ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

AN APPROACH FOR DEVELOPING ROAD TRAFFIC NOISE ANNOYANCE PREDICTION MODEL

Ph.D. THESIS

Mine DİNCER

Department of Architecture

Construction Sciences Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KARAYOLU TRAFİK GÜRÜLTÜSÜ RAHATSIZLIĞI TAHMİN MODELİ GELİŞTİRMEK İÇİN BİR YAKLAŞIM

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Mine Dincer, **a Ph.D.** student of ITU **Graduate School of Science Engineering and Technology** student ID **502082017**, successfully defended the **dissertation** entitled "**AN APPROACH FOR DEVELOPING ROAD TRAFFIC NOISE ANNOYANCE PREDICTION MODEL**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 21 December 2015
Date of Defense : 12 February 2016

To my family,

FOREWORD

I would like to express my deepest gratitude to my advisor Prof. Dr. Sevtap Yılmaz for her support of my graduate studies and her positive guidance throughout my academic career. I am very grateful to my thesis committee, Prof. Dr. Neşe Yüğrük Akdağ and Asst. Prof. Dr. Nurgün Tamer Bayazıt, for their continuous support of my Ph.D. study, insightful comments and positive guidance.

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ABBREVIATIONS

%A : Percentage of people annoyed
%HA : Percentage of people highly annoyed
%SD : Percentage of people sleep disturbed
%HSD : Percentage of people highly sleep disturbed
AA : Atmospheric absorption
ABPRS : Address Based Population Registration System
ANFOR : Association Française de Normalisation
CNOSSOS-EU : Common Noise Assessment Methods in Europe
E.C. : European Commission
ECAC.CEAC : European Civil Aviation Conference - Conference Européenne de l'Aviation Civile
EEA : European Environment Agency
EEG : Electroencephalograph
EN : European standards
END : Directive relating to the Assessment and Management of Environmental Noise (European Parliament and Council, 2002)
EU : European Union
GD : Geometric divergence
ICBEN : The International Commission on the Biological Effects of Noise
IEC : International Electrotechnical Commission
INDSCAL : Individual multidimensional scaling
ISO : International Organization for Standardization
NIPTS : Noise-induced permanent threshold shift
SPL : Sound pressure level
TNI : Traffic noise index
T.C. : Republic of Turkey
TurkStat : Turkish Statistical Institute
WHO : World Health Organization
WG-AEN : European Commission Working Group on Assessment of Exposure to Noise
WG-HSEA : European Commission Working Group on Health and Socio-Economic Aspects

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A : Area of building element, m^2
dB : The unit for sound pressure level, Decibels
dB(A) : A-weighted Decibels
DNL : Day–night equivalent sound level, dB(A)
D_{nT} : Standardized level difference, dB
$D_{tr,2m,nT}$: Standardized level difference (source traffic noise), dB
$D_{tr,2m}$: Level difference (source traffic noise), dB
h_s : Source height, m
h_r : Receiver height, m
Hz : The unit of frequency, Hertz
l : Length, m
$L_{1,2m}$: Outdoor sound pressure level 2 m in front of the façade, dB
L_2 : Averaged sound pressure level in the receiving room, dB
L_{Aeq} : Equivalent continuous A-weighted sound pressure level, dB(A)
L_{AE} : A-weighted sound exposure level, dB(A)
$L_{AN,T}$: A-weighted pressure level exceeded during N% of the total observed period T, dB(A)
L_{day} : A-weighted long-term average sound level for day, hours 07:00-19:00, dBA
L_{den} : Day–evening–night level, dB(A)
L_{dn} : Day–night equivalent sound level, dB(A)
$L_{evening}$: A-weighted long-term average sound level for evening, hours 19:00-23:00, dBA
L_{night} : A-weighted long-term average sound level for night, hours 23:00-07:00, dBA
L_p : Sound pressure level, dB
L_{SE} : Sound exposure level, dB
L_w : Noise power level, dB
P : The unit of loudness level, Phon
p_0 : Reference pressure, Pa
R : Sound reduction index, dB
S : The unit for loudness, Sone
S : Area of building element, m^2
SEL : Sound exposure level, dB
SPL : Sound pressure level, dB
t : Sample duration, s or h
T : Reverberation time, s
T_0 : Reference value of the reverberation time, T_0 = 0,5 s
TNI : Traffic noise index
V : Volume of room, m^3

AN APPROACH FOR DEVELOPING ROAD TRAFFIC NOISE ANNOYANCE PREDICTION MODEL

SUMMARY

The main objective of “Assessment and Management of Environmental Noise (2002/49/EC)” Directive (The European Parliament and The Council of The European Union, 2002) is to define a common approach intended to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. To that end, noise mapping, informing the public and action planning shall be implemented.

The term, ‘annoyance’ is defined in the Directive as ‘the degree of community noise annoyance as determined by means of field surveys’. L_{den} and L_{night} are defined as noise indicators for annoyance and for sleep disturbance, respectively. Noise annoyance dose-effect relations are to be established for these given indicators. It is stated in the Directive that each action plan should contain estimates in terms of reduction in number of people annoyed and sleep disturbed.

Although the main purpose of the Directive and of noise control studies over the world is to reduce noise annoyance, the implementation is focused mostly on reducing noise levels, not annoyance, because annoyance levels are directly linked to noise levels in dose-effect relationships. Dose-effect relationships linking L_{den} and L_{night} noise indicators to annoyance levels are provided by European Commission Working Groups. The dose-effect relationships were created from socio-acoustic surveys, made in countries of North Europe, North America and Australia. These relationships do not necessarily apply to other countries to consider social factors of annoyance. In some studies it is concluded that in dose effect relationships, social, psychological or economic factors, are far more important than acoustic or physical factors. On the other hand, many studies have shown that the indicators used, such as A-weighted values or L_{den} and L_{night}, do not reflect many aspects of annoyance.

A more efficient and accurate way to determine annoyance might be to eliminate global noise indicators and to create local models which use all the information collected for noise mapping as input, and provide annoyance levels as a direct output, taking into account physical and non-physical factors. To that end, this study is designed to create an approach for developing a road traffic noise annoyance prediction model. This approach allows authorities to develop their own annoyance prediction models, taking into account characteristics of traffic, urban development and population.

The objective of this approach is to create an accurate local road traffic noise annoyance prediction model which considers not only acoustical aspects but also social aspects, without using noise indicators. The approach to develop the model includes well known methods such as noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings and listening tests. Using all of these methods together, provides detailed information on noise sources, urban propagation

conditions and people's responses to certain types of noise heard inside their homes, which help to create an accurate model.

Using an accurate annoyance prediction model may provide cost effective action plans which focus on decreasing annoyance levels, and not only noise levels. Planning actions against annoyance may be easier to organize because the model helps to understand the factors which effect annoyance levels.

