. (2018) on the same case-study, deepened and extended the simulation about the façade influence on SPL focusing on the pollution generated by the so called “talking noise or leisure noise”.

Further combination of the items influencing the SPL on façade have been investigated, as the different arrangements of the balconies, the shape variations of the façade elements and cladding variations.

In the following
Figure **3-9** and Figure 3-10 are shown the case-study model sketch and the different configuration of façade elements examined.

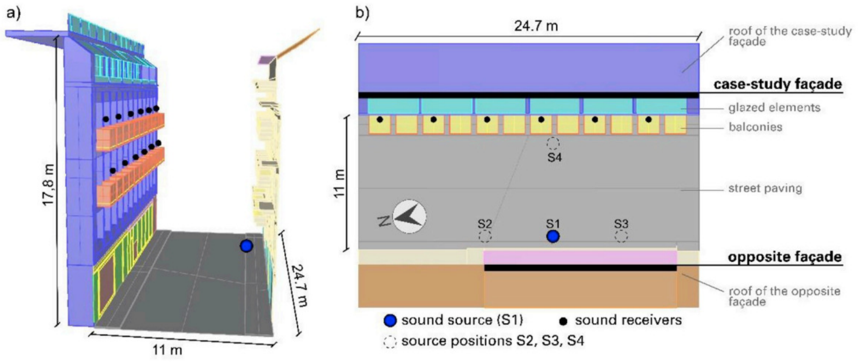

Figure 3-9- Case-study model (Badino E., et al., 2019)

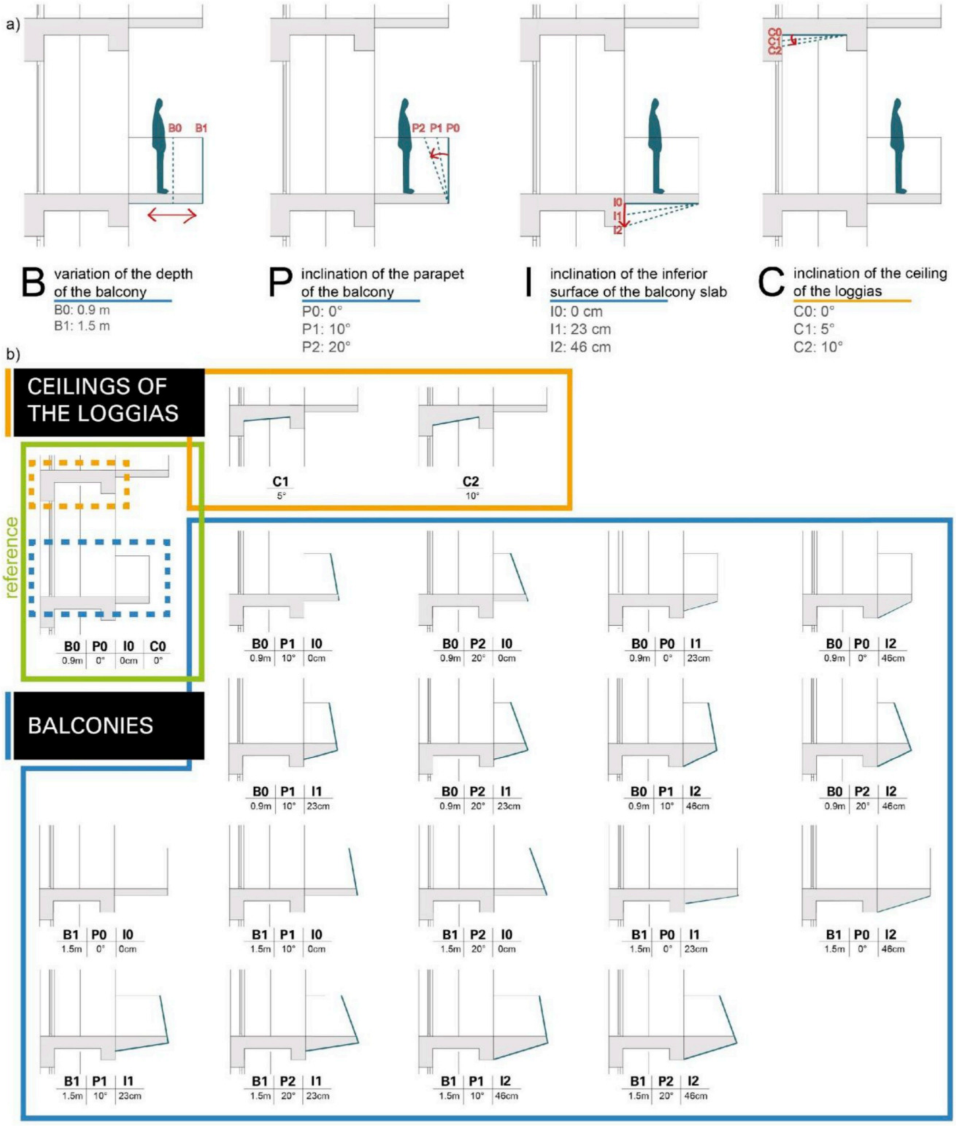

Figure 3-10- Shape variations of balconies and their elements (Badino E. et al. 2019)

The results highlight the screening effect provided by the balconies that increase with the floor height, and the benefits of the application of sound absorbing material over the façade.

Sensible decrease on the mean level (up to 1 dB) is obtained over the entire façade when the balconies depth passes from 0,9 m to 1,5 m with a maximum abatement of 2,8 dB at the highest floor

The introduction of adsorbing material for the cladding results in a mean noise level decrease up to 10 dB over the façade and contribute also to a reduction up to 3 dB over the opposite building façade.

All these reductions obtained by the façade interventions are sensibly higher than those obtained by adopting a sound adsorbing street paving, limited to 1,5 dB on average, underlining the importance of façade role in outdoor noise mitigation.

Combinations of these potential improvement have been evaluated, with care in the positioning of the receiver in respect of the reflecting surface in the two balconies typology.

3.4 Influence of road design

It is important to remember that the instantaneous noise production of a vehicle is defined by two main parameters, i.e. category and speed.

The rolling noise due to the tyre/road interaction depends on the nature of tires and road surface condition, while the propulsion noise depends on the driveline (engine, vehicle intake and exhaust discharge, transmission gears); aerodynamic noise is incorporated in the rolling noise sources (CNOSSOS 2012). All these factors are out of the control of architects and civil engineers.

In the already mentioned study of Echevarria S. et al. (2015) some calculations have been done about the influence of the road and relevant barriers.

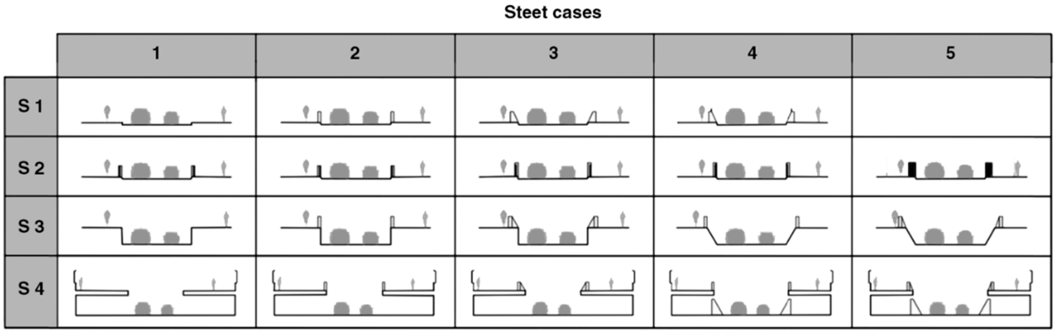

Figure 3-11- Street cases (Echevarria S. et al. 2015)

Low barriers next to the carriageway (sequence S1 of Figure 3-11) should be preferably inclined, additionally reducing 3.4 dB(A) for pedestrians, yielding a total road traffic noise reduction of 8.8 dB(A) with a small vertical lamina on its top. No important effect is observed along the façade except for lower storeys.

Absorption treatments on a vertical low barrier (sequence S2 of Figure 3-11) show a remarkable effect on the whole façade and large reductions for pedestrians.

The most advantageous case includes absorption on the source side, top and receiver side of the low barrier, however, the efficiency of this case is similar to a small inclined barrier without absorption.

A depressed road (sequence S3 of Figure 3-11) is highly efficient if its retaining walls are inclined. The median value is reduced by 10.6 dB(A) for pedestrians and large reductions are also found on the first floors. The addition of absorption material on the inclined retaining walls is only efficient if they are vertical.

Positioning the road at a second level (sequence S4 of Figure 3-11) has a strong beneficial effect for the sound pressure levels to which pedestrians are exposed and along the façade. A reduction up to 11.3 dB(A) is predicted for pedestrians and up to 11.5 dB(A) at the ground floor window.

About the incidental barriers an interesting study was performed by Montes González D. et al. (2017) where the effect of parking lines in urban street design on sound level distribution was numerically studied with the Boundary Element Method (BEM).

A screening effect was observed associated with the presence of parking lines. This effect varied depending from different factors as the height for measurement, the distances between the facades and the parking line, between the sound source and the parking line and the façade Figure 3-12

The results showed that the effect could be significant in many urban street configurations to determine the exposure of dwellings to traffic noise.

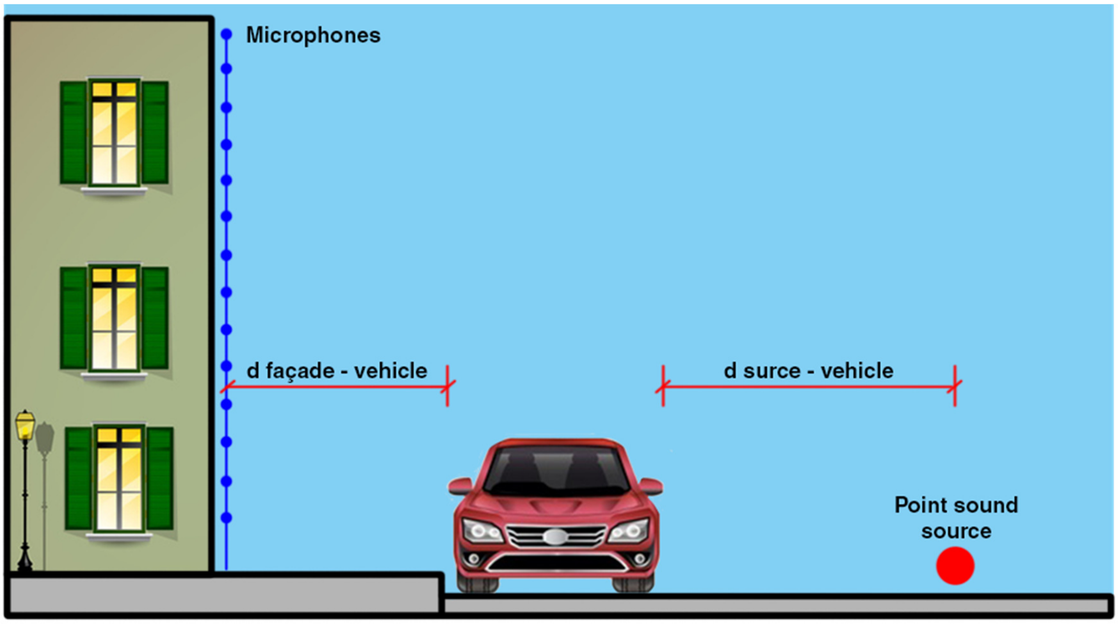

Figure 3-12 – Parking line scheme (Montes González D. et al. 2017)

Considering a fixed position of the parked vehicles with respect to the building façade under evaluation, the distance of the sound source was varied to simulate different urban context.

The most common configuration in urban design is that where the traffic lanes are close to the parking lines, positioned not exceeding 4 m while a distance greater than 4 m corresponds to many secondary avenues of cities.

For distances between the source and the parking line not exceeding 4 m, and for many heights of the façade there are important differences between the situations with and without a parked vehicle, for example, more than 3 dB at 2 m height.

In the cases of receivers located at heights of 1.5 and 2 m, curves for the differences of sound levels showed values, for all distances, of between 3 and 6 dB; at these heights, a large screen effect is detected by all the source-vehicle distances studied.

For the remainder of the heights, a decrease of the screening effect was observed as the distance between the source and parked vehicles increases.

Considering instead a fixed position for the sound source and varying the distance of parking line in respect of the building façade (increasing from 1m to 8 m), it was noted as general trend a decreasing of sound level with the parked cars progressively closer to the sound source.

However, the results also showed a dependency from the height of the receiver; with a receiver located at 1,5 metres, the difference in sound levels is fairly constant, regardless of the distance between the façade and the vehicle.

The large difference due to the presence of cars (over 5 dB) was recorded between the results found at 1.5 m and 4 m height up to a façade-vehicle distance of 4 m.

For other receivers placed at heights between 4 and 8 m, the difference in noise levels was negligible until a distance of 4 m between the façade and the vehicle, increasing sensibly from this point onward.

As general conclusion, a screening of the presence of parking lines for vehicles on the sides of urban was observed and the results demonstrated the importance of this effect in the selection of the height for measurements and in the validation of calculated noise maps assessing the impact of traffic noise on the population.

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4 NOISE LEVEL MEASUREMENT ON FAÇADE

The measurement of the noise level on a building façade is a difficult task to be carried out and results obtained shows always a certain margin of uncertainty (Barrigon Morillas et al.2016).

Dedicated norms provide rules and indications on how to perform the measurements and also on how to evaluate the corrections to be applied.

The purpose of the following paragraphs is to briefly describe how these issues have been faced by different researchers.

4.1 Sound Pressure Level measurement according to ISO 1996-2 (2007 and 2017 versions)

The ISO 1996-2:2017 describes how can be determined the Sound Pressure Level (SPL) intended as a basis for assessing environmental noise limits or comparison of scenarios in spatial studies.

This norm can be applied on all kinds of environmental noise sources such as road and rail traffic noise, aircraft noise and industrial noise.

The new release of 2017 contains widenings and more Annexes than the previous version dated 2007; it is meaningful that the title of Part 2 has been changed from the previous “Determination of environmental noise” into “Determination of sound pressure level”.

The determination can be done by direct measurement and by extrapolation of measurement results by means of calculation.

This norm is primarily intended to be used outdoors; the user performs the measurement and, accordingly, the evaluation of its uncertainty accordingly to the suggested rules.

No limits for allowable maximum uncertainty are set up (https://www.iso.org/standard).

The ISO 1992-2 explains in detailed manner how to proceed to determine the sound pressure defining the instrumentation, the principle and the strategies for the acoustical measurements, how to operate with the environmental sound sources keeping into consideration the different type traffic and the meteorological conditions.

An important part is dedicated to the measurement procedures, microphone location and to the evaluation of results.

An interesting and detailed study about this norm has been done by Barrigón Morillas et al. (2016) reviewing the proposed measurement procedures and investigating how other researchers have faced the problem of measurement uncertainty.

Barrigon Morillas performed a detailed review of the literature to study the relationships between the measurement procedure and the accuracy of the estimations of noise levels highlighting where discrepancies have been found in respect of the suggested default corrections of the ISO 1996-2 version 2007.

In fact. this paper was presented when the new version of this norm (dated 2017) was not yet released, and it can be noted that some modification has been introduced concerning the discrepancy issues raised by the literature.

These proposed sound corrections have been checked by different authors in urban environments by using “in situ” measurements or simulations discovering differences in respect of the original ISO indications.

In particular the investigations evaluated the influence of different microphones positions in respect of reflecting surface and noise source; the investigations were also extended to the height of microphone position.

In the following tables are reported the differences of the two versions of the ISO 1996-2 regarding the paragraph of “Measurement procedure” and the Annex B (informative) “Microphone locations relative to reflecting surfaces”.

The tables are divided in two columns to compare the correspondent sections of the two versions of the ISO 1996-2 issued in 2007 on the left side and in 2017 on the right side.

The differences found in the sentences are highlighted by the colours (red or green) and where necessary some specific note has been added.

Table 4-1– ISO 1996-2 (2007 vs 2017) Measurement procedure (I)

ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
8	MEASUREMENT PROCEDURE	9	MEASUREMENT PROCEDURES
8.1	Principle		(No correspondence)
8.2	Selection of measurement time interval	9.1	Selection of measurement time interval
	General indications about long term and short term measurements	9.1.1	Long-term measurements
			More detailed indications about long-term measurements
		9.1.2	Short-term measurements
			More detailed indications about Short-term measurements
8.3	Microphone location	9.2	Microphone location
8.3.1	Outdoors	9.2.1	Outdoors
	(No indications)	9.2.1.1	Selection of measurement site
			Generical indication given and added the suggestion to refer to Annex C for guidance in the site selection.

Table 4-2– ISO 1996-2 (2007 vs 2017) Measurement procedure (II)

ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
8.3.1	Outdoors	9.2.1.2	Selection of microphone location
	a) Incident sound field (reference condition)		1) Incident sound field (reference condition) - Same indications
	b) Location with the microphone flush-mounted on the reflecting surface.		2) Location with the microphone flush-mounted on the reflecting surface.
	• *In this case, the correction to use to get the incident field is -6 dB. The guidance of the conditions to be verified is in Annex B*		• *In this case, the correction to use to get free field is up to 6 dB. It is 5,7 dB if the conditions in Annex B are met.*
	• *For other conditions, other corrections have to be used.*		• *(same indication)*
	• *Note 1: +6 dB is the difference between a façade mounted microphone and a free-field microphone in an ideal case. In practice, minor deviations from this value will occur.*		• *Note 2 (same indication of Note 1 ed.. 2017) Reference to Annex B added.*
	c) Location with the microphone 0,5 m to 2 m in front of the reflecting surface.		3) Location with the microphone 0,5 m to 2 m in front of the reflecting surface.
	• *In this case, the correction to use to get the incident field is -3 dB. The guidance of the conditions to be verified is in Annex B*		• *In this case, the correction to use to get free field is up to 3 dB. It is 3 dB if the conditions in Annex B are met.*
	• *For other conditions, other corrections have to be used.*		• *(same indication)*
	• *Note 2: (Here are reported only the sentences showing differences)*		• *Note 3 (Here are reported only the sentences showing differences)*
	For general mapping use a microphone height of ➢ 4,0 ± 0,5 m in multi-storey residential areas.		*For general mapping, unless otherwise specified, use a microphone height of ➢ 4,0 ± 0,2 m in multi-storey residential areas.*
	In residential areas with a single floor and recreational areas use the microphone at a height of ➢ 1,2 ± 0,1 m or ➢ 1,5 ± 0,1 m For permanent noise monitoring other heights and microphone can be used [Other indication about acoustic mapping are reported]		[Equivalent sentence no longer reported]
8.3.2	Indoors	9.2.2	Indoors
	(out of the scope of this confrontation table)		(out of the scope of this confrontation table)
8.4	Measurements	9.3	Measurements
	(out of the scope of this confrontation table)		(out of the scope of this confrontation table)

Table 4-3– ISO 1996-2 (2007 vs 2017) Annex B (I)

ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
Annex B (informative)	Microphone position relative to reflecting surface	Annex B (informative)	Microphone locations relative to reflecting surfaces
	(Not present)	B.1	General
			General indications and reference to free-field sound pressure level has described in B.3
	(Not present)	B.2	Standard uncertainty of corrections for different locations
			A new section has been introduced about correction for different locations doing reference to a new Table B.1 (see below)

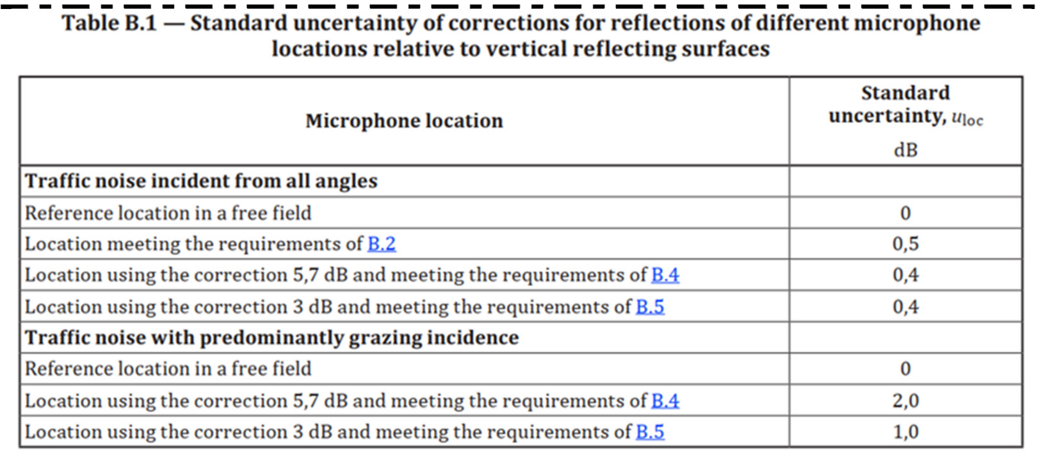


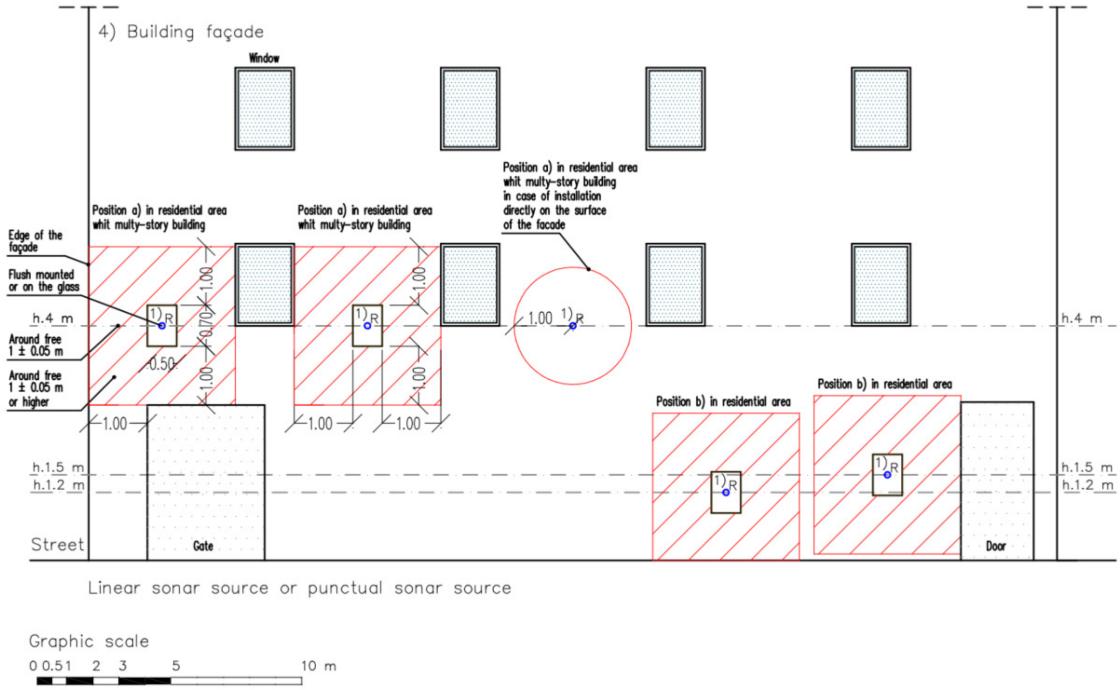
Table B.1 — Standard uncertainty of corrections for reflections of different microphone locations relative to vertical reflecting surfaces

Microphone location	Standard uncertainty, u_{loc} dB
Traffic noise incident from all angles	
Reference location in a free field	0
Location meeting the requirements of B.2	0,5
Location using the correction 5,7 dB and meeting the requirements of B.4	0,4
Location using the correction 3 dB and meeting the requirements of B.5	0,4
Traffic noise with predominantly grazing incidence	
Reference location in a free field	0
Location using the correction 5,7 dB and meeting the requirements of B.4	2,0
Location using the correction 3 dB and meeting the requirements of B.5	1,0

B.1	Free-field location	B.3	Free-field location
	Definition of free-field location *The distance from the microphone to any sound reflecting surface apart from the ground shall be at least twice the distance from the microphone to the dominating part of the sound source.*		[Same content]

Table 4-4– ISO 1996-2 (2007 vs 2017) Annex B (II)

ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
Annex B (informative)	Microphone position relative to reflecting surface	Annex B (informative)	Microphone locations relative to reflecting surfaces
B.2	Microphone directly on the surface	B.4	Microphone directly on the surface — Conditions for nominally +6 dB correction (The "+" sign is reported as such in the original text)



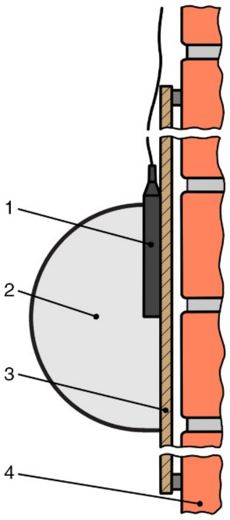


Fig B.1 - Microphone mounting on reflecting surface

Legenda

1 Rubber stripping
(no more mention in ISO 1996-2:2018)
2 Microphone
3 Windscreen
4 Wall or reflecting surface

Note: same scheme and content in both version 2007 and 2017.

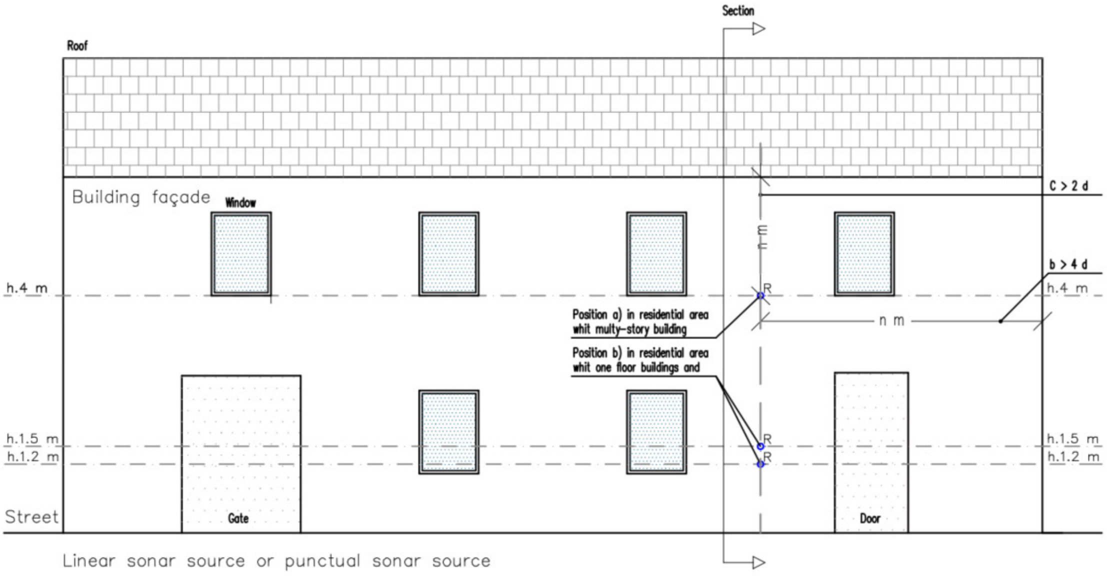
Table 4-5 – ISO 1996-2 (2007 vs 2017) Annex B (III)

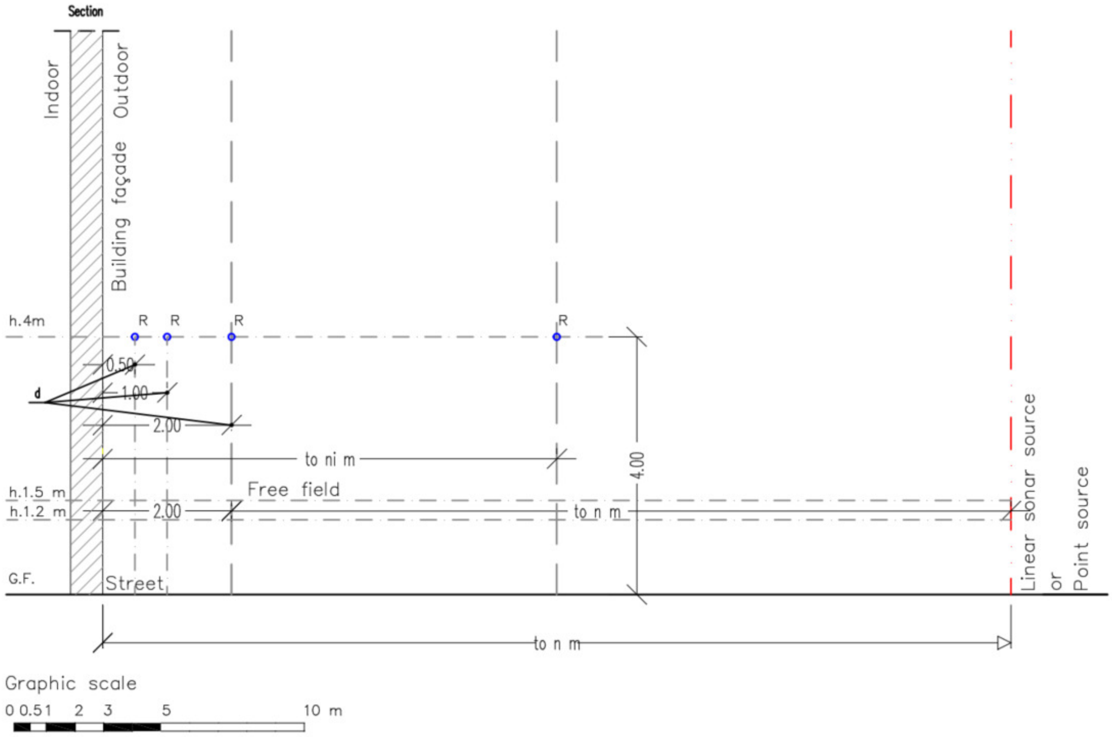
ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
Annex B (informative)	Microphone position relative to reflecting surface	Annex B (informative)	Microphone locations relative to reflecting surfaces
B.2	Microphone directly on the surface	B.4	Microphone directly on the surface — Conditions for nominally +6 dB correction (The "+" sign is reported as such in the original text)
• *Based on the restrictions and requirements described below, this position aims to achieve a well-defined* ➢ *+6 dB* *increase in the sound pressure level of the incident sound ("free field" level).*		• The default correction for this location is ➢ 5,7 dB **NOTE:** **the correction to be considered is now 5,7 dB**	
• *This location is flush-mounted on a reflecting surface and the direct and reflected sound will be in phase below a certain frequency, f. For broad band traffic noise with sound incident from many angles, f is about 4 kHz for a13 mm microphone mounted on the reflecting surface. This location should be avoided if the sound arrives predominantly at grazing incidence.*		• [same indication]	
• *The façade shall be plane within ±0,05 m within a distance of 1 m from the microphone and the distance from the microphone to the surface edges of the façade wall shall be larger than 1 m. The microphone can be mounted as shown in Figure B.1 or with the microphone membrane flush with the surface of the mounting plate. The plate should not be thicker than 25 mm and its dimensions not less than 0,5 m × 0,7 m. The distance from the microphone to the edges and symmetry axes of the mounting plate shall be greater than 0,1 m to reduce the influence of diffraction at the plate edges.*		• [same indication]	
• *The plate must be of acoustically hard and rigid material, such as for example painted plywood thicker than about 19 mm or a 5 mm aluminium plate with a minimum of 3 mm of damping material on the side facing the wall, to avoid sound absorption and resonance in the frequency range of interest.* *The plate in figure B.1 rests on flexible rubber strips to compensate for irregularities in the facade.* *Care should be taken not to create any disturbing aerodynamic noise between the plate and a rough facade.*		• [Same contents with different wording]	
• *The microphone can be used without a plate when the wall is made of concrete, stone, glass, wood or similar hard material. In this case, the wall surface should be flat within ±0,01 m within a radius of 1 m from the microphone.* *For octave-band measurements, a 13 mm microphone or smaller should be used. If the frequency range is expanded above 4 kHz, a 6 mm microphone should be used.*		• [Same contents with different wording]	

Table 4-6– ISO 1996-2 (2007 vs 2017) Annex B (IV)

ISO 1996-2 [Second edition 2007-03]	
Annex B (informative)	Microphone position relative to reflecting surface
B.3	Microphone near reflecting surface

ISO 1996-2 [Third edition 2017-07]	
Annex B (informative)	Microphone locations relative to reflecting surfaces
B.5	Microphone near reflecting surface — Conditions for nominally +3 dB correction





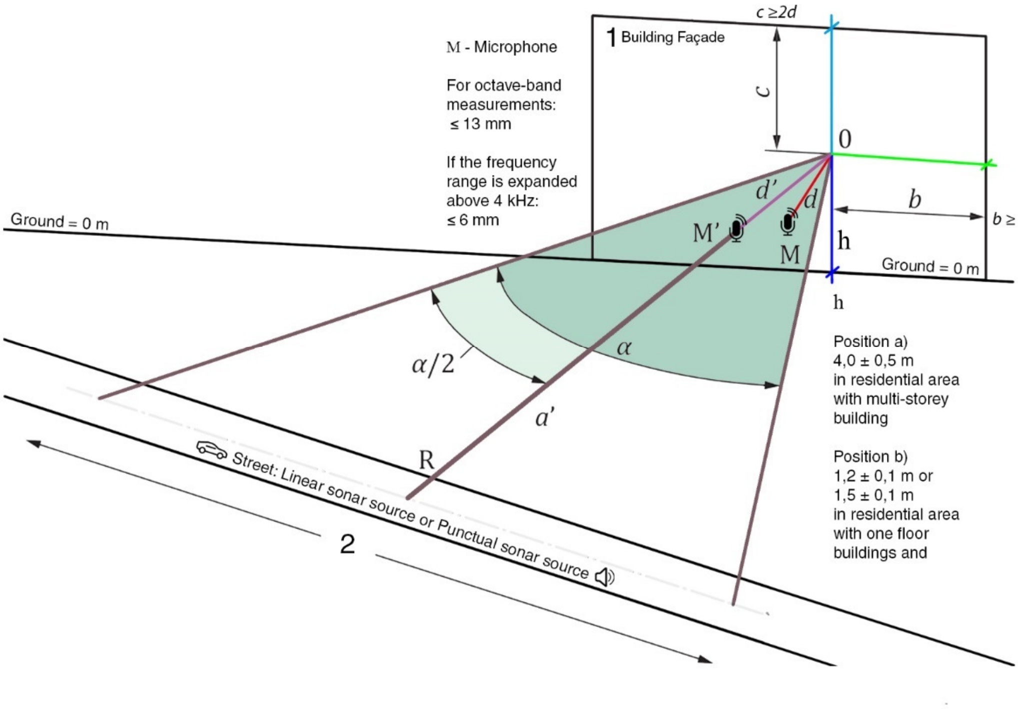


Fig B.1 – Geometry of microphone location near reflecting surface

Legenda

0	Point of the reflecting surface in front of which the microphone is mounted	α	Angle of view of road/rail on one side of the normal seen from 0
1	Building façade or other reflecting surface	M'	Equivalent microphone position on the line R0
2	Extended source	d	Perpendicular distance from the microphone position to the reflecting surface, 0
M	Microphone position	d'	Distance 0M'
R	Point where the ray from 0 meets the centerline of the road	a'	Distance 0R
R0	Dividing line of the angle in two halves	b, c	Distances to the edges of the reflecting surface
h	Microphone height from the ground		

Note: same figure and content in both version 2007 and 2017

Table 4-7– ISO 1996-2 (2007 vs 2017) Annex B (V)

ISO 1996-2 [Second edition 2007-03]		ISO 1996-2 [Third edition 2017-07]	
Annex B (informative)	Microphone position relative to reflecting surface	Annex B (informative)	Microphone locations relative to reflecting surfaces
B.3	Microphone near reflecting surface	B.5	Microphone near reflecting surface — Conditions for nominally +3 dB correction
This position aims to obtain a +3 dB increase in the sound pressure level of the incident sound ("free field" level).		Conditions for nominally +3 dB correction	
When the microphone is at a distance from a reflecting surface, the direct and reflected sound is equally intense and, when the frequency band considered is sufficiently wide, the reflection causes a doubling of the direct sound field energy and a 3 dB increase in sound pressure level.		[Same contents]	
The facade must be flat within ± 0.3 m. *The microphone must not be positioned in positions where the sound field is influenced by the multiple reflection of the sound between protruding surfaces of buildings.*		[Same contents]	
The windows must be considered as part of the facade and must be closed during the measurement.		*Windows shall be considered as any other part of the façade. They shall be closed during measurement, but a small opening for the microphone cable is allowed.*	
[here following are reported formulas concerning the condition of geometrical parameters]			
$b \geq 4d$ and $c \geq 2d$		Renamed as Criterion B.1 (same content)	
$d' \leq 0{,}1a'$ (extended source) $d' \leq 0{,}05a'$(point source)		Renamed as Criterion B.2 (same content)	
$d' \geq 0{,}5$ m (overall A weighted pressure level) $d' \geq 1{,}6$ m (octave band sound pressure level)		Renamed as Criterion B.2 (same content)	
$d' \geq 1{,}0$ m (overall A weighted pressure level $d' \geq 5{,}4$ m (octave band sound pressure level)		Renamed as Criterion B.3 (same content)	

4.2 Literature review on noise levels measurements on façade

Analysing the results obtained in different studies, significative variations were found regarding the corrections suggested by the ISO 1996-2; these variations could be motivated by very diverse circumstances, and they seem to be associated with the complex urban environment of the cities (Barrigon Morillas et al. 2016).

The urban environment implies the existence of distances between the sound source and façade that, for certain measurement configurations, do not allow compliance with the recommendations of the ISO 1996-2. Moreover, the sound field can be influenced in its propagation by size and shape of the façades or by urban elements such as parking lanes, and in some cases, it could become variable in time.

In the following tables have been reported the results of the comparison of the correction values obtained in the measurements with those recommended by the standard.

The measurements have been done following the indication of the ISO 1996-2 and varying in some cases, the position of microphones to check the influence on the sound corrections.

In the tables are reported test conditions with the measurement results obtained by different authors, showing if the correction suggested by the standard was verified or not.

The corrections describing what is recommended by the ISO 1996 -2 in both version 2007 and the new edition of 2017.

The “flush mounted position”, the “microphone position in front of the reflecting surface” and finally “microphone with respect of height” have been exploited.

Dedicated schemes show the geometrical position of microphones used in the tests are also shown.

Table 4-8– Flush mounted microphone

2007 ISO 1996-2 [Second edition 2007-03] Annex B (informative)	2008 Memoli et al. (2008) Flush mounted microphone	2017 ISO 1996-2 [Third edition 2017-07] Annex B (informative)
Microphone flush mounted on plate or directly on the reflecting surface ✓ *Correction 6 dB*	Test condition: • 2 microphones • h = 4.0 m height • range of distance (source – façade) from 6,6 to 34 m ✓ Recorded difference of 5,7 dB ± 0,8 (95% level of confidence)	Microphone flush mounted on plate: (same configuration of previous version) ✓ Default correction 5,7 dB

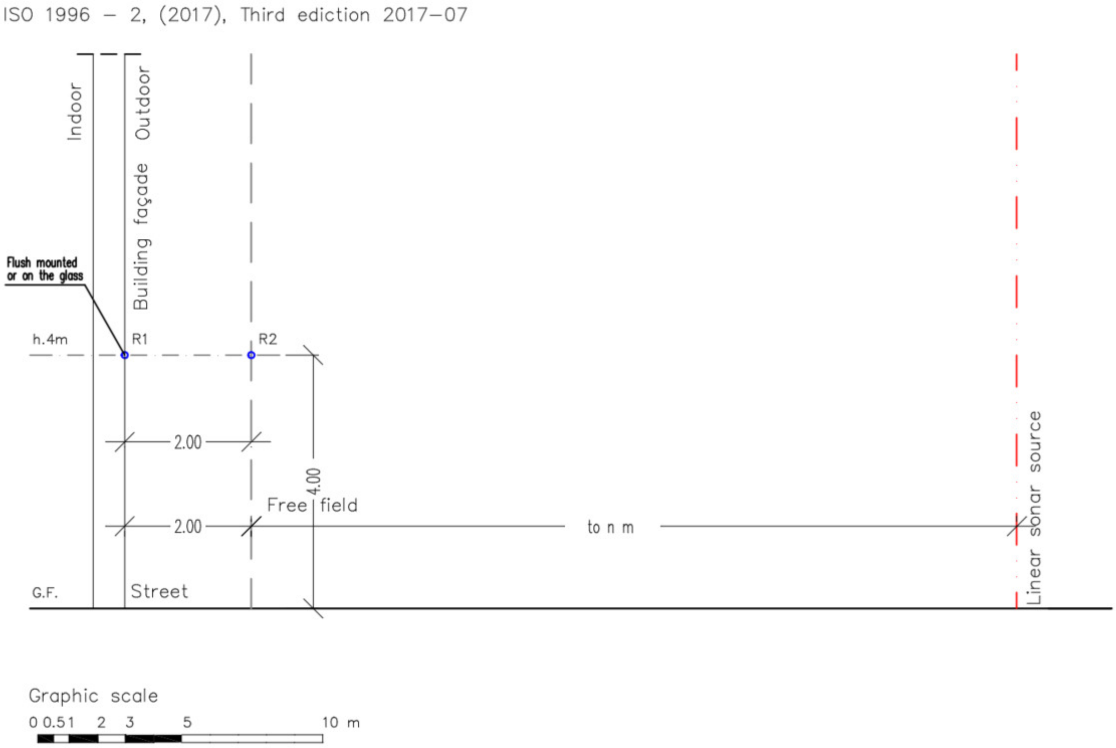


Figure 4-1– Flush mounted microphone [I]. (Memoli et al. 2008)

Table 4-9– Microphone in front of reflecting surface (I)

2007 ISO 1996-2 [Second edition 2007-03] Annex B (informative)	2009 Memoli et al. (2009) Microphone In front of reflecting surface	2017 ISO 1996-2 [Third edition 2017-07] Annex B (informative)
8.3.1 c) position with microphone 0,5 m to 2 m in front of the reflecting surface (No positioning specified from 0 to 0,5 m) 65	Test conditions: • One microphone d = 0,5 m; 1,0 m; 2,0 m and one microphone in free field • range of distance (source – façade) from 6,6 m to 34 m	Same microphone position
✓ *Correction 3dB*	✓ Difference of 3,0 dB ± 0,8 (95% level of confidence) for the range 0,5 ÷2,0 m and free field ✓ Difference of 2,7 dB ± 0,6 (95% level of confidence) for the range 0,5 ÷2,0 m and receiver flush mounted A part the tolerances, measurement matches with the ISO 1996	✓ *Correction 3 dB*

Memoli, G., Paviotti, M., Kephalopoulos, S., Licitra, G., (2008) – Applied Acoustics 69, 479–495.