There are some limitations to this approach. The approach is only for road traffic noise sources, but further studies may be used to implement the approach for other noise sources. This approach is for general noise annoyance and not sleep disturbance, because this study does not include awakening, motility or health effects. Meteorological effects are not taken into account because of the negligible attenuation in urban conditions.

In this thesis, the approach is implemented to create an annoyance prediction model in the urban area of Besiktas in Istanbul city of Turkey, for road traffic noise. All the steps of the approach, noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings, sound clips and listening tests are used to develop and to validate the model.

KARAYOLU TRAFİK GÜRÜLTÜSÜ RAHATSIZLIĞI TAHMİN MODELİ GELİŞTİRMEK İÇİN BİR YAKLAŞIM

ÖZET

Gürültü rahatsızlığı çalışmaları, kişilerin gürültüye maruz kaldıklarında gösterdikleri tepkileri, kişilerin belirli bir tip çevresel gürültüye maruz kaldıklarında ne kadar rahatsız olduklarını sorgulayarak değerlendirir. Avrupa Parlamentosu ve Konseyi tarafından yayımlanan Çevresel Gürültü Yönetmeliği (2002/49/EC), Türkiye'de de 'Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği' olarak yayımlanmıştır. Bu Yönetmeliğin amacı, çevresel gürültüye maruz kalınması sonucu kişilerin huzur ve sükûnunun, beden ve ruh sağlığının bozulmaması için gerekli tedbirlerin alınmasını sağlamaktır. Bu amaçla, sırasıyla çevresel gürültüye maruz kalma seviyelerinin belirlenmesi için gürültü haritalama teknikleri, kamuoyunun bilgilendirilmesi ve eylem planlarının oluşturulması adımları uygulanmalıdır. Tüm bu adımların nihai sonucu, özellikle çevresel gürültüye maruz kalma seviyelerinin insan sağlığı üzerinde zararlı etkilere sebep olabileceği ve çevresel gürültü kalitesini korumanın gerekli olduğu yerlerde, gürültüyü önleme ve azaltmaya yönelik eylemlerin uygulamaya konmasıdır.

Bu yönetmeliklere göre gürültü rahatsızlığı, belirli bir bölgenin gürültü haritalarının ve bu bölgede yaşayan kişilerle yapılacak anketlerin karşılaştırılarak, doz-etki ilişkilerinin ortaya çıkartılması ile belirlenmelidir. Gürültü rahatsızlığı ve uyku bozulması için sırasıyla gürültü haritalama sonucunda ortaya konan L_{gag} ve L_{gece} gürültü göstergeleri belirlenmiştir. Yönetmeliklerde, gürültü haritalarının gürültüye maruz kalan bir alanda ikamet eden tahmini insan sayısını, eylem planlarının ise etkilenen (rahatsız edilen, uykusu bozulan veya başka türlü) insan sayısındaki azalma tahminlerini içermesi gerekliliği vurgulanmıştır.

Yönetmeliğin ve dünyadaki gürültü kontrolü çalışmalarının ana amacı gürültü rahatsızlığını azaltmak olsa da, uygulamalar gürültü seviyelerini azaltmak üzerine yoğunlaşmıştır. Bunun nedeni gürültünün ölçülebilir ve hesap modelleri ile tahmin edilebilir olması, gürültü rahatsızlığının ise doz-etki ilişkileriyle gürültü göstergelerine bağlanmış olmasıdır. L_{gag} ve L_{gece} gürültü göstergelerini gürültü rahatsızlığı ve uyku bozulması ile bağlayan doz-etki ilişkileri Avrupa Komisyonu çalışma gruplarınca tavsiye niteliğinde derlenmiştir. Bu doz-etki ilişkileri Kuzey Avrupa, Kuzey Amerika ve Avustralya'da gerçekleştirilmiş olan sosyo-akustik anketlerin sonuçlarından oluşturulmuştur. Bu ilişkiler rahatsızlığın sosyal etmenlerini içermediği için diğer ülkelerde uygulanması doğru sonuçlar vermemektedir. Bazı çalışmalarda doz-etki ilişkilerinde sosyal, psikolojik veya ekonomik faktörlerin, akustik veya fiziksel faktörlerden çok daha önemli olduğu bulunmuştur. Diğer yandan, bir çok çalışma, A ağırlıklı gürültü göstergelerinin veya L_{gag} ve L_{gece}'nin, gürültü rahatsızlığının bir çok özelliğini yansıtmadığını ortaya konmuştur.

Gürültü rahatsızlığını belirlemede daha etkili olacak ve daha kesin sonuçlara ulaştıracak bir yöntem, küresel gürültü göstergelerinden vazgeçmek ve gürültü

haritaları için toplanan veriyi girdi olarak alıp, fiziksel ve fiziksel olmayan etkenleri de ele alarak gürültü rahatsızlığını çıktı olarak veren yerel modeller oluşturmak olabilir. Bu amaçla, bu tez çalışması, karayolu trafik gürültüsü rahatsızlığı tahmin modeli geliştirmek için bir yaklaşım ortaya koymaktadır. Bu yaklaşım, trafik, kentsel gelişim ve toplumun özelliklerini de göz önüne alarak yetkili makamların kendi gürültü rahatsızlığı tahmin modellerini oluşturmalarını sağlamaktadır.

Bu yaklaşımın amacı, gürültü göstergeleri kullanmadan, hem akustik hem de sosyal etkenleri işin içine katan yerel karayolu trafik gürültüsü rahatsızlığı tahmin modeli geliştirmektir. Modeli oluşturan yaklaşım, gürültü haritalama, sosyo-akustik anketler, ses yalıtım ölçümleri, ses kayıtları ve dinleme testleri gibi bilinen yöntemleri bir araya getirmektedir. Bu yöntemlerin hepsinin birlikte kullanımı gürültü kaynakları, kentsel ses yayılımı ve evlerinde duydukları gürültü tiplerine insanların tepkileri üzerine detaylı bilgi sağlamakta ve daha kesin sonuçları olan bir model yaratmaya yardımcı olmaktadır.

Gürültü rahatsızlığı tahmin modeli, sadece gürültü düzeylerini azaltmaya değil, gürültü rahatsızlığını azaltmaya odaklanmış, maliyet etkin, eylem planları yaratmaya yardımcı olacaktır. Tahmin modeli gürültü rahatsızlığına etki eden etkenleri ayrıntılı olarak belirlediği için eylemlerin planlanması ve sonuçların anında hesaplanması mümkün olacaktır.

Bu yaklaşım için bazı sınırlamalar bulunmaktadır. Yaklaşım sadece karayolu trafik gürültüsü için tasarlanmıştır fakat ileride diğer çevresel gürültü kaynakları için de uyarlanabilir. Çalışma gece saatleri için uyanma, hareketlilik veya sağlık etkilerini içermediği için uyku bozulmasını içermemekte, sadece gürültü rahatsızlığını içermektedir. Kentsel ölçekte ses azalmasında meteorolojik etkiler ihmal edilebilir olduğu için meteorolojik etkiler yaklaşımda yer almamaktadır.

Yaklaşımda çalışma yapılacak bölge seçildikten sonra ilk ana adım gürültü haritalamadır. Gürültü haritalama, yöntemin uygulanmasında kullanılmayacaktır fakat yöntemin oluşturulması aşamasında kullanılmaktadır. Varsa bölgenin mevcut gürültü haritası kullanılabilir ya da yönetmeliğin önerdiği yöntemle gürültü haritalama gerçekleştirilebilir. Gürültü haritalama için uygun simülasyon programının seçilmesi, gerekli verilerin toplanması, modelin oluşturulması ve doğrulama ölçümlerinin yapılması gerekmektedir. Gürültü haritalama sonucunda hem gürültü haritaları, hem etkilenen kişi sayıları hem de cephelerde gürültü düzeyleri ortaya konmaktadır.

Yaklaşımda ikinci ana adım, bölgede sosyo-akustik anketlerin gerçekleştirilmesidir. Bunun için örnek sorulardan anketler oluşturulur, anketler bölgede uygulanır, istatiksel yöntemlerle anketlerin güvenilirliği belirlenir ve gürültü haritalarından elde edilen cephelerde gürültü düzeyleri ile sosyo-akustik anket sonuçları karşılaştırılarak doz-etki ilişkileri belirlenir.

Yaklaşımda üçüncü ana adım cephe ses yalıtımı ölçümleridir. Bunun için cephe elemanları belirlenir, sahada ölçüm yapılabilecek cepheler belirlenir, ölçümler gerçekleştirilir ve örneklem sayısının doğrulanır. Bunların tamamlanamaması durumunda laboratuvar ölçümleri ya da benzer saha çalışmalarından yardım alınabilir. Bu adımın sonunda cephe ses yalıtımı filtresi oluşturulur.

Yaklaşımda dördüncü ana adım ses kayıtlarıdır. Bölgedeki en yaygın karayolu araç tipleri ve araç kullanma koşulları belirlenerek, standartlara uygun koşullardaki test yollarında tekil araçların farklı trafik durumlarında yarattıkları sesler kaydedilir.

Yaklaşımda beşinci ana adım ses parçalarıdır. Bu adımda öncelikle tekil araçların ses kayıtları bir araya getirilerek bölgedeki farklı yol tiplerinde duyulabilecek ses parçaları oluşturulur. Daha sonra bölgedeki kentsel ses yayılımı incelenerek ses yayılımı filtreleri oluşturulur. Uzaklık ve atmosferik yutuculuk filtreleri, ses yayılımı filtreleri ve daha önce oluşturulan cephe ses yalıtım filtresi uygulanarak bölgede farklı evlerin içerisinde duyulabilecek ses parçaları oluşturulur.

Yaklaşımda altıncı ana adım dinleme testleridir. Dinleme testleri anket soruları ve ses parçaları ile oluşturulur, kontrollü bir ortamda bölgede yaşayanlarla testler gerçekleştirilir, sonuçlar analiz edilerek bir karayolu trafik gürültüsü rahatsızlık modeli oluşturulur.

Son adım için dinleme testleri sonucunda oluşturulan karayolu trafik gürültüsü rahatsızlık modeli sahada gerçekleştirilen sosyo-akustik anketlerle karşılaştırılarak doğrulanmış bir karayolu trafik gürültüsü rahatsızlık tahmin modeli oluşturulur.

Bu tez çalışmasında, önerilen yaklaşım İstanbul'un Beşiktaş ilçesinde bir karayolu trafik gürültüsü rahatsızlık tahmin modeli geliştirmek için uygulanmıştır. Yaklaşımın tüm adımları, gürültü haritalama, sosyo-akustik anketler, ses yalıtım ölçümleri, ses kayıtları, ses parçaları ve dinleme testleri, tahmin modelini geliştirmek ve doğrulamak için uygulanmıştır.

Çalışmanın sonucunda rahatsızlığı etkileyen ve tahmin modellerinde kullanılabilecek önemli ilişkilere ulaşılmıştır. Yol tiplerinin ve sesin şehirde yayılımının rahatsızlığı tahmin etmede önemi ve uygulanabilirliği ortaya çıkmıştır. Gürültü haritalarında dikkate alınmayan ikincil yolların, korna ve motosiklet gibi trafik elemanlarının gürültü rahatsızlığının belirlenmesindeki önemi ortaya çıkmıştır. Ana yollar ile direk görsel temasın uzaklık azaltımının rahatsızlık üzerindeki etkisini eleyebileceği belirlenmiştir.

İleride araştırmaya açık konular, bu yaklaşımın, basitleştirilmesi diğer ulaşım türleri için denemesi ve uyku bozukluğu için geliştirilmesi olabilir.

Bu tip rahatsızlık tahmin modelleri farklı ülkeler, farklı yerleşimler, farklı sosyal ve ekonomik bölgeler için oluşturulabilir. Karayolu gürültü rahatsızlığı tahmin modeli, trafik elemanlarının, yolların ve yerleşimlerin, gürültü rahatsızlığı üzerine etkilerini ortaya çıkartarak, yeni yerleşim alanlarının planlanmasında veya gürültü eylem planlarının oluşturulmasında yardımcı olacaktır.

1. INTRODUCTION

The main objective of “Assessment and Management of Environmental Noise (2002/49/EC)” Directive (The European Parliament and The Council of The European Union, 2002) is to define a common approach intended to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. To that end, noise mapping, informing the public and action planning shall be implemented.

The term, ‘annoyance’ is defined in the Directive as ‘the degree of community noise annoyance as determined by means of field surveys’. L_{den} and L_{night} are defined as noise indicators for annoyance and for sleep disturbance, respectively. Noise annoyance dose-effect relations are to be established for these given indicators. It is stated in the Directive that each action plan should contain estimates in terms of reduction in number of people annoyed and sleep disturbed.

Although the main purpose of the Directive and of noise control studies over the world is to reduce noise annoyance, the implementation is focused mostly on reducing noise levels, not annoyance, because annoyance levels are directly linked to noise levels in dose-effect relationships. Dose-effect relationships linking L_{den} and L_{night} noise indicators to annoyance levels are provided by European Commission Working Groups. The dose-effect relationships were created from socio-acoustic surveys, made in countries of North Europe, North America and Australia. These relationships do not necessarily apply to other countries to consider social factors of annoyance. In some studies it is concluded that in dose effect relationships, social, psychological or economic factors, are far more important than acoustic or physical factors. On the other hand, many studies have shown that the indicators used, such as A-weighted values or L_{den} and L_{night}, do not reflect many aspects of annoyance.