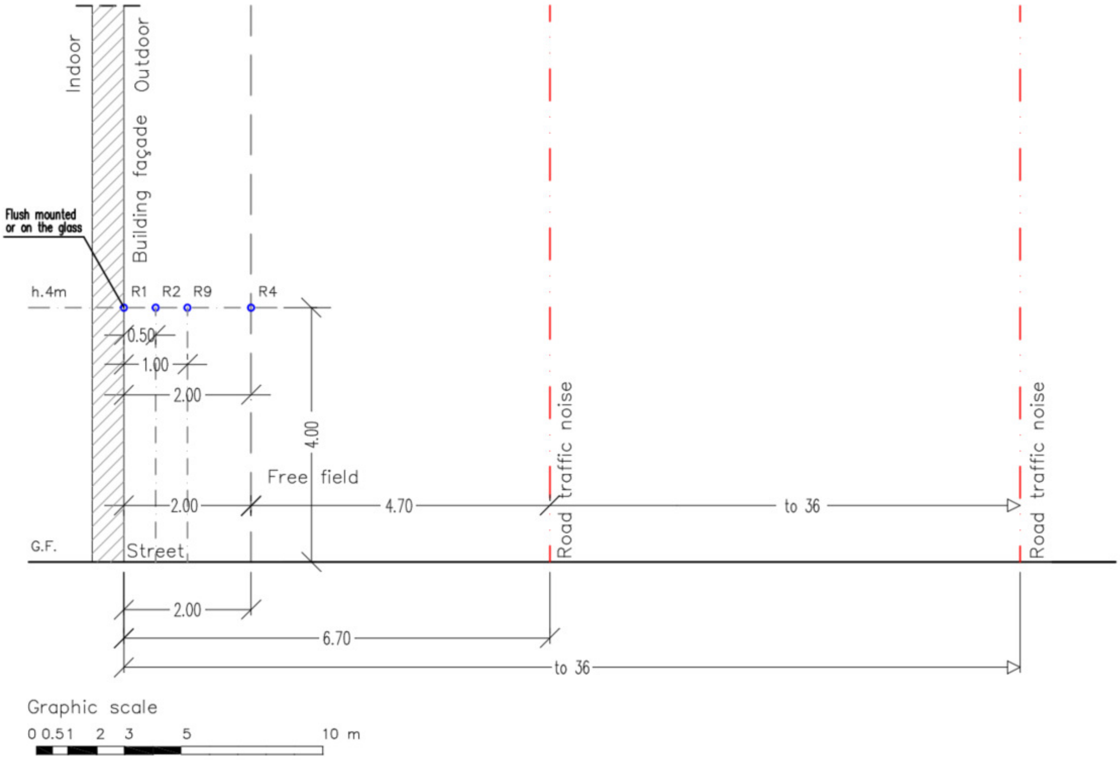
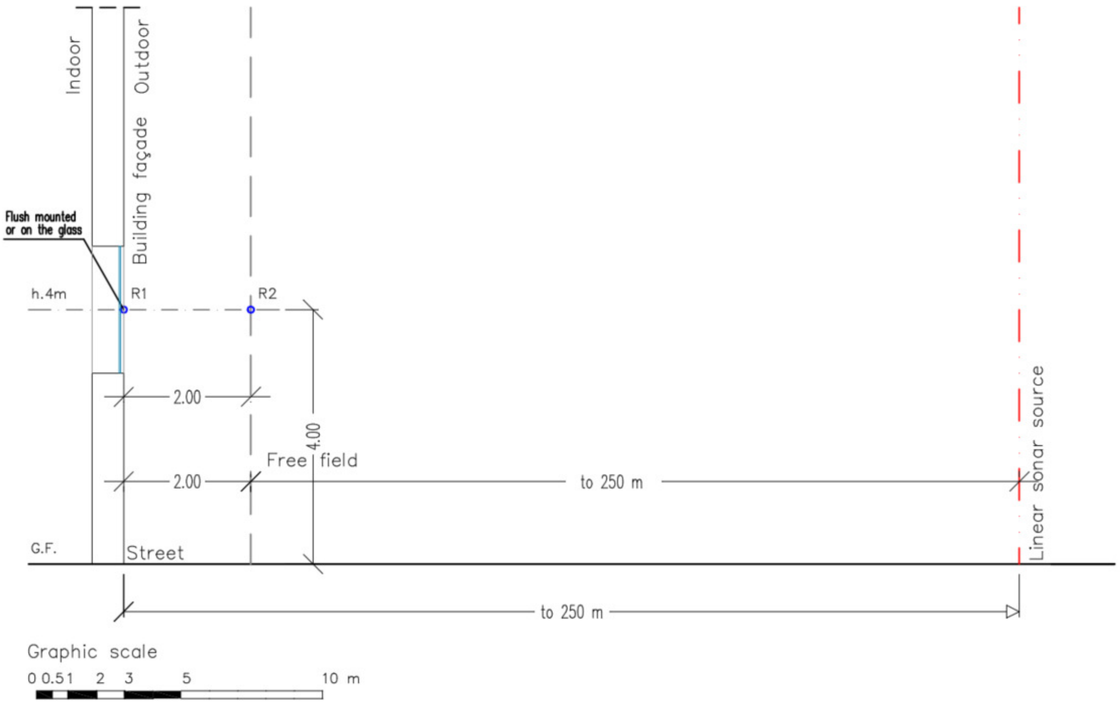


Figure 4-2– Microphone in front of reflecting surface (I). Memoli et al. (2009)

Table 4-10– Microphone in front of reflecting surface (II)

2007 ISO 1996-2 [Second edition 2007-03] Annex B (informative)	2014 Jagniatinskis and Fiks (2014) Microphone In front of reflecting surface	2017 ISO 1996-2 [Third edition 2017-07] Annex B (informative)
8.3.1 c) position with microphone 0,5 m to 2 m in front of the reflecting surface (No positioning specified from 0 to 0,5 m) ✓ *Correction 3dB*	Test conditions: • One microphone d = 2,0 m and one microphone flush mounted on a window • Range of distance (source – façade) 250 m ✓ Difference of about 3,0 dB ✓ sensible variation for measurement done by night (-2 dB) in respect of daytime probably depending on sound source	Same microphone position of previous edition ✓ *Correction 3 dB*



Jagniatinskis, A., Fiks, B., (2014) — Applied Acoustics 76, 377–385

Figure 4-3 - Microphone in front of reflecting surface (II).
Jagniatinskis and Fiks (2014)

Table 4-11– Microphone in front of reflecting surface (III)

2007 ISO 1996-2 [Second edition 2007-03] Annex B (informative)	2015 Montes González et al. (2015) Microphone In front of reflecting surface	2017 ISO 1996-2 [Third edition 2017-07] Annex B (informative)
8.3.1 c) position with microphone 0,5 m to 2 m in front of the reflecting surface (No positioning specified from 0 to 0,5 m) ✓ *Correction 3dB*	Test condition: • 1 mobile microphone d = 0,0m, 0,5 m; 1,2 m; 3,0 m • 1 reference microphone d = 2 m • range of distance (source – façade) from 8,2 m to 28,4 m • height according to ISO for mapping (1,5 m and 4,0 m) at h=1,5 m ✓ Difference of 1,1 dB if distance correction applied ✓ Difference of 1,7 dB if distance correction not applied at h= 4,0 m ✓ Difference of 2,0 dB if distance correction applied ✓ Difference of 2,6 dB if correction not applied Significant differences are noted	Same microphone position ✓ *Correction 3 dB*

Montes González, D., Barrigón Morillas, J.M., Rey, G.G., (2015) – Applied Acoustics 90, 64–73

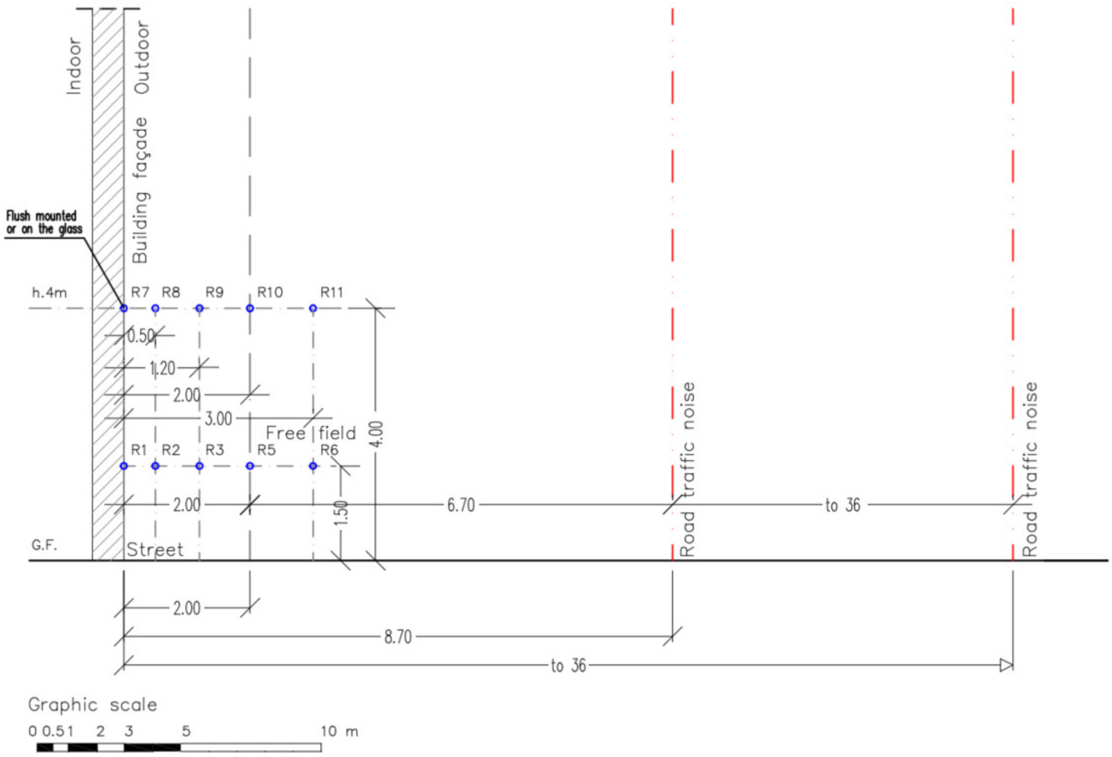


Figure 4-4 – Microphone in front of reflecting surface (III). Montes González et al. (2015)

References

- 2002/49/EC Directive of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise
- Barrigon Morillas J. M., Montez Gonzales D., Rey Gozalo G. (2016) – A review of measurement procedure of the ISO 1996 standard. Relationship with Europen Noise Directive.
- CETUR “Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores” 1980
- ISO 1996-2:2007 Acoustics -- Description, measurement and assessment of environmental noise., Part 2: Determination of environmental noise levels. www.iso.org/standard
- ISO 1996-2:2017 Acoustics -- Description, measurement and assessment of environmental noise., Part 2: Determination of sound pressure levels. www.iso.org/standard
- Jagniatinskis, A., Fiks, B., 2014. Assessment of environmental noise from long-term window microphone measurements. Appl. Acoust. 76, 377–385.
- Montes González, D., Barrigón Morillas, J.M., Rey, G.G., 2015. Influence of equipment location on results of urban noise measurements. Appl. Acoust. 90, 64–73.

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5 FAÇADE SHAPE LEVEL DIFFERENCE – UNI EN ISO 12354-3

The UNI EN ISO 12354-3:2017 standard specifies a calculation model to estimate the sound insulation or the sound pressure level difference of a façade or other external surface of a building.

This standard describes the façade as the whole outer surface of a room that can consist of different elements, e.g. window, door, wall, roof, ventilation equipment. The transmission of sound through the façade is due to the transmission by each of these elements assuming that this transmission for each element is independent from the those the others it includes direct and flanking transmission

5.1 Possible cases of façade shapes

In Annex C (informative) of the ISO 12354-3 it is taken into consideration the influence of the exterior shape of the façades which can have a positive or a negative effect on sound transmission.

The positive effect is due to the shielding or partial shielding by balconies or other objects, while the negative effect is due to extra-reflections and to a sound field that could be considered to be reverberant in case of balcony enclosures around the façade plane.

The Figure 5-1 shows the geometric parameters used for the evaluation of level difference while in Table 5-1 are reported the façade shape level difference ΔL_{fs} [dB] corresponding to a series of façade shapes represented by a vertical cross-section with the sound orientations indicated by the height of sight line on the façade.

The associated data represents a weighted average over frequency and these values can be used as a first estimate for frequency bands; in that case the data underestimates the effect in higher frequencies for differences larger than 3dB [ISO 12354-3]

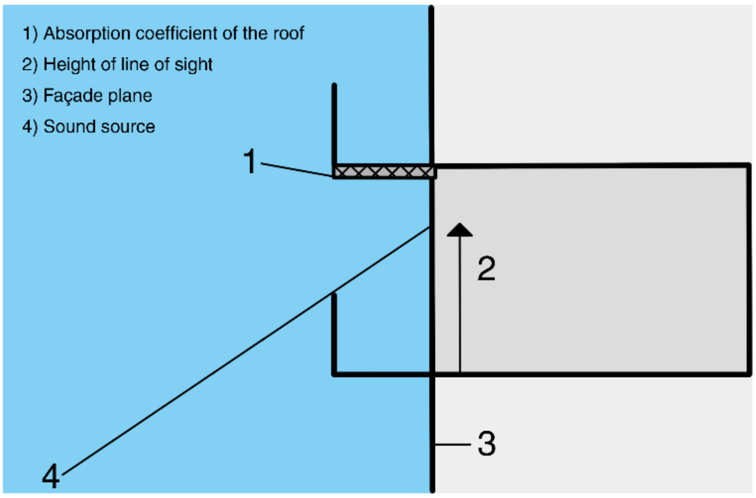
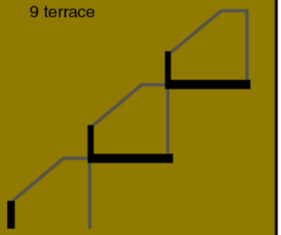


Figure 5-1 – Illustration of relevant parameters for façade shape
[Figure C.1 - ISO 12354-3:2017]

Table 5-1– Façade shape level difference for different façade shapes
[Tab C.1 - ISO 12354-3:2017]

ΔL_{fs} dB	1 plane façade 			2 gallery 			3 gallery 			4 gallery 			5 gallery 		
absorption roof (α_w) ⇒	does not apply			≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9
line-of-sight on façade : <1,5m	0			-1	-1	0	-1	-1	0	0	0	1	does not apply		
(1,5-2,5) m	0			does not apply			-1	0	2	0	1	3			
>2,5 m	0						1	1	2	2	2	3	3	4	6
ΔL_{fs} dB	6 balcony 			7 balcony 			8 balcony 			9 terrace 					
										open fence			closed fence		
absorption roof (α_w) ⇒	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9	≤0,3	0,6	≥0,9
line-of-sight on façade : <1,5m	-1	-1	0	0	0	1	1	1	2	1	1	1	3	3	3
(1,5-2,5) m	-1	1	3	0	2	4	1	1	2	3	4	5	5	6	7
>2,5 m	1	2	3	2	3	4	1	1	2	4	4	5	6	6	7

To use this table, it is necessary to identify the type of façade shape, the absorption capability of the balcony ceiling and the height of the line of sight.

As example, in Table 5-1 referring to the “3 gallery” there is a negative effect on the façade of -1 dB when there is no contribution of the absorption by the roof and the line of sight is ≤ 1,5 m. Increasing both height of the line of sight and absorption capability, the effect improves progressively up to +2 dB.

In the introduction of this standard is reported that the “calculation gives results which correspond approximately to the results from field measurements in accordance with ISO 16283−3”, but the accuracy of the prediction method is not specified.

In the paper of (Saarinen A. 2002) the tolerance of the method is studied by comparing the calculation with the laboratory and field measurement results of different types of facades.

The accuracy of the predictions by using the standard EN 12354-3 in laboratory conditions is satisfactory for airborne sound insulation. Considering the weighted sound reduction index of facade for diffuse incident sound field, the mean and standard deviation of the difference between the calculated and measured values is 0.3±0.4 dB in laboratory conditions.

The modification of the source room sound field or the profile of the façade has not influenced considerably the measured weighted sound reduction index values of the façade. No explicit refence to balcony influence is mentioned even if a balcony was present in the laboratory model.

In field conditions when the diffuse field part predominate the total sound field, the empirical estimation of acoustical properties of building facade elements lead to quite large tolerances in the evaluation method compared to laboratory results (3,8 ± 3,8 dB mean and standard deviation).

The conclusion of this study shows that the empirical estimation of acoustical properties of building facade elements lead to quite large tolerances in the evaluation method compared to laboratory results. When the acoustic data are based primarily on standardized laboratory measurements, the calculation method delivers very satisfactory estimation.

As already mentioned In the previous paragraph 3.3 “influence of façade design”, the ISO 12354-3 was applied by Secchi S. et al. (2010). The estimation of the level difference ΔL_{fs} [dB] was done by mean of the specific formula of the ISO standard, but even the empirical method of Table C.1 is mentioned with the consideration that it takes into account only few kinds of façade shapes.

References

- UNI EN ISO 12354-3 (2017) - Estimation of acoustic performance of buildings from the performance of elements Part 3: Airborne sound insulation against outdoor sound
- Saarinen A. (2002) – Reduction of external noise by building facades: tolerance of standard EN 12354-3.
- Secchi S., Busa L., Baldini S. (2010). Effect of façade shape for the acoustic protection of buildings. Building Acoustics 17 (04) (2010) 317–338

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6 Influence of the position receivers on the measurement of SLP: simulation with Odeon 13.

6.1 Purpose of the simulation

The purpose of the simulation is to investigate the effect on the Sound Pressure Level (SPL) measurement by varying the distance of a reference microphone from the building façade.

The simulation has been repeated considering different cases of façade geometries belonging to a building located in the narrow Via Saluzzo, that crosses the San Salvario district in Turin.

The present work has explored possible optimal distances to obtain accurate measurements, starting from what is recommended by the standards and from what has been analysed by various authors in the specialistic literature, all that considering the influence of different façade geometries.

The study is based on the previous works done in their Master Theses by Roberto Manca (2017) and Elena Badino (2018), focused on the effect that a new façade design has on the acoustic environment of the street where the building is located, that in this case, can be ranked as a street canyon. The same 3D model has been used for the new acoustic simulations performed with the Odeon 13 software tool.

6.2 Localization of the building used as model in the simulations

The urban section considered in the simulation, is located in Via Saluzzo (Turin) and includes the building to which belongs the refence façade (house number 29) and the facing construction (house number 42).

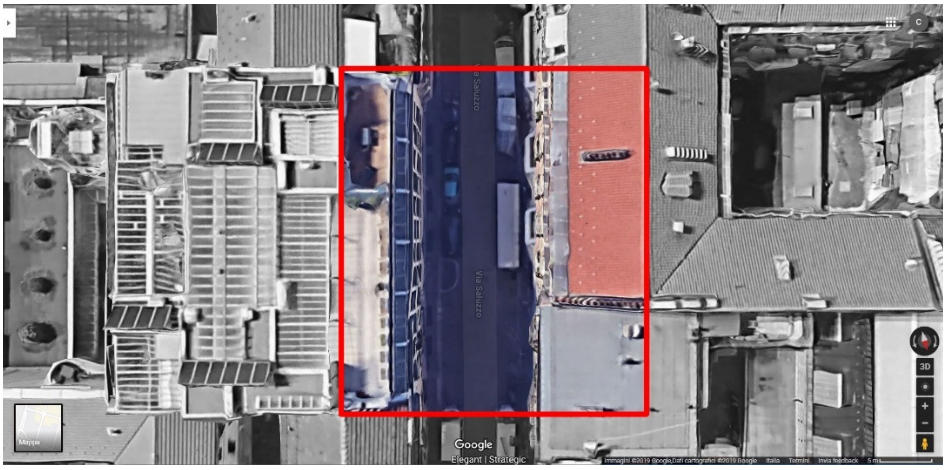


Figure 6-1 – Torino, Via Saluzzo, no. 29 to the left, no. 42 to the right (www.google.com/maps)

The case-study is modern construction designed in 2010 by the architects Rolla and Raschiatore and it is part of San Salvario, an historical district composed by residential buildings of the 19th century mainly.

Today the San Salvario district, positioned in the heart of the city of Turin, maintains its characteristics with high density of building, population, many commercial and leisure activities; in addition, it has become recently the theatre of Turin's “movida”.

Via Saluzzo, which crosses Largo Saluzzo square close to the building, in fact, is crowded both during the day and the night, with an high concentration of accommodation facilities such as bars, restaurants, pubs as well as retail and services.

This case-study has 5 floors above ground where the residential apartments occupy the first up to the fourth floor, while in the ground floor are located offices and other commercial activities.

The facade of the building is characterized by the presence of alternate balconies on the first and second floor, while the third and fourth floor have loggias along their entire length.

The choice of this building was based on the consideration that its architectural morphology, its recent design and the presence of both balconies and loggias, make it a suitable starting point to investigate how the facade design is able to contribute to the enhancement of acoustic comfort in urban areas, and also to help the definition of guidelines for building designers to be used use in new and retrofit projects.

Figure 6-2 – Torino, Via Saluzzo with case-study building to the left (I) (www.google.com/maps)

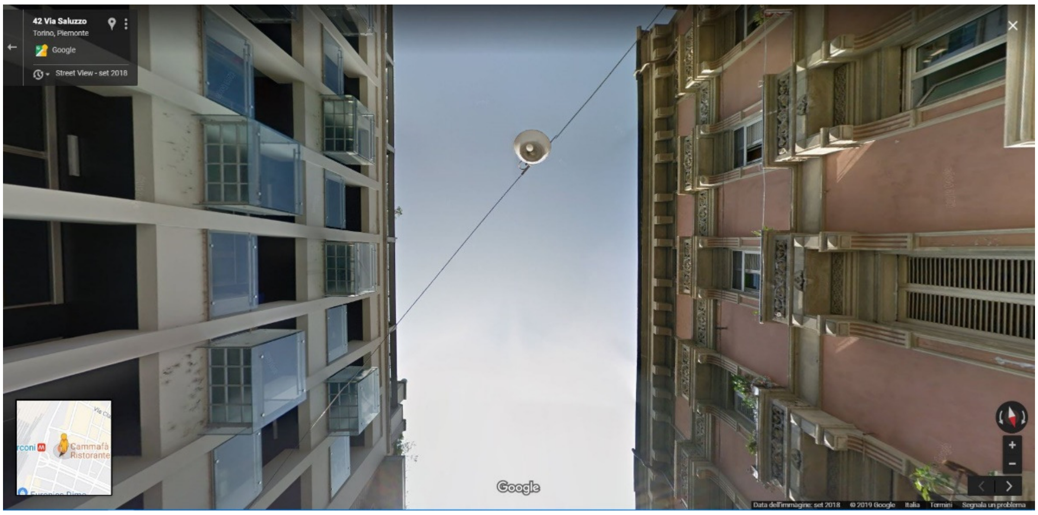


Figure 6-3 – Torino, Via Saluzzo, case-study building to the left (II) (www.google.com/maps)

Figure 6-4 – Torino, San Salvario district (www.google.com/maps)

Figure 6-5 – Torino, Largo Saluzzo, Via Saluzzo (www.google.com/maps)

6.3 Introduction to simulation

The determination of the acoustic field in large environments is usually performed by doing reference to a geometric type approximation, applicable when the sound wavelength has negligible dimensions with respect to the elements constituting the surrounding environment.

Odeon 13, the tool used to run the simulations, is a software based on the laws of geometric acoustics and is able to simulate the acoustic conditions of a closed environment or an open environment if the model is appropriately built.

Therefore, to perform a simulation in open environment, as the case-study of Via Saluzzo, it is necessary to create a completely sealed volume to include the 3D model in such a way that the software tool can correctly work. The sealed volume is built attributing to its surfaces a totally adsorbent acoustic property and therefore their behaviour simulates the free field of an open space.

The 3D models of street section with different façades was created using Rhinoceros by Badino E. (2018) starting from the original version of Manca R. (2019) and then it was imported into Odeon 13.

To each surface of the models imported, were assigned the specific acoustic characteristics of the different materials of the façade.

Odeon 13 contains a library of materials to which the specific acoustic parameters are associated, but considering the complexity of the environment to be studied and the large number of different surfaces to which to assign the coefficients, a new specific library has been created to approximate in better way the real status of façade. In this work, same materials have been used.

In the simulations the acoustic beams are launched from an omnidirectional punctual source and from a linear source in all directions up to the maximum order of reflection; these sources are appropriately positioned in the models as well as the receivers are positioned accurately for the purpose of the simulations.

6.3.1 Street and building data

The length of the modelled street is 80 m and its width from the opposite façades is 11 m; the height of the facing buildings is in between 14 and 18 meters. The street is a one-way vehicular road, that is normally subjected to a low level of traffic; the main noise source is generated by people talking on the street platforms, especially at night times.

Figure 6-6 – Torino, Via Saluzzo, South - North direction (www.google.com/maps)

Figure 6-7 – Torino, Via Saluzzo, North - South direction (www.google.com/maps)

Figure 6-8 – Torino, Via Saluzzo, façade of house number no.29 and floor markers (www.google.com/maps)

- The overall height of the building is 17.8 m while its width is 24.7 m.
- The ground floor has a flat and homogeneous front made up of a glass surface (shop windows).
- The first floor is characterized by loggias, which occupy the entire length of the building façade, which have a depth of 0.95 m.
- the second and third floors have loggias and balconies arranged with alternating and staggered rhythm. The balconies protrude the façade by 0.9 m, they have a width of 1.56 m and height of 1.30 m.
- the top floor has interconnected loggias, covered by the inclined plane of the roof where there is a terrace.

6.3.2 Receivers position

The different positions of the microphone in respect of the façade have been placed in the model in accordance with the ISO 1996–2:2017 and with the indication taken from the papers of Memoli, G. at al, (2008), Jagniatinskis, A. at al, (2014), Montes González, D. (2015).

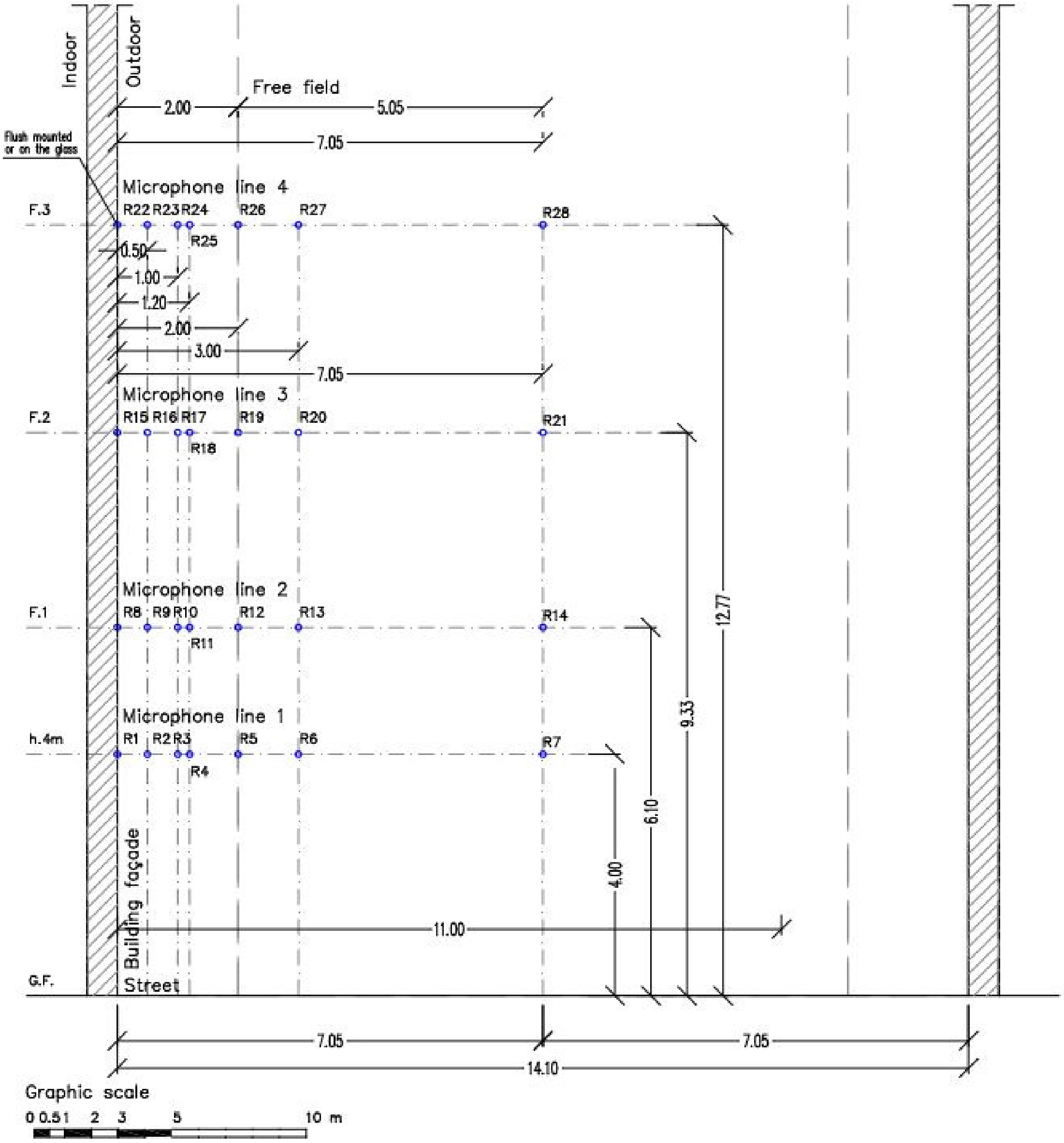


Figure 6-9 – Diagram of the arrangement of the receivers

- The fixed receivers are placed on the façade in four lines at heights of 4 m, 6.10 m, 9.33 m and 12.77 m. The four lines are horizontal and parallel to the building façade.
- The 4 m line corresponds approximately to the level separating the ground floor from the first one and it is at the height given by the ISO 1996 – 2:2017.
- The 6.10 m, 9.33 m and 12.77 m receivers lines corresponding to the first, second and third floors, are positioned at 1.6 m high from each floor level.

- The receivers are placed, in all the four lines, at the following distances from the façade:
  - 0,00 m (flush mounted)
  - 0.50 m
  - 1,00 m
  - 2.00 m
  - 3.00 m (free field)
  - 7.05 m (in free field and geometrical axis of to the street)

There is a difference in the model in respect of the real façade of the building because the ground floor is set back by 1.60 m; therefore, the receivers placed at the ground floors are not in line with those located on the upper floors.

In Figure 6-10 is showed the positions of microphones in respect of the street section.

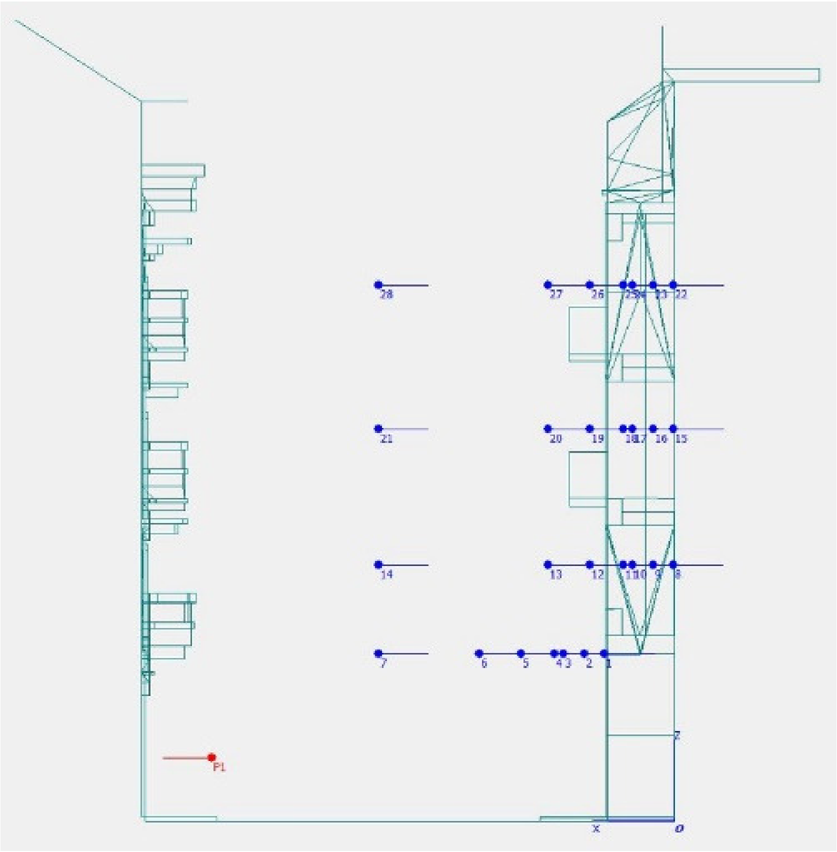


Figure 6-10 – Diagram of the arrangement of microphones in the street section by Odeon 13

In the following FigureFigure 6-11, Figure 6-12, Figure 6-13, Figure 6-14 and Figure 6-15 are reported different views taken from the 3D model in Odeon 13.

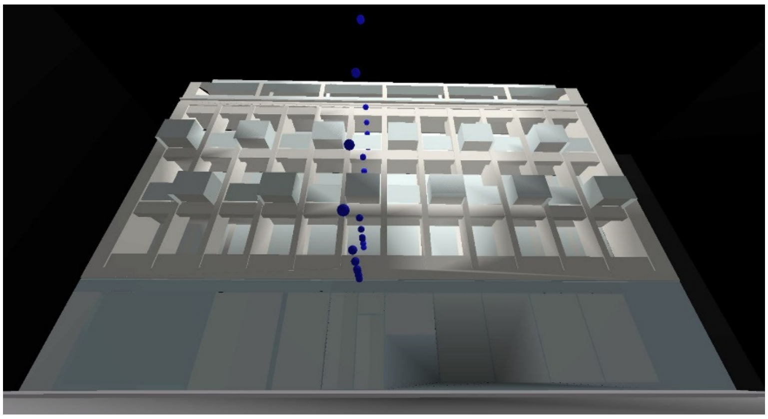


Figure 6-11 – Receivers on the current facade of the building. 3D model in Odeon 13 (I)

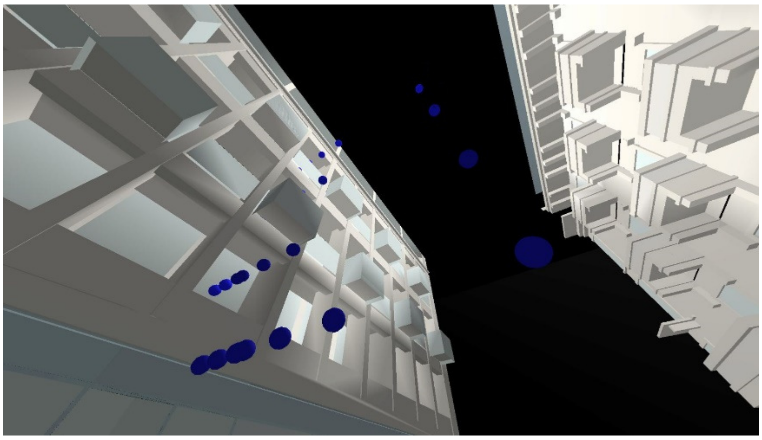


Figure 6-12 - Receivers on the current facade of the building. 3D model in Odeon 13 (II)

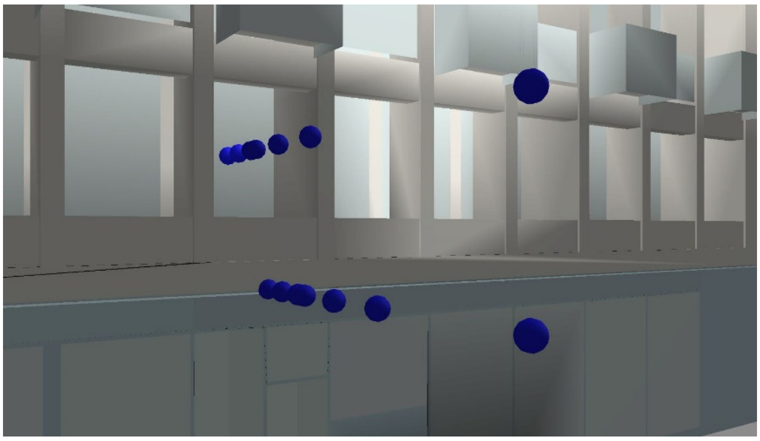


Figure 6-13 – Receivers on the current facade of the building. 3D model in Odeon 13 (III)

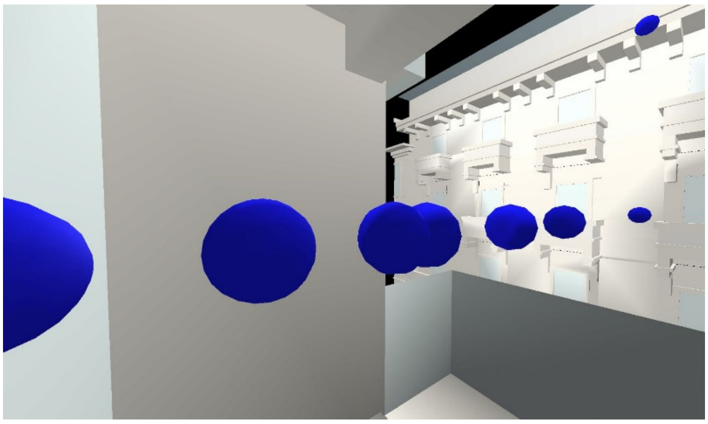


Figure 6-14 – Receivers on the current facade of the building. 3D model in Odeon 13 (IV)

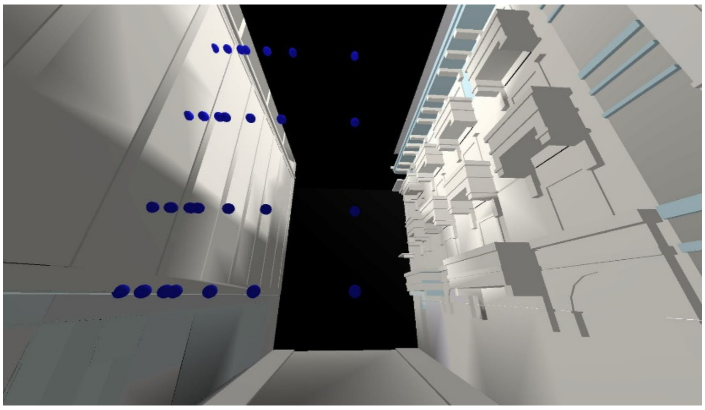


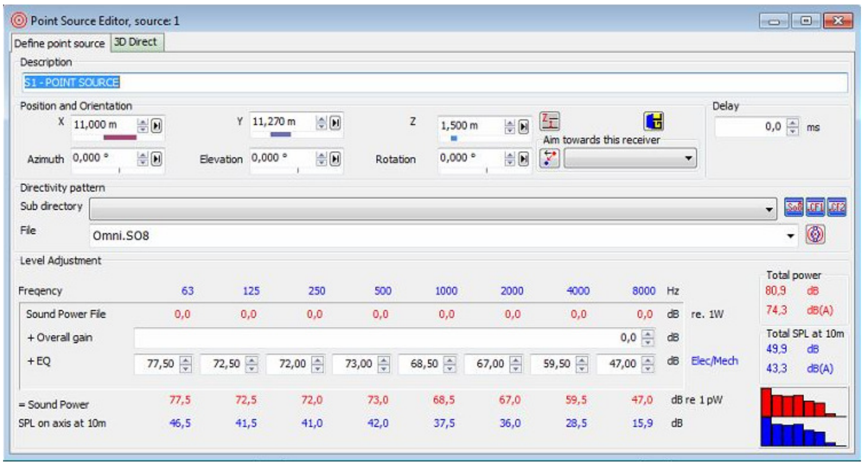
Figure 6-15 - Receivers on the current facade of the building. 3D model in Odeon 13 (V)

6.3.3 Sound source position

As previously reported, two sound sources have been utilized:

- A punctual sound source located at 1.5 m from the street level and at 11 m in front of the facade with the physical characteristics shown in Figure 6-16.

Same source type and sound characteristics were used by Badino E. (2018) for the simulation of movida noise.