Dick Botteldooren is full time research professor in acoustics at Ghent University and is the head of the Acoustics Research Group. He gave a Distinguished Plenary Lecture at ICSV22 (The 22nd International Congress on Sound and Vibration – 12-16 July 2015) on “Modeling and Monitoring the Effects of Environmental Sound in Private and Public Space". The speech was on environmental noise evaluation's past, present and future. Some of the important research needs he pointed out were the need for new noise indicators and studies on annoyance models.

The first round of noise mapping in EU, in 2007, proved that due to quality of input data, noise maps may have a local uncertainty as large as 5 dB. The first round of action planning in EU, in 2008, showed that although noise maps are very effective in determining hot spots, they do not function accurately in quiet areas and areas in between which are called gray areas. In these quiet and gray areas, the lack of defining minor noise sources and lack of identifying perceived noise cause insufficient understanding of noise annoyance (Licitra, 2012).

A more efficient and accurate way to determine annoyance might be to eliminate global noise indicators and to create local models which use all the information collected for noise mapping as input, and provide annoyance levels as a direct output, taking into account physical and non-physical factors. To that end, this study is designed to create an approach for developing a road traffic noise annoyance prediction model. This approach allows authorities to develop their own annoyance prediction models, taking into account characteristics of traffic, urban development and population.

The objective of this approach is to create an accurate local road traffic noise annoyance prediction model which considers not only acoustical aspects but also social aspects, without using noise indicators. The approach to develop the model includes well known methods such as noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings and listening tests. Using all of these methods together, provides detailed information on noise sources, urban propagation conditions and people's responses to certain types of noise heard inside their homes, which help to create an accurate model.

Using an accurate annoyance prediction model may provide cost effective action plans which focus on decreasing annoyance levels, and not only noise levels. Planning actions against annoyance may be easier to organize because the model helps to understand the factors which effect annoyance levels.

There are some limitations to this approach. The approach is only for road traffic noise sources, but further studies may be used to implement the approach for other noise sources. This approach is for general noise annoyance and not sleep disturbance, because this study does not include awakening, motility or health effects. Meteorological effects are not taken into account because of the negligible attenuation in urban conditions.

In this thesis, the approach is implemented to create an annoyance prediction model in the urban area of Besiktas in Istanbul city of Turkey, for road traffic noise. All the steps of the approach, noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings, sound clips and listening tests are used to develop and to validate the model.

2. TRAFFIC NOISE CHARACTERISTICS AND EFFECTS

In a modern society, traffic noise effects almost everyone. In the European Union, more than 40 % of the total population are exposed to road traffic noise levels above 55 dBA and about 20 % of the people are exposed to noise levels above 65 dBA (L_{Aeq}). Noise pollution in developing countries is caused mainly by traffic and alongside densely travelled roads equivalent sound pressure levels for 24 hours can reach 75–80 dB(A). In contrast to many other environmental problems, noise pollution continues to grow (WHO, 1999).

Noise, causes serious psychological, physiological and social effects: feelings of disturbance, stress reactions and sleep disorders, some hormonal changes, increased blood pressure, increased risk of myocardial infarction, and impairment of well-being and general quality of life (Passchier-Vermeer & Passchier, 2000). Understanding characteristics of noise are essential in the efforts to reduce the negative effects on noise on humans.

In this section, characteristics of traffic noise and indicators defining traffic noise are explained, physical and psychological effects of noise are described. Directives and standards on environmental noise and especially traffic noise are summarized.

2.1 Traffic Noise Characteristics and Indicators

Emission of traffic noise depends on traffic volume, types of vehicles which form the traffic flow and speed of flow. The sound environment forms as a result of the factors which effect propagation of sound, such as ground topography, barriers and climatic factors. The spectral characteristics and descriptors are the key points of identifying traffic noise.

2.1.1 Traffic noise spectral characteristics

The frequency spectrum of noise, highly influences sound quality. High frequency noise emerging from traffic noise increases annoyance (Nelson, 1987). Road traffic with strong low frequency content deteriorates urban soundscape (European Commission, 2000).

Traffic noise prediction has four main steps: (i) a traffic model that estimates the characteristics of traffic flow (speeds, flow rates, etc.), (ii) a noise emission model that gives the noise power level Lw emitted by vehicles, (iii) a sound propagation model that gives the sound pressure level Lp at a receiver, and (iv) the calculation of noise indicators to highlight sound characteristics. Each of these steps should simulate spectral contents accurately to display characteristics of urban traffic noise. (Can et al., 2010).

The significance of traffic noise spectrum is apparent in all related actions. For example, acquiring noise attenuation by noise barriers in low frequencies is quite hard and their shape design is frequency dependent (Can et al., 2010). Actions on reducing annoyance or on changing soundscape requires an accurate frequency spectrum information.

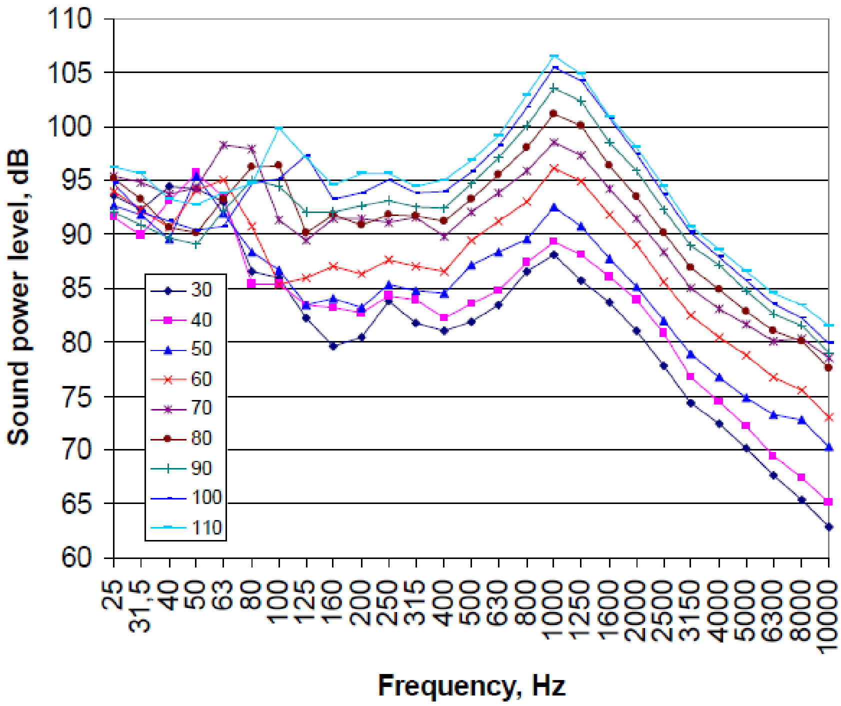


Figure 2.1 : Examples of sound power levels of cars with different speeds (km/h) (Jonasson et al., 2004).

Figure 2.1 (Jonasson et al., 2004) gives the frequency spectrum of sound power levels of passenger cars with different speeds, for the frequency range 25-10000 Hz, from the Nord 2000 model. It is clearly seen that as vehicle speed increases, sound power levels increase as well, in middle and high frequency ranges. On the other hand, in low frequencies, vehicle speed has almost the reverse effect on sound power levels. The peak towards 1000 Hz is apparent in all speeds. In low frequency range, sound power level of each speed has a smaller peak. As the speed increases, the frequency of the smaller peak increases as well.

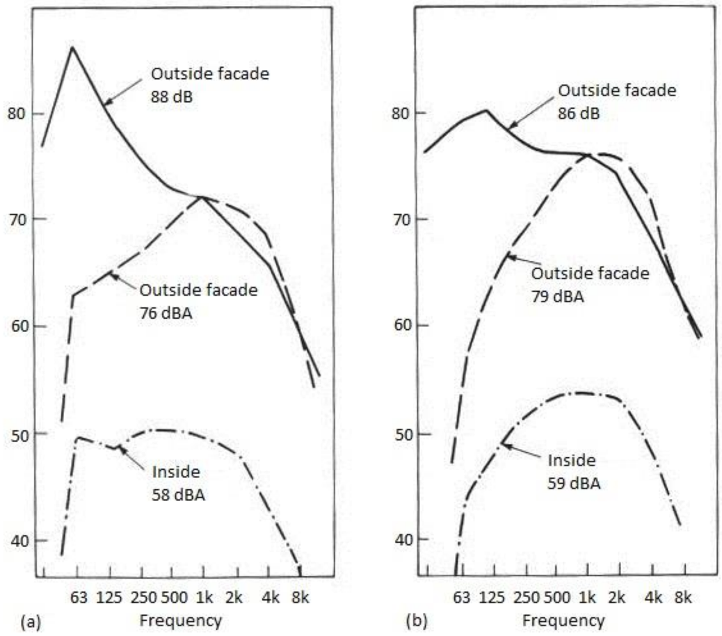


Figure 2.2 : Typical octave band spectrum recorded outside and inside buildings for (a) interrupted flow and (b) freely flowing traffic (Nelson, 1987).

Figure 2.2 gives typical octave band spectrum recorded outside and inside buildings for both interrupted flow and freely flowing traffic. The figure demonstrates spectrum with no weighting (dB) for outside measurements and spectrum with A weighting (dBA) for both outside and inside measurements. In the frequency spectrum which shows city traffic (less than 60 km/h), most of the acoustical energy is at 63 Hz band. The main reason of this spectral property is the exhaust noise. In the traffic with a steady flow (more than 80 km/h), spectrum does not show a peak in low frequency spectrum, because the vehicles operate in steady speed, in high gear. But in these high speed flows, tire - road noise and motor noise increase the acoustic energy in high frequencies. When the spectra are A weighted, low frequency noise levels decrease in both cases, resulting in having a higher free flowing traffic level. Looking at A weighted levels in inside the buildings, it is seen that low frequency noise is higher because sound insulation is more effective in high frequencies. This example shows the importance of traffic spectrum in designing sound insulation and perception of sound by the listener. A weighted noise levels may cause problems because of the difficulties in controlling low frequency noise (Nelson, 1987).

Can et al. (2010) compares static and dynamic traffic representations of for the assessment of urban noise frequency spectrum. Static traffic representation depends on mean vehicle speeds and flow rates, dynamic one considers vehicle interactions along the traffic network. These two representations are compared to recordings on-site, on a three lane busy street. Static traffic representation underestimates low frequencies, but dynamic one is successful. In the study, the Harmonoise model was used to predict the sound power level $L_{w,k}$ of one given vehicle k, in terms of its speed v_k and its acceleration a_k as seen in Figure 2.3 (Can et al., 2010).

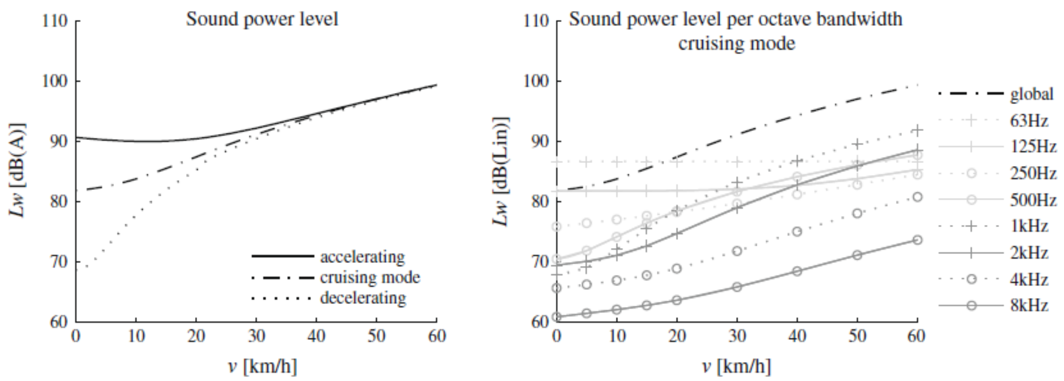


Figure 2.3 : Sound power levels for light vehicles, accelerating (a = 0.8 m/s^2), cruising (a = 0 m/s^2) or decelerating (a = -3 m/s^2) (Can et al., 2010).

Figure 2.4 gives noise spectra at four different measurement and calculation points, with noise rating curves (ISO 1996-1, 2003). The sound levels decrease with the increasing frequency, which is typical of traffic noise spectrum, reaching at least 20 dB over the whole spectrum. Measurement spectra always show peaks at 1000 Hz, which is mainly caused by the contact of tires on the road. The overestimated values for the static model at P4 is explained by the model not taking into account the stopping and slowing down of vehicles at an intersection. The underestimation for the dynamic model at P4 is explained by propagation conditions (Can et al., 2010).