Description: S1 - POINT SOURCE

Position and Orientation
X 11,000 m
Y 11,270 m
Z 1,500 m
Azimuth 0,000 °
Elevation 0,000 °
Rotation 0,000 °
Delay 0,0 ms

Directivity pattern
Sub directory
File Omni.SO8

Level Adjustment

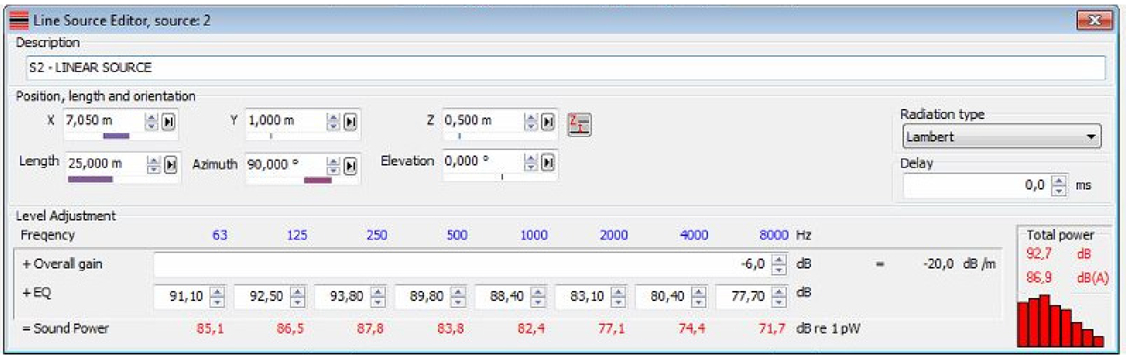
Freqency	63	125	250	500	1000	2000	4000	8000	Hz	
Sound Power File	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dB	re. 1W
+ Overall gain								0,0	dB	
+ EQ	77,50	72,50	72,00	73,00	68,50	67,00	59,50	47,00	dB	Elec/Mech
= Sound Power	77,5	72,5	72,0	73,0	68,5	67,0	59,5	47,0	dB re 1 pW	
SPL on axis at 10m	46,5	41,5	41,0	42,0	37,5	36,0	28,5	15,9	dB	

Total power
80,9 dB
74,3 dB(A)

Total SPL at 10m
49,9 dB
43,3 dB(A)

Figure 6-16 – Punctual sound source parameters set in Odeon 13

- A linear sound source located at 0.5 m from the street level and 7.05 m in front of the façade with the physical characteristics shown in **Errore. L'origine riferimento non è stata trovata.**-



Description: S2 - LINEAR SOURCE

Position, length and orientation
X 7,050 m
Y 1,000 m
Z 0,500 m
Length 25,000 m
Azimuth 90,000 °
Elevation 0,000 °
Radiation type Lambert
Delay 0,0 ms

Level Adjustment

Freqency	63	125	250	500	1000	2000	4000	8000	Hz
+ Overall gain								-6,0	dB = -20,0 dB /m
+ EQ	91,10	92,50	93,80	89,80	88,40	83,10	80,40	77,70	dB
= Sound Power	85,1	86,5	87,8	83,8	82,4	77,1	74,4	71,7	dB re 1 pW

Total power
92,7 dB
86,9 dB(A)

Figure 6-17 – Linear sound source parameters set in Odeon 13

Same type source and sound characteristics were used by Daniela Falzone (2012) in a simulation done for her three-year degree thesis; she measured “on the field” the traffic noise in Largo Saluzzo (a square hundred meters away from the building) and then calibrated the linear sound source with respect to the model of the square.

Figure 6-18 – Torino, Via Saluzzo, distance between Largo Saluzzo and the building study case (www.google.com/maps)

The original sound power of 92.7 dB has been reduced by -6 dB because Via Saluzzo is less subject to vehicular traffic than the adjacent Largo Saluzzo.
To determine the subtraction of -6 dB, the value of 92.7 dB was compared with those of City of Turin acoustic mapping, which are 60 - 64 dB (A) and 65 - 69 dB (A) in the area between Via Saluzzo and Largo Saluzzo are (see next Figure 6-19).

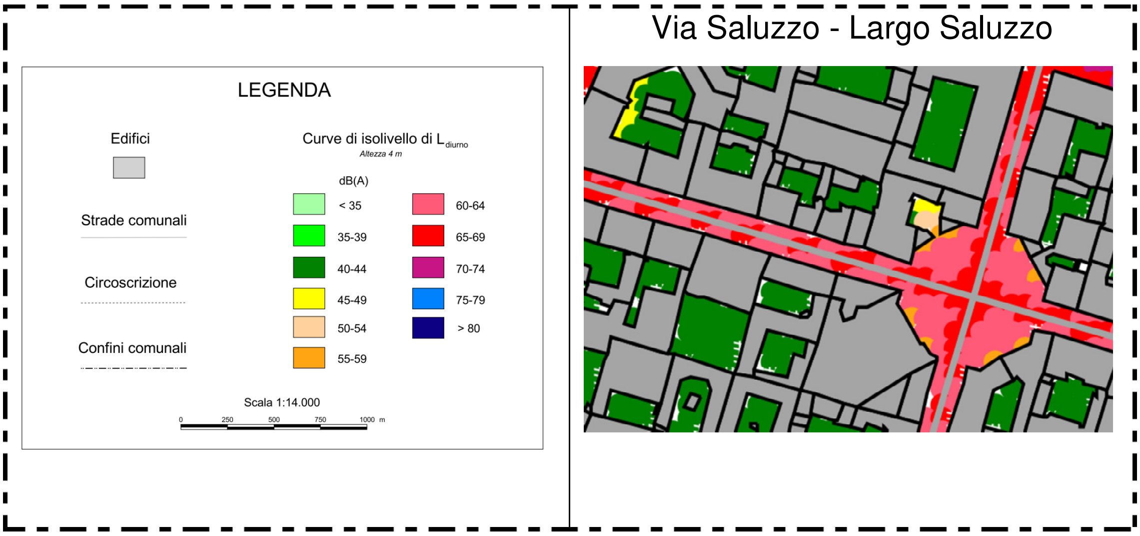


Figure 6-19 – Acoustic mapping of the road infrastructure of the City of Turin (Law 447/95 and Legislative Decree 194/05, District 8, San Salvario

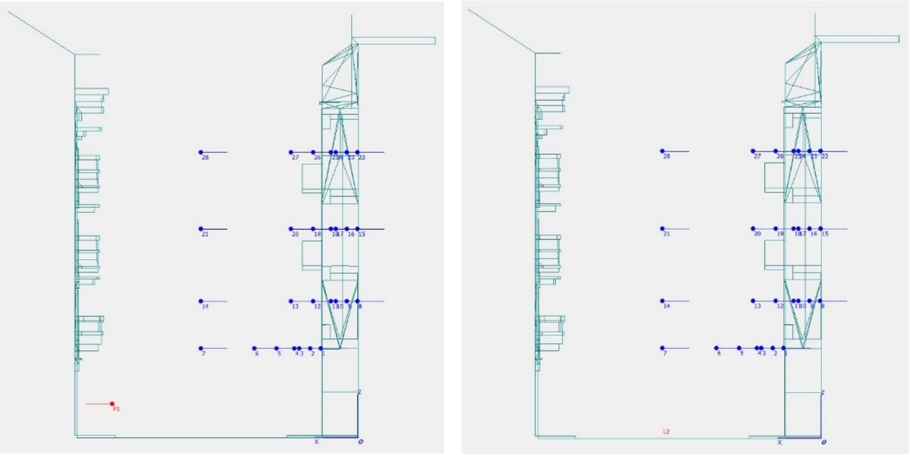


Figure 6-20 – Receivers and point and linear source positions (Odeon 13)

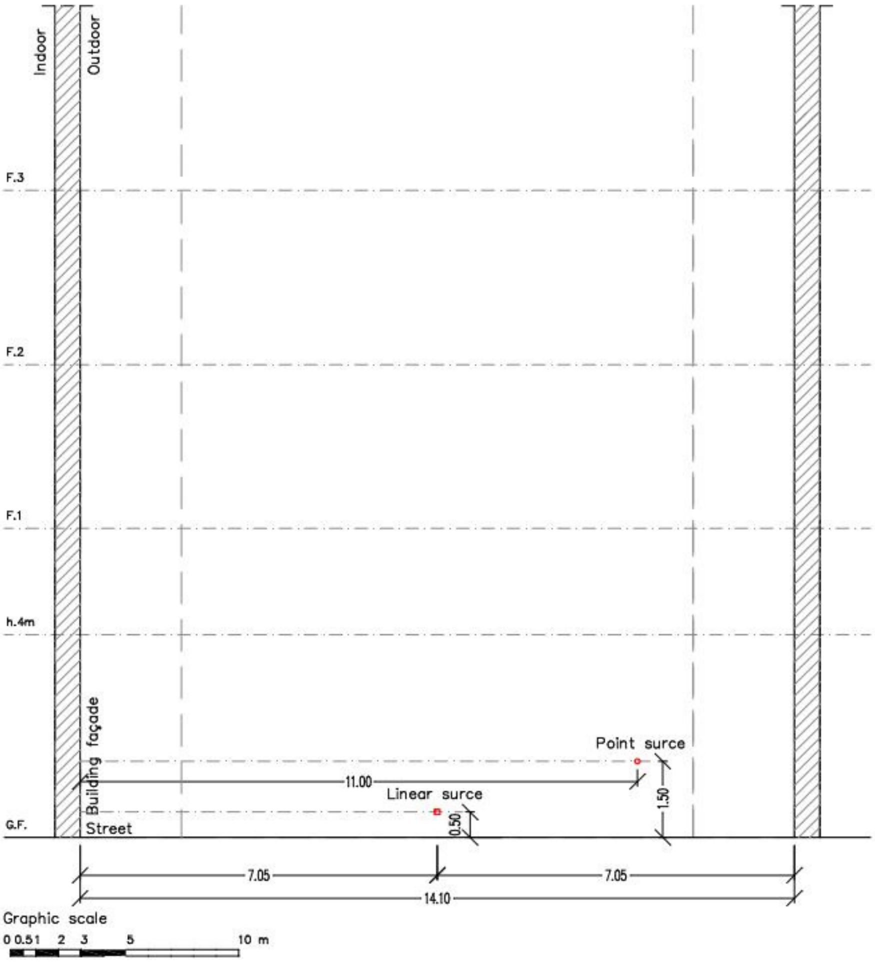


Figure 6-21 – Diagram of the arrangement of the sound sources

6.3.4 Five façade configurations

The five type of façade utilized in the simulation are showed in the following figures as represented in 3D model in Rhinoceros environment.

A. Current state of the building of façade

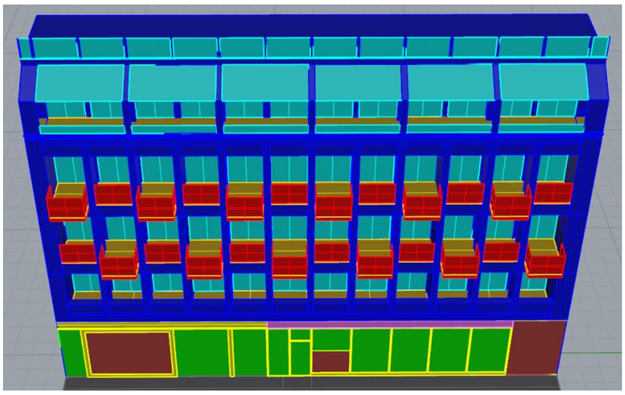


Figure 6-22 – Current state of the building of façade

B. Flat façade

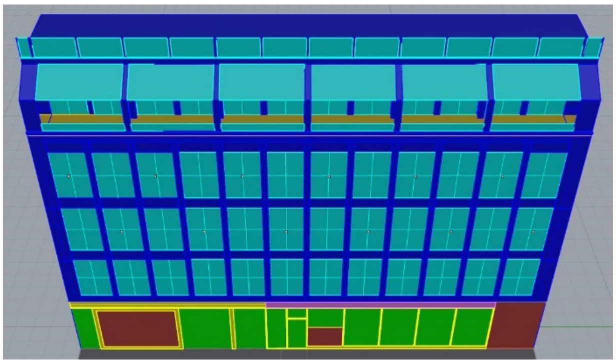


Figure 6-23 – Flat façade

C. Façade with balconies

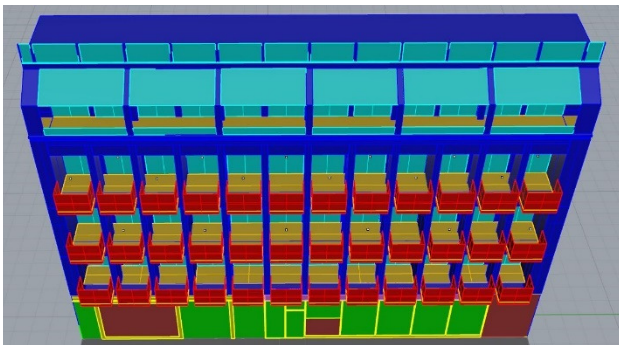


Figure 6-24 – Façade with balconies

D. Façade with loggias

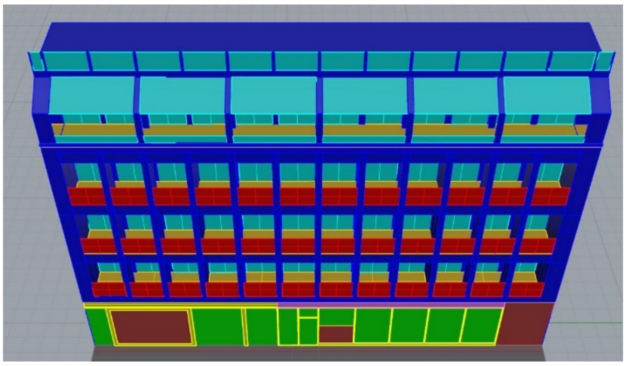


Figure 6-25 – Façade with loggias

E. Façade with balconies and loggias

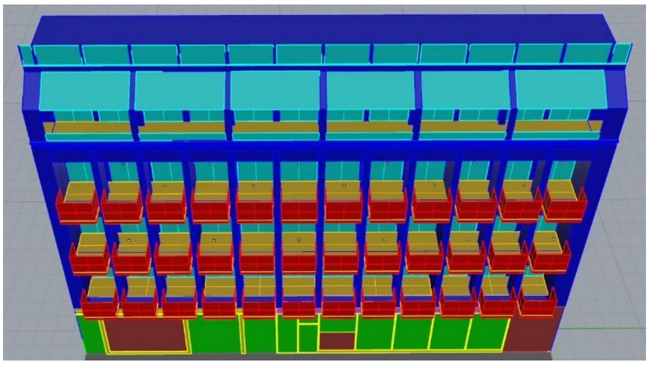


Figure 6-26 – Façade with balconies and loggias

6.3.5 Simulation on Odeon 13, five cases for two sound sources

Ten simulations have been performed in order cover all the cases considering the five façade type with the two type of sound source.

In the following pages are reported the picture from Odeon 13 of all cases

Table 6-1– A - Current state of the building of façade

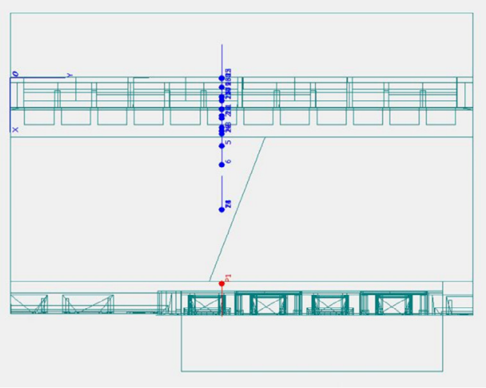
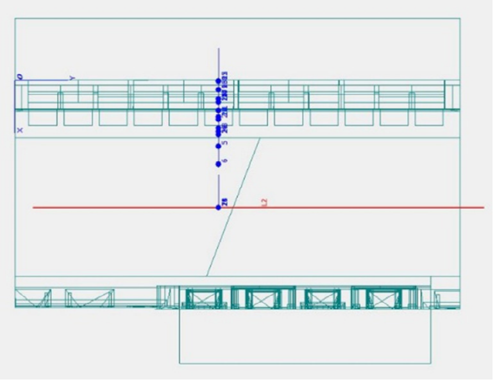
A - Current state of the building of façade	
Point source	Linear source
Simulation no.1	Simulation no.2
	

Table 6-2 – B - Flat façade

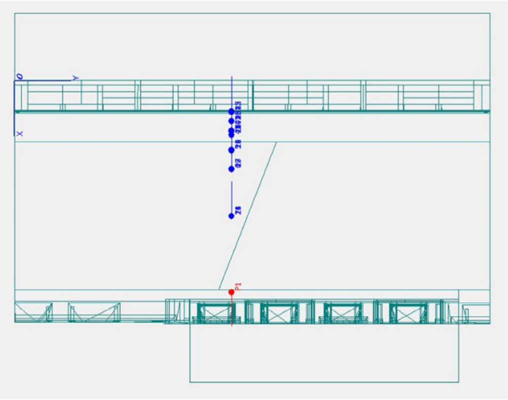
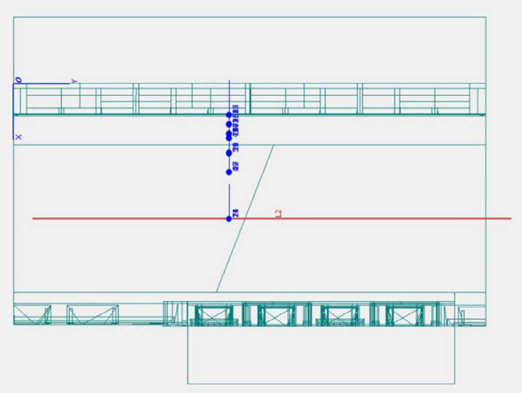
B - Flat façade	
Point source	Linear source
Simulation no.3	Simulation no.4
	

Table 6-3 – C - Façade with balconies

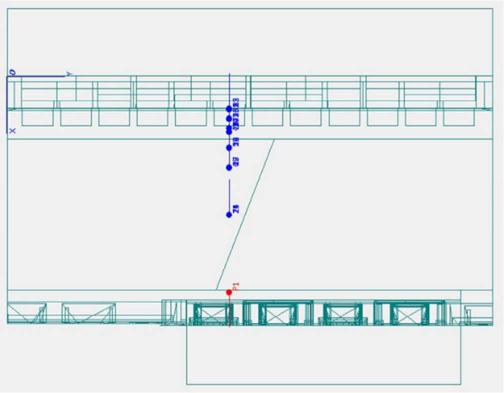
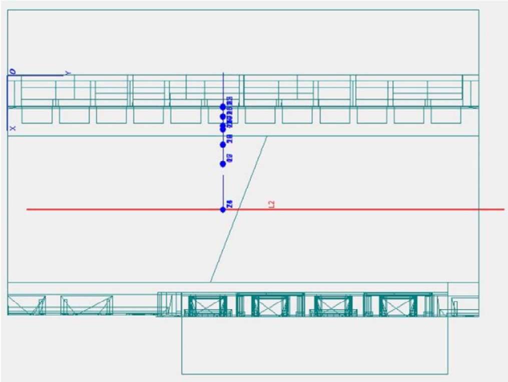
C - Façade with balconies	
Point source	Linear source
Simulation no.5	Simulation no.6
	

Table 6-4 – D - Façade with loggias

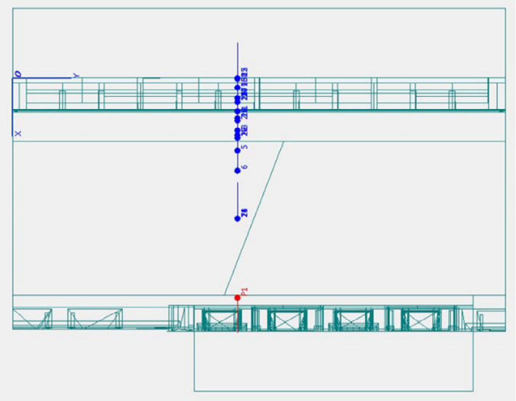
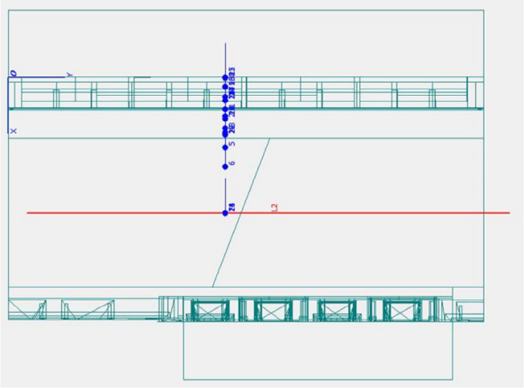
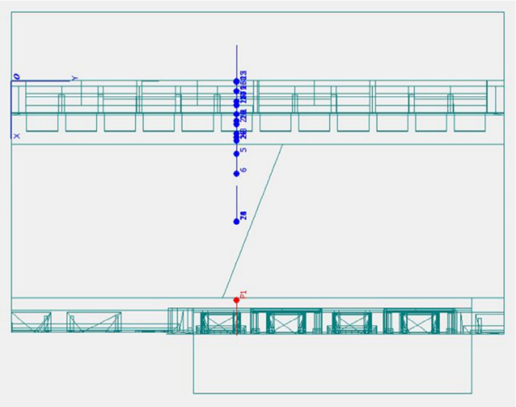
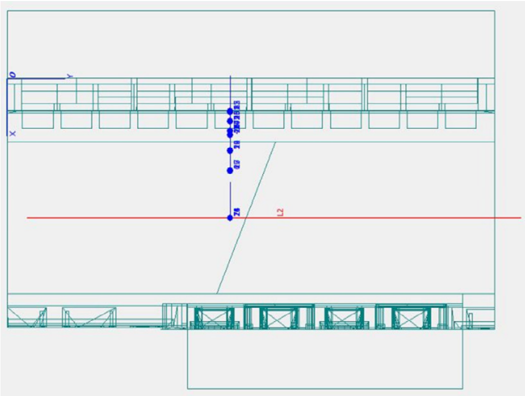
D - Façade with loggias	
Point source	Linear source
Simulation no.7	Simulation no.8
	

Table 6-5 – E - Façade with balconies and loggias

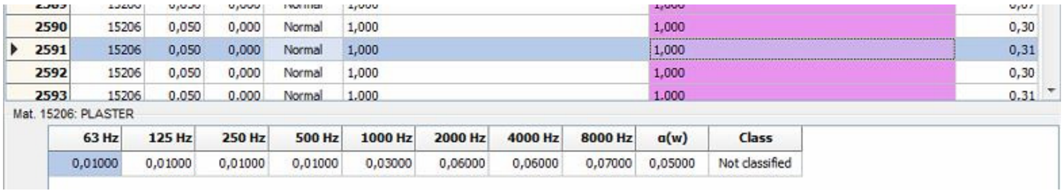
E - Façade with balconies and loggias

Point source	Linear source
Simulation no.9	Simulation no.10
	

6.3.6 Façade materials assignment in the simulation model.

The Odeon 13 tool does not proceed in any simulation if a material has not been assigned to each surface of the model.

The database of materials adopted was created for this specific case study by Badino E. (2018), implementing the Odeon 13 material default data bank.

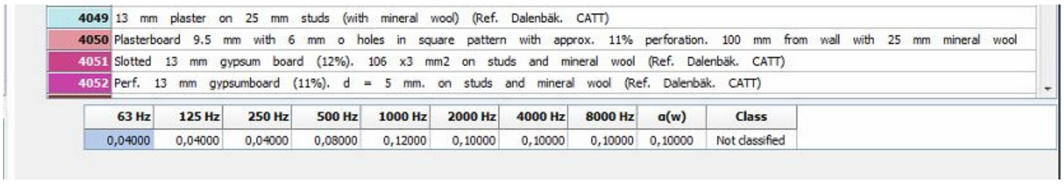


2590	15206	0,050	0,000	Normal	1,000		1,000	0,30
▶ 2591	15206	0,050	0,000	Normal	1,000		1,000	0,31
2592	15206	0,050	0,000	Normal	1,000		1,000	0,30
2593	15206	0,050	0,000	Normal	1,000		1,000	0,31

Mat. 15206: PLASTER

63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α(w)	Class
0,01000	0,01000	0,01000	0,01000	0,03000	0,06000	0,06000	0,07000	0,05000	Not classified

Figure 6-27 – Materials assigned to the surfaces of the model - Odeon 13



4049	13 mm plaster on 25 mm studs (with mineral wool) (Ref. Dalenbäk. CATT)
4050	Plasterboard 9.5 mm with 6 mm o holes in square pattern with approx. 11% perforation. 100 mm from wall with 25 mm mineral wool
4051	Slotted 13 mm gypsum board (12%). 106 x3 mm2 on studs and mineral wool (Ref. Dalenbäk. CATT)
4052	Perf. 13 mm gypsumboard (11%). d = 5 mm. on studs and mineral wool (Ref. Dalenbäk. CATT)

63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α(w)	Class
0,04000	0,04000	0,04000	0,08000	0,12000	0,10000	0,10000	0,10000	0,10000	Not classified

Figure 6-28 – Abacus materials - Odeon 13 (I)

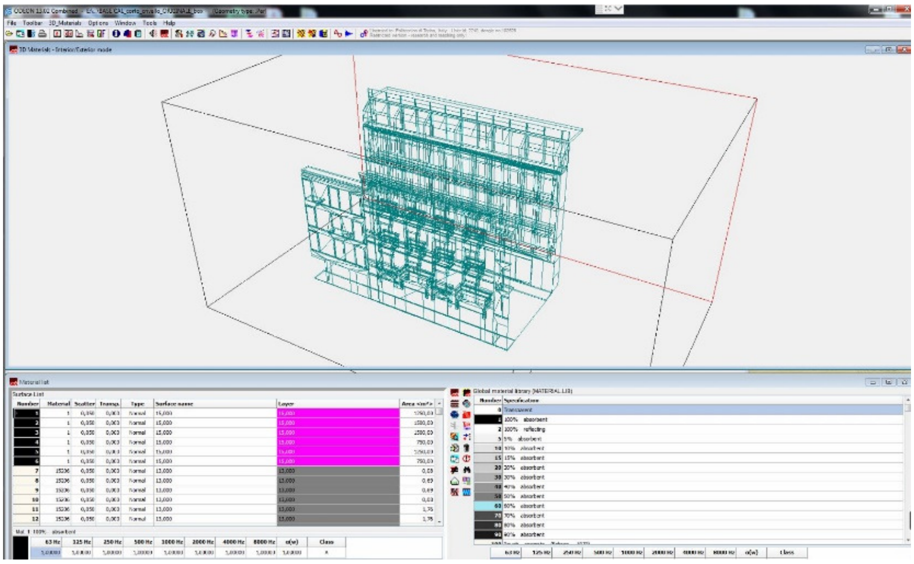
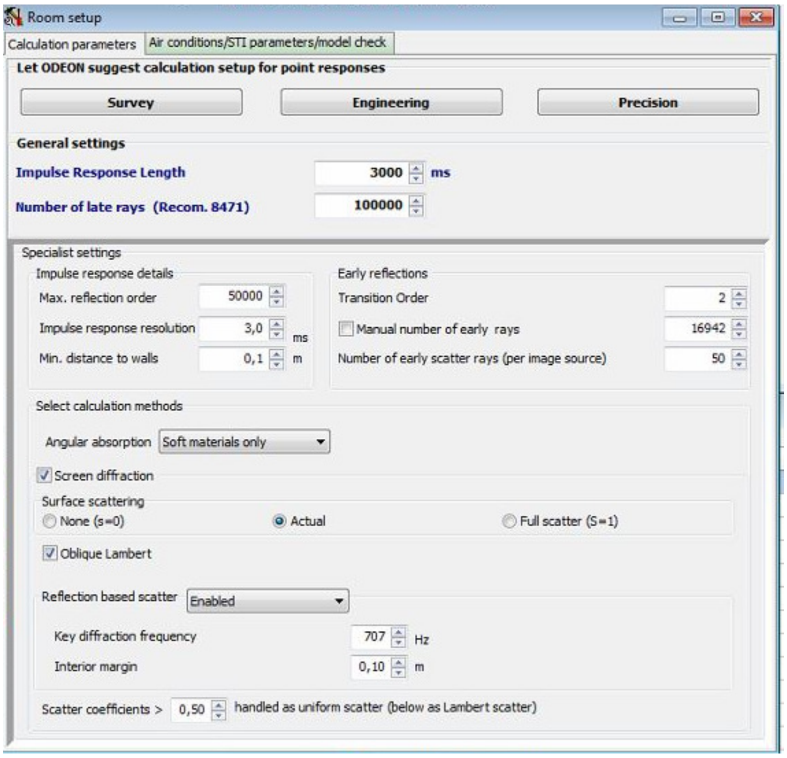


Figure 6-29 – Abacus materials - Odeon 13 (II)

6.3.7 Calculation parameters for simulation execution

The parameters adopted are those utilized by Badino E. (2018) for the simulations of the same case-study.



Let ODEON suggest calculation setup for point responses

General settings

Impulse Response Length 3000 ms

Number of late rays (Recom. 8471) 100000

Specialist settings

Impulse response details

Max. reflection order 50000

Impulse response resolution 3,0 ms

Min. distance to walls 0,1 m

Early reflections

Transition Order 2

☐ Manual number of early rays 16942

Number of early scatter rays (per image source) 50

Select calculation methods

Angular absorption Soft materials only

☑ Screen diffraction

Surface scattering

○ None (s=0) ● Actual ○ Full scatter (S=1)

☑ Oblique Lambert

Reflection based scatter Enabled

Key diffraction frequency 707 Hz

Interior margin 0,10 m

Scatter coefficients > 0,50 handled as uniform scatter (below as Lambert scatter)

Figure 6-30 – Parameter assignment panel for the simulation in Odeon 13

References

- Bianco, M., Scaglione M. (2013), San Salvario, I Borghi di Torino edizione Graphot Editrice, Torino.
- Manca, R. (2017). Acoustic optimization of the urban Façade in the preliminary stagesof the project. Master Thesis, Polytechnic University of Turin, Turin, Italy
- Badino, E. (2018). Acoustic performance – based design: exploration of the effects of different geometries and acoustical properties of an urban façade on the mitigation of chatting noise in a street canyon. Master Thesis, Polytechnic University of Turin, Turin, Italy
- Falzone, D. (2012). Il Soundscape di Largo Saluzzo a Torino: misure in campo e simulazioni acustiche, Polytechnic University of Turin, Turin, Italy

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7 Simulations with the Odeon 13 models

7.1 SPL measurement in the Odeon 13 models

The Sound Pressure Level (SPL) values were evaluated in the simulation using microphones located at different distances from the facade, i.e. at 0 m, 0.5 m, 1 m, 1.2 m, 3 m and 7.05 m as showed in Figure 7-1.

Five types of façade configuration were considered (current state, flat façade, facade with balconies, façade with loggias and façade with balconies and loggias.

The receivers on the facade were positioned on four lines at different heights: 4 m, 6.10 m, 9.33 m and 12.77 m.

In Table 7-1 and Table 7-2 are reported the results obtained respectively considering the linear sound source and the punctual sound source respectively.

Below, the SPL diagrams are reported for all the ten cases, where the point-values of each measure at different microphone position, have been interpolated by a trend line to evaluated the measurement behaviour.

The trend lines chosen are the logarithmic in most of the case and polynomial (2^{nd} order) in the other: the criteria adopted to choose these lines consists in the best obtainable R^2 (fitting coefficient).

Considering the case with the "linear sound source" (from**Errore. L'origine riferimento non è stata trovata.** Figure 7-2 up to Figure 7-6) the SPL values recorded by Line 1 (at 4 m height) have the better behavior in all the façade types except one, i.e. the discrete points can be easily linked by a trend line.

On the contrary the Line 3 (at 9.33 m height) shows the worst SPL behavior with a greater dispersion of the SPL values, in all the façade types.

Line 2 and 4 have an intermediate SPL behavior showing dispersion on the facades with loggias and balconies plus loggias.

Referring to the façade type, the better behaviours globally are shown by the current facade, the flat façade and that with balconies, while the façades with loggias and balcony plus loggias show more differences.

In the case of the "punctual sound source" (from Figure 7-7 up to Figure 7-11) similar consideration can be done, with an improvement of Line 3.

Finally, the SPL (A) values respect the limit set by Regulation 318 of Turin (which refers to DPCM 14/11/1997) of 55 dB (A) (Destination classes land use II - Predominantly residential areas) measured in agreement to the DM 16/03/1998 for all five façade configurations only in the case of the point source for the daytime time slot (06: 00-22: 00), while for all the other tested conditions the limit is always clearly marked above exceeded. (Table 7-3 and Table 7-4)

7.1 Correction factor (f.c.)

The “correction factors” (c.f.) to determine the influence of the shape of the facade calculated on the basis of the SPL values obtained from the simulation of the flat facade case for the Line 1 h = 4 m, because it is the only condition suitable for this type of verification are very different from those given by ISO 1996-2:2017, both in the case of the linear source and in the case of the point source.

The values of the “c.f.” calculated in the simulation are very different from those proposed by Memoli et al. (2009) which confirmed the values given by mentioned ISO with a tolerance margin of about ± 0.5 dB.

These values instead, are closer to the values proposed by Montes González et al., (2015) and in particular in the case of the linear source, which are near to coincide with the simulation values.

7.2 ΔL_{fs} according to ISO 12354-3:2017

As briefly introduced in paragraph 5.1 the ΔL_{fs} is defined in the standard as the difference in sound pressure level of the incoming sound field and the sound on the surface of the façade plus 6dB, thus being 0 (zero) dB for a reflecting, plane façade.

It can be measured with a reasonable accuracy with the following formula:

$$\Delta Lfs = L1{,}2m - L1{,}s + 3\ dB$$

where:

L1,2m = average sound pressure level at 2 m in front of the (shaped) façade [dB]

L1,s = average sound pressure level on the outside surface of the façade plane, including the reflecting effect of that plane [dB]

Based on above formula, the ΔL_{fs} evaluation has been done with the microphone at the distance of 0 m, 1 m, 1,2 and 2m from the façade.

In Table 7-11 are summarized the ΔL_{fs} obtained in the case of linear sound source at different distances associated with the façade types and In Table 7-12 the ΔL_{fs} measured at 2 m is presented alone: on both these table is also reported the ΔL_{fs} values taken from Table C1 of the ISO 12354-3.

All above, concerning the punctual sound source simulation, is repeated in Table 7-23 and Table 7-24 respectively.

The results are reported by the histograms where the values are grouped according to the receivers Line 1 (at 4 m high), Line 2 (at 6,10 m high), Line 3 (ta 9,33 m high) and Line 4 (At 12,77 m high).

For each of these groups are reported the bars of the ΔL_{fs} evaluated at the above-mentioned distances and it has been added the fifth bar on the left reporting the ΔL_{fs} derived from the Table C1 of the same ISO standard (refer to Table 5-1 of paragraph 5.1).

Histograms considering the linear sound source are reported by Figure 7-14 up to Figure 7-18, while from Figure 7-19 up to Figure 7-23 are those representing the punctual sound source.

7.3 Performed simulations data tables

Here following are reported the tables containing the results of the simulation done.

A. Linear sound source - Current state of the building of façade
B. Linear sound source - Flat façade
C. Linear sound source - Façade with balconies
D. Linear sound source – D - Façade with loggias
E. Linear sound source – E - Façade with balconies and loggias

A. Point sound source - Current state of the building of façade
B. Point sound source - Flat façade
C. Point sound source - Façade with balconies
D. Point sound source - Façade with loggias
E. Point sound source - Façade with balconies and loggias

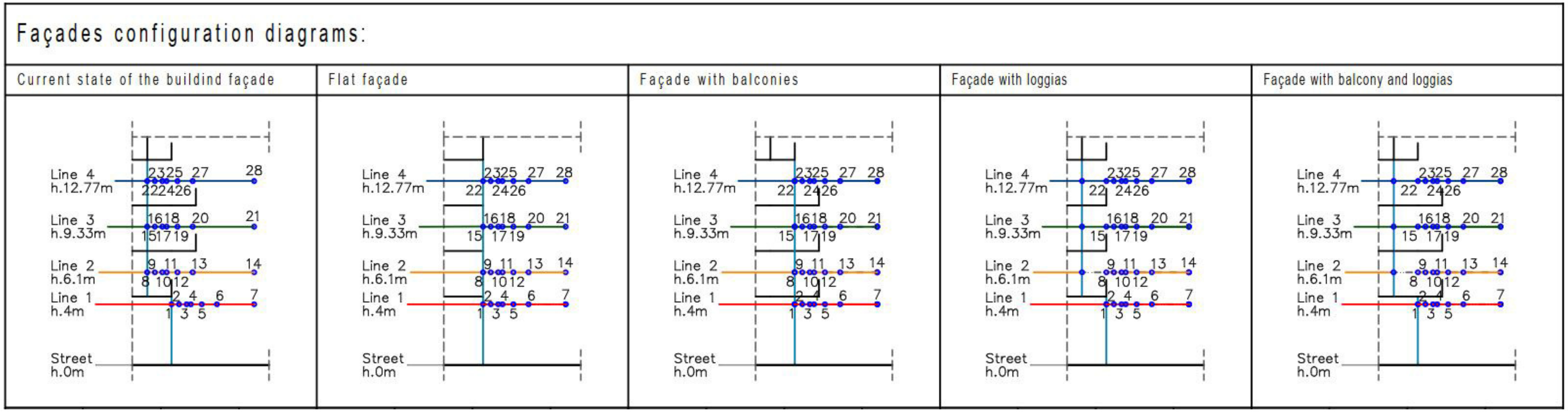


Figure 7-1 – Façades configuration diagrams

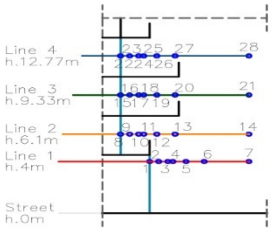
7.4 Linear source - SPL variation vs façade distance diagrams

Table 7-1– Linear sound source – Simulation results

Linear sound sorce

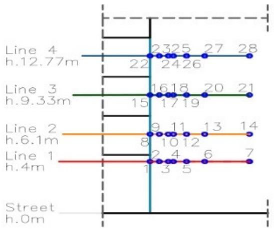
Façades configuration diagrams:

Current state of the buildind façade



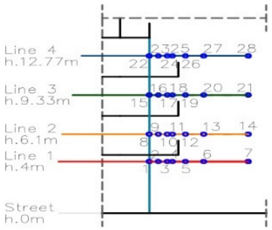
Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	74,7	68,3
0,50 m	R2	73,2	67,3
1,00 m	R3	72,7	66,9
1,20 m	R4	72,6	66,7
2,00 m	R5	72,6	66,5
3,00 m	R6	72,2	66,4
7,05 m	R7	72,3	66,5
Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	74,8	68,7
0,50 m	R9	72,8	66,0
1,00 m	R10	71,8	65,9
1,20 m	R11	71,7	65,8
2,00 m	R12	72,5	66,6
3,00 m	R13	71,9	66,0
7,05 m	R14	71,2	65,4
Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	71,9	65,9
0,50 m	R16	68,4	62,4
1,00 m	R17	67,7	61,8
1,20 m	R18	67,5	61,6
2,00 m	R19	68,2	62,3
3,00 m	R20	70,2	64,3
7,05 m	R21	69,6	63,8
Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	65,1	59,0
0,50 m	R23	66,6	59,7
1,00 m	R24	65,5	59,7
1,20 m	R25	65,7	59,9
2,00 m	R26	68,2	62,4
3,00 m	R27	68,2	62,3
7,05 m	R28	68,0	62,1

Flat façade



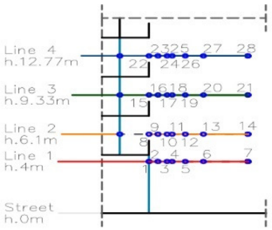
Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	72,5	68,7
0,50 m	R2	73,6	67,4
1,00 m	R3	73,0	66,8
1,20 m	R4	72,9	66,7
2,00 m	R5	72,5	66,5
3,00 m	R6	72,3	66,4
7,05 m	R7	72,4	66,5
Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	74,3	68,1
0,50 m	R9	74,1	66,9
1,00 m	R10	72,5	66,4
1,20 m	R11	72,4	66,3
2,00 m	R12	71,9	65,8
3,00 m	R13	71,5	65,6
7,05 m	R14	71,3	65,4
Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	70,6	64,4
0,50 m	R16	72,6	65,7
1,00 m	R17	71,4	65,2
1,20 m	R18	71,2	65,1
2,00 m	R19	70,7	64,7
3,00 m	R20	70,3	64,4
7,05 m	R21	70,0	64,0
Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	70,5	64,2
0,50 m	R23	70,1	63,9
1,00 m	R24	69,7	63,6
1,20 m	R25	69,6	63,5
2,00 m	R26	69,2	63,2
3,00 m	R27	68,9	62,9
7,05 m	R28	68,3	62,6

Façade with balconies



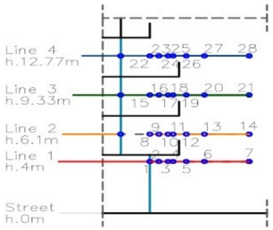
Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	76,2	69,3
0,50 m	R2	74,5	68,4
1,00 m	R3	73,9	67,5
1,20 m	R4	73,7	67,3
2,00 m	R5	73,1	67,0
3,00 m	R6	72,8	66,8
7,05 m	R7	72,7	66,8
Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	73,1	66,8
0,50 m	R9	71,9	65,8
1,00 m	R10	72,5	66,2
1,20 m	R11	72,4	66,2
2,00 m	R12	72,2	66,1
3,00 m	R13	71,9	65,9
7,05 m	R14	71,6	65,6
Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	69,4	63,0
0,50 m	R16	69,2	63,0
1,00 m	R17	70,9	64,6
1,20 m	R18	70,8	64,6
2,00 m	R19	70,6	64,5
3,00 m	R20	70,4	64,4
7,05 m	R21	70,1	64,1
Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	65,4	58,7
0,50 m	R23	65,9	59,6
1,00 m	R24	68,5	62,3
1,20 m	R25	68,6	62,4
2,00 m	R26	68,5	62,4
3,00 m	R27	68,4	62,4
7,05 m	R28	68,4	62,4

Façade with loggias



Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	75,4	68,9
0,50 m	R2	73,4	67,3
1,00 m	R3	72,7	66,7
1,20 m	R4	72,6	66,6
2,00 m	R5	72,3	66,4
3,00 m	R6	72,2	66,3
7,05 m	R7	72,3	66,5
Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	70,1	64,6
0,50 m	R9	70,9	64,7
1,00 m	R10	70,5	64,3
1,20 m	R11	71,2	65,1
2,00 m	R12	72,6	66,5
3,00 m	R13	71,9	65,9
7,05 m	R14	71,2	65,3
Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	70,6	64,1
0,50 m	R16	68,9	62,6
1,00 m	R17	68,4	62,3
1,20 m	R18	68,3	62,2
2,00 m	R19	70,9	64,8
3,00 m	R20	70,4	64,4
7,05 m	R21	69,7	63,8
Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	66,6	60,2
0,50 m	R23	66,2	59,9
1,00 m	R24	65,9	59,8
1,20 m	R25	66,0	59,9
2,00 m	R26	69,0	62,9
3,00 m	R27	68,7	62,7
7,05 m	R28	68,2	62,1

Façade with balcony and loggias



Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	75,5	68,9
0,50 m	R2	74,3	68,3
1,00 m	R3	73,3	67,1
1,20 m	R4	73,0	66,9
2,00 m	R5	72,6	66,6
3,00 m	R6	72,4	65,5
7,05 m	R7	72,5	6,66
Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	72,1	65,8
0,50 m	R9	70,8	64,7
1,00 m	R10	70,5	64,5
1,20 m	R11	70,4	64,5
2,00 m	R12	70,9	65,1
3,00 m	R13	71,2	65,3
7,05 m	R14	71,3	65,4
Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	71,3	65,4
0,50 m	R16	68,7	62,3
1,00 m	R17	68,6	62,3
1,20 m	R18	68,2	62,1
2,00 m	R19	68,1	62,1
3,00 m	R20	68,7	62,8
7,05 m	R21	69,5	63,6
Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	69,5	63,7
0,50 m	R23	64,5	58,3
1,00 m	R24	64,2	58,2
1,20 m	R25	64,0	58,0
2,00 m	R26	65,1	51,1
3,00 m	R27	67,3	61,3
7,05 m	R28	67,9	61,8

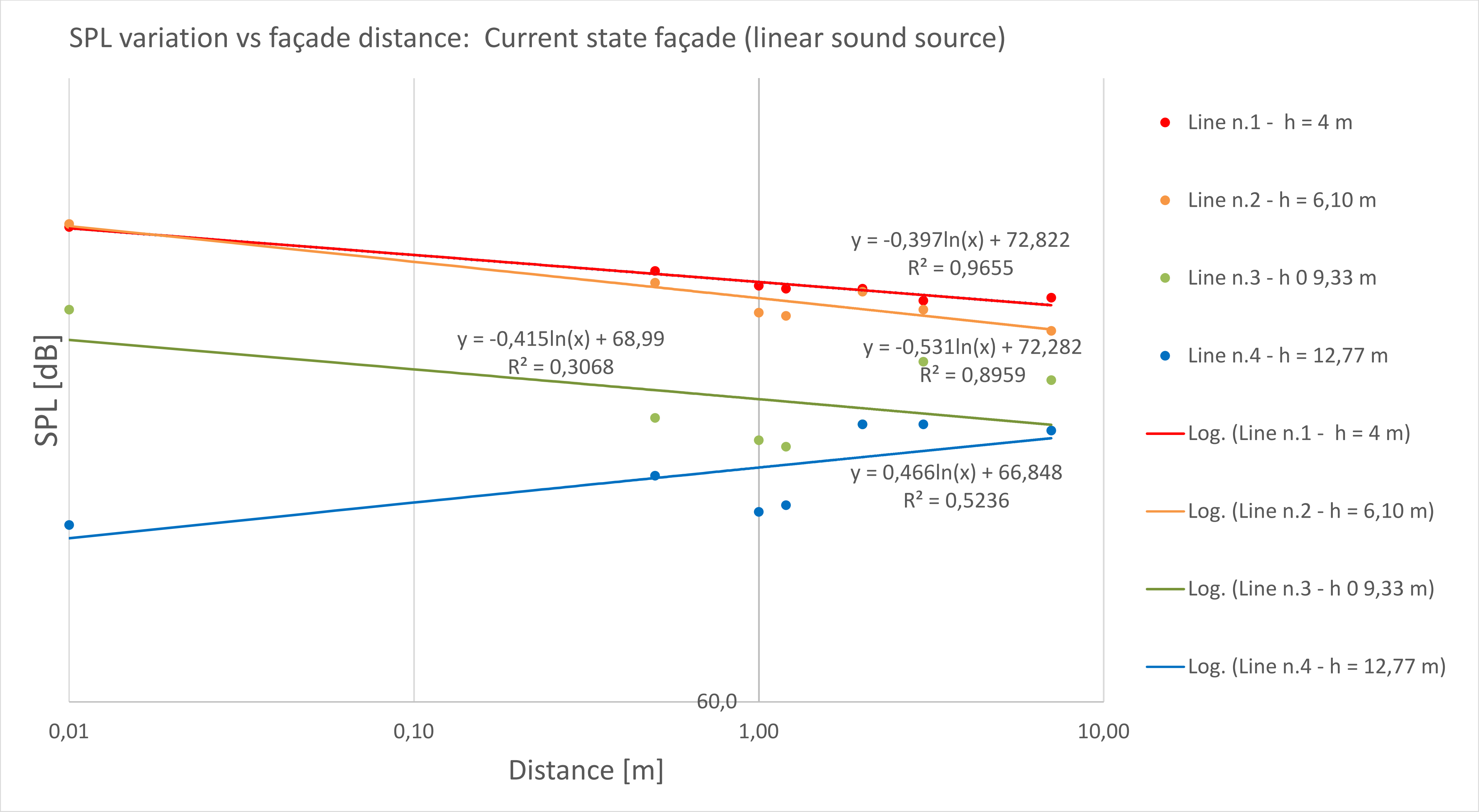


Figure 7-2 – SPL – Current status façade – linear s.s.

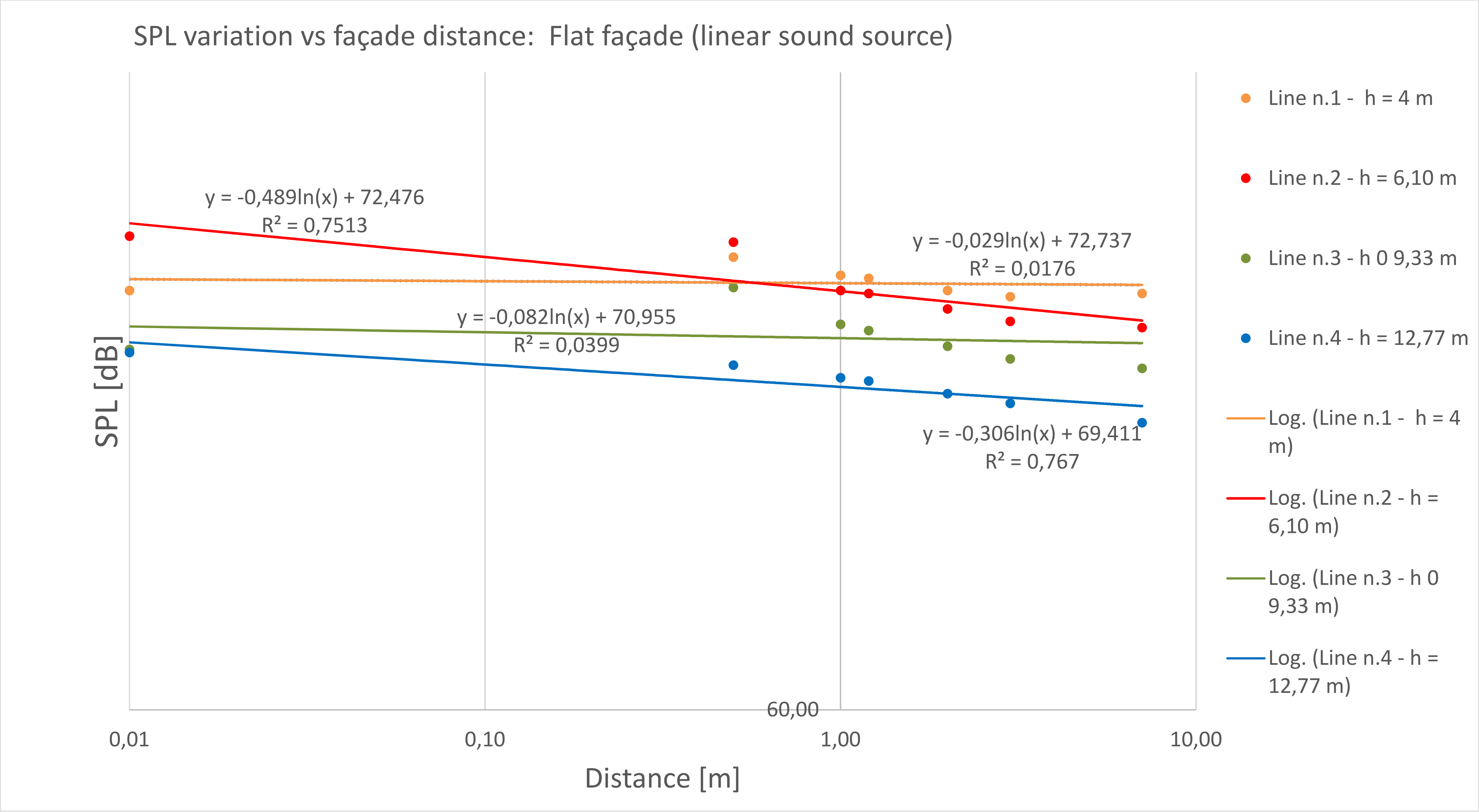


Figure 7-3 – SPL – Flat façade – linear s.s.

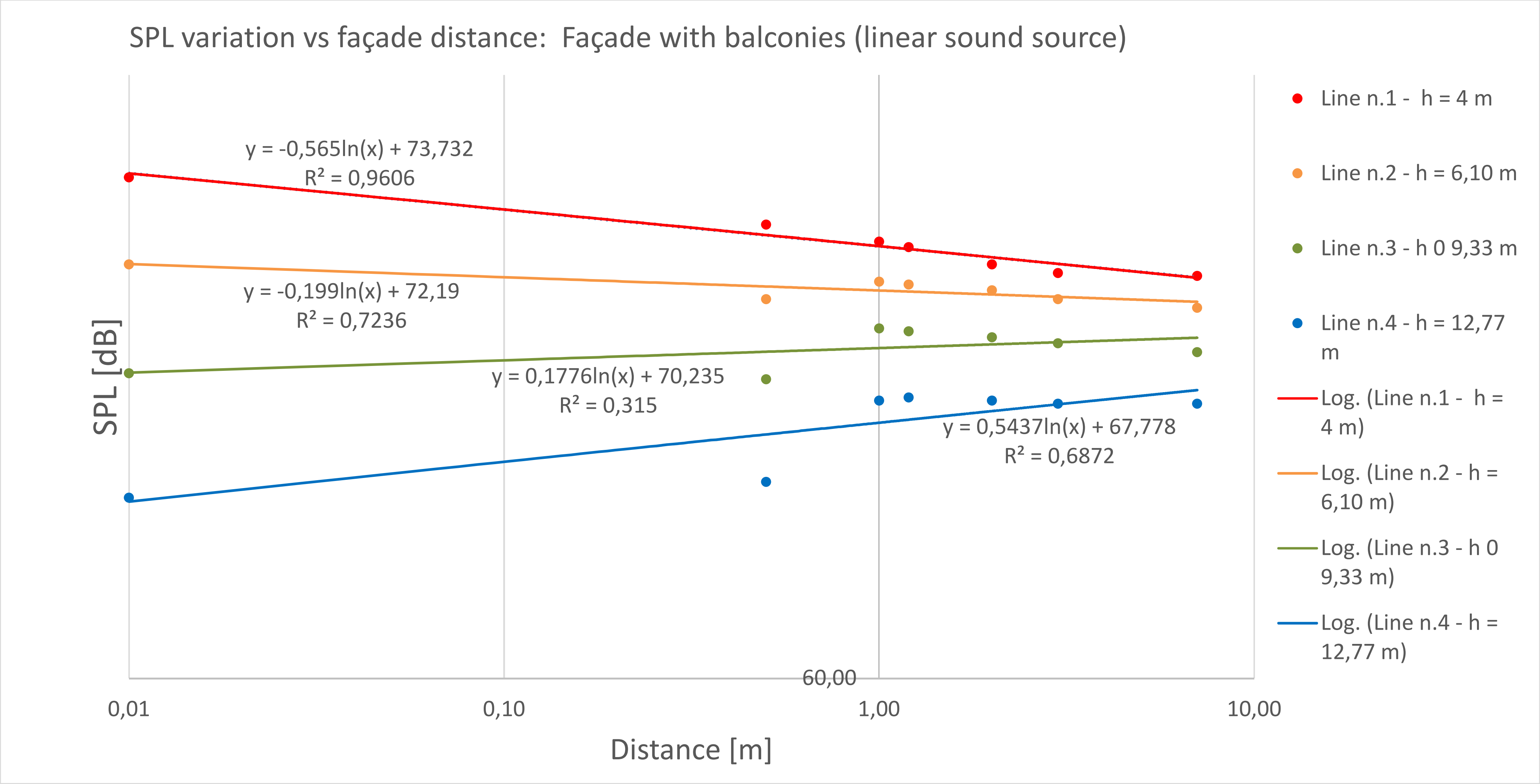


Figure 7-4 – SPL – Façade with balconies – linear s.s.

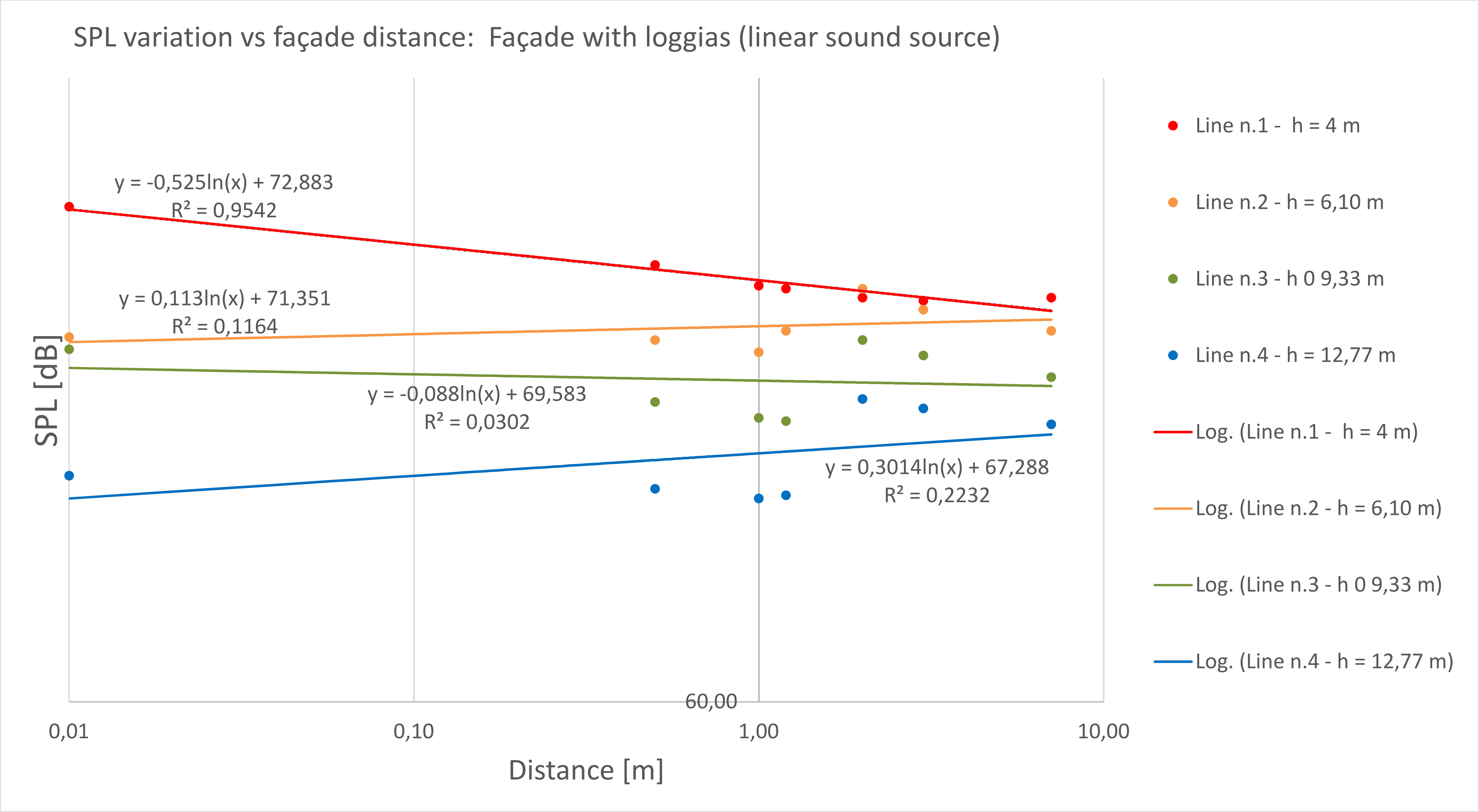


Figure 7-5 – SPL – Façade with loggias – linear s.s.

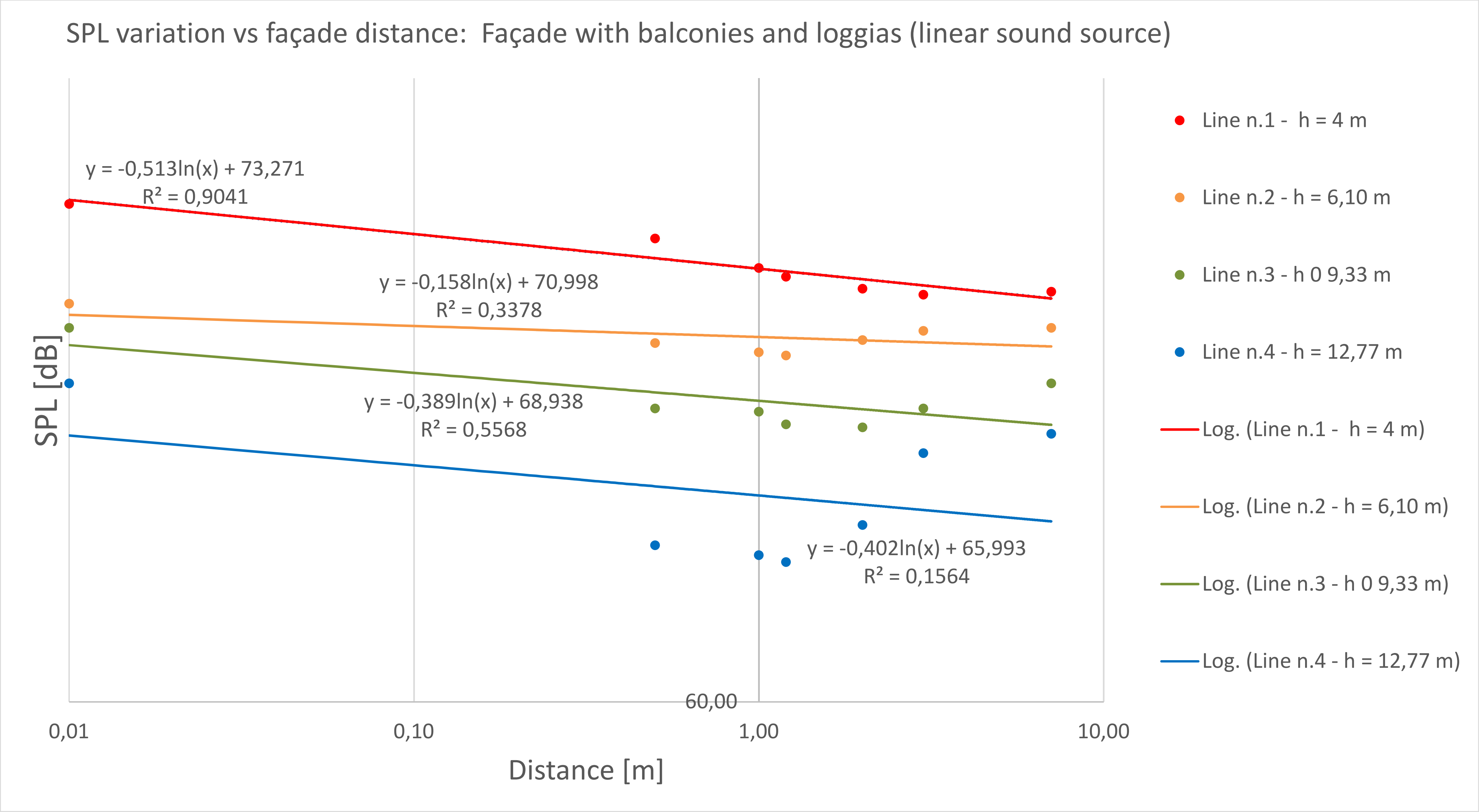


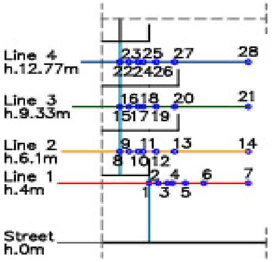
Figure 7-6 – SPL – Façade with balconies and loggias – linear s.s.

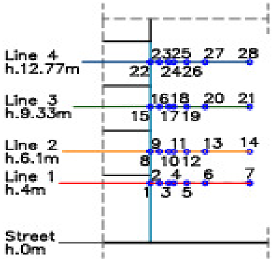
7.5 Point source - SPL variation vs façade distance diagrams

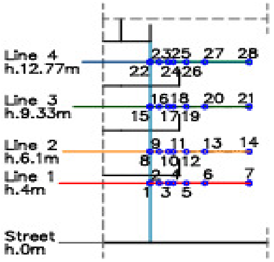
Table 7-2– Point sound source – Simulation results

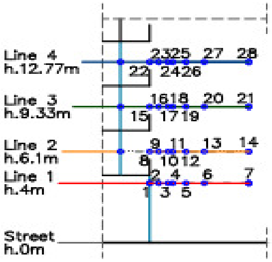
Point sound sorce

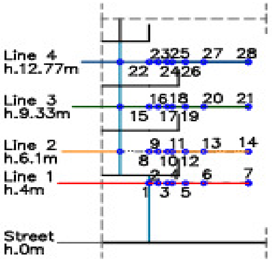
Façades configuration diagrams:











Current state of the buildind façade				Flat façade				Façade with balconies				Façade with loggias				Façade with balcony and loggias			
Line 1	R.m. no.	SPL	SPL (A)	Line 1	R.m. no.	SPL	SPL (A)	Line 1	R.m. no.	SPL	SPL (A)	Line 1	R.m. no.	SPL	SPL (A)	Line 1	R.m. no.	SPL	SPL (A)
0,00 m	R1	60,9	53,4	0,00 m	R1	60,6	53,0	0,00 m	R1	63,0	55,2	0,00 m	R1	60,7	53,1	0,00 m	R1	62,3	54,8
0,50 m	R2	59,3	52,9	0,50 m	R2	59.4	52,6	0,50 m	R2	60,4	53,9	0,50 m	R2	59,4	52,8	0,50 m	R2	60,3	53,9
1,00 m	R3	59,1	52,6	1,00 m	R3	59.2	52,3	1,00 m	R3	60,1	53,2	1,00 m	R3	59,1	52,4	1,00 m	R3	59,7	53,0
1,20 m	R4	59,2	58,8	1,20 m	R4	59.2	52,5	1,20 m	R4	60,0	53,2	1,20 m	R4	59,2	52,6	1,20 m	R4	59,7	51,1
2,00 m	R5	59,4	53,0	2,00 m	R5	59.3	52,6	2,00 m	R5	59,9	53,1	2,00 m	R5	59,3	52,7	2,00 m	R5	59,6	52,9
3,00 m	R6	60,2	53,6	3,00 m	R6	60,1	53,4	3,00 m	R6	60,6	53,8	3,00 m	R6	60,0	53,2	3,00 m	R6	60,2	53,4
7,05 m	R7	61,6	54,9	7,05 m	R7	61.4	54,5	7,05 m	R7	61,8	54,8	7,05 m	R7	61,1	54,8	7,05 m	R7	61,8	54,9
Line 2	R.m. no.	SPL	SPL (A)	Line 2	R.m. no.	SPL	SPL (A)	Line 2	R.m. no.	SPL	SPL (A)	Line 2	R.m. no.	SPL	SPL (A)	Line 2	R.m. no.	SPL	SPL (A)
0,00 m	R8	60,7	53,9	0,00 m	R8	60,6	56,7	0,00 m	R8	62,3	55,2	0,00 m	R8	59,4	52,2	0,00 m	R8	58,7	51,4
0,50 m	R9	59,5	52,9	0,50 m	R9	59,7	52,7	0,50 m	R9	58,8	51,9	0,50 m	R9	58,5	51,4	0,50 m	R9	57,8	50,8
1,00 m	R10	59,0	52,5	1,00 m	R10	59,3	52,5	1,00 m	R10	58,9	51,8	1,00 m	R10	58,5	51,7	1,00 m	R10	57,6	51,0
1,20 m	R11	58,5	52,0	1,20 m	R11	59,3	52,4	1,20 m	R11	59,1	52,1	1,20 m	R11	58,4	51,5	1,20 m	R11	57,5	50,8
2,00 m	R12	59,1	52,5	2,00 m	R12	59,2	52,4	2,00 m	R12	59,2	52,5	2,00 m	R12	59,1	52,1	2,00 m	R12	59,1	52,4
3,00 m	R13	58,2	52,0	3,00 m	R13	59,3	52,3	3,00 m	R13	60.0	53,2	3,00 m	R13	59,2	52,5	3,00 m	R13	58,6	52,0
7,05 m	R14	60,1	53,6	7,05 m	R14	60,0	53,3	7,05 m	R14	60,5	53,7	7,05 m	R14	60,1	53,5	7,05 m	R14	60,4	53,7
Line 3	R.m. no.	SPL	SPL (A)	Line 3	R.m. no.	SPL	SPL (A)	Line 3	R.m. no.	SPL	SPL (A)	Line 3	R.m. no.	SPL	SPL (A)	Line 3	R.m. no.	SPL	SPL (A)
0,00 m	R15	57,7	51,1	0,00 m	R15	58,4	51,2	0,00 m	R15	54,8	47,5	0,00 m	R15	57,9	50,7	0,00 m	R15	59,5	52,3
0,50 m	R16	55,2	48,7	0,50 m	R16	58,8	51,7	0,50 m	R16	57,5	50,4	0,50 m	R16	57,0	49,9	0,50 m	R16	56,6	49,8
1,00 m	R17	55,1	48,8	1,00 m	R17	58,6	51,5	1,00 m	R17	58,2	51,1	1,00 m	R17	57,4	50,5	1,00 m	R17	56,6	49,9
1,20 m	R18	54,5	48,1	1,20 m	R18	58,5	51,5	1,20 m	R18	58,0	51,0	1,20 m	R18	57,7	50,8	1,20 m	R18	55,7	49,3
2,00 m	R19	56,4	49,8	2,00 m	R19	58,2	51,2	2,00 m	R19	58,6	51,9	2,00 m	R19	58,1	51,2	2,00 m	R19	57,2	50,5
3,00 m	R20	57,6	51,0	3,00 m	R20	58,2	51,4	3,00 m	R20	58,5	51,7	3,00 m	R20	58,3	51,5	3,00 m	R20	57,6	51,0
7,05 m	R21	57,9	51,4	7,05 m	R21	58,2	51,5	7,05 m	R21	58,5	51,7	7,05 m	R21	58,0	51,3	7,05 m	R21	57,8	51,1
Line 4	R.m. no.	SPL	SPL (A)	Line 4	R.m. no.	SPL	SPL (A)	Line 4	R.m. no.	SPL	SPL (A)	Line 4	R.m. no.	SPL	SPL (A)	Line 4	R.m. no.	SPL	SPL (A)
0,00 m	R22	56,1	49.5	0,00 m	R22	58,6	51,5	0,00 m	R22	44,1	44,1	0,00 m	R22	57,0	50,2	0,00 m	R22	57,3	49,9
0,50 m	R23	55,7	49.3	0,50 m	R23	57,4	50,6	0,50 m	R23	47,6	47,6	0,50 m	R23	55,8	48,8	0,50 m	R23	53,5	46,6
1,00 m	R24	54,5	48,3	1,00 m	R24	57,1	50,4	1,00 m	R24	49,0	49,0	1,00 m	R24	54,7	48,0	1,00 m	R24	51,4	44,7
1,20 m	R25	55,0	48,7	1,20 m	R25	57,1	50,3	1,20 m	R25	49,0	49,0	1,20 m	R25	55,2	48,4	1,20 m	R25	51,3	44,6
2,00 m	R26	56,0	49,6	2,00 m	R26	56,8	50,2	2,00 m	R26	50,1	50,1	2,00 m	R26	56,4	49,7	2,00 m	R26	53,2	46,4
3,00 m	R27	56,5	50,0	3,00 m	R27	55,8	49,3	3,00 m	R27	49,3	49,3	3,00 m	R27	56,8	50,1	3,00 m	R27	55,9	49,3
7,05 m	R28	55,9	49,9	7,05 m	R28	56,6	50,0	7,05 m	R28	49,7	49.7	7,05 m	R28	56,6	50,0	7,05 m	R28	55,9	49,4

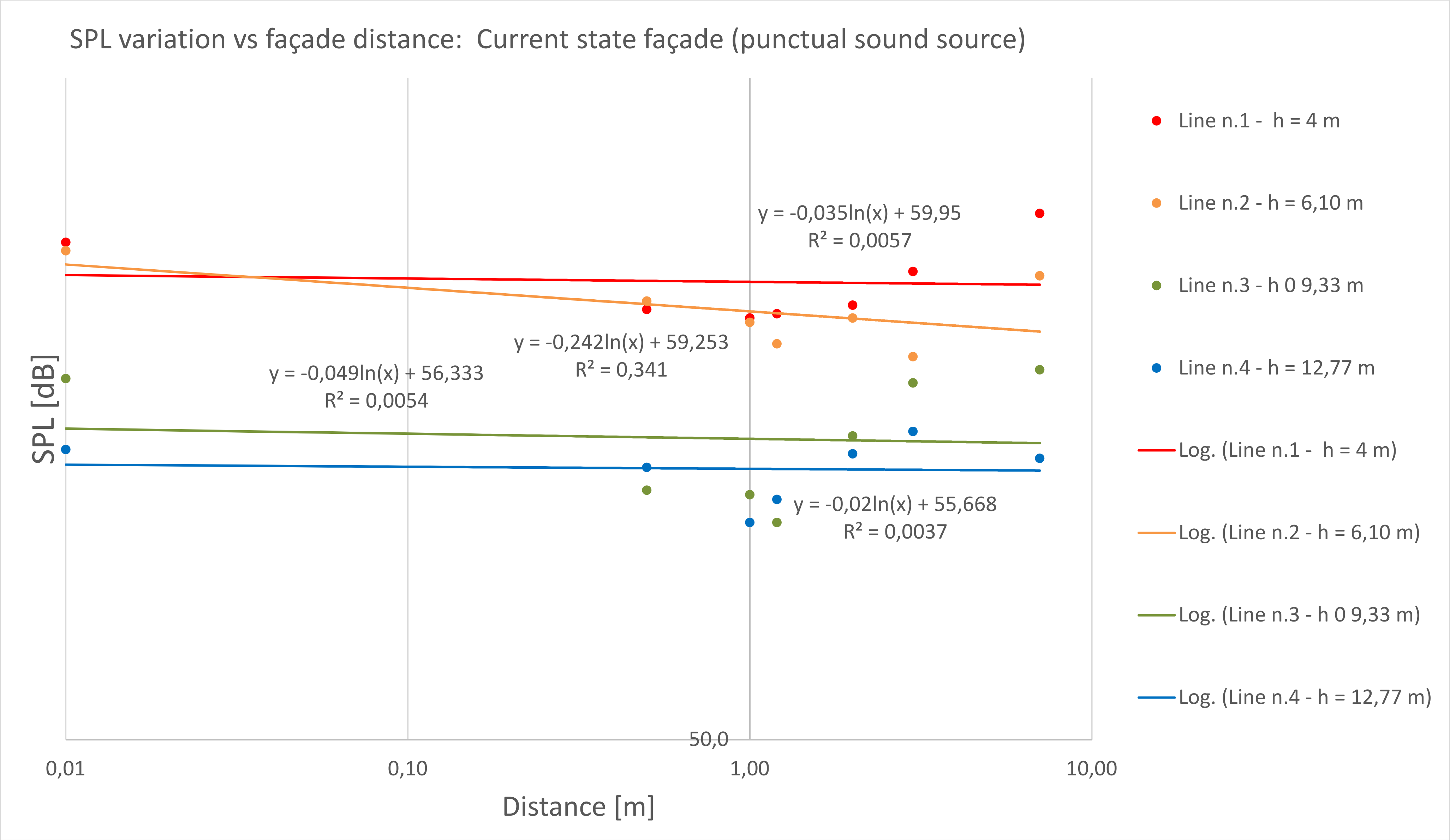


Figure 7-7 – SPL – Current status façade – punctual s. s.

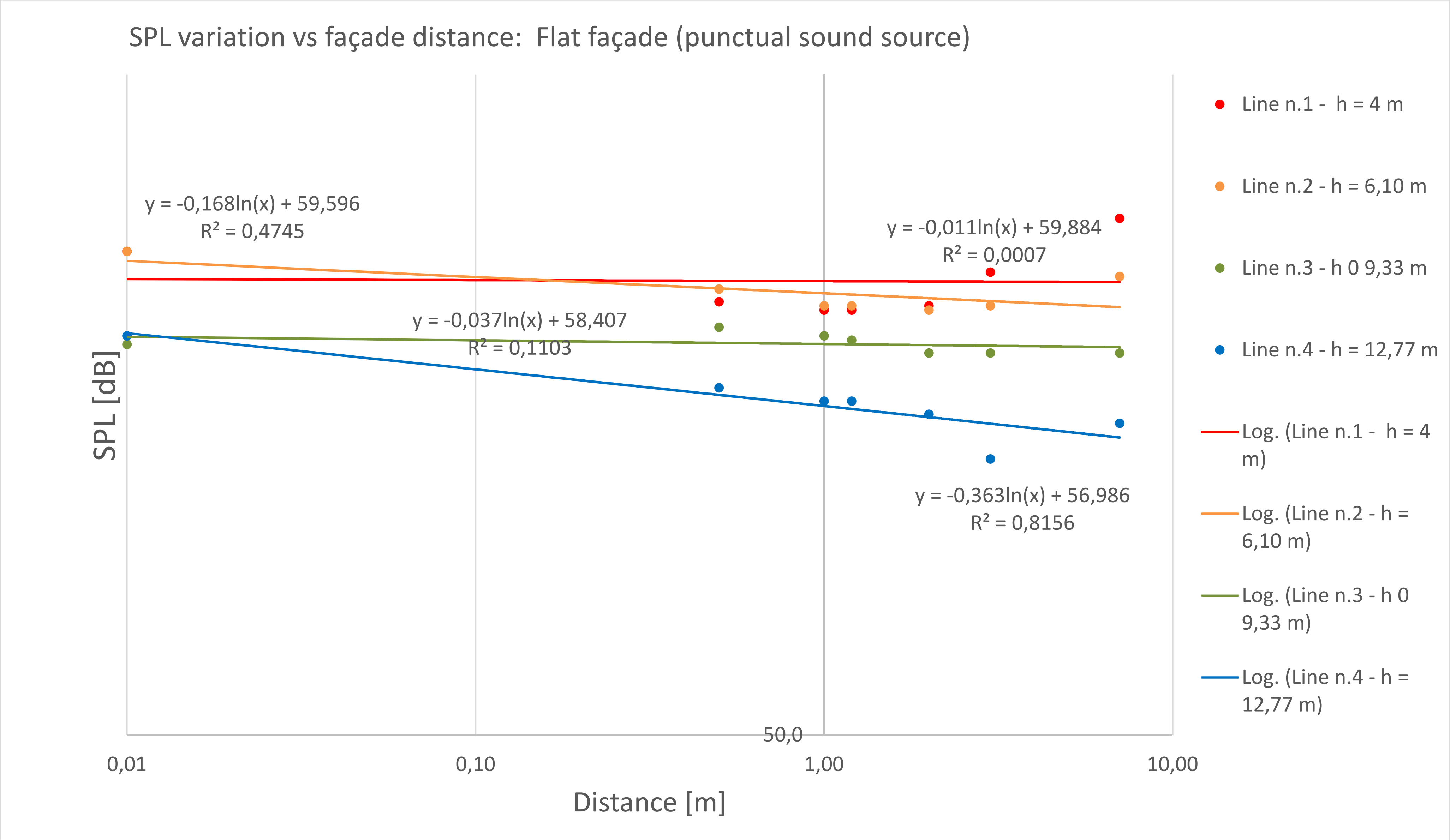


Figure 7-8 – SPL – Flat façade – punctual s. s.

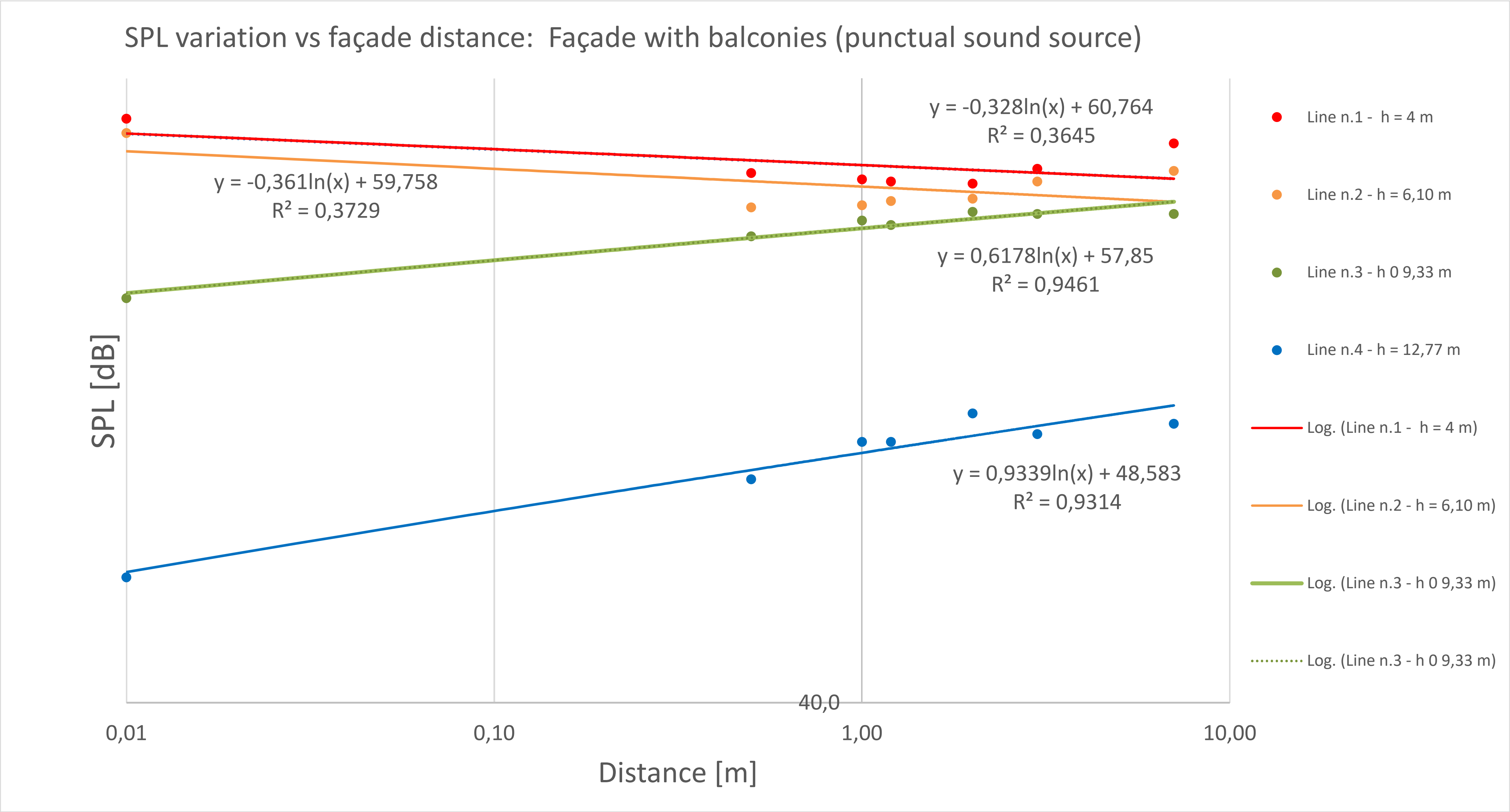


Figure 7-9 – SPL – Façade with balconies– punctual s. s.