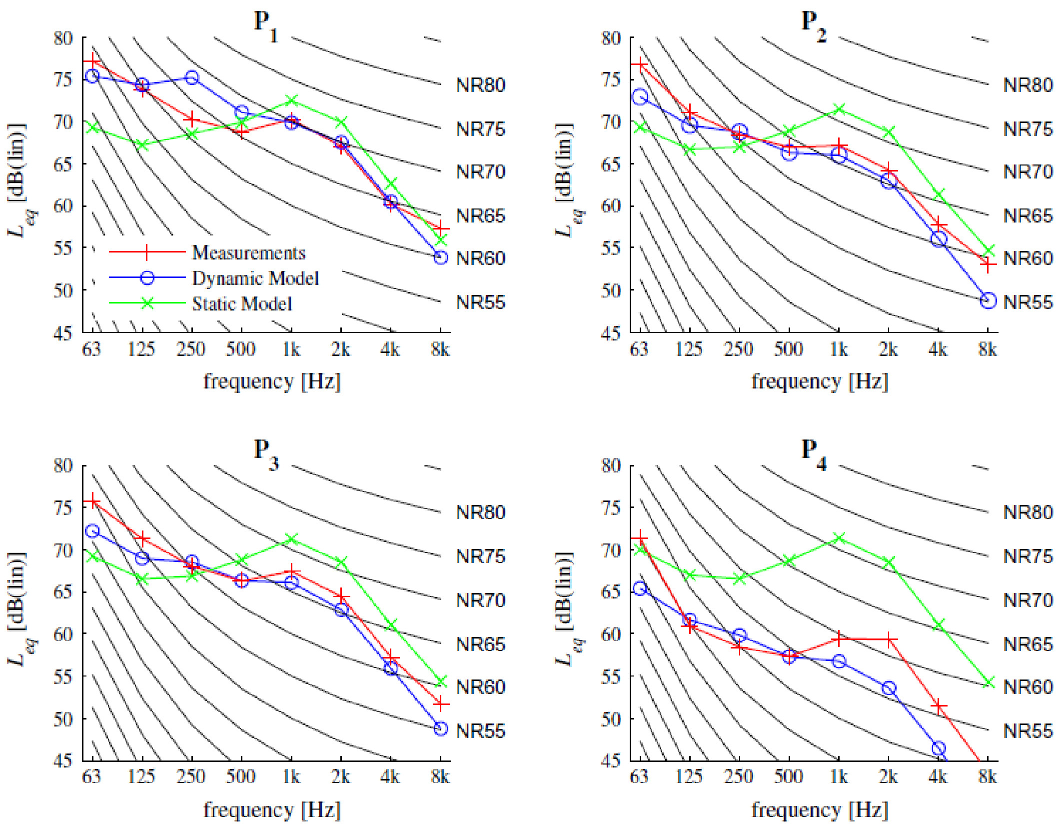


Figure 2.4 : Equivalent sound pressure level spectrum at four different measurement and calculation locations (Can et al., 2010).

2.1.2 Traffic noise descriptors and indicators

Traffic noise varies with time, as shown in Figure, which provides some insight to the A weighted sound levels commonly used. It is almost impossible to find a single measure, which can accurately quantify and correlate with what is heard (Peters et al., 2010).

2.1.2.1 Weighted sound levels

Frequency weighting considers typical human response to sound. To accomplish that, the sound level in each frequency is adjusted. The adjusted levels are then added to produce a single number in decibels. Weighting networks are A, B, C and D, and the outcome of these weightings are dBA, dBB, dBC and dBD. The most common is A-weighting network, which was originally designed to estimate the response of the human ear at relatively low sound levels (Kang, 2007). Figure 2.6 shows the A, B, C and D weightings on graph.

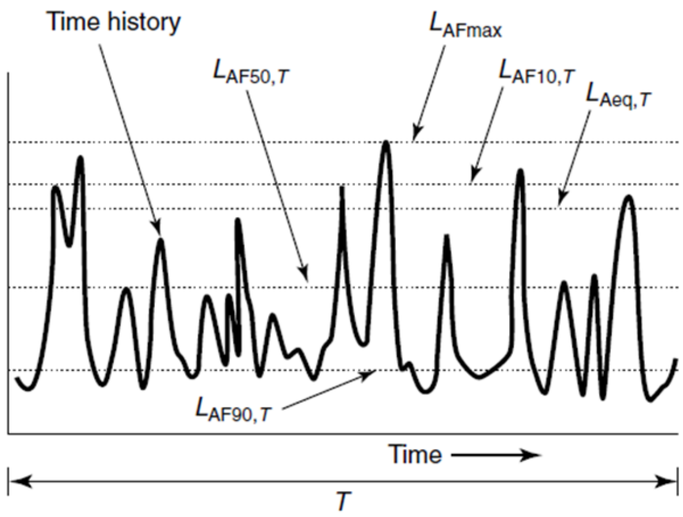


Figure 2.5 : Sample of A weighted time varying noise, over a sample duration of T seconds (Peters et al., 2010).

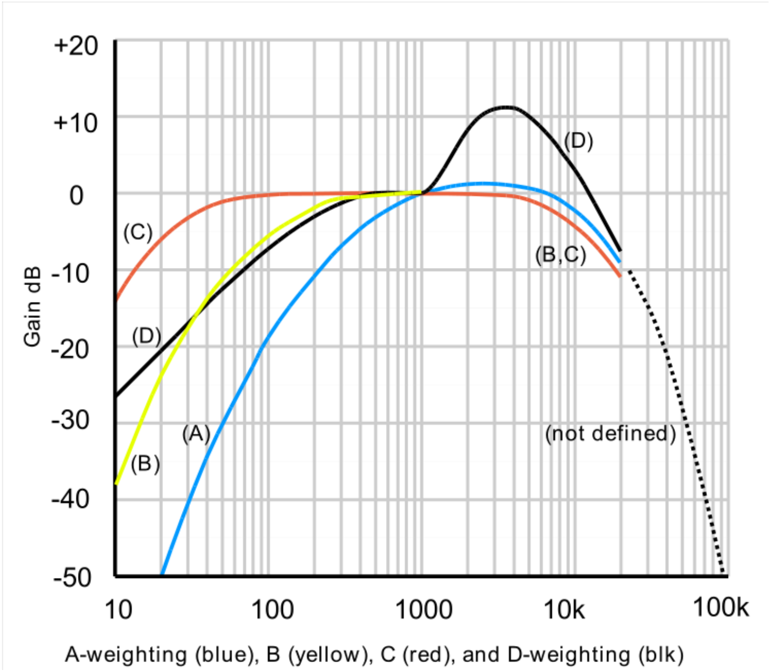


Figure 2.6 : A-weighing (blue), B-weighing (yellow), C-weighing (red) and D-weighing (black) on graph (Kang, 2007)

2.1.2.2 Energy based descriptors

Sound pressure level

Sound pressure level (SPL) is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The standard reference sound pressure in air or other gases is 20 µPa, which is usually considered the threshold of human hearing (at 1 kHz) (Kang, 2007).

Equivalent continuous sound pressure level

The equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$ is calculated by the equation:

$$L_{Aeq,T} = 10\log\left(\frac{1}{T}\sum_{t=1}^{T} 10\,\frac{L_{Aeq,1s(t)}}{10}\right) \tag{2.1}$$

In this equation, T is used for indicating period of time, in seconds. Recommended T values for dealing with environmental noise stand between 1 h and 24 h. Energy-based descriptors are correlated with long-term effects of noise, but their ability for evaluating fluctuating sounds are weak (Can et al., 2008).