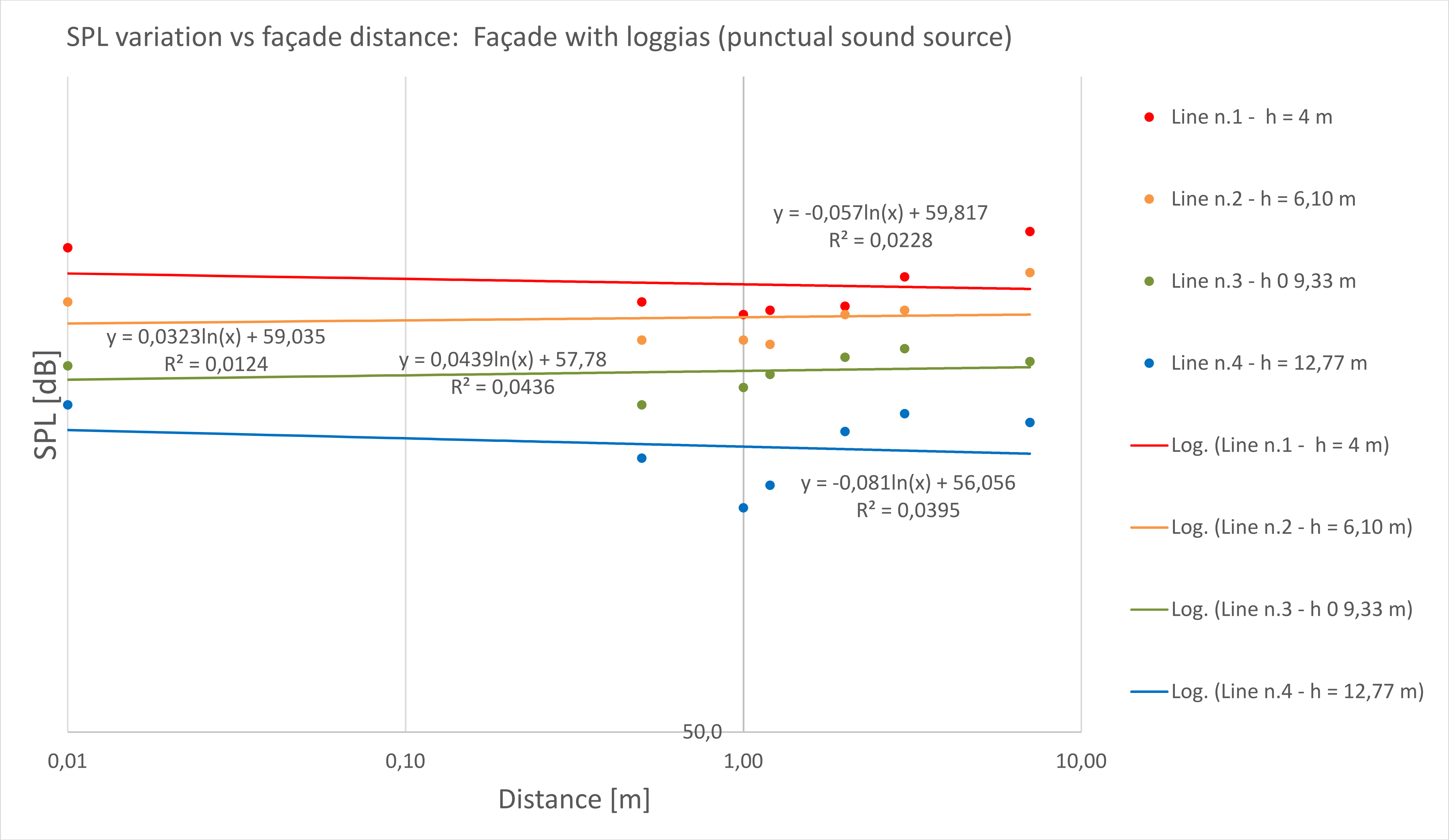


Figure 7-10 – SPL – Façade with loggias– punctual s. s.

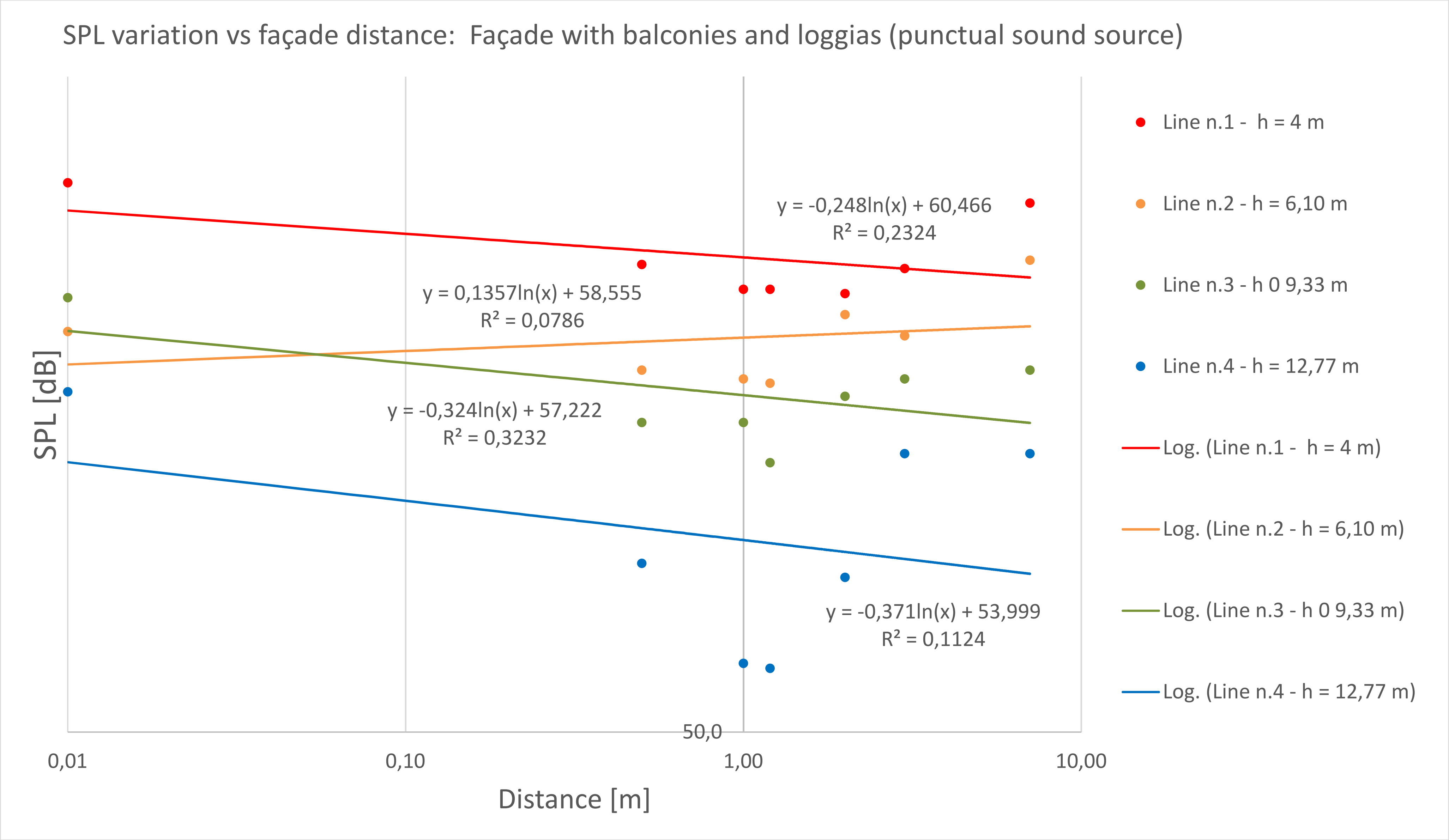


Figure 7-11 – SPL – Façade with balconies loggias– punctual s. s.

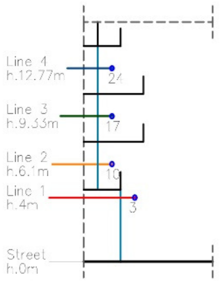
7.6 SPL (A) verification according to Regulation 318 of Turin (Linear sound source)

Table 7-3– SPL (A) with different microphone positions and façade configuration (Linear sound source) (I)

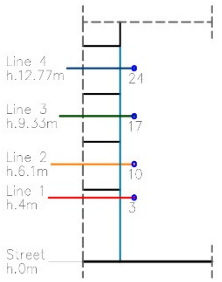
Linear sound sorce

Façades configuration diagrams:

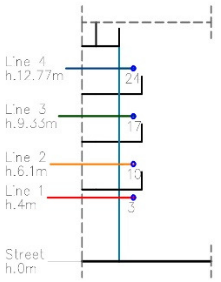
Current state of the buildind façade



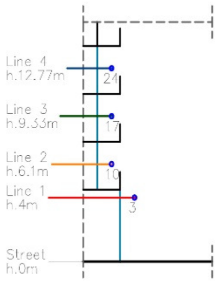
Flat façade



Façade with balconies



Façade with loggias



Façade with balcony and loggias

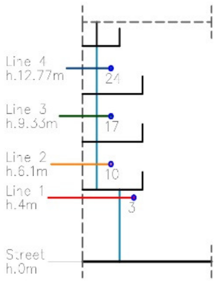


Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A)	> 55 dB (A)	Nigth (22: 00-06:00)	≤ 45 dB (A)	> 45 dB (A)

Simulated measured in according to D.M. 16/03/1998

Diurnal (06: 00-22:00)

	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)
Line 1	R3	1 m	66,9	Line 1	R3	1 m	66,8	Line 1	R3	1 m	67,5	Line 1	R3	1 m	66,7	Line 1	R3	1 m	67,1
Line 2	R10	1 m	65,9	Line 2	R10	1 m	66,4	Line 2	R10	1 m	66,2	Line 2	R10	1 m	64,3	Line 2	R10	1 m	64,5
Line 3	R17	1 m	61,8	Line 3	R17	1 m	65,2	Line 3	R17	1 m	64,6	Line 3	R17	1 m	62,3	Line 3	R17	1 m	62,3
Line 4	R24	1 m	59,7	Line 4	R24	1 m	63,6	Line 4	R24	1 m	62,3	Line 4	R24	1 m	59,8	Line 4	R24	1 m	58,2

Nigth (22: 00-06:00)

	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)
Line 1	R3	1 m	66,9	Line 1	R3	1 m	66,8	Line 1	R3	1 m	67,5	Line 1	R3	1 m	66,7	Line 1	R3	1 m	67,1
Line 2	R10	1 m	65,9	Line 2	R10	1 m	66,4	Line 2	R10	1 m	66,2	Line 2	R10	1 m	64,3	Line 2	R10	1 m	64,5
Line 3	R17	1 m	61,8	Line 3	R17	1 m	65,2	Line 3	R17	1 m	64,6	Line 3	R17	1 m	62,3	Line 3	R17	1 m	62,3
Line 4	R24	1 m	59,7	Line 4	R24	1 m	63,6	Line 4	R24	1 m	62,3	Line 4	R24	1 m	59,8	Line 4	R24	1 m	58,2

Table 7-4– SPL (A) with different microphone positions and façade configuration (Linear sound source) (II)

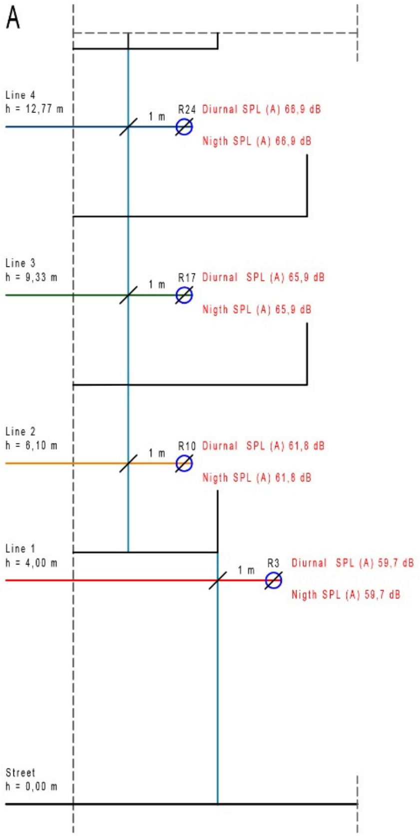
Linear sound sorce

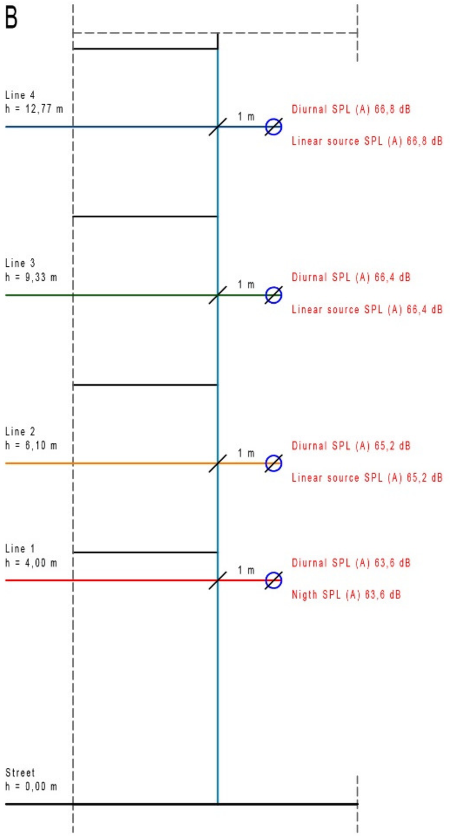
Façades configuration diagrams: A - Current state of the buildind façade, B - Flat façade, C - Façade with balconies

Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A) > 55 dB (A)	Nigth (22: 00-06:00)	≤ 45 dB (A) > 45 dB (A)

Simulated measured in according to D.M. 16/03/1998





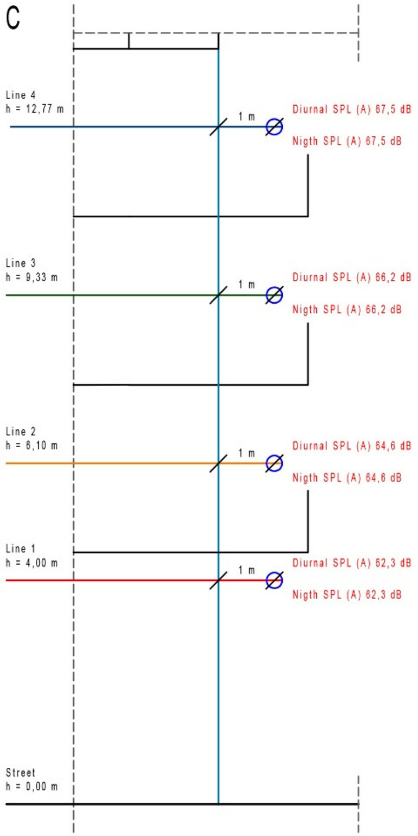


Table 7-5– SPL (A) with different microphone positions and façade configuration (Linear sound source) (III)

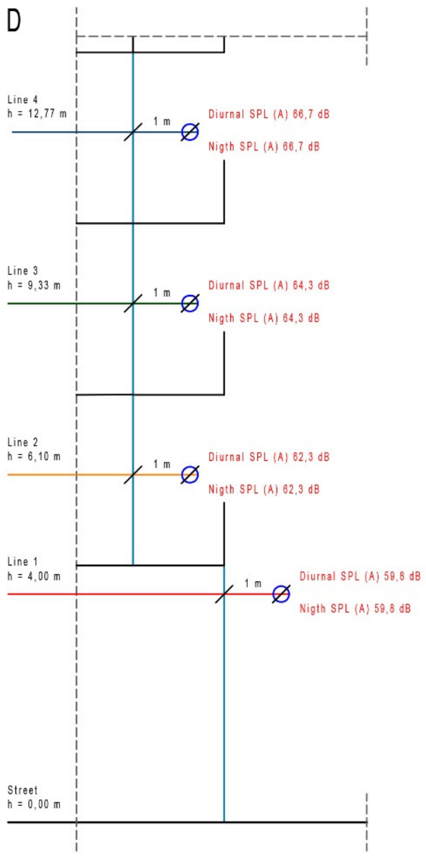
Linear sound sorce

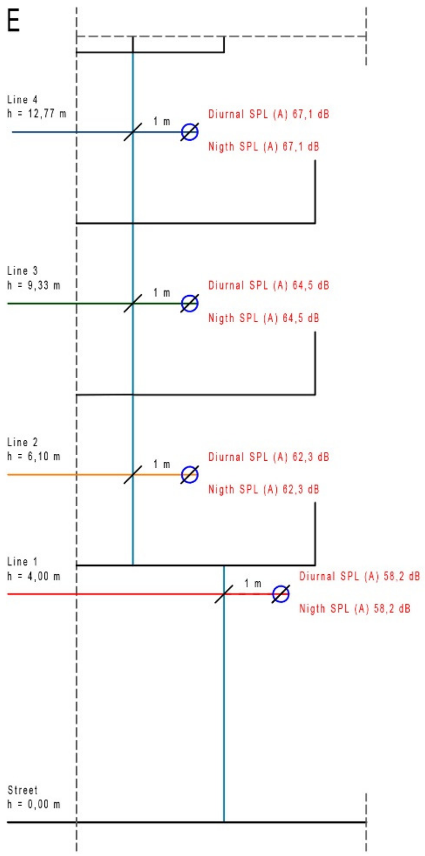
Façades configuration diagrams: D - Façade with loggias, E - Façade with balcony and loggias

Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A)	> 55 dB (A)	Nigth (22: 00-06:00)	≤ 45 dB (A) > 45 dB (A)

Simulated measured in according to D.M. 16/03/1998





7.7 SPL (A) verification according to Regulation 318 of Turin (Punctual sound source)

Table 7-6– SPL (A) with different microphone positions and façade configuration (Punctual sound source) (I)

Point sound sorce

Façades configuration diagrams:

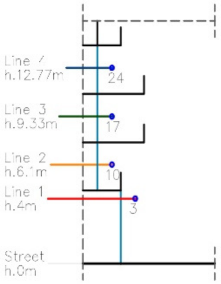
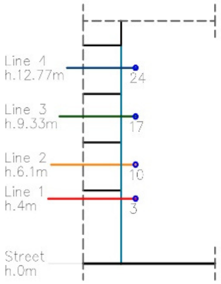
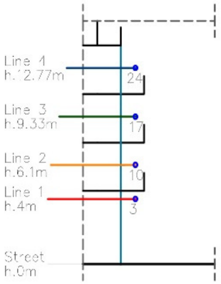
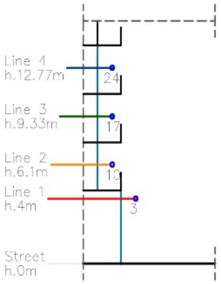
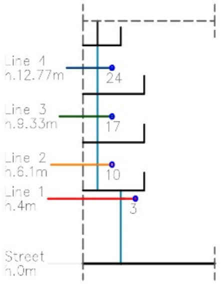
Current state of the buildind façade	Flat façade	Façade with balconies	Façade with loggias	Façade with balcony and loggias
				

Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A)	> 55 dB (A)	Nigth (22: 00-06:00)	≤ 45 dB (A)	> 45 dB (A)

Simulated measured in according to D.M. 16/03/1998

Diurnal (06: 00-22:00)

	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)
Line 1	R3	1 m	52,6	Line 1	R3	1 m	52,3	Line 1	R3	1 m	53,2	Line 1	R3	1 m	52,4	Line 1	R3	1 m	53,0
Line 2	R10	1 m	52,5	Line 2	R10	1 m	52,5	Line 2	R10	1 m	51,8	Line 2	R10	1 m	51,7	Line 2	R10	1 m	51,0
Line 3	R17	1 m	48,8	Line 3	R17	1 m	51,5	Line 3	R17	1 m	51,1	Line 3	R17	1 m	50,5	Line 3	R17	1 m	49,9
Line 4	R24	1 m	48,3	Line 4	R24	1 m	50,4	Line 4	R24	1 m	49,0	Line 4	R24	1 m	48,0	Line 4	R24	1 m	44,7

Nigth (22: 00-06:00)

	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)	d = 1 m	R.m. no.	distance	SPL (A)
Line 1	R3	1 m	52,6	Line 1	R3	1 m	52,3	Line 1	R3	1 m	53,2	Line 1	R3	1 m	52,4	Line 1	R3	1 m	53,0
Line 2	R10	1 m	52,5	Line 2	R10	1 m	52,5	Line 2	R10	1 m	51,8	Line 2	R10	1 m	51,7	Line 2	R10	1 m	51,0
Line 3	R17	1 m	48,8	Line 3	R17	1 m	51,5	Line 3	R17	1 m	51,1	Line 3	R17	1 m	50,5	Line 3	R17	1 m	49,9
Line 4	R24	1 m	48,3	Line 4	R24	1 m	50,4	Line 4	R24	1 m	49,0	Line 4	R24	1 m	48,0	Line 4	R24	1 m	44,7

Table 7-7– SPL (A) with different microphone positions and façade configuration (Punctual sound source) (II)

Point sound sorce

Façades configuration diagrams: A - Current state of the buildind façade, B - Flat façade, C - Façade with balconies

Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A) > 55 dB (A)	Nigth (22: 00-06:00)	≤ 45 dB (A) > 45 dB (A)

Simulated measured in according to D.M. 16/03/1998

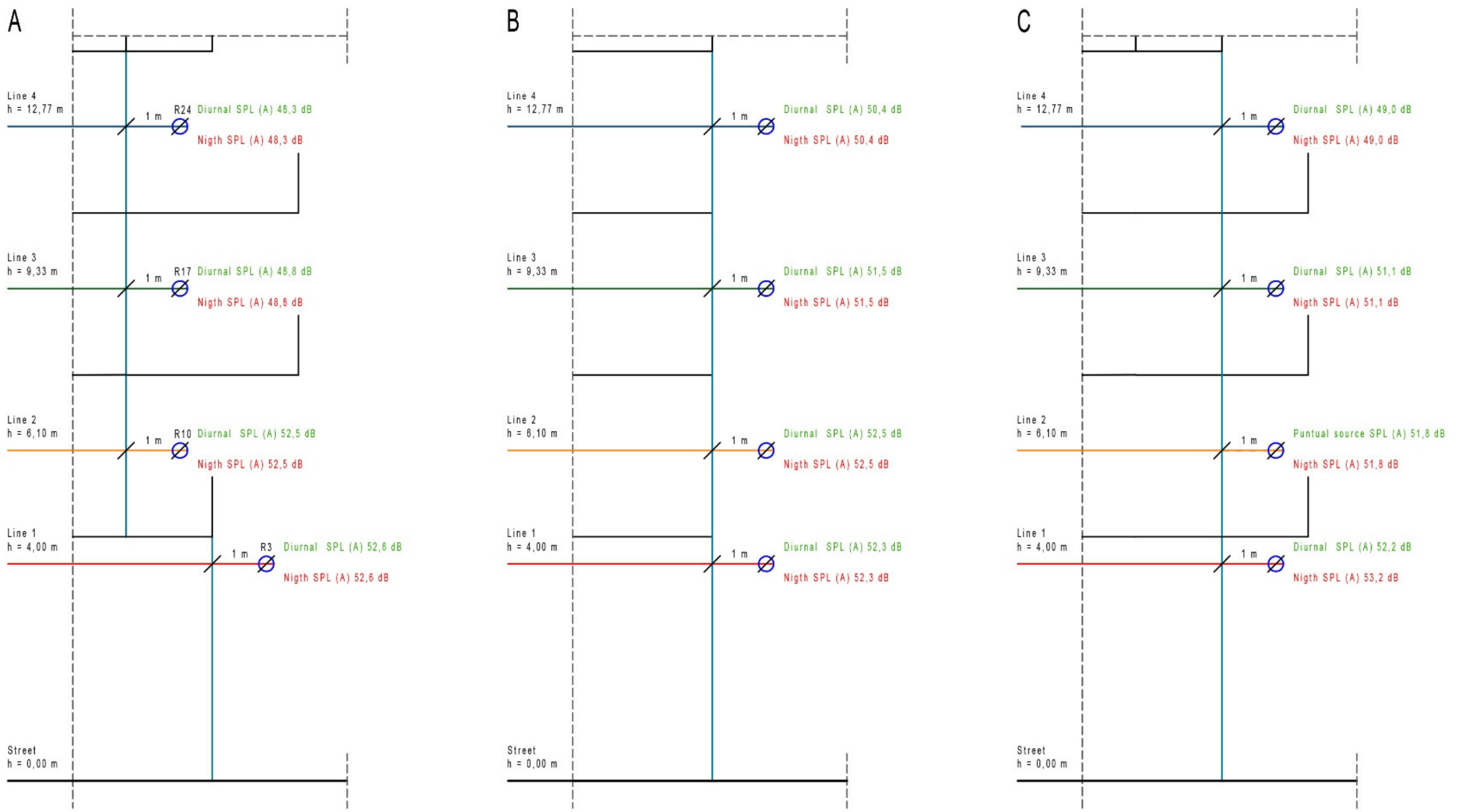


Table 7-8– SPL (A) with different microphone positions and façade configuration (Punctual sound source) (III)

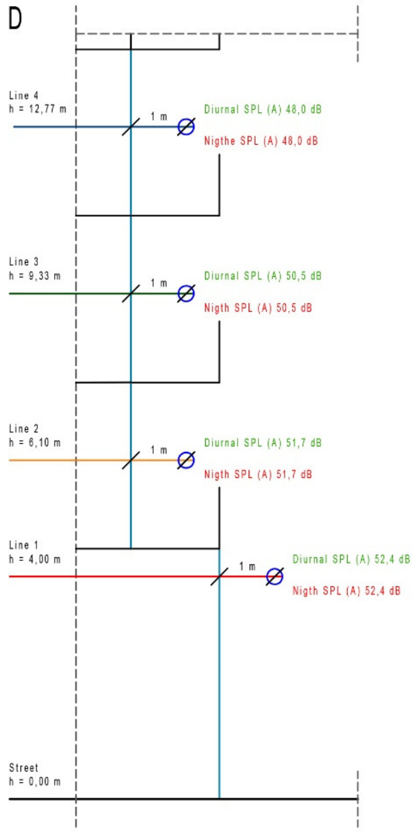
Point sound sorce

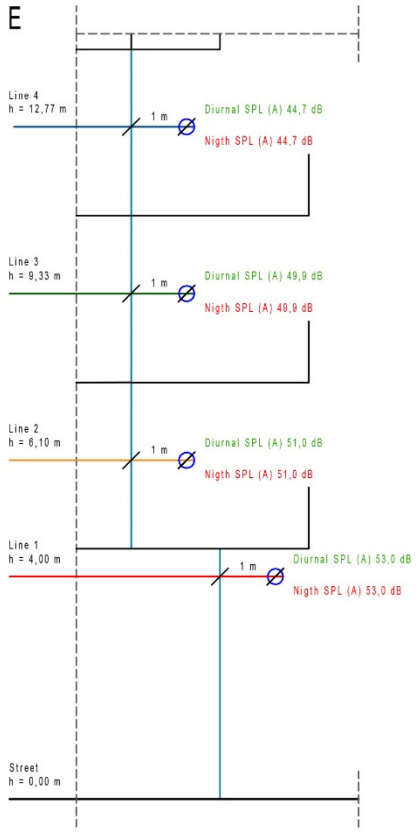
Façades configuration diagrams: D - Façade with loggias, E - Façade with balcony and loggias

Table A: absolute limit values - D.P.C.M. 14/11/1997

Destination classes land use	II - Predominantly residential areas	Emission limits Leq in dB (A)	Diurnal (06: 00-22:00)	≤ 55 dB (A) > 55 dB (A)	Nigth (22: 00-06:00)		≤ 45 dB (A) > 45 dB (A)

Simulated measured in according to D.M. 16/03/1998





7.8 The correction factor (c.f.) with different microphone positions and façade configuration

Table 7-9– Punctual sound source – Simulation results

	on the façade	Near the façade				free field
	R_0	R_0,5	R_1	R_1,2	R_2	R_7,05
d = im [m]	0	0,50	1	1,20	2	7
SPL [dB]	60,6	59,4	59,2	59,2	59,3	61,4
c.f. calculated	**-0,8**	**-2,0**	**-2,2**	**-2,2**	**-2,1**	
c.f. ISO 1996-2: 2017	5,7	3	3	3	3	
c.f. Memoli G.	6,2	3,5	3,5	3,5	3,5	
c.f. Memoli G.	5,2	2,5	2,5	2,5	2,5	
Montes Gonzàlez D.	2,6	1,1	0,8	0,5	0,2	

Line of microphones no. 1 - height from street level 4 [m]

d = im [m] - distance from the building façade

R_i - Receiver microphones placed at progressive distances from the facade of the building

SPL [dB] - sound pressure level

c.f. [dB] correction factor inside the formula of ΔL_{fs} (ΔL_{fs} - Shape coefficient of the facade)

Calculation formula of the correction factor (c.f.) - c.f. = R_7,05 - R_in

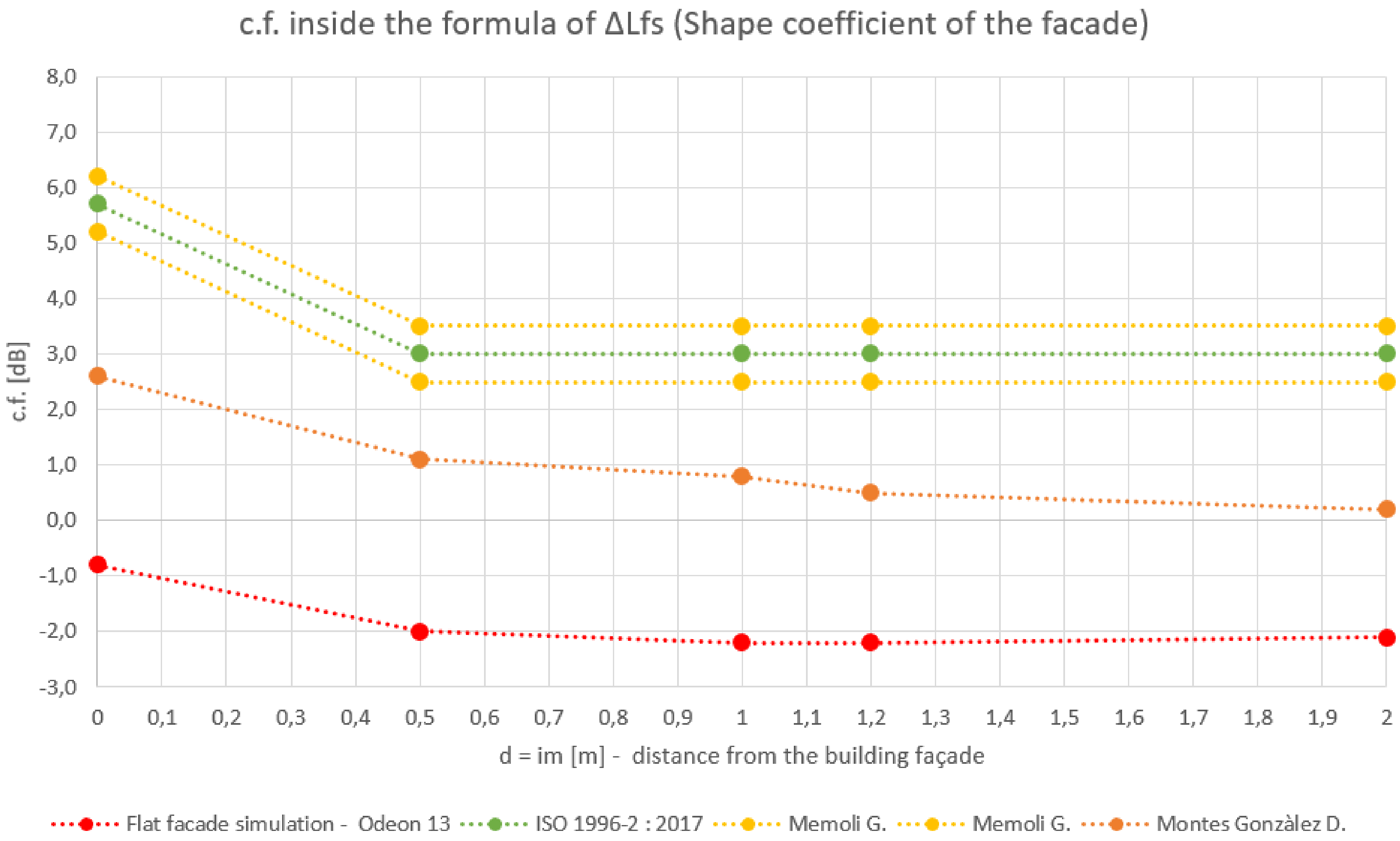


Figure 7-12 – c.f. inside the formula of ΔL_{fs} (Shape coefficient of the facade) (I)

Table 7-10– Linear sound source – Simulation results

	on the façade	Near the façade				free field
	R_0	R_0,5	R_1	R_1,2	R_2	R_7,05
d = im [m]	0	0,50	1	1,20	2	7
SPL [dB]	75,2	73,6	73,0	72,9	72,5	72,4
c.f. calculated	**2,8**	**1,2**	**0,6**	**0,5**	**0,1**	
c.f. ISO 1996-2: 2017	5,7	3	3	3	3	
c.f. Memoli G.	6,2	3,5	3,5	3,5	3,5	
c.f. Memoli G.	5,2	2,5	2,5	2,5	2,5	
Montes Gonzàlez D.	2,6	1,1	/	0,5	/	

Line of microphones no. 1 - height from street level 4 [m]

d = im [m] - distance from the building façade

R_i - Receiver microphones placed at progressive distances from the facade of the building

SPL [dB] - sound pressure level

c.f. [dB] correction factor inside the formula of ΔL_{fs} (ΔL_{fs} - Shape coefficient of the facade)

Calculation formula of the correction factor (c.f.) - c.f. = R_7,05 - R_in

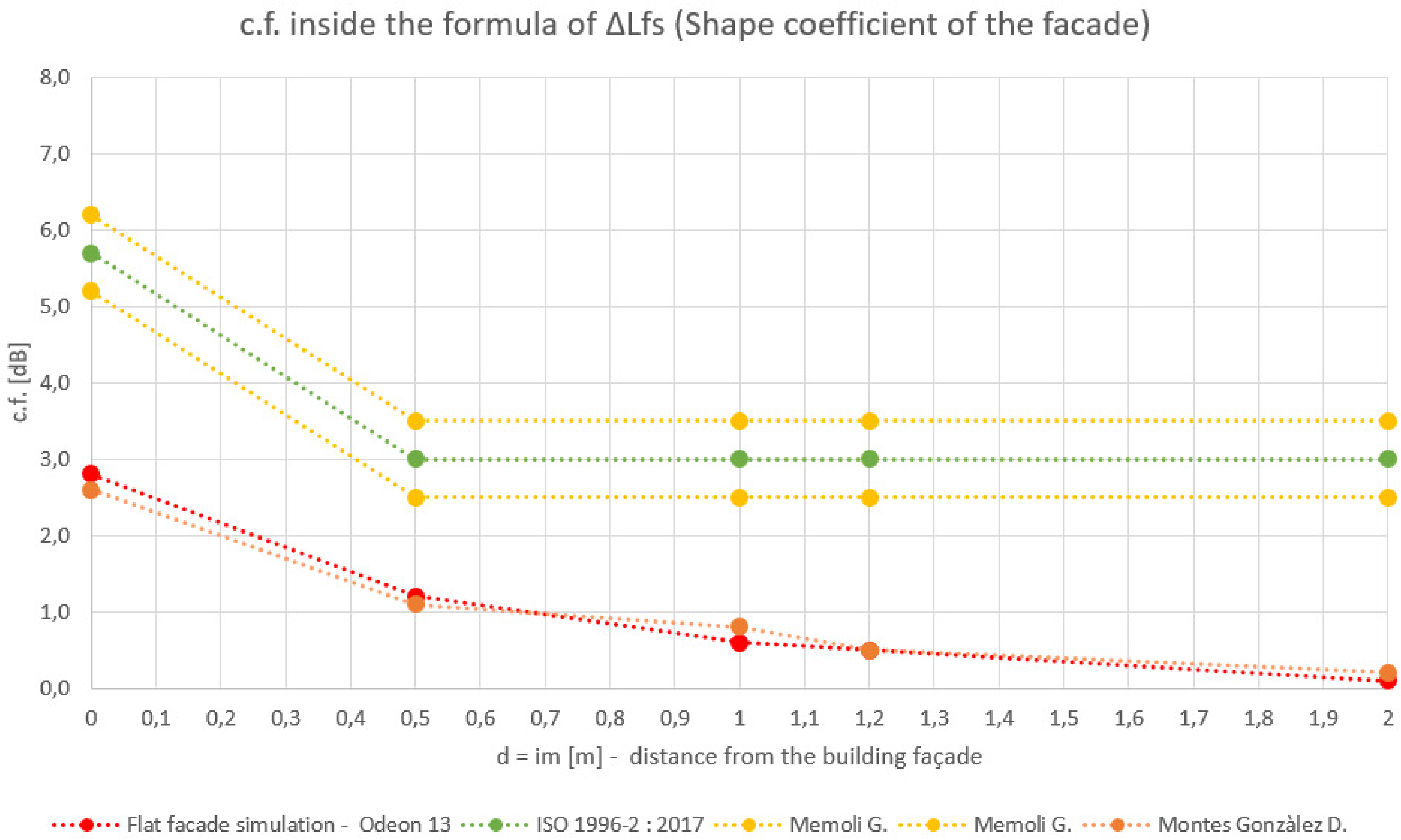
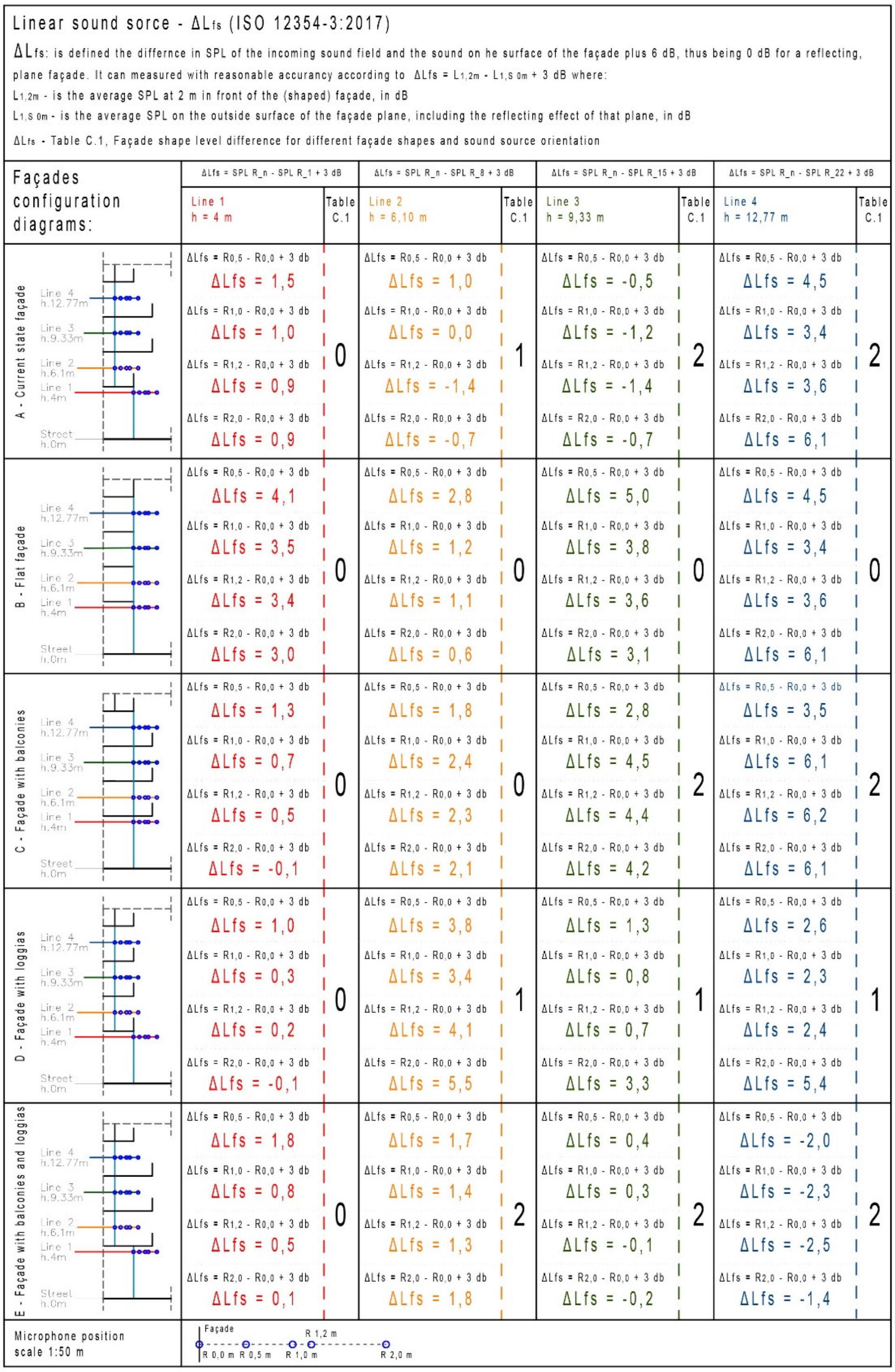


Figure 7-13 – c.f. inside the formula of ΔL_{fs} (Shape coefficient of the facade) (II)

7.9 ΔL_{fs} with different microphone positions and façade configuration (Linear sound source)

Table 7-11– ΔL_{fs} with different microphone positions and façade configuration

(Linear sound source) (I)



Linear sound sorce - ΔL_{fs} (ISO 12354-3:2017)

ΔL_{fs}: is defined the differnce in SPL of the incoming sound field and the sound on he surface of the façade plus 6 dB, thus being 0 dB for a reflecting, plane façade. It can measured with reasonable accurancy according to $\Delta L_{fs} = L_{1,2m} - L_{1,S\,0m} + 3$ dB where:

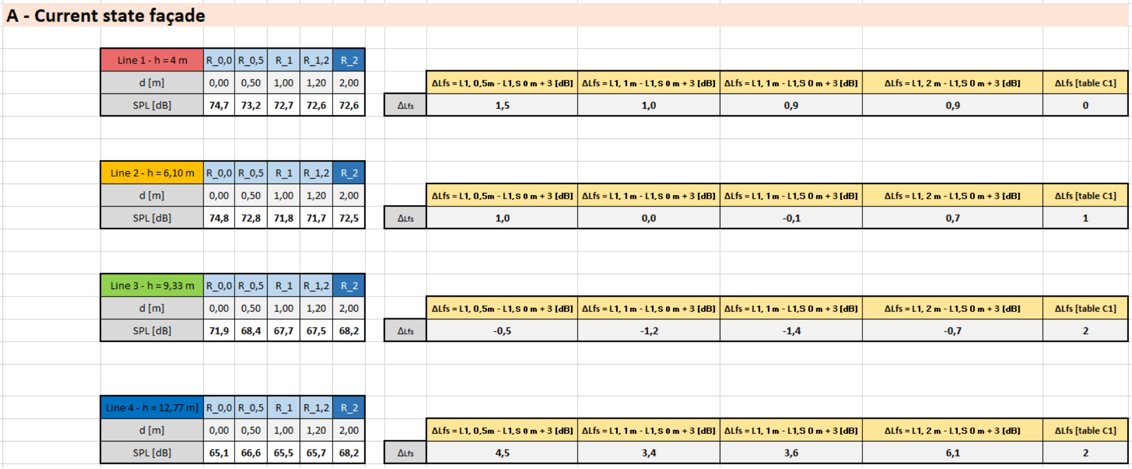
$L_{1,2m}$ - is the average SPL at 2 m in front of the (shaped) façade, in dB

$L_{1,S\,0m}$ - is the average SPL on the outside surface of the façade plane, including the reflecting effect of that plane, in dB

ΔL_{fs} - Table C.1, Façade shape level difference for different façade shapes and sound source orientation

Façades configuration diagrams:	ΔLfs = SPL R_n - SPL R_1 + 3 dB		ΔLfs = SPL R_n - SPL R_8 + 3 dB		ΔLfs = SPL R_n - SPL R_15 + 3 dB		ΔLfs = SPL R_n - SPL R_22 + 3 dB	
	Line 1 h = 4 m	Table C.1	Line 2 h = 6,10 m	Table C.1	Line 3 h = 9,33 m	Table C.1	Line 4 h = 12,77 m	Table C.1
A - Current state façade	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,0 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,9 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 0,9	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,0 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,0 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -1,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,7	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = -0,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = -1,2 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -1,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,7	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 4,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 3,6 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 6,1	2
B - Flat façade	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 4,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,5 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 3,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 3,0	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,2 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,1 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 0,6	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 5,0 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,8 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 3,6 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 3,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 4,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 3,6 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 6,1	0
C - Façade with balconies	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,3 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,7 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,5 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 2,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 2,3 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 4,5 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 4,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 4,2	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 3,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 6,1 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 6,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 6,1	2
D - Façade with loggias	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,0 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,3 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 3,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 4,1 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 5,5	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,3 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,8 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,7 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 3,3	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,6 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 2,3 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 2,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 5,4	1
E - Façade with balconies and loggias	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,8 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,5 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 0,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,7 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,3 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,8	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 0,4 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,3 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -0,1 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,2	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = -2,0 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = -2,3 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -2,5 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -1,4	2
Microphone position scale 1:50 m								

Table 7-12– ΔLfs (Linear sound source) – A -Current state façade (I)



A - Current state façade

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	74,7	73,2	72,7	72,6	72,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,5	1,0	0,9	0,9	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	74,8	72,8	71,8	71,7	72,5

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,0	0,0	-0,1	0,7	1

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	71,9	68,4	67,7	67,5	68,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	-0,5	-1,2	-1,4	-0,7	2

Line 4 - h = 12,77 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	65,1	66,6	65,5	65,7	68,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	4,5	3,4	3,6	6,1	2

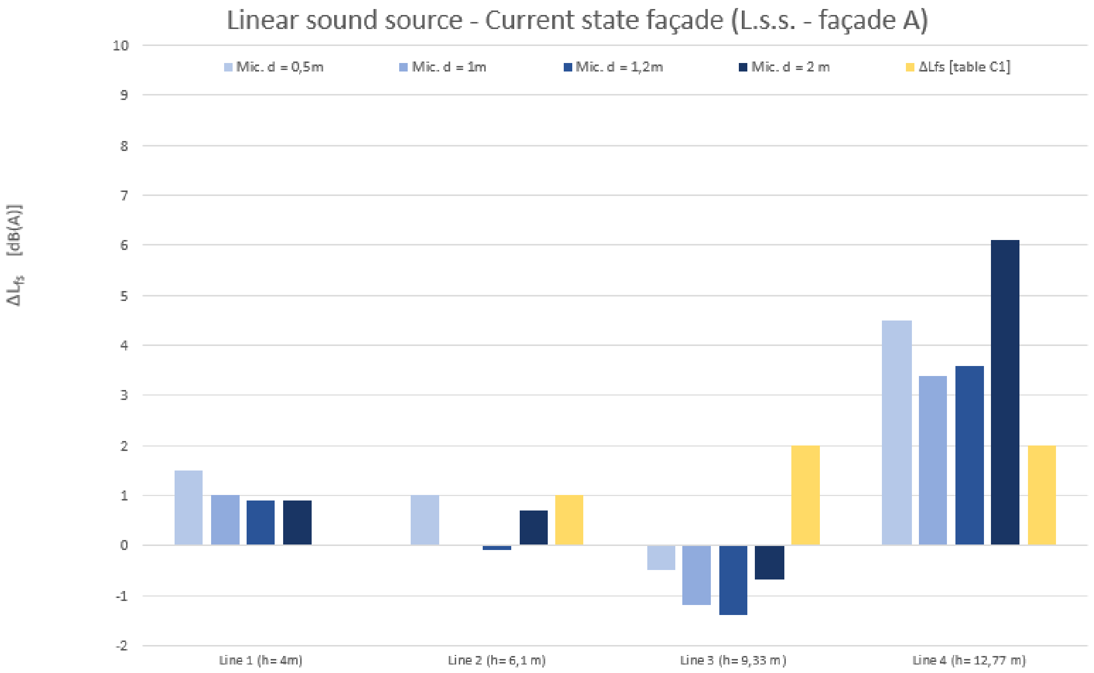
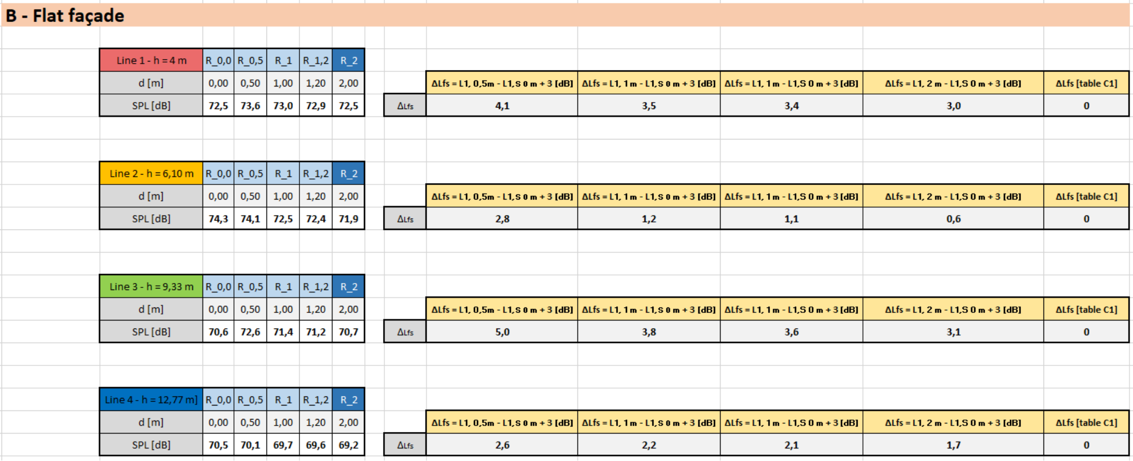


Figure 7-14 – ΔLfs (Linear sound source) – A -Current state façade

Table 7-13– ΔLfs (Linear sound source) – A -Current state façade (II)

L.s.s. - façade A	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h= 4m)	1,5	1,0	0,9	0,9	0
Line 2 (h= 6,1 m)	1,0	0,0	-0,1	0,7	1
Line 3 (h= 9,33 m)	-0,5	-1,2	-1,4	-0,7	2
Line 4 (h= 12,77 m)	4,5	3,4	3,6	6,1	2

Table 7-14– ΔLfs (Linear sound source) – B -Flat façade (I)



B - Flat façade

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	72,5	73,6	73,0	72,9	72,5

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	4,1	3,5	3,4	3,0	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	74,3	74,1	72,5	72,4	71,9

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,8	1,2	1,1	0,6	0

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	70,6	72,6	71,4	71,2	70,7

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	5,0	3,8	3,6	3,1	0

Line 4 - h = 12,77 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	70,5	70,1	69,7	69,6	69,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,6	2,2	2,1	1,7	0

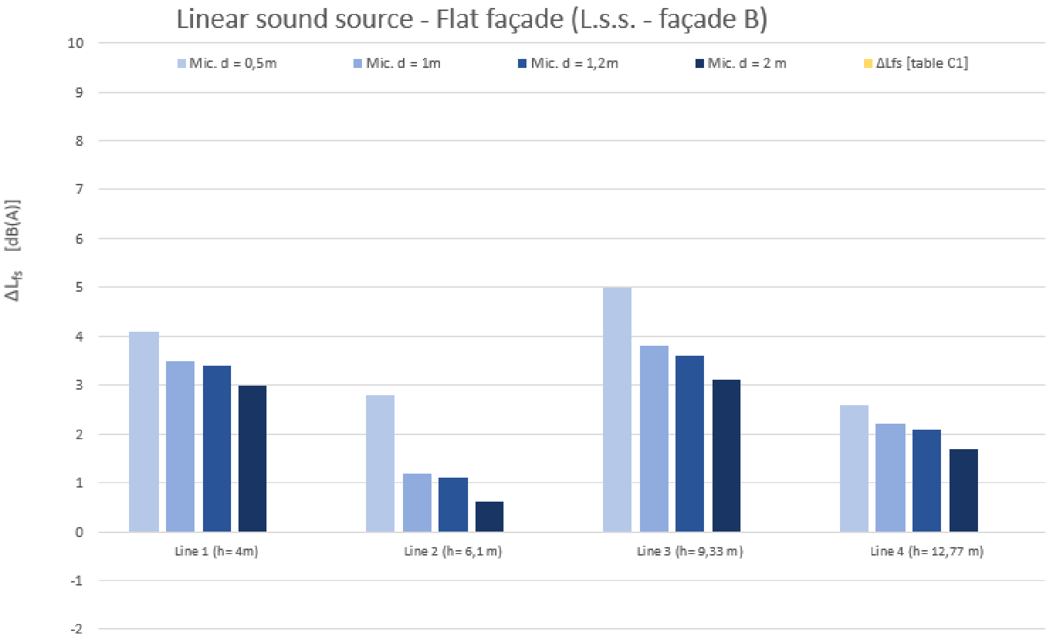
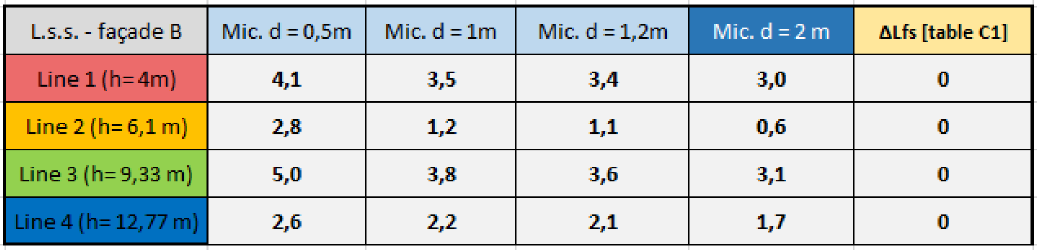


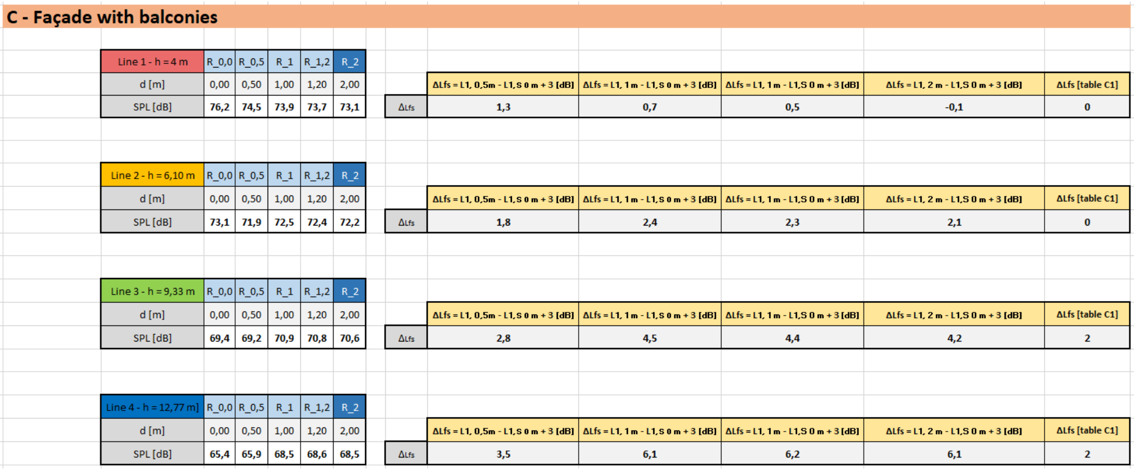
Figure 7-15 – ΔLfs (Linear sound source) – B -Flat façade

Table 7-15– ΔLfs (Linear sound source) – B -Flat façade (II)



L.s.s. - façade B	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h=4m)	4,1	3,5	3,4	3,0	0
Line 2 (h= 6,1 m)	2,8	1,2	1,1	0,6	0
Line 3 (h= 9,33 m)	5,0	3,8	3,6	3,1	0
Line 4 (h= 12,77 m)	2,6	2,2	2,1	1,7	0

Table 7-16– ΔLfs (Linear sound source) – C -Façade with balconies (I)



C - Façade with balconies

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	76,2	74,5	73,9	73,7	73,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,3	0,7	0,5	-0,1	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	73,1	71,9	72,5	72,4	72,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,8	2,4	2,3	2,1	0

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	69,4	69,2	70,9	70,8	70,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,8	4,5	4,4	4,2	2

Line 4 - h = 12,77 m)	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	65,4	65,9	68,5	68,6	68,5

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	3,5	6,1	6,2	6,1	2

Figure 7-16 – ΔLfs (Linear sound source) – C -Façade with balconies

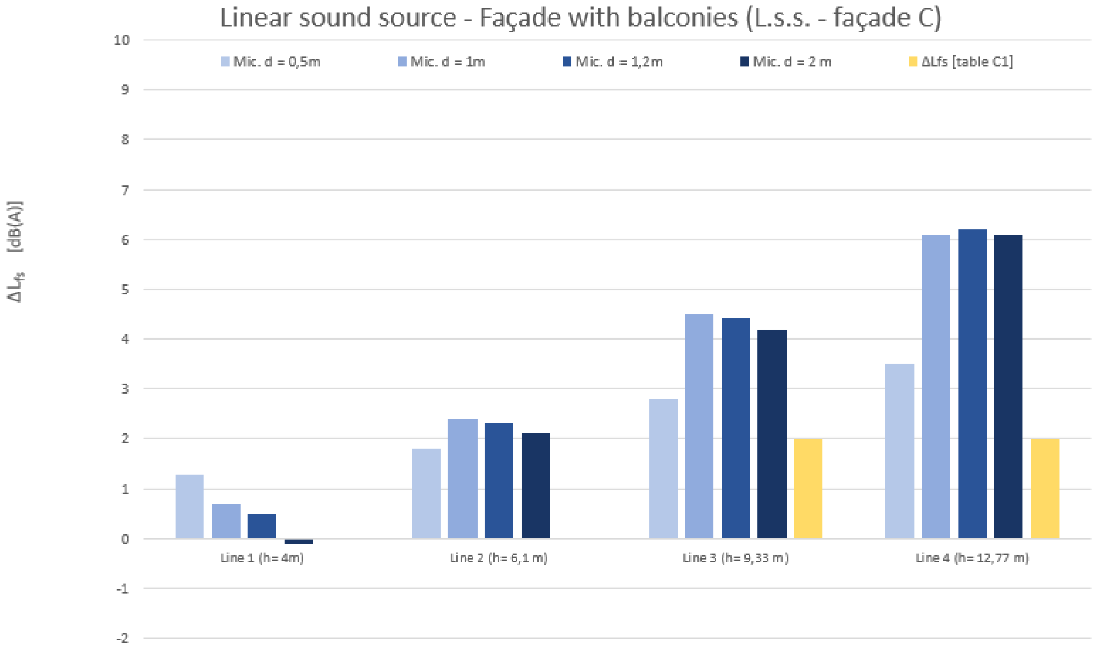
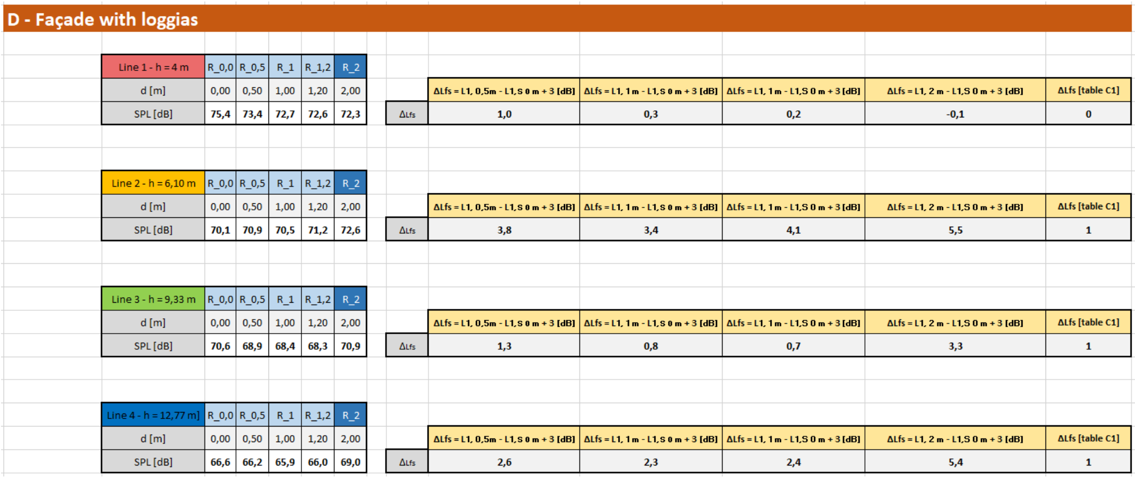


Table 7-17– ΔLfs (Linear sound source) – C -Façade with balconies (II)

L.s.s. - façade C	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,3**	**0,7**	**0,5**	**-0,1**	**0**
Line 2 (h= 6,1 m)	**1,8**	**2,4**	**2,3**	**2,1**	**0**
Line 3 (h= 9,33 m)	**2,8**	**4,5**	**4,4**	**4,2**	**2**
Line 4 (h= 12,77 m)	**3,5**	**6,1**	**6,2**	**6,1**	**2**

Table 7-18– ΔLfs (Linear sound source) – D -Façade with loggias (I)



D - Façade with loggias

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	75,4	73,4	72,7	72,6	72,3

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,0	0,3	0,2	-0,1	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	70,1	70,9	70,5	71,2	72,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	3,8	3,4	4,1	5,5	1

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	70,6	68,9	68,4	68,3	70,9

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,3	0,8	0,7	3,3	1

Line 4 - h = 12,77 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	66,6	66,2	65,9	66,0	69,0

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,6	2,3	2,4	5,4	1

Figure 7-17 – ΔLfs (Linear sound source) – D -Façade with loggias

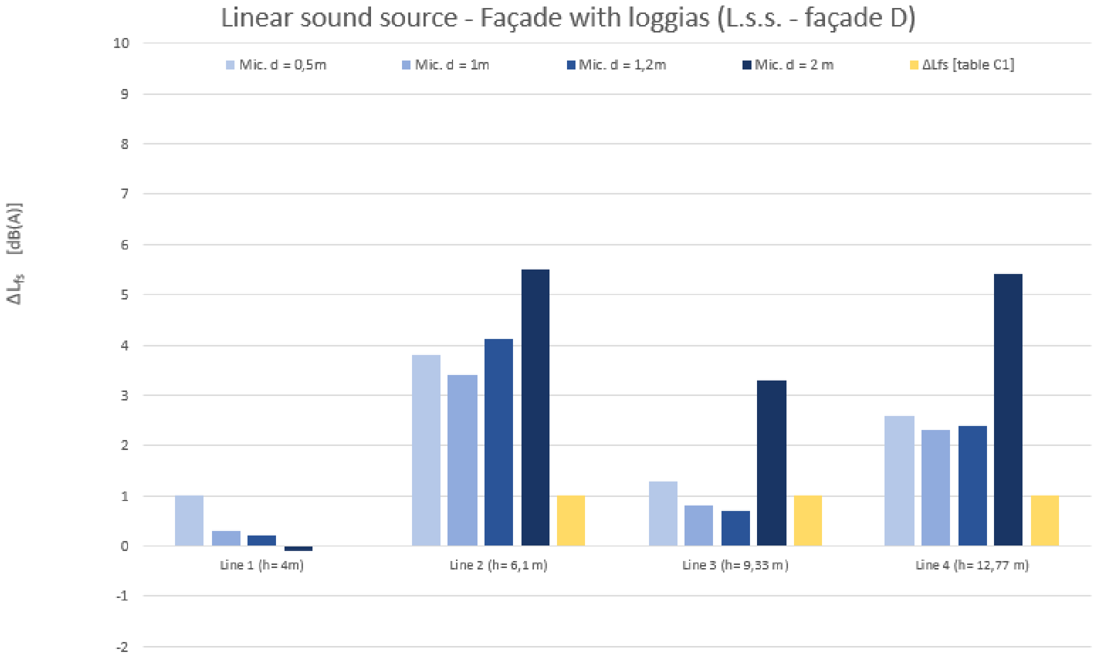
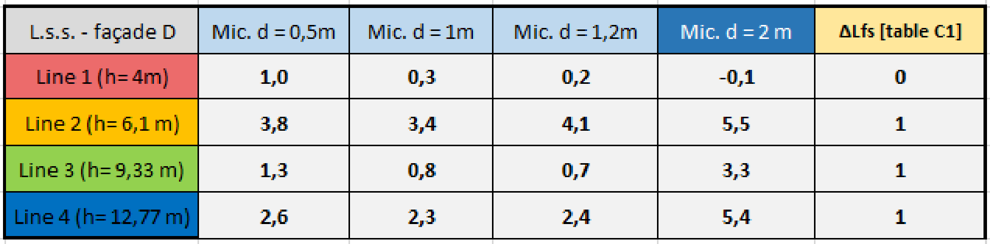
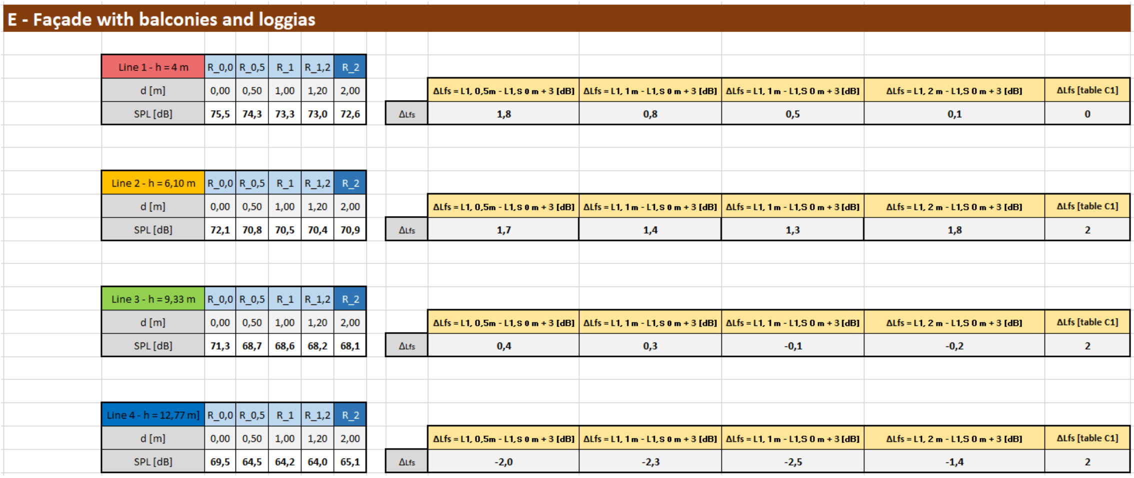


Table 7-19– ΔLfs (Linear sound source) – D -Façade with loggias (II)



L.s.s. - façade D	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h= 4m)	1,0	0,3	0,2	-0,1	0
Line 2 (h= 6,1 m)	3,8	3,4	4,1	5,5	1
Line 3 (h= 9,33 m)	1,3	0,8	0,7	3,3	1
Line 4 (h= 12,77 m)	2,6	2,3	2,4	5,4	1

Table 7-20– ΔLfs (Linear sound source) – E -Façade with balconies and loggias (I)



E - Façade with balconies and loggias

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	75,5	74,3	73,3	73,0	72,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,8	0,8	0,5	0,1	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	72,1	70,8	70,5	70,4	70,9

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,7	1,4	1,3	1,8	2

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	71,3	68,7	68,6	68,2	68,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	0,4	0,3	-0,1	-0,2	2

Line 4 - h = 12,77 m]	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	69,5	64,5	64,2	64,0	65,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	-2,0	-2,3	-2,5	-1,4	2

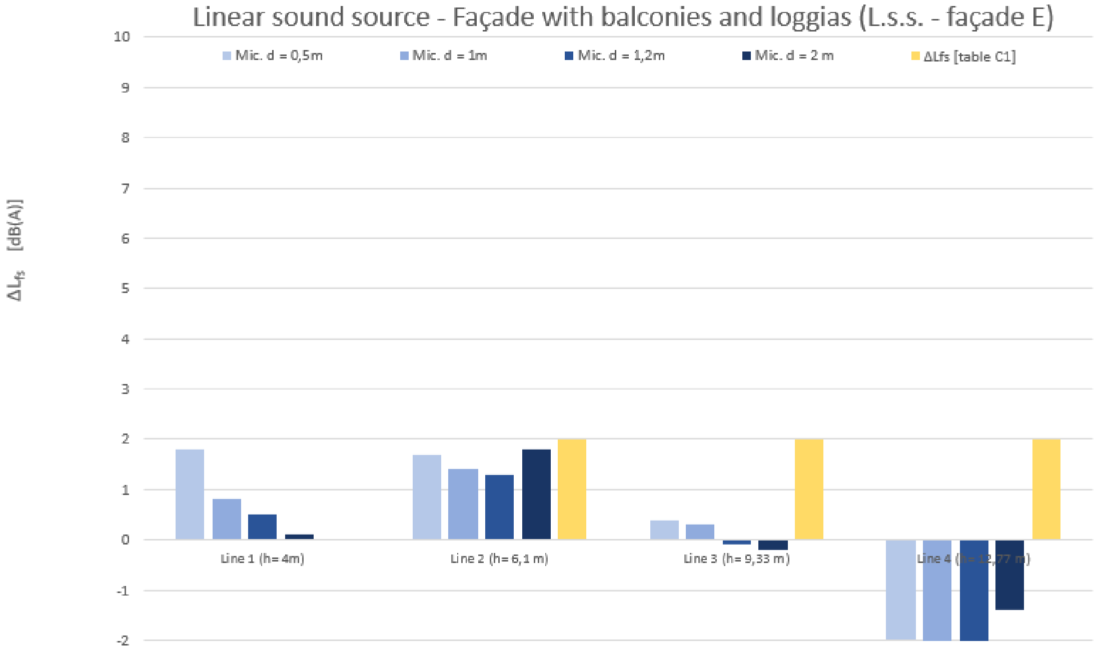
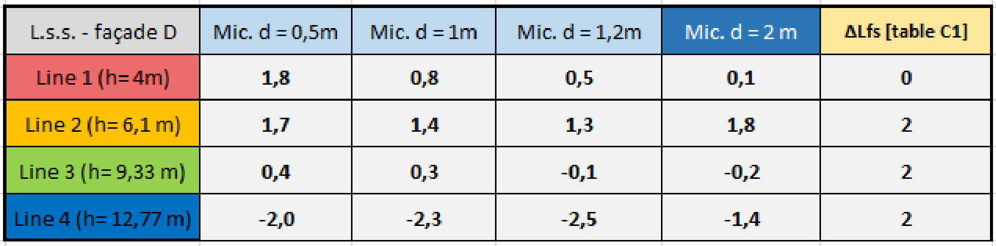


Figure 7-18 – ΔLfs (Linear sound source) – E -Façade with balconies and loggias

Table 7-21– ΔLfs (Linear sound source) – E -Façade with balconies and loggias (II)



L.s.s. - façade D	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h= 4m)	1,8	0,8	0,5	0,1	0
Line 2 (h= 6,1 m)	1,7	1,4	1,3	1,8	2
Line 3 (h= 9,33 m)	0,4	0,3	-0,1	-0,2	2
Line 4 (h= 12,77 m)	-2,0	-2,3	-2,5	-1,4	2

Table 7-22– ΔL_{fs} with different microphone positions and façade configuration

(Linear sound source) (II)

Linear sound sorce - ΔL_{fs} (ISO 12354-3:2017)

ΔL_{fs}: is defined the differnce in SPL of the incoming sound field and the sound on he surface of the façade plus 6 dB, thus being 0 dB for a reflecting, plane façade. It can measured with reasonable accurancy according to $\Delta L_{fs} = L_{1,2m} - L_{1,S\ 0m}$ where:

$L_{1,2m}$ - is the average SPL at 2 m in front of the (shaped) façade, in dB

$L_{1,S\ 0m}$ - is the average SPL on the outside surface of the façade plane, including the reflecting effect of that plane, in dB

ΔL_{fs} - Table C.1, Façade shape level difference for different façade shapes and sound source orientation

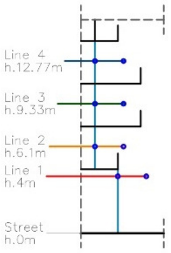
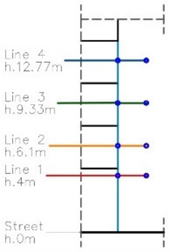
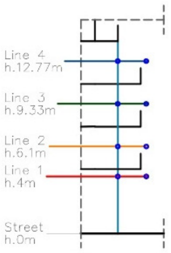
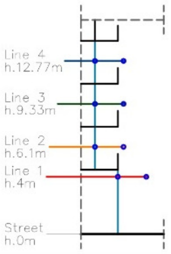
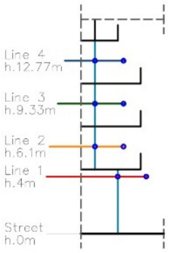
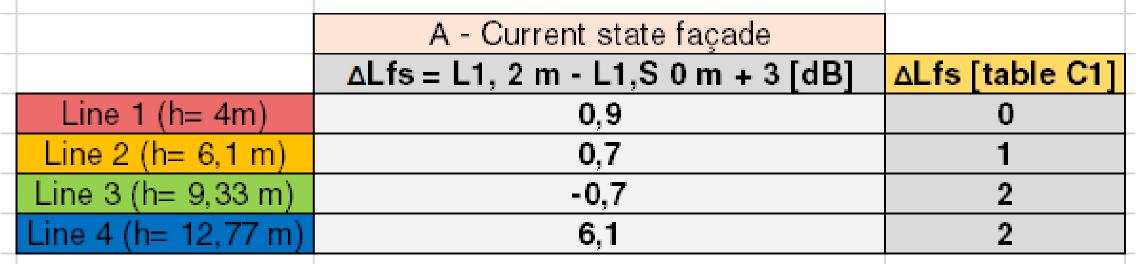
Façades configuration diagrams:	ΔLfs = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔLfs = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔLfs = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔLfs = SPL R 2,0m - SPL R 0,0m + 3 dB	
	Line 1 h = 4 m d = 0 - 2 m	Table C.1	Line 2 h = 6,10 m d = 0 - 2 m	Table C.1	Line 3 h = 9,33 m d = 0 - 2 m	Table C.1	Line 4 h = 12,77 m d = 0 - 2 m	Table C.1
A - Current state façade  	0,9	0	0,7	1	-0,7	2	6,1	2
B - Flat façade  	3	0	0,6	0	3,1	0	1,7	0
C - Façade with balconies  	-0,1	0	2,1	0	4,2	2	6,1	2
D - Façade with loggias  	-0,1	0	5,5	1	3,3	1	5,4	1
E - Façade with balconies and loggias  	0,1	0	1,8	2	-0,2	2	-1,4	2
Microphone position scale 1:50 m	 							

Table 7-23– ΔL_{fs} (Linear sound source)
A - Current state façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	A - Current state façade	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**0,9**	**0**
Line 2 (h= 6,1 m)	**0,7**	**1**
Line 3 (h= 9,33 m)	**-0,7**	**2**
Line 4 (h= 12,77 m)	**6,1**	**2**

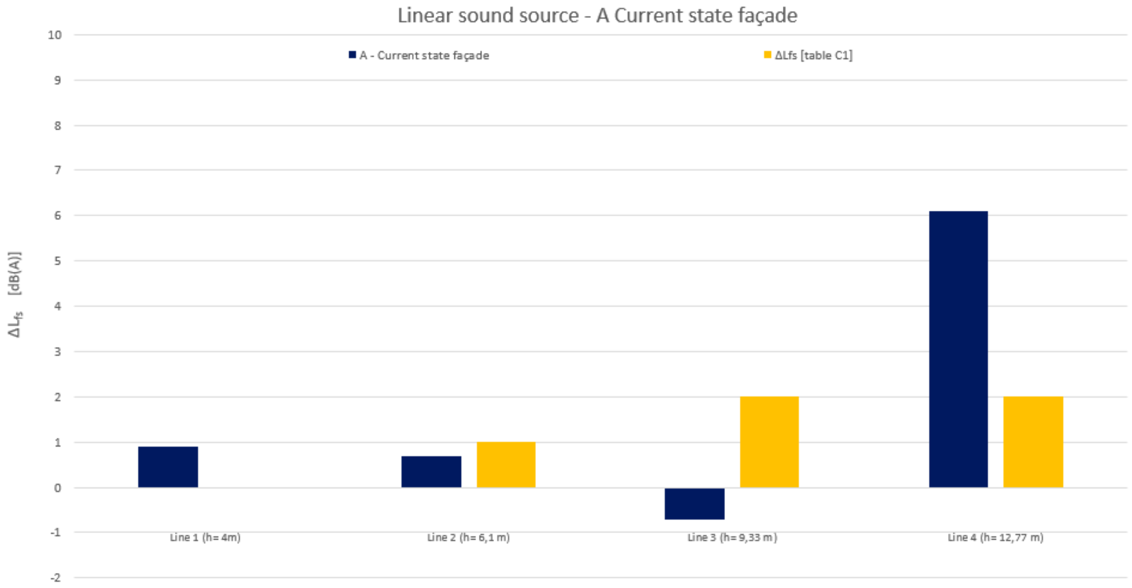


Figure 7-19 – ΔL_{fs} (Linear sound source)
A - Current state façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-24– ΔLfs (Linear sound source)
B - Flat façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

	B - Flat façade	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**3,0**	**0**
Line 2 (h= 6,1 m)	**0,6**	**0**
Line 3 (h= 9,33 m)	**3,1**	**0**
Line 4 (h= 12,77 m)	**1,7**	**0**

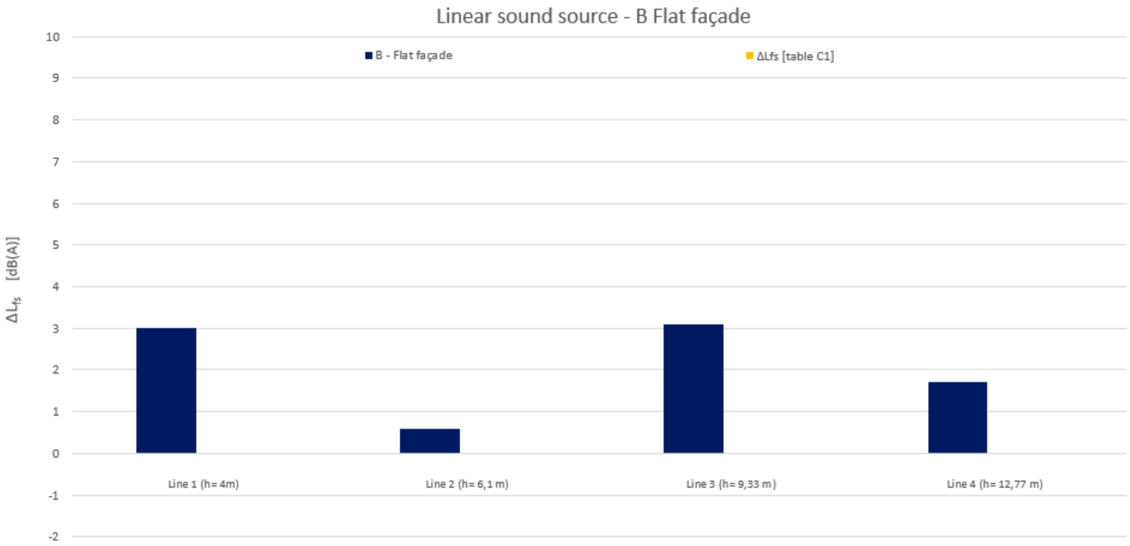
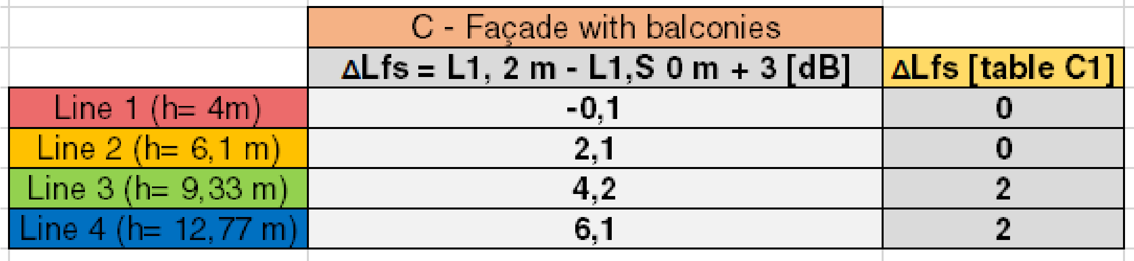


Figure 7-20 – ΔLfs (Linear sound source)
B - Flat façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-25– ΔL_{fs} (Linear sound source)
C - Façade with balconies - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	C - Façade with balconies	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
Line 1 (h= 4m)	-0,1	0
Line 2 (h= 6,1 m)	2,1	0
Line 3 (h= 9,33 m)	4,2	2
Line 4 (h= 12,77 m)	6,1	2

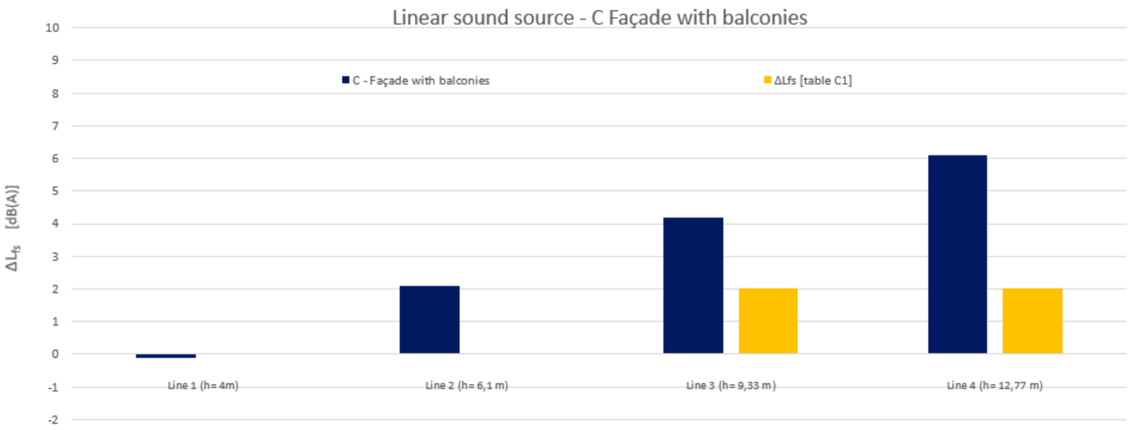
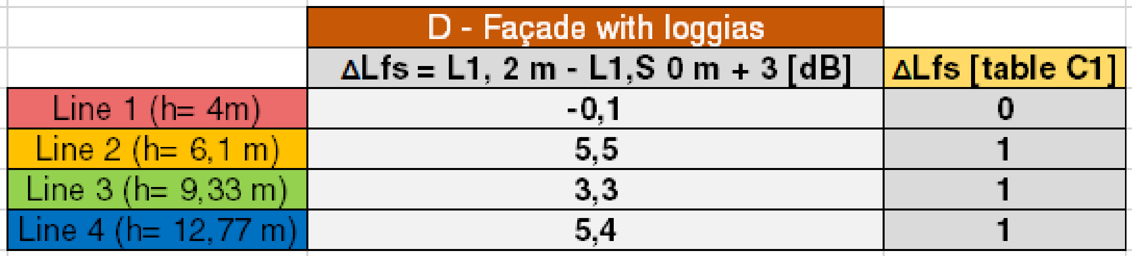


Figure 7-21 – ΔL_{fs} (Linear sound source)
C - Façade with balconies - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-26– ΔL_{fs} (Linear sound source)
D - Façade with loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	D - Façade with loggias	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**-0,1**	**0**
Line 2 (h= 6,1 m)	**5,5**	**1**
Line 3 (h= 9,33 m)	**3,3**	**1**
Line 4 (h= 12,77 m)	**5,4**	**1**

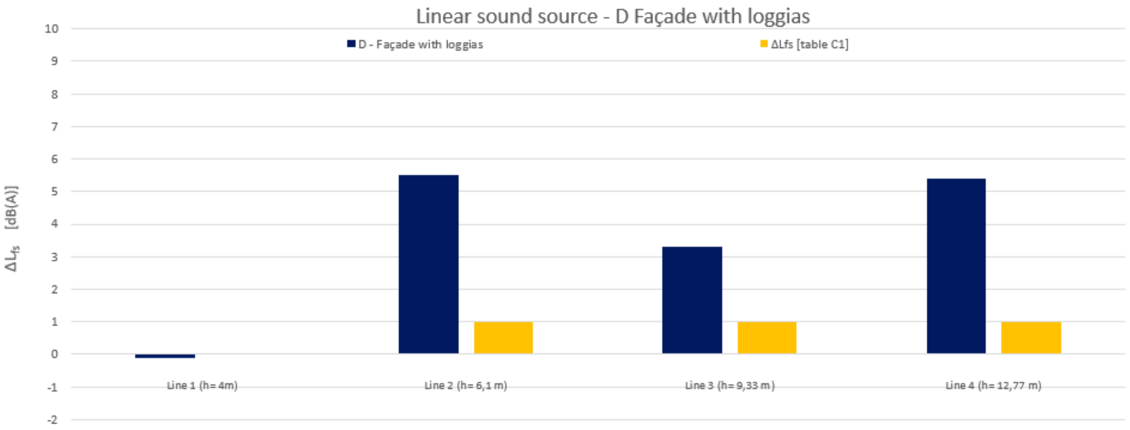


Figure 7-22 – ΔL_{fs} (Linear sound source)
D - Façade with loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-27– ΔL_{fs} (Linear sound source)
E - Façade with balconies and loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