Sound exposure level

Sound exposure level, SEL or L_{SE}, is used to quantify short duration noise events such as aircraft flyover, impulsive or impact noise, or single vehicle pass-by. It is the sound level that if maintained constant for 1s contains the same acoustic energy as a varying noise level. L_{SE} is expressed as L_{AE} if A-weighting is applied. (Kang, 2007) The equation is given below.

$$L_{SE} = 10\log\int_{0}^{T}\frac{p^2(t)}{p_0^2}\,dt \tag{2.2}$$

where,

p_0: reference pressure, p_0= 2x10 N/m.

2.1.2.3 Statistical descriptors

Statistical descriptors are used for demonstrating noise distribution. The level $L_{AN,T}$ represents the A-weighted pressure level exceeded during N% of the total observed period T. $L_{AN,T}$ is traditionally assessed over long periods, such as 18 or 24 hours. Minimum flow rate of 500 vehicles/hour and minimum period of at least 5 or 15 min are recommended. (Can et al., 2008) Usually, L_1 represents the maximum, L_{10}, the intrusive, L_{50}, the median and L_{90}, the background sound levels (Kang, 2007).

Noise distribution is another statistical description of noise levels. It portrays the percentage of occurrences in terms of 1 or 5 dB(A) bandwidths (Can et al., 2008).

Traffic noise index

Traffic noise index (TNI) is based on A-weighted sound levels statistically sampled over a 24h day. It depends on fluctuations in noise level over time and the background noise (Schultz, 1982). The equation is given below.

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30 \tag{2.3}$$

2.1.2.4 Loudness

Perception of sound depends on the auditory capabilities of humans. The audio range of humans are between 20 Hz and 20 kHz. The minimum sound pressure level audible to the average human ear is 0 dB at 1 kHz. But in normal day life, a constant sound level of 10–15 dB is barely audible. A sound pressure level of 130 dB will cause a painful sensation and 140dB will increase the risk of irreparable nerve damage. A change of 1dB is just perceptible to humans. A change of 3dB or more is perceived as significant. An increase of 10dB generates the sensation of an approximate doubling of the strength (Schaudinischky 1976).

Subjective comparative measurements have been made over the years, in free field with sinusoidal tones (pure tones), by researchers, in order to acquire equal-loudness-level contours. These are Fletcher and Munson in 1933, Fastl and Zwicker in 1987, Robinson and Dadson in 1956; Suzuki and Takeshima in 2004. The equal loudness graph that is mostly used is given in ISO 226 (2003) and shown in Figure 2.7. Figure 2.8 shows a comparison of the contours based on the current ISO data (ISO 226, 2003), Fletcher-Munson (1933) and Robinson-Dadson (1956).

The unit of loudness level, P, is phon, and its value is the same as the sound pressure level at 1kHz. The unit for loudness S, sone, is defined as:

$$S = 40 + 10 \log_2 P \tag{2.4}$$

Contours of equal noisiness were determined by laboratory subjective tests on noisiness and annoyance.

The unit of subjectively perceived noisiness is ‘noy’, defined with perceived noise level (PNL, L_{PN}) in dB. A sound of 2 noy is perceived as twice as noisy as a sound of 1 noy (Kang, 2007).

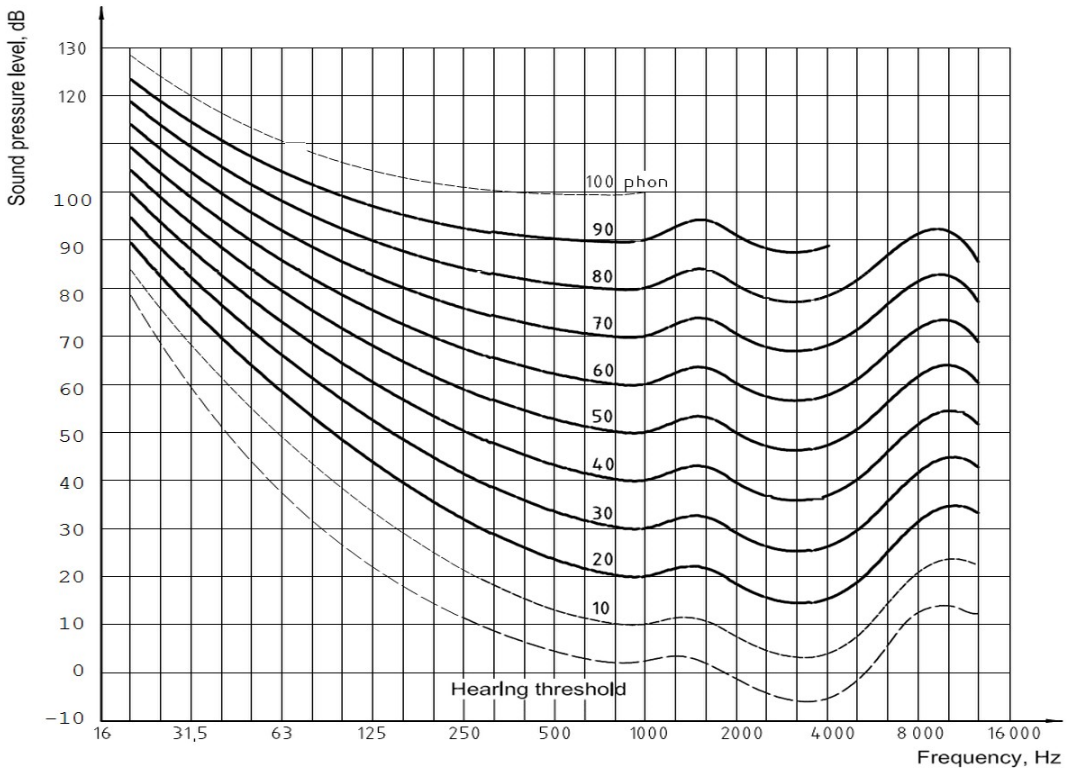


Figure 2.7 : Equal Loudness Graph (ISO 226, 2003).