	E - Façade with balconies and loggias	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
Line 1 (h= 4m)	0,1	0
Line 2 (h= 6,1 m)	1,8	2
Line 3 (h= 9,33 m)	-0,2	2
Line 4 (h= 12,77 m)	-1,4	2

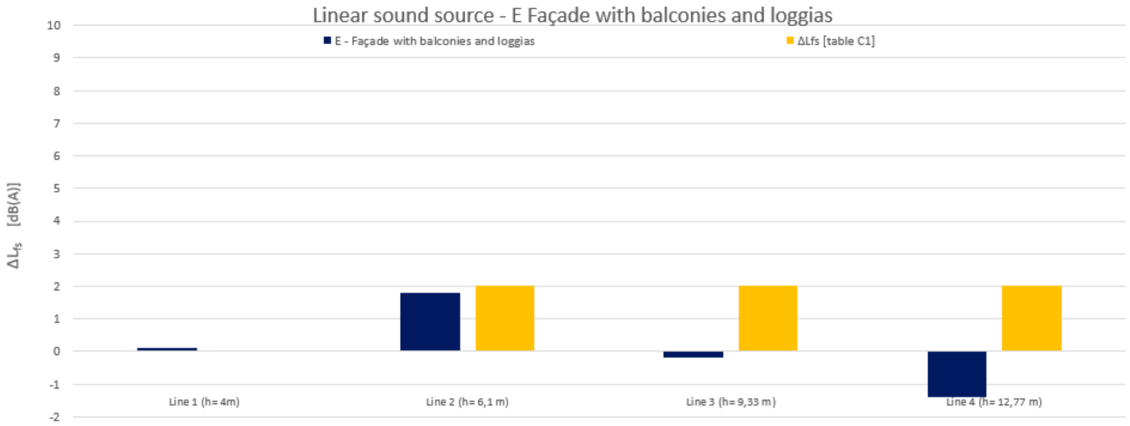


Figure 7-23 – ΔL_{fs} (Linear sound source)
E - Façade with balconies and loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

7.10 ΔLfs with different microphone positions and façade configuration (Punctual sound source)

Table 7-28– ΔLfs with different microphone positions and façade configuration (Punctual sound source) (I)

Point sound sorce - ΔLfs (ISO 12354-3:2017)

ΔLfs: is defined the differnce in SPL of the incoming sound field and the sound on he surface of the façade plus 6 dB, thus being 0 dB for a reflecting, plane façade. It can measured with reasonable accurancy according to $\Delta L_{fs} = L_{1,2m} - L_{1,S\ 0m} + 3$ dB where:

$L_{1,2m}$ - is the average SPL at 2 m in front of the (shaped) façade, in dB

$L_{1,S\ 0m}$ - is the average SPL on the outside surface of the façade plane, including the reflecting effect of that plane, in dB

ΔLfs - Table C.1, Façade shape level difference for different façade shapes and sound source orientation

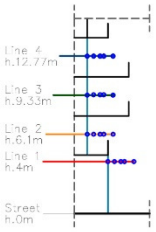
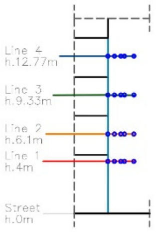
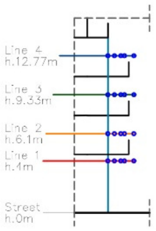
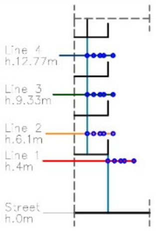
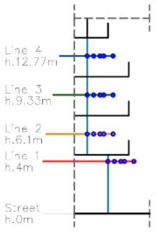
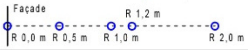
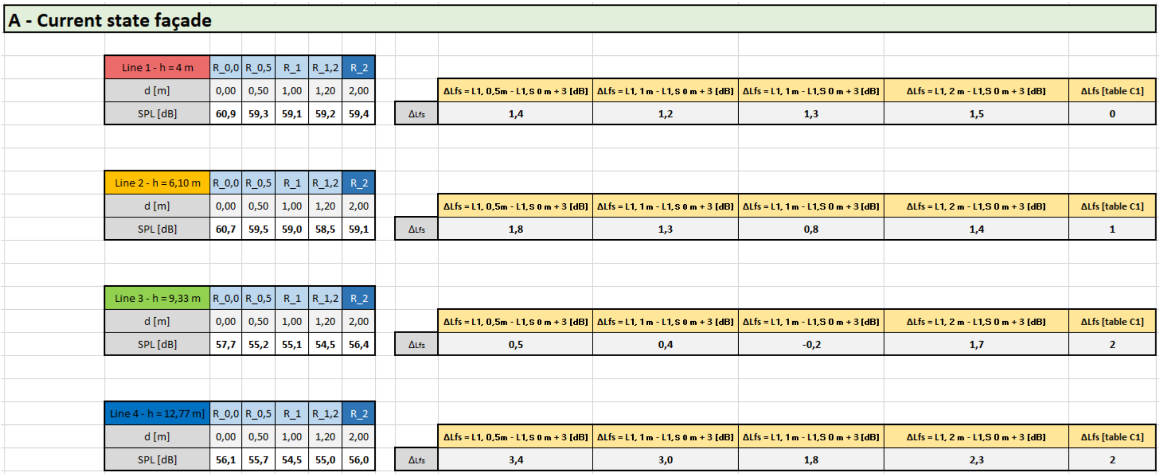
Façades configuration diagrams:	ΔLfs = SPL R_n - SPL R_1 + 3 dB		ΔLfs = SPL R_n - SPL R_8 + 3 dB		ΔLfs = SPL R_n - SPL R_15 + 3 dB		ΔLfs = SPL R_n - SPL R_22 + 3 dB	
	Line 1 h = 4 m	Table C.1	Line 2 h = 6,10 m	Table C.1	Line 3 h = 9,33 m	Table C.1	Line 4 h = 12,77 m	Table C.1
A - Current state façade 	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,4 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,2 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,3 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,5	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,3 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,8 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,4	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 0,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -0,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,7	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 3,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,0 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,3	2
B - Flat façade 	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,6 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,6 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,7	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,7 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,7 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,8	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 3,4 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 3,2 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 3,1 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,8	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,5 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,5 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,2	0
C - Façade with balconies 	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 0,4 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,1 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,0 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = -0,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = -0,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -0,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -0,1	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 5,7 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 6,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 6,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 6,8	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 6,5 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 7,9 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 7,9 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 9,0	2
D - Façade with loggias 	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,7 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,5 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 1,6	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 2,1 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 2,0 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,7	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 2,5 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 2,8 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 3,2	1	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,7 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,2 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 2,4	1
E - Façade with balconies and loggias 	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 1,0 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,4 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 0,4 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 0,3	0	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 2,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 1,9 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = 1,8 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 3,4	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = 0,1 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = 0,1 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -0,8 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = 0,7	2	ΔLfs = R0,5 - R0,0 + 3 db ΔLfs = -0,8 ΔLfs = R1,0 - R0,0 + 3 db ΔLfs = -2,9 ΔLfs = R1,2 - R0,0 + 3 db ΔLfs = -3,0 ΔLfs = R2,0 - R0,0 + 3 db ΔLfs = -1,1	2
Microphone position scale 1:50 m								

Table 7-29– ΔLfs (Punctual sound source) – A -Current state façade (I)



A - Current state façade

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	**60,9**	**59,3**	**59,1**	**59,2**	**59,4**

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	**1,4**	**1,2**	**1,3**	**1,5**	**0**

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	**60,7**	**59,5**	**59,0**	**58,5**	**59,1**

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	**1,8**	**1,3**	**0,8**	**1,4**	**1**

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	**57,7**	**55,2**	**55,1**	**54,5**	**56,4**

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	**0,5**	**0,4**	**-0,2**	**1,7**	**2**

Line 4 - h = 12,77 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	**56,1**	**55,7**	**54,5**	**55,0**	**56,0**

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	**3,4**	**3,0**	**1,8**	**2,3**	**2**

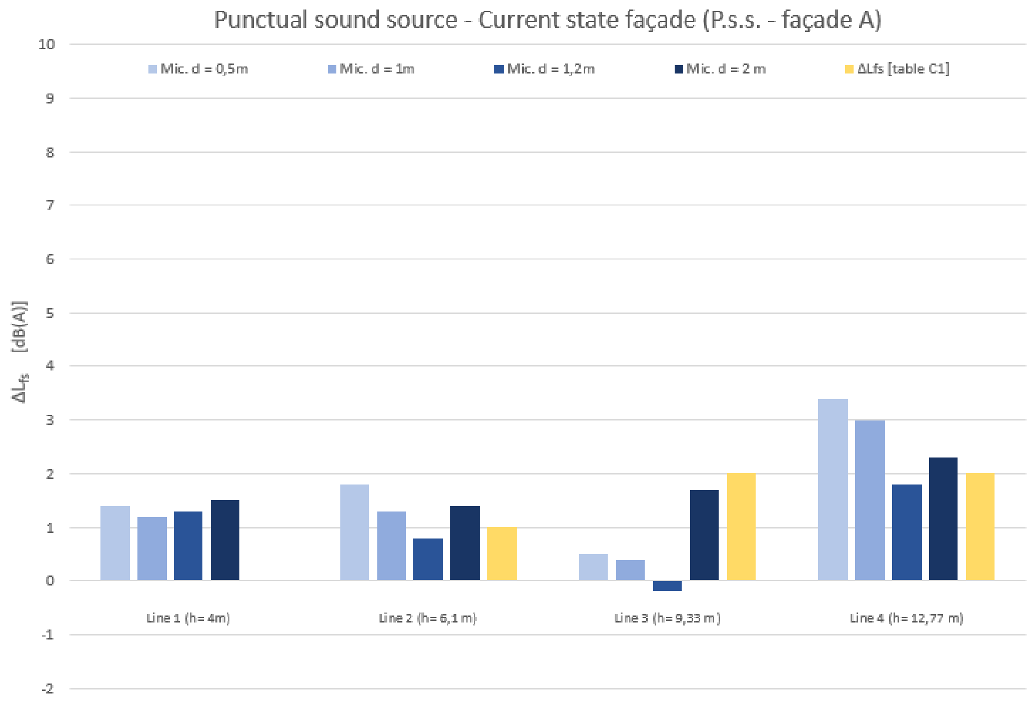
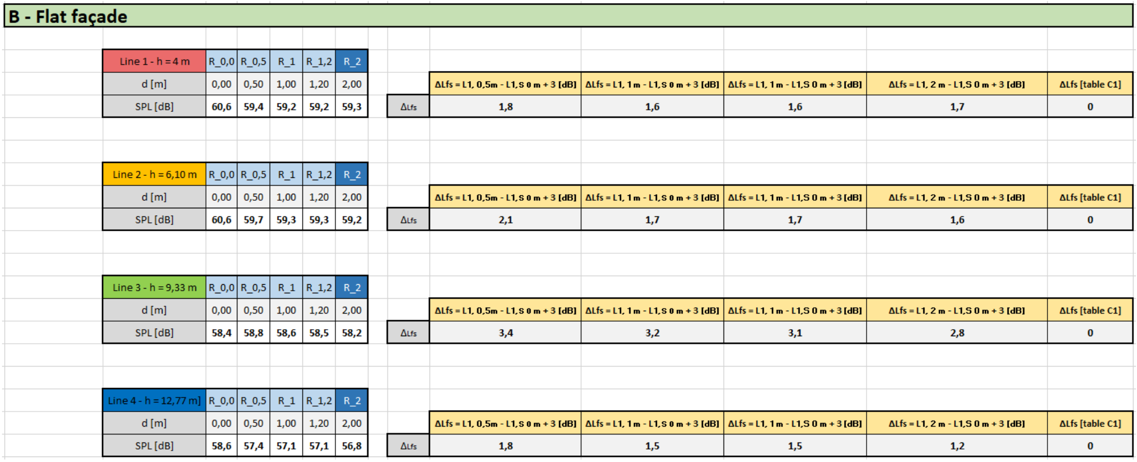


Figure 7-24 – ΔLfs (Punctual sound source) – A -Current state façade

Table 7-30– ΔLfs (Punctual sound source) – A -Current state façade (II)

P.s.s. - façade A	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,4**	**1,2**	**1,3**	**1,5**	**0**
Line 2 (h= 6,1 m)	**1,8**	**1,3**	**0,8**	**1,4**	**1**
Line 3 (h= 9,33 m)	**0,5**	**0,4**	**-0,2**	**1,7**	**2**
Line 4 (h= 12,77 m)	**3,4**	**3,0**	**1,8**	**2,3**	**2**

Table 7-31– ΔL$_{fs}$ (Punctual sound source) – B -Flat façade (I)



B - Flat façade

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	60,6	59,4	59,2	59,2	59,3

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,8	1,6	1,6	1,7	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	60,6	59,7	59,3	59,3	59,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,1	1,7	1,7	1,6	0

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	58,4	58,8	58,6	58,5	58,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	3,4	3,2	3,1	2,8	0

Line 4 - h = 12,77 m]	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	58,6	57,4	57,1	57,1	56,8

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,8	1,5	1,5	1,2	0

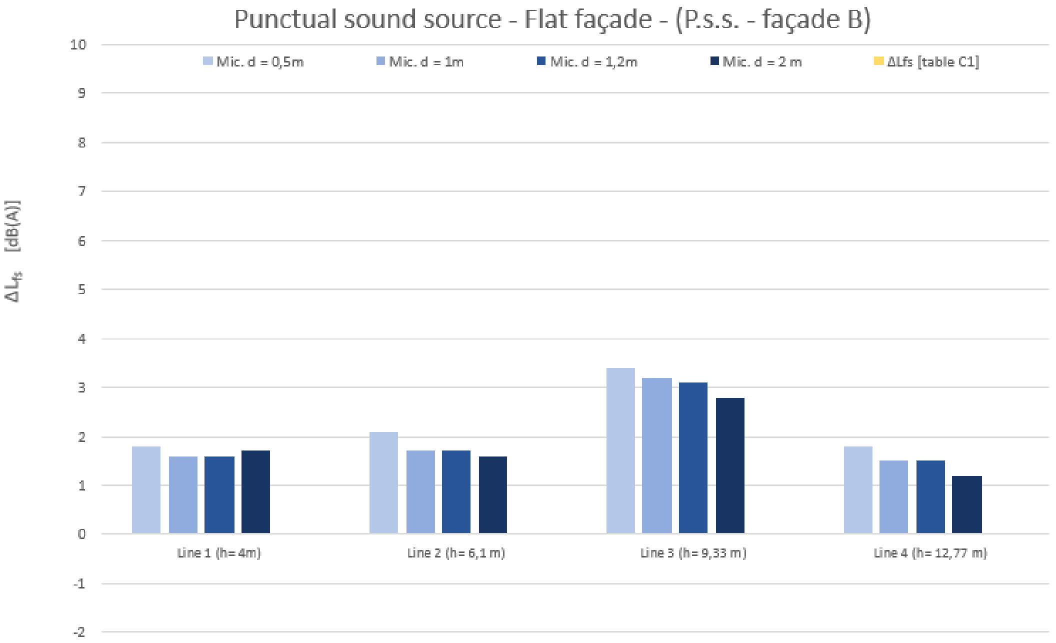
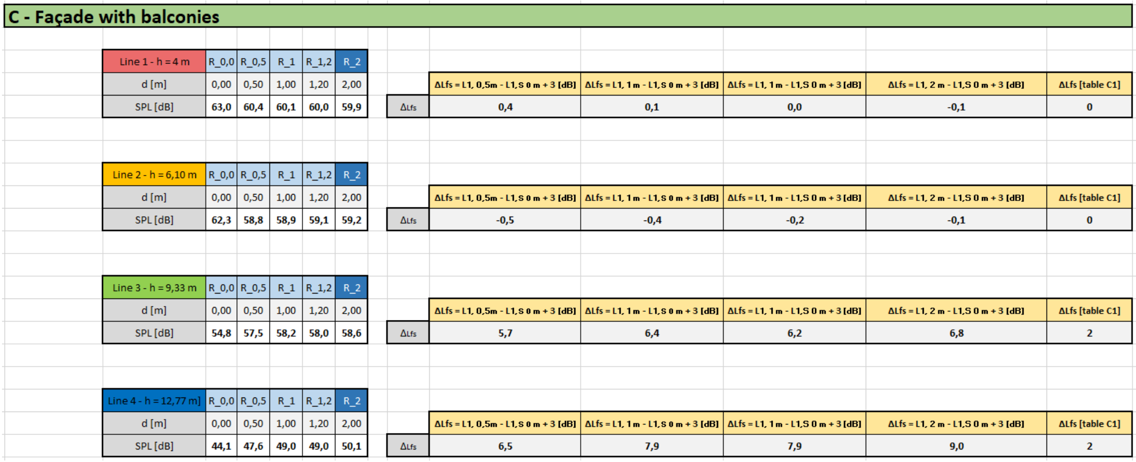


Figure 7-25 – ΔL$_{fs}$ (Punctual sound source) – B - Flat façade

Table 7-32– ΔL$_{fs}$ (Punctual sound source) – B -Flat façade (II)

P.s.s. - façade B	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,8**	**1,6**	**1,6**	**1,7**	**0**
Line 2 (h= 6,1 m)	**2,1**	**1,7**	**1,7**	**1,6**	**0**
Line 3 (h= 9,33 m)	**3,4**	**3,2**	**3,1**	**2,8**	**0**
Line 4 (h= 12,77 m)	**1,8**	**1,5**	**1,5**	**1,2**	**0**

Table 7-33– ΔLfs (Punctual sound source) – C -Façade with balconies (I)



C - Façade with balconies

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	63,0	60,4	60,1	60,0	59,9

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	0,4	0,1	0,0	-0,1	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	62,3	58,8	58,9	59,1	59,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	-0,5	-0,4	-0,2	-0,1	0

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	54,8	57,5	58,2	58,0	58,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	5,7	6,4	6,2	6,8	2

Line 4 - h = 12,77 m]	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	44,1	47,6	49,0	49,0	50,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	6,5	7,9	7,9	9,0	2

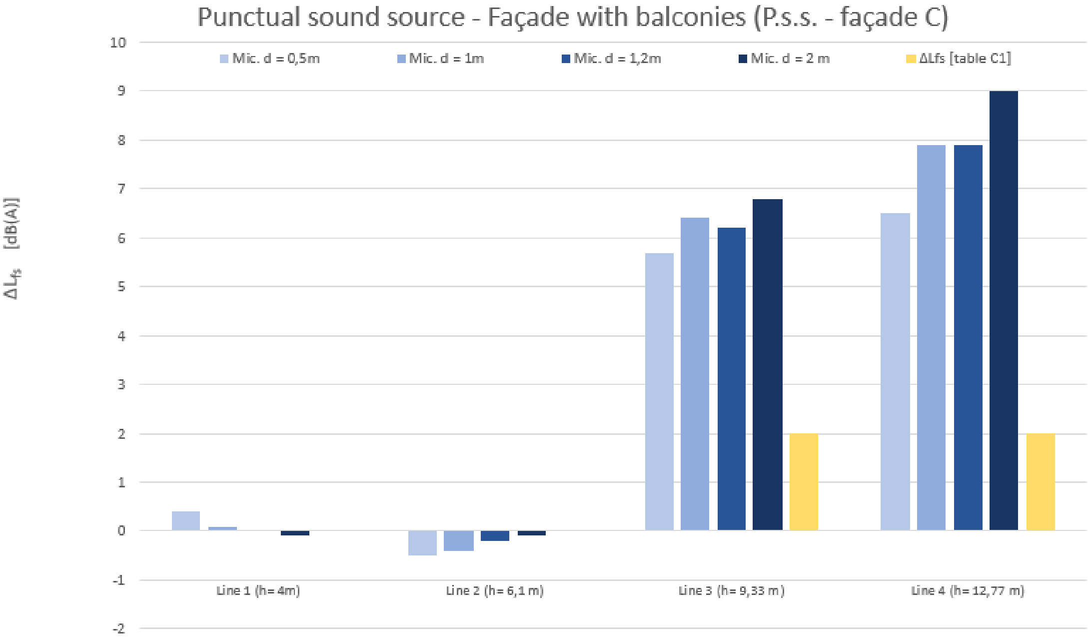
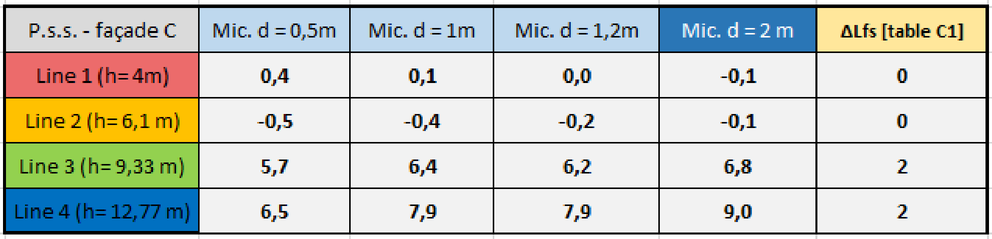


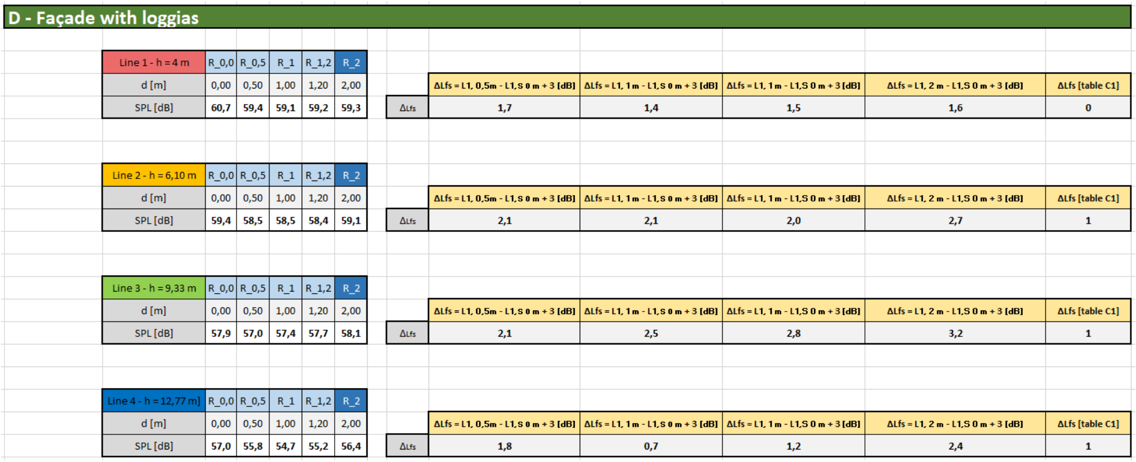
Figure 7-26 – ΔLfs (Punctual sound source) – C - Façade with balconies

Table 7-34– ΔLfs (Punctual sound source) – C -Façade with balconies (II)



P.s.s. - façade C	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h= 4m)	0,4	0,1	0,0	-0,1	0
Line 2 (h= 6,1 m)	-0,5	-0,4	-0,2	-0,1	0
Line 3 (h= 9,33 m)	5,7	6,4	6,2	6,8	2
Line 4 (h= 12,77 m)	6,5	7,9	7,9	9,0	2

Table 7-35– ΔL_{fs} (Punctual sound source) – D -Façade with loggias (I)



D - Façade with loggias

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	60,7	59,4	59,1	59,2	59,3

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,7	1,4	1,5	1,6	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	59,4	58,5	58,5	58,4	59,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,1	2,1	2,0	2,7	1

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	57,9	57,0	57,4	57,7	58,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,1	2,5	2,8	3,2	1

Line 4 - h = 12,77 m]	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	57,0	55,8	54,7	55,2	56,4

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,8	0,7	1,2	2,4	1

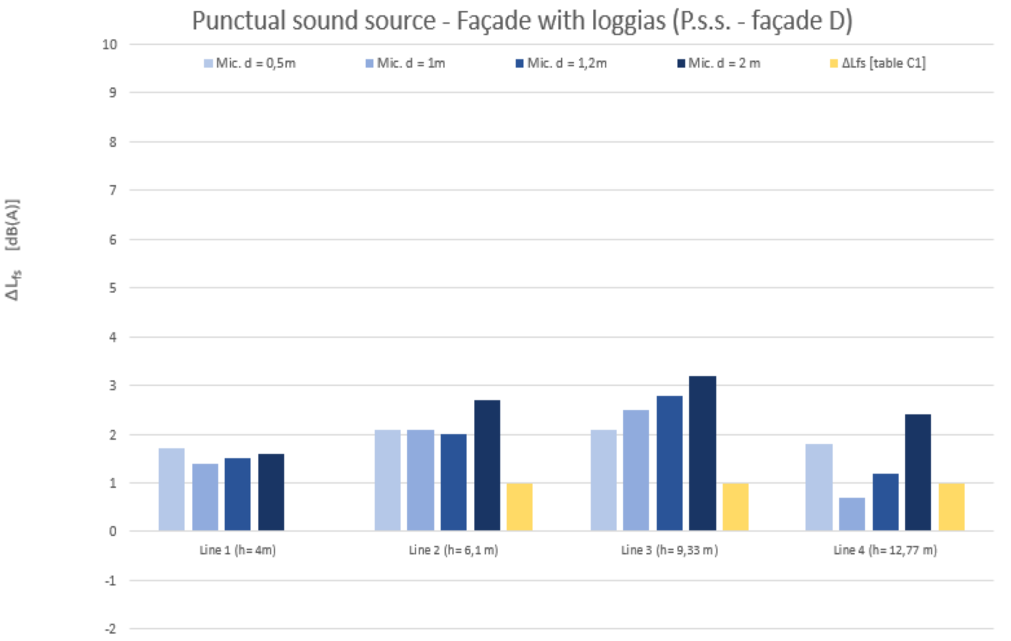
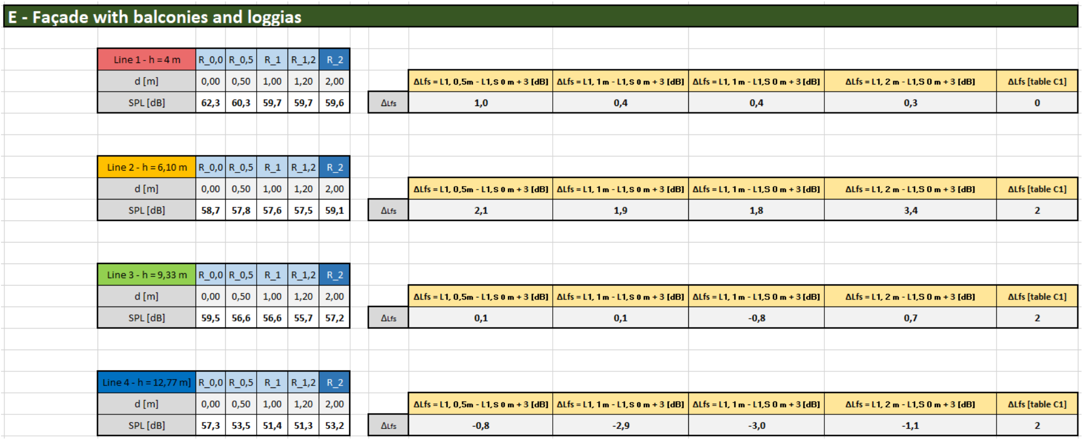


Figure 7-27 – ΔL_{fs} (Punctual sound source) –D - Façade with loggias

Table 7-36– ΔL_{fs} (Punctual sound source) – D -Façade with loggias (II)

P.s.s. - façade D	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,7**	**1,4**	**1,5**	**1,6**	**0**
Line 2 (h= 6,1 m)	**2,1**	**2,1**	**2,0**	**2,7**	**1**
Line 3 (h= 9,33 m)	**2,1**	**2,5**	**2,8**	**3,2**	**1**
Line 4 (h= 12,77 m)	**1,8**	**0,7**	**1,2**	**2,4**	**1**

Table 7-37– ΔLfs (Punctual sound source) – D -Façade with balconies and loggias (I)



E - Façade with balconies and loggias

Line 1 - h = 4 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	62,3	60,3	59,7	59,7	59,6

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	1,0	0,4	0,4	0,3	0

Line 2 - h = 6,10 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	58,7	57,8	57,6	57,5	59,1

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	2,1	1,9	1,8	3,4	2

Line 3 - h = 9,33 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	59,5	56,6	56,6	55,7	57,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	0,1	0,1	-0,8	0,7	2

Line 4 - h = 12,77 m	R_0,0	R_0,5	R_1	R_1,2	R_2
d [m]	0,00	0,50	1,00	1,20	2,00
SPL [dB]	57,3	53,5	51,4	51,3	53,2

	ΔLfs = L1, 0,5m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 1 m - L1,S 0 m + 3 [dB]	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
ΔLfs	-0,8	-2,9	-3,0	-1,1	2

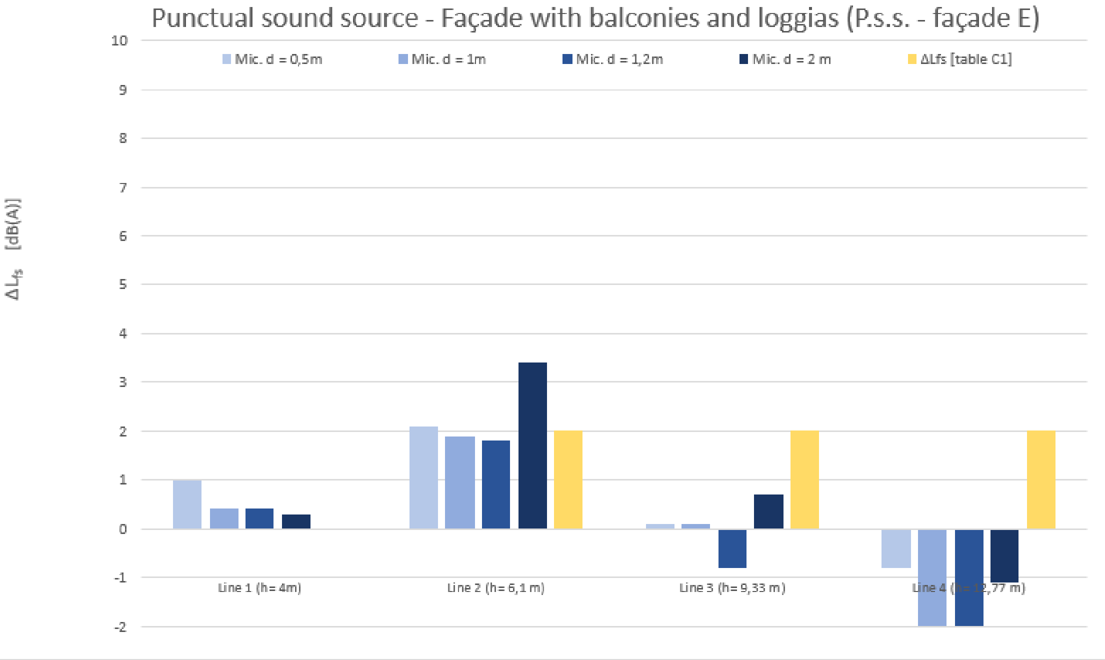
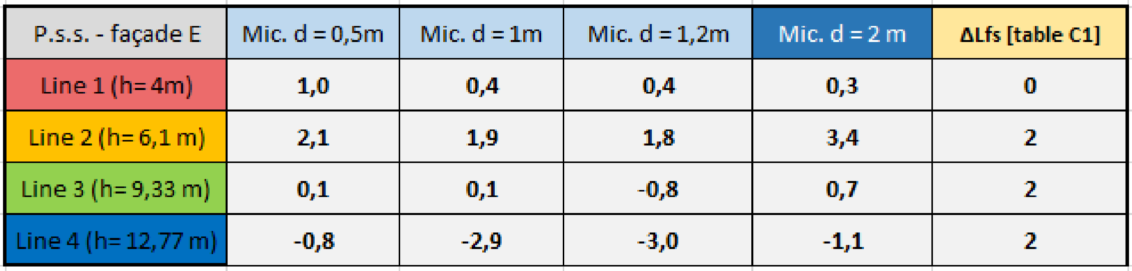


Figure 7-28 – ΔLfs (Punctual sound source) – D - Façade with balconies and loggias

Table 7-38– ΔLfs (Punctual sound source) – D -Façade with balconies and loggias (II)



P.s.s. - façade E	Mic. d = 0,5m	Mic. d = 1m	Mic. d = 1,2m	Mic. d = 2 m	ΔLfs [table C1]
Line 1 (h= 4m)	1,0	0,4	0,4	0,3	0
Line 2 (h= 6,1 m)	2,1	1,9	1,8	3,4	2
Line 3 (h= 9,33 m)	0,1	0,1	-0,8	0,7	2
Line 4 (h= 12,77 m)	-0,8	-2,9	-3,0	-1,1	2

Table 7-39– ΔL_{fs} with different microphone positions and façade configuration

(Punctual sound source) (II)

Point sound sorce - ΔL_{fs} (ISO 12354-3:2017)

ΔL_{fs}: is defined the differnce in SPL of the incoming sound field and the sound on he surface of the façade plus 6 dB, thus being 0 dB for a reflecting, plane façade. It can measured with reasonable accurancy according to $\Delta L_{fs} = L_{1,2m} - L_{1,S\ 0m} + 3$ dB where:

$L_{1,2m}$ - is the average SPL at 2 m in front of the (shaped) façade, in dB

$L_{1,S\ 0m}$ - is the average SPL on the outside surface of the façade plane, including the reflecting effect of that plane, in dB

ΔL_{fs} - Table C.1, Façade shape level difference for different façade shapes and sound source orientation

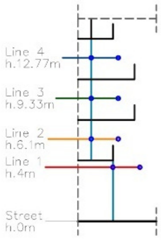
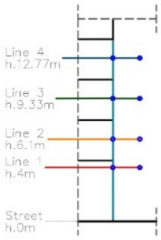
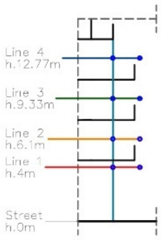
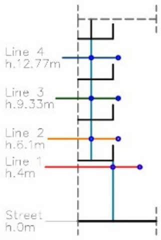
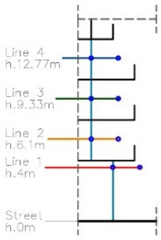
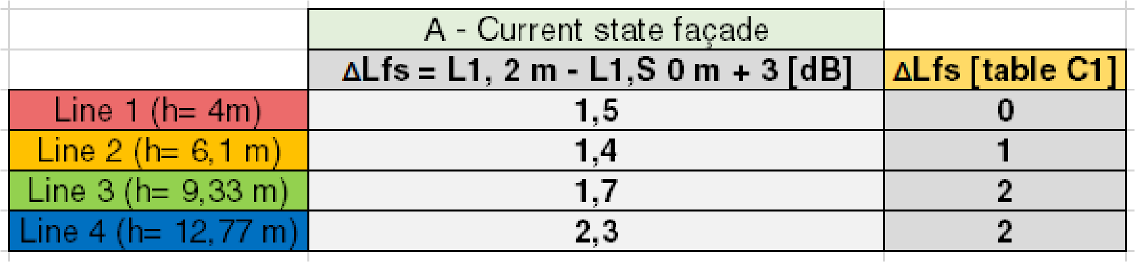
Façades configuration diagrams:	ΔL_{fs} = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔL_{fs} = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔL_{fs} = SPL R 2,0m - SPL R 0,0m + 3 dB		ΔL_{fs} = SPL R 2,0m - SPL R 0,0m + 3 dB	
	Line 1 h = 4 m d. m.r. = 0 - 2 m	Table C.1	Line 2 h = 6,10 m d. m.r. = 0 - 2 m	Table C.1	Line 3 h = 9,33 m d. m.r. = 0 - 2 m	Table C.1	Line 4 h = 12,77 m d. m.r. = 0 - 2 m	Table C.1
A - Current state façade 	1,5	0	1,4	1	1,7	2	2,3	2
B - Flat façade 	1,7	0	1,6	0	2,8	0	1,2	0
C - Façade with balconies 	-0,1	0	-0,1	0	6,8	2	9	2
D - Façade with loggias 	1,6	0	2,7	1	3,2	1	2,4	1
E - Façade with balconies and loggias 	0,3	0	3,4	2	0,7	2	-1,1	2
Microphone position scale 1:50 m								

Table 7-40– ΔLfs (Punctual sound source)
A - Current state façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	A - Current state façade	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,5**	**0**
Line 2 (h= 6,1 m)	**1,4**	**1**
Line 3 (h= 9,33 m)	**1,7**	**2**
Line 4 (h= 12,77 m)	**2,3**	**2**

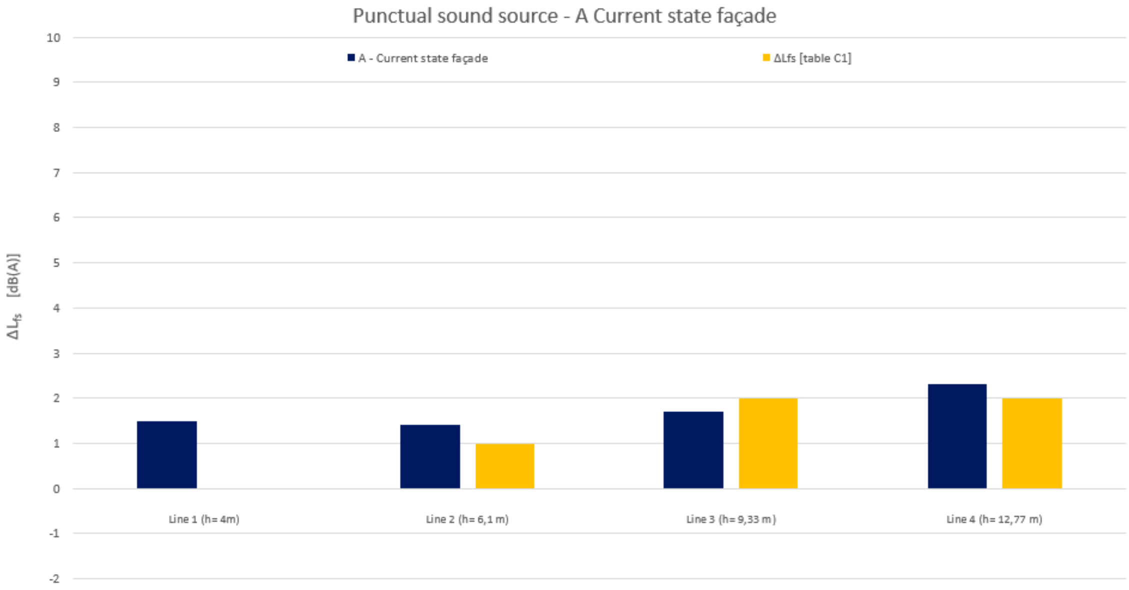
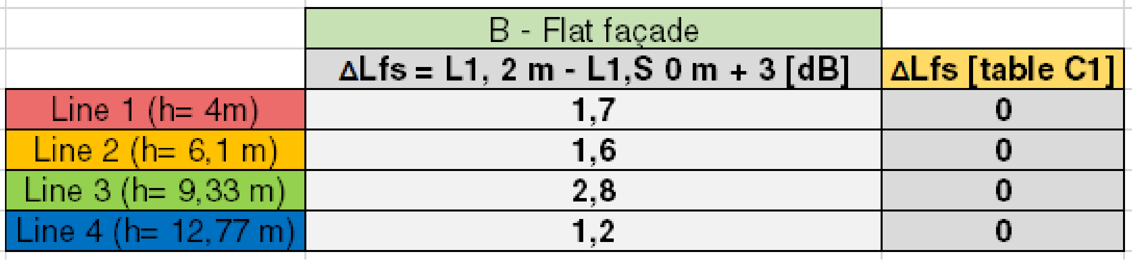


Figure 7-29 – ΔLfs (Punctual sound source)
A - Current state façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-41– ΔLfs (Punctual sound source)
B - Flat façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	B - Flat façade	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**1,7**	**0**
Line 2 (h= 6,1 m)	**1,6**	**0**
Line 3 (h= 9,33 m)	**2,8**	**0**
Line 4 (h= 12,77 m)	**1,2**	**0**

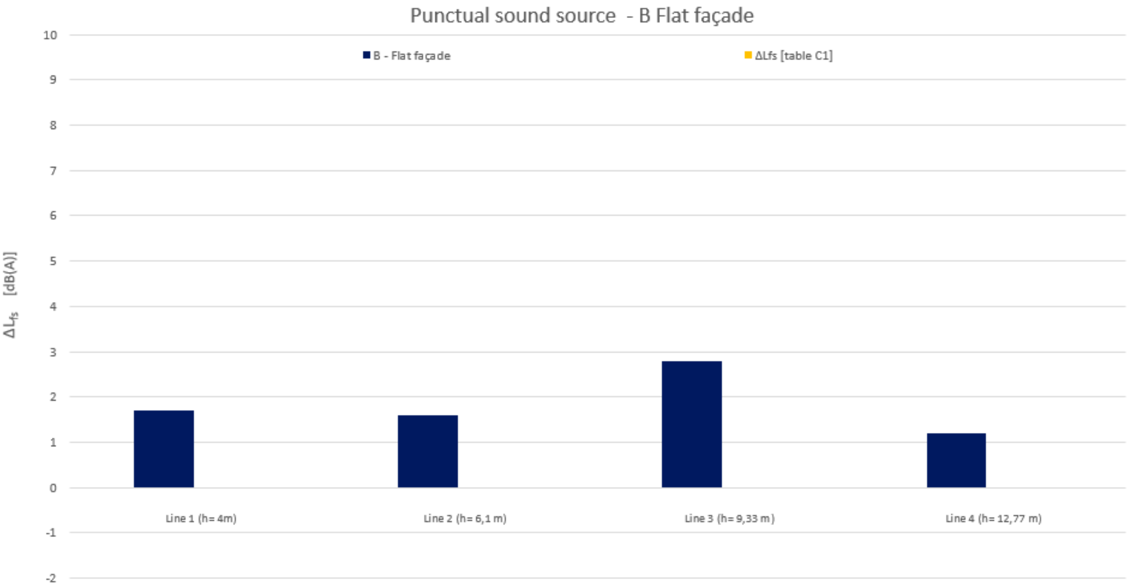
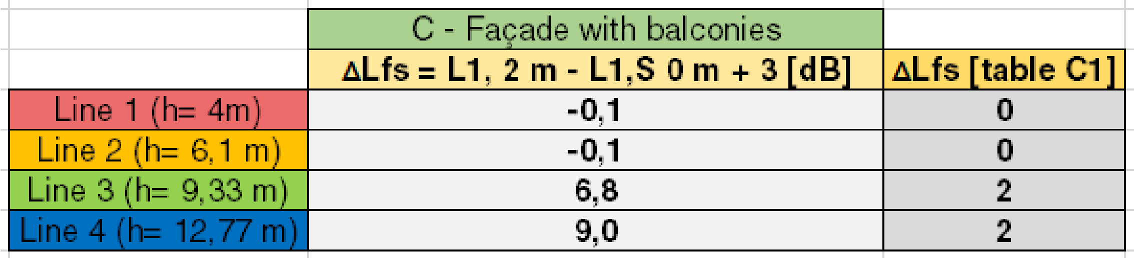


Figure 7-30 – ΔLfs (Punctual sound source)
B - Flat façade - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-42– ΔL_{fs} (Punctual sound source)
C - Façade with balconies- ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	C - Façade with balconies	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	**ΔLfs [table C1]**
Line 1 (h= 4m)	**-0,1**	**0**
Line 2 (h= 6,1 m)	**-0,1**	**0**
Line 3 (h= 9,33 m)	**6,8**	**2**
Line 4 (h= 12,77 m)	**9,0**	**2**

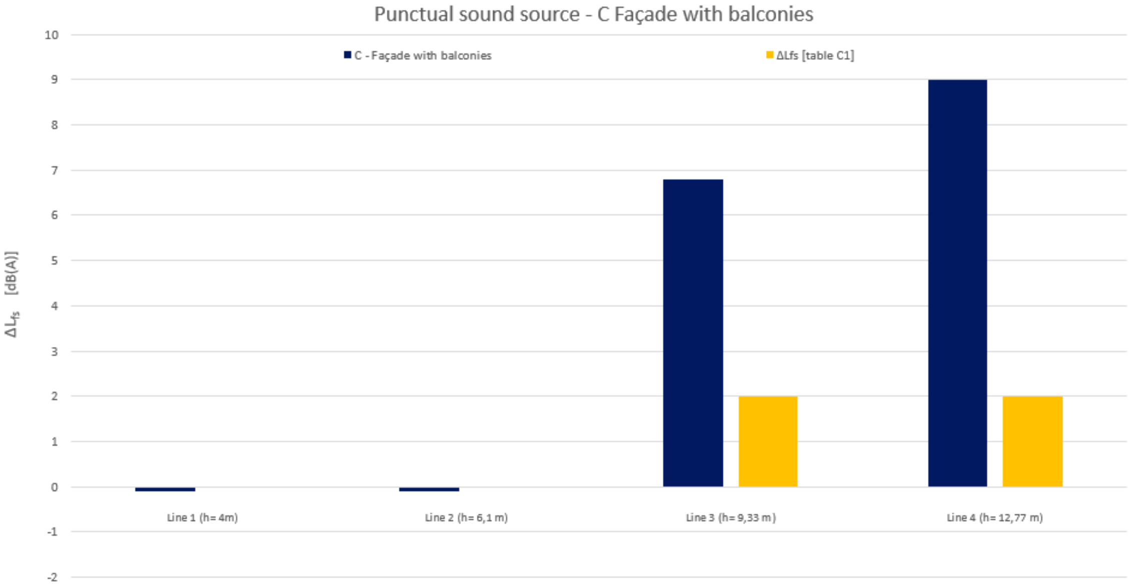
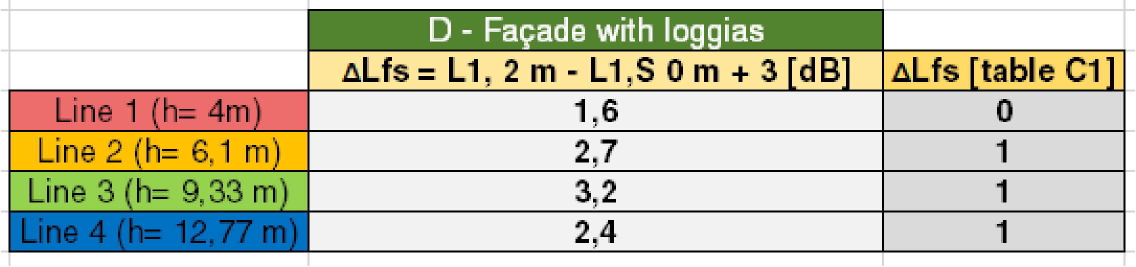


Figure 7-31 – ΔL_{fs} (Punctual sound source)
C - Façade with balconies - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-43– ΔL_{fs} (Punctual sound source)
D - Façade with loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	D - Façade with loggias	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
Line 1 (h= 4m)	1,6	0
Line 2 (h= 6,1 m)	2,7	1
Line 3 (h= 9,33 m)	3,2	1
Line 4 (h= 12,77 m)	2,4	1

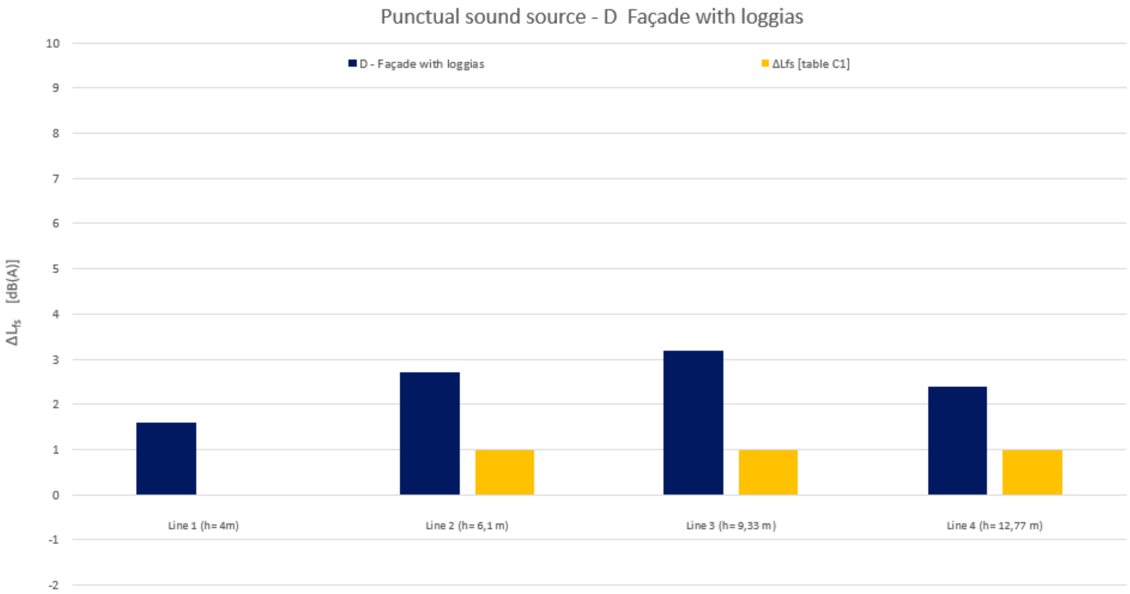
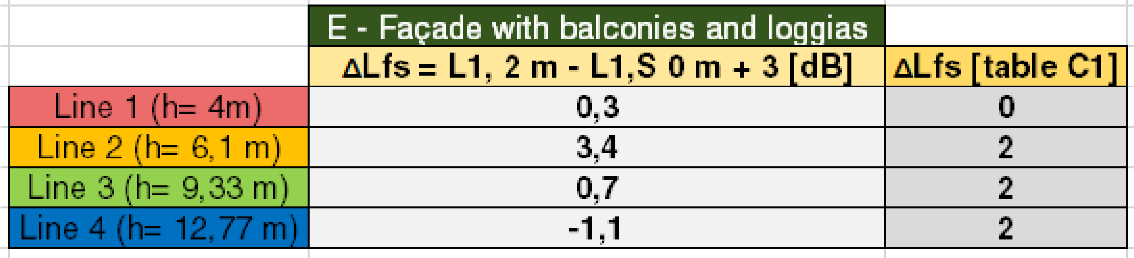


Figure 7-32 – ΔL_{fs} (Punctual sound source)
D - Façade with loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

Table 7-44– ΔL_{fs} (Punctual sound source)
E - Façade with balconies and loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]



	E - Façade with balconies and loggias	
	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
Line 1 (h= 4m)	0,3	0
Line 2 (h= 6,1 m)	3,4	2
Line 3 (h= 9,33 m)	0,7	2
Line 4 (h= 12,77 m)	-1,1	2

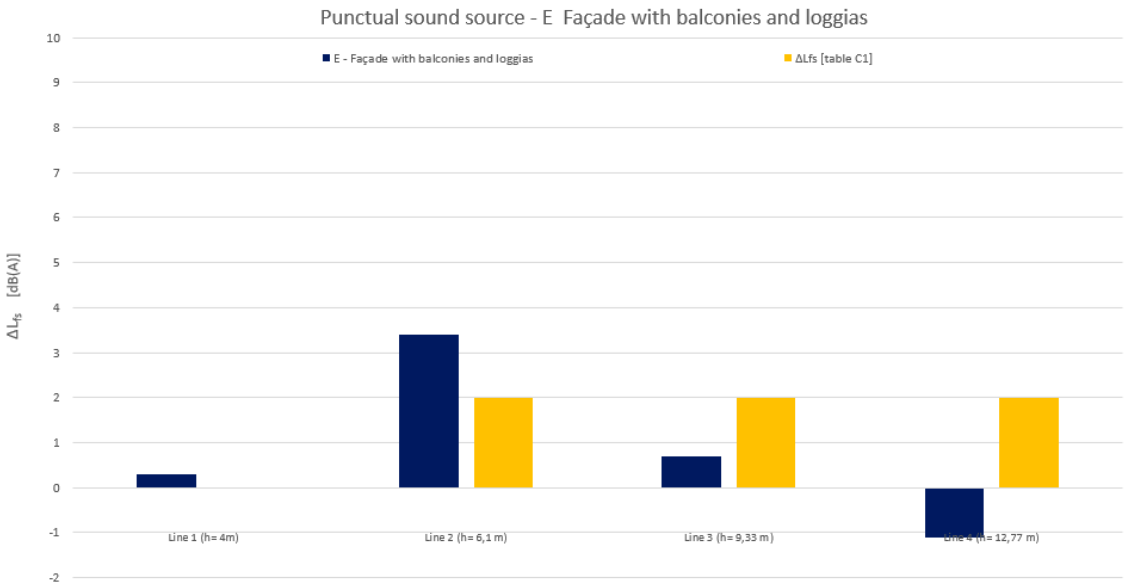
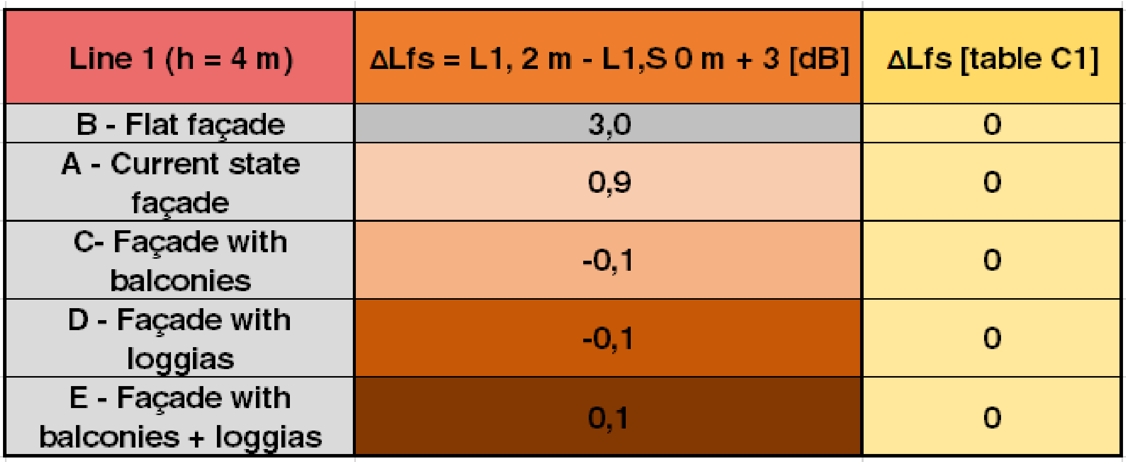


Figure 7-33 – ΔL_{fs} (Punctual sound source)
E - Façade with balconies and loggias - ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]

7.11 Variation of ΔL_{fs} for each façade configuration to the same line of microphones

7.11.1 Linear sound source

Table 7-45– ΔL_{fs} for each façade configuration to Line 1 (h = 4 m)
(Linear sound source)



Line 1 (h = 4 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	3,0	0
A - Current state façade	0,9	0
C- Façade with balconies	-0,1	0
D - Façade with loggias	-0,1	0
E - Façade with balconies + loggias	0,1	0

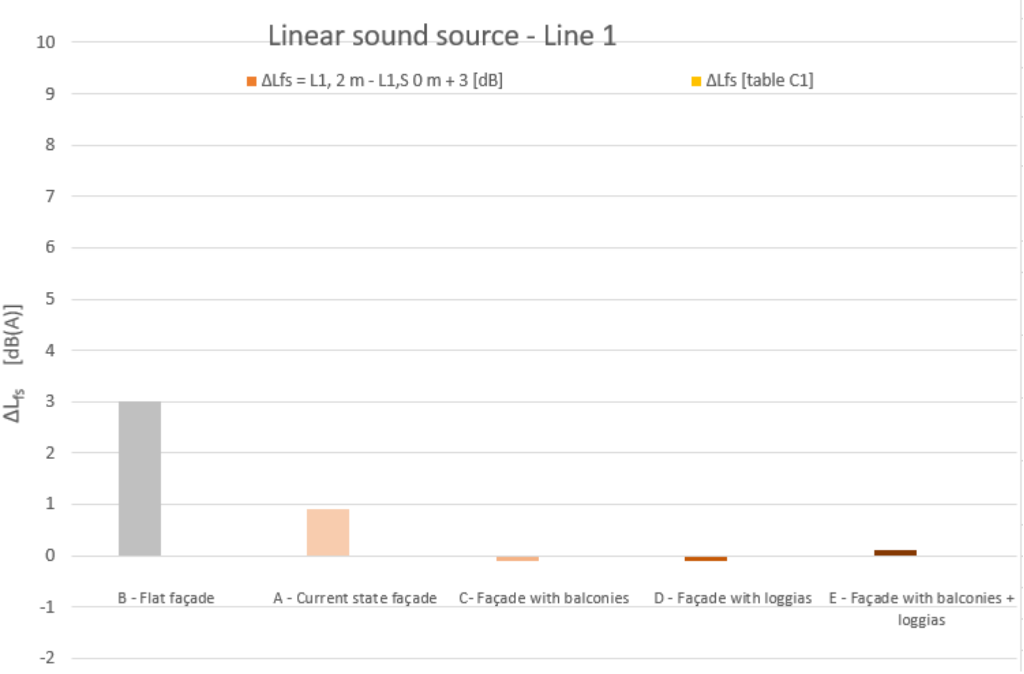


Figure 7-34 – ΔLfs for each façade configuration to Line 1 (h = 4 m)
(Linear sound source)

Table 7-46– ΔLfs for each façade configuration to Line 2 (h = 6,10 m)
(Linear sound source)

Line 2 (h = 6,10 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	0,6	0
A - Current state façade	0,7	1
C- Façade with balconies	2,1	0
D - Façade with loggias	5,5	1
E - Façade with balconies + loggias	1,8	2

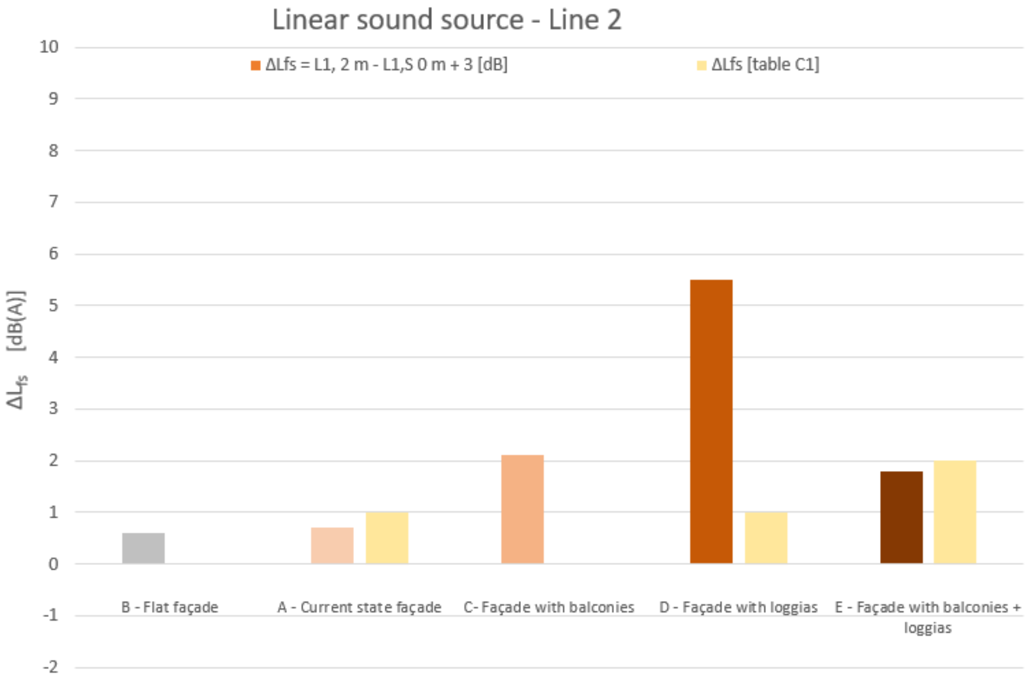


Figure 7-35 – ΔLfs for each façade configuration to Line 2 (h = 6,10 m)
(Linear sound source)

Table 7-47– ΔL_{fs} for each façade configuration to Line 3 (h = 9,33 m)
(Linear sound source)

Line 3 (h = 9,33 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	3,1	0
A - Current state façade	-0,7	2
C- Façade with balconies	4,2	2
D - Façade with loggias	3,3	1
E - Façade with balconies + loggias	-0,2	2

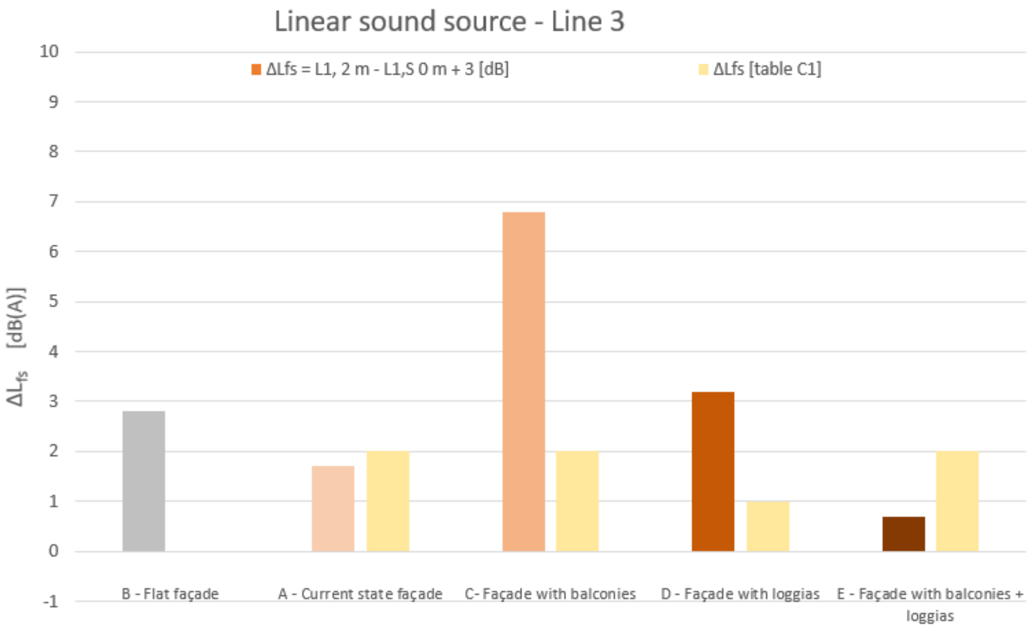


Figure 7-36 – ΔL_{fs} for each façade configuration to Line 3 (h = 9,33 m)
(Linear sound source)

Table 7-48– ΔLfs for each façade configuration to Line 4 (h = 12,77 m)
(Linear sound source)

Line 4 (h = 12,77 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	1,7	0
A - Current state façade	6,1	2
C- Façade with balconies	6,1	2
D - Façade with loggias	5,4	1
E - Façade with balconies + loggias	-1,4	2

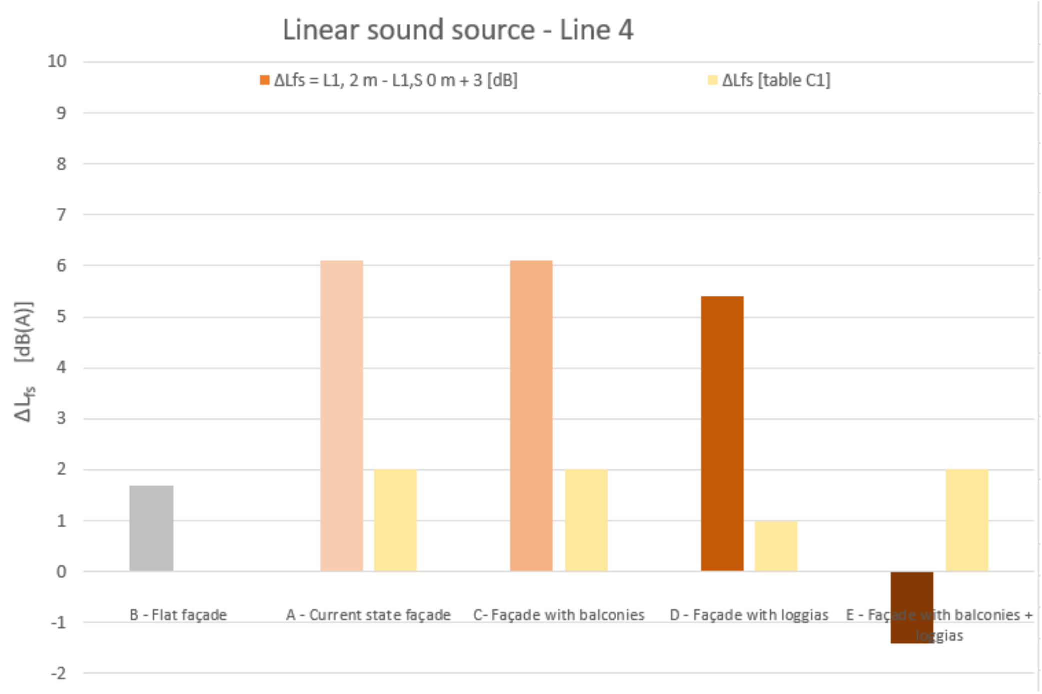


Figure 7-37 – ΔLfs for each façade configuration to Line 4 (h = 12,77m
(Linear sound source)

7.11.2 Punctual sound source

Table 7-49– ΔLfs for each façade configuration to Line 1 (h = 4 m)
(Punctual sound source)

Line 1 (h = 4 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	1,7	0
A - Current state façade	1,5	0
C- Façade with balconies	-0,1	0
D - Façade with loggias	1,6	0
E - Façade with balconies + loggias	0,3	2

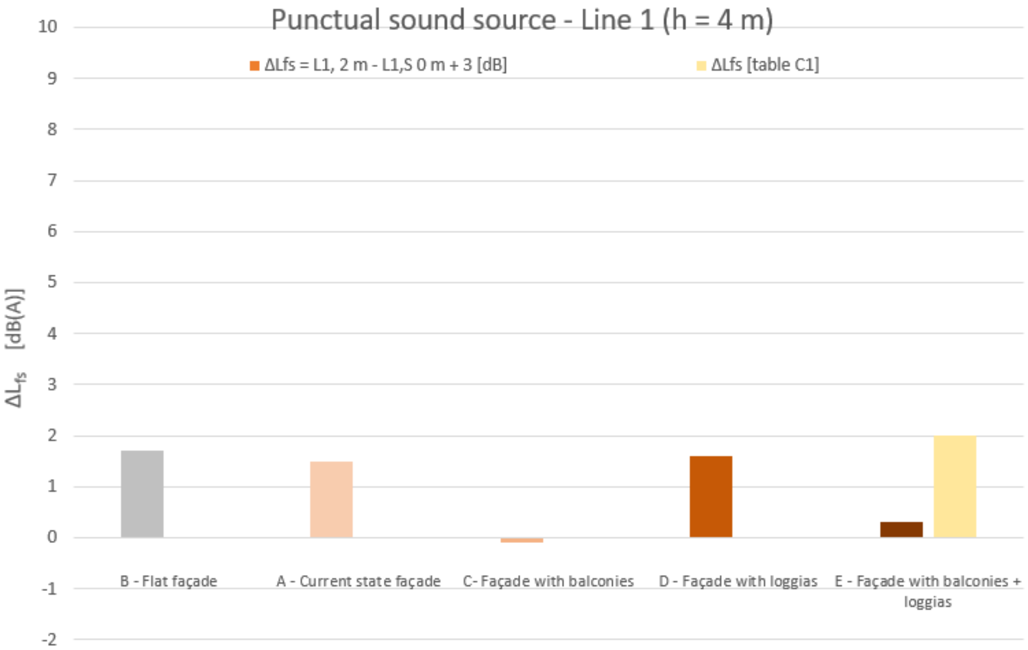


Figure 7-38 – ΔLfs for each façade configuration to Line 1 (h = 4 m)
(Punctual sound source)

Table 7-50– ΔLfs for each façade configuration to Line 2 (h = 6,10 m)
(Punctual sound source)

Line 2 (h = 6,1 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	1,6	0
A - Current state façade	1,4	1
C- Façade with balconies	-0,1	0
D - Façade with loggias	2,7	1
E - Façade with balconies + loggias	3,4	2

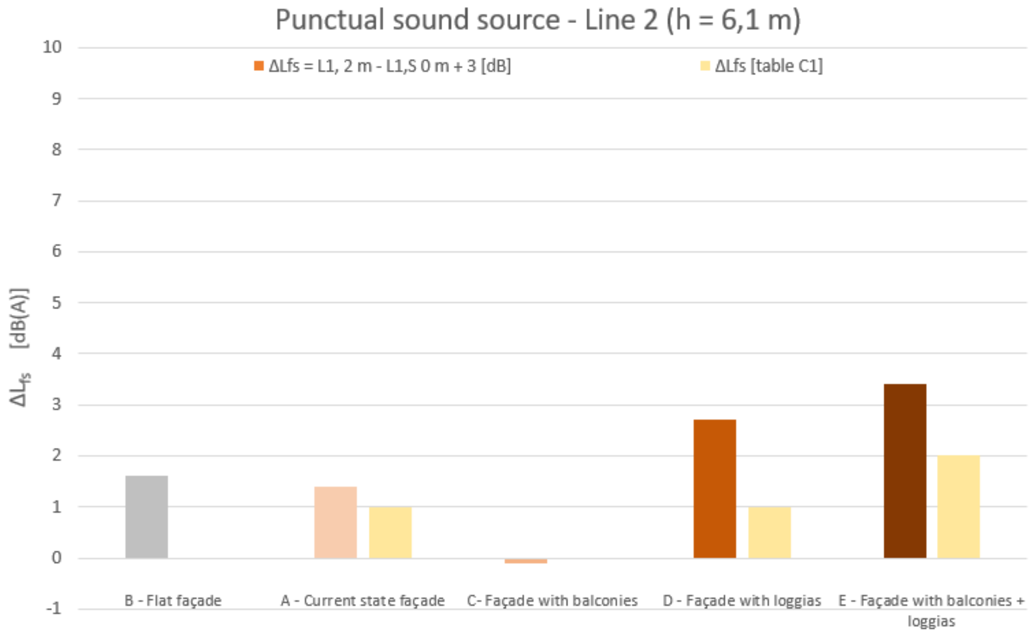


Figure 7-39 – ΔLfs for each façade configuration to Line 2 (h = 6,10 m)
(Punctual sound source)

Table 7-51– ΔLfs for each façade configuration to Line 3 (h = 9,33 m)
(Punctual sound source)

Line 3 (h = 9,33 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	2,8	0
A - Current state façade	1,7	2
C- Façade with balconies	6,8	2
D - Façade with loggias	3,2	1
E - Façade with balconies + loggias	0,7	2

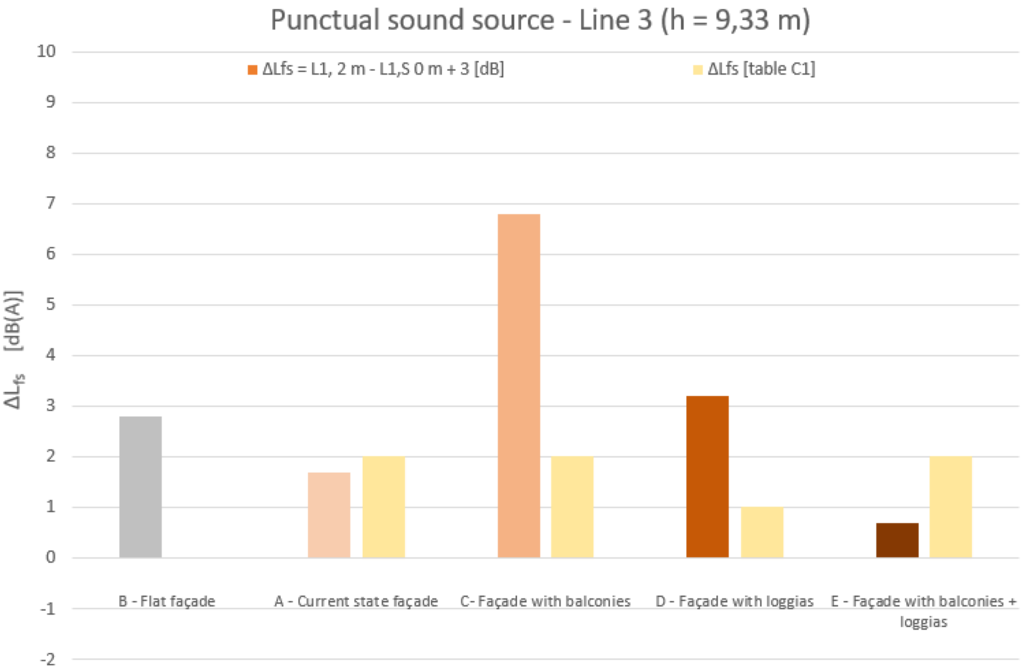


Figure 7-40 – ΔLfs for each façade configuration to Line 3 (h = 9,33 m)
(Punctual sound source)

Table 7-52– ΔL_{fs} for each façade configuration to Line 4 (h = 12,77 m)
(Punctual sound source)

Line 4 (h = 12,77 m)	ΔLfs = L1, 2 m - L1,S 0 m + 3 [dB]	ΔLfs [table C1]
B - Flat façade	1,2	0
A - Current state façade	2,3	2
C- Façade with balconies	9,0	2
D - Façade with loggias	2,4	1
E - Façade with balconies + loggias	-1,1	2

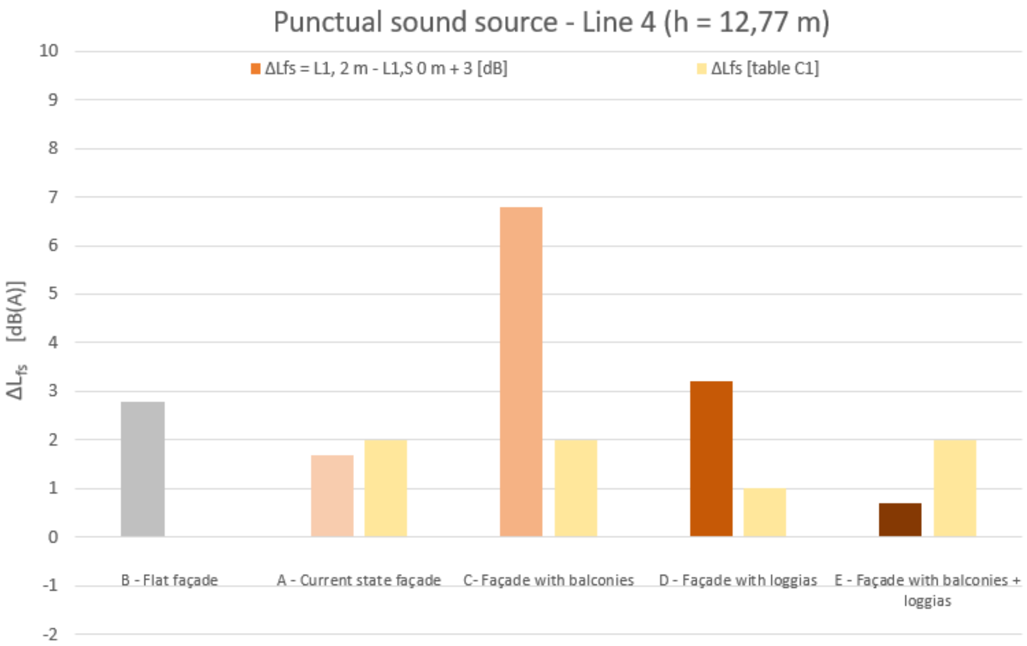


Figure 7-41 – ΔLfs for each façade configuration to Line 4 (h = 12,77 m)
(Punctual sound source)

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8 Conclusion

The simulation performed with ODEON 13 applied to a 3D model of an existing building in the city of Turin has been used to investigate the behaviour of the Sound Pressure Level (SPL) measurement in front of the façade.

It has been evaluated the effect on the SPL by varying the position of the reference microphone from the façade itself (at 0 m, 0.5 m, 1 m, 1.2 m, 3 m and 7.05 m), with receivers on the facade positioned on four lines at different heights: 4 m, 6.10 m, 9.33 m and 12.77 m. and keeping into account of 5 building façade shape (the current façade, a flat façade and façades with balconies, with loggias and with loggias and balconies together respectively).

Then the correction factor (c.f.) used to determine the influence of the shape of the facade on SLP measurement, has been calculated using the simulation data and compared with those of the ISO 1996-2:2017 and with the results obtained by researcher investigations.

Another investigation has been done to evaluate the effect on the ΔL_{fs} (shape coefficient of the façade) reported by the ISO 12354-3:2017, always by varying the microphone distance from the façade (in this case at 0 m, 0.5 m, 1 m, 1.2 m, 2).

Finally, the values of SPA (A) obtained by the simulation has been compared with the limits imposed by the City of Turin regulation 318.

The SPL diagrams for all the ten cases, the point-values of each measure, have been interpolated by a trend line to evaluated the measurement behaviour.

The trend lines chosen are the logarithmic in most of the case and polynomial (2nd order) in the other: the criteria adopted to choose these lines consists in the best obtainable R^2 (fitting coefficient).

Concerning the SPL (with the linear sound source) all the values recorded tend to decrease with the height (I.e. passing from line 1, the lower one, to Line 4 the upper); they vary from a maximum of about 75 ÷ 76 dB to a minimum of 65 ÷ 66 on the façade, and from 72 ÷ 73 dB to 68 ÷ 69 dB at 7,05 m (middle of the street) considering all the façade types.

In all the cases, the SPL recorded on the façade is greater than the other values progressively far from it, with the exception of cases concerning the highest Line 4 (all facades with the exception of the flat façade) this probably due to some shield effect.

The SPL values recorded by Line 1 (at 4 m height) have the better behavior in all the façade types except one (flat façade); on the contrary the Line 3 (at 9.33 m height) shows the worst SPL behavior with a greater dispersion of the SPL values, in all the façade types.

Line 2 and 4 have an intermediate SPL behavior showing dispersion on the facades with loggias and balconies plus loggias.

Referring to the façade type, the better behaviours globally are shown by the current facade, the flat façade and that with balconies, while the façades with loggias and balcony plus loggias show more differences.

In the case of the "punctual sound source" the SPL levels are lower, passing from a maximum of about 60 ÷ 62 dB to a minimum of 55 ÷ 57 dB on the façade, and from 62 ÷ 63 dB to 56 ÷ 57 dB at 7,05 m (middle of the street) considering all the façade types. There is only exception for the Line 4 of the façade with balconies where the SPL at 0 m is about 49 dB and similar consideration can be done as those of linear sound source.

The SPL (A) values have been recorded by each microphone placed at 1 m from the façade and at 4 m high from the street level, which are the requested conditions by the “Acoustic mapping of the city of Turin” according to the Law 447/95 and Legislative Decree 194/05.

The measured dB (A) values comply with the limits established by Turin Regulation 318 (which refers to DPCM 14/11/1997) for each of the five geometry façade types, evaluated with the punctual sound source, which in this case simulates the “movida” noise for the daytime time slot (06:00 ÷ 22: 00). The requested level limit shall be 55 dB (A) applicable to destination Class II - Predominantly residential areas.

The best façade configuration for compliance with the aforementioned limit is the façade with balconies whose microphone recorded a value of 53.2 dB (A) that is close to the values registered for the other four facade geometry configurations.

Regarding the nightly dB (A) limit (22:00 ÷ 06:00) that shall be 45 dB (A) for the same destination area none of the five façade comply with this limit because all values are greater than 52 dB (A). This is probably due to the fact that the punctual sound source it is not set to simulate night noise.

In the case of linear sound source reproducing road traffic noise, the non-compliance with the Regulation limits is common to for all five façade types in both time bands where the recorded values are all > 66 dB (A).

According to the results obtained, it seems to be necessary a further improvement of the measures adopted to reduce the noise on the façade by implementing new arrangement to increase sound absorption performance and to reduce reflection

The "correction factors" (c.f.) to determine the influence of the shape of the facade calculated on the basis of the SPL values obtained from the simulation of the flat facade case for the Line 1 h = 4 m, because it is the only condition suitable for this type of verification) are very different from those given by ISO 1996-2:2017, both in the case of the linear source and in the case of the point source.

The values of the "c.f." calculated in the simulation are very different from those proposed by Memoli et al. (2009) which confirmed the values given by mentioned ISO with a tolerance margin of about ± 0.5 dB.

These values instead, are closer to the values proposed by Montes González et al., (2015) and in particular in the case of the linear source, which are near to coincide with the simulation values.

It seems to be difficult to estimate the real "correction factor" because the ideal condition foreseen by the standard are quite difficult to be applied or repeated and this difficulty has been noted by the different researchers. For instance, the simulation scenario, being located in a narrow street that can be considered a street canyon, may have influenced the measurement done.

About the ΔL_{fs} evaluation according to the ISO 12354-3:2017 that propose a dedicated table, the microphone distance of 0 m, 1 m, 1,2 and 2m from the façade has been taken.

In the case of linear sound source, it is noted that in general the ΔL_{fs} varies in all the cases examined without showing a certain similarity of behaviour; considering the Current state façade the ΔL_{fs} remains low (or negative) except for a sensible increase at Line 4 (the upper). The flat façade has medium correction (2 ÷ 4 dB) for all the Lines with a common behaviour i.e. with a decrease of the correction moving away from the façade.

Concerning the façade with balconies the ΔL_{fs} increase progressively from the lower Line 1 up to the higher Line 4 passing from about 1 dB up to 6 dB, maintaining at the same Line level values quite close.

About the façade with loggias ΔL_{fs} is relatively low (0 ÷ 1 dB) at Line 1 and Line 3 and greater at Line 2 and 4 (3 ÷ 4 dB) with a maximum of 5 dB at 2 m distance.

The façade with balconies and loggias shows globally a good behaviour passing from 1 dB to negative value - 1 dB at the upper level

In all above case there is no compliance with the ΔL_{fs} values reported by the Table C1 of the ISO 12354-3.

In the punctual sound source simulation, in general, the correction are lower and regular except in the façade with balconies where the Line 3 and 4 reach the maximum values (7 ÷ 9 dB). The same façade correction null at Line 1 and 2. The most regular is the flat façade at all levels (2 ÷ 3 dB)

Some case of compliance with the ISO Table C1 are recorded, but in general the recommended values are not meet. A possible justification may consist into the not easy application of the C1 table to the real configuration of the facades and the complexity of the model used.

Similarly, to the evaluation of “correction factor”, the evaluation of the ΔL_{fs} results quite difficult because if compared with the suggested values from the table C1 of ISO 12354-3 there is significative differences.

The impact of noise on human health is briefly mentioned taking into account the direct effect on the auditory system with other non-auditory effects such as sleep disturbance, cardiovascular and physiological effects, and so on.

It is underlined that the effects on human health and the welfare is important generating social costs.

The public authorities try to manage this problem by issuing regulations and laws on the environmental noise and this complex panorama has been summarized starting from the European Environmental Noise Directive (END) up to national regulation as the Law. 447/1995 “the framework law on noise pollution”, regional

L.R. 52/2000 and local regulations as the Municipal regulation for the protection from noise pollution no. 318 of Turin.

Interpreting the regulation in a rigorous and literal way, each street should be assigned the limit value of the acoustic class of the area it crosses.

In the case of the Piedmont Region this interpretation is difficult to apply. In fact, the Regional Guidelines for the acoustic classification establish that the way for the zone classification does not take into account the presence of transport infrastructures.

Consequently, the acoustic classifications in Piedmont were carried out considering only the presence of residential, sensitive and productive settlements in the territory. For this reason, the classification of an area can be, in several cases, fragmented and not correlated with the types of road infrastructures which cross it.

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(Punctual sound source)

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