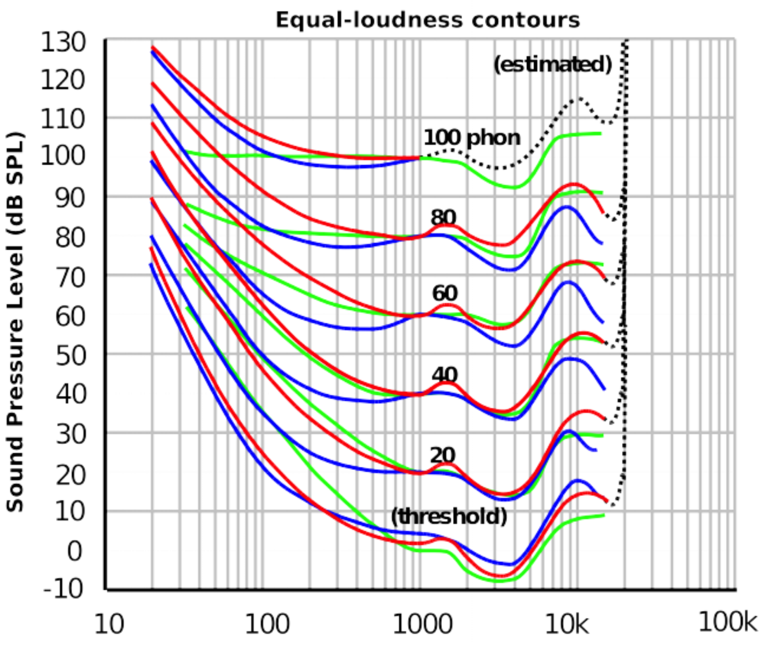


Figure 2.8 : Comparison of the contours based on the current ISO 226 (2003), Fletcher-Munson (1933) and Robinson-Dadson (1956).

2.1.2.5 Emergence descriptors

Maximum noise levels have a strong relationship with annoyance (Sato et al., 1999). Some of the emergence descriptors which are related to traffic noise are as follows:

$NNE_L > L_\alpha$ is the number of noise events exceeding a given threshold L_α.

Mask index $MI_L > L_\alpha$ is the cumulative time (seconds or percentage) when $L_{Aeq,1s}$ exceeds L_α.

The intensity of emergent events can be characterized by considering the averaged sound pressure level $L_L > L_\alpha$ where $L_{Aeq,1s} \geq L_\alpha$. Threshold value for emergence descriptors may be chosen according to the event type. It can be fixed to a given value, such as 80 dBA in urban areas, or be defined by a descriptor, such as $L_{Aeq,T}$ + 10 (Can et al., 2008).

2.1.2.6 Calmness descriptors

Calm periods influence urban noise quality. Some descriptors were developed in relation to calm periods. $NNE_L < L_\alpha$ is the number of noise events where $L_{Aeq,1s}$ does not exceed $_\alpha$. $MI_L < L_\alpha$ is the cumulative time period where $L_{Aeq,1s}$ does not exceed $_\alpha$. Threshold can be fixed (i.e., 60 dBA) or defined by another descriptor such as L_{A90} (Can et al., 2008).

2.1.2.7 Day period descriptors

Day-night level

DNL, or day–night equivalent sound level, L_{dn}, is the average over a 24h period but the noise level during the nighttime period, 22:00–07:00, is penalised by the addition of 10dBA (Kang, 2007).

$$L_{dn} = 10\log\frac{1}{24}\left(15\int_{7}^{22} 10^{Lp/10}dt + 9\int_{22}^{7} 10^{(Lp+10)/10}dt\right) \qquad (2.5)$$

where,

L_{dn}: Day–night equivalent sound level, dB.

L_p: Sound pressure level, dB.

Day–evening–night level

Day–evening–night level, L_{den}, is similar to DNL but an evening period is considered, penalized by an addition of 5dBA. It is widely used in Europe due to the current regulation (European Commission, 2003). L_{den} is defined with the following equation:

$$L_{den} = 10\log\frac{1}{24}\left[12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening}+5}{10}} + 8 * 10^{\frac{L_{night}+10}{10}}\right] \qquad (2.6)$$

In this equation, L_{day}, $L_{evening}$ and L_{night} are the A-weighted long-term average sound levels, determined over all the day periods, evening periods, and night periods of a year, respectively. Typically, the day is 12h long, the evening is 4h and the night is 8h, with default values 07:00–19:00, 19:00–23:00 and 23:00–07:00 local time respectively (European Commission, 2003).

2.2 Effects of Environmental Noise on Humans

Passchier-Vermeer and Passchier (2000) published a review on noise exposure and public health, explaining effects of noise on humans. This review was based on an assessment on the health effects of environmental and occupational noise exposure, by The Committee on Noise and Health, an international committee of the Health Council of the Netherlands (Health Council of the Netherlands, 2014). The review provided a table about the adverse effects related to environmental and occupational noise exposure.

Table 2.1 : Long-term effects related to exposure to environmental noise and classification of the evidence for a causal relationship between noise and effect (Passchier-Vermeer & Passchier, 2000).

Effect	Classification of evidence	Observation threshold		
		Metric	Value,dBA	Indoors/outdoors
Hearing impairment	Sufficient	$L_{Aeq,24h}$	70	Indoors
Hypertension	Sufficient	L_{dn}	70	Outdoors
Ischemic heart disease	Sufficient	L_{dn}	70	Outdoors
Biochemical effects	Limited			
Immune effects	Limited			
Birth weight	Limited			
Congenital effects	Lacking			
Psychiatric disorders	Limited			
Annoyance	Sufficient	L_{dn}	42	Outdoors
Psychosocial well-being	Limited			
Sleep disturbance, changes in				
Sleep pattern	Sufficient	$L_{Aeq,night}$	<60	Outdoors
Awakening	Sufficient	SEL	55	Indoors
Sleep stages	Sufficient	SEL	35	Indoors
Subjective sleep quality	Sufficient	$L_{Aeq,night}$	40	Outdoors
Heart rate	Sufficient	SEL	40	Indoors
Hormone levels	Limited			
Immune system	Inadequate			
Mood next day	Sufficient	$L_{Aeq,night}$	< 60	Outdoors
Performance next day	Limited			

Table 2.1 gives long-term effects related to exposure to environmental noise and classification of the evidence for relationship between noise and effect (Passchier-Vermeer & Passchier, 2000).

The evidence is rated in terms of categories used by the International Agency on the Research of Cancer as "sufficient," "limited," "inadequate," or "lacking". In the last three columns, observation thresholds for adverse health effects are given for effects with sufficient evidence. The observation threshold for an effect is the lowest noise exposure value where the effect is observed in epidemiologic studies (Passchier-Vermeer & Passchier, 2000).

2.2.1 Noise-induced hearing impairment

Hearing impairment is a partial or total inability to hear, in which partial inability in hearing increases the hearing threshold level. Hearing impairment is associated with aging, certain diseases, exposure to some industrial chemicals, ototoxic drugs, head injuries, accidents, or factors that are of hereditary origin. Noise-induced hearing impairment takes place primarily in the high frequency range, 3000 to 6000 Hz, with strongest effects observed at 4000 Hz (Passchier-Vermeer & Passchier, 2000).

ISO 1999 (2013) provides the method for estimation of noise-induced hearing loss. It presents, the relationship between noise exposures and the “noise-induced permanent threshold shift” (NIPTS) in people of various ages. It focuses mainly on occupational noise, but it may also be used to calculate the hearing loss to be expected from the combined total daily noise exposure. Some studies show that instead of using $L_{Aeq,8h}$ for occupational noise, $L_{Aeq,24h}$ for environmental noise may be used for this method. Therefore, it may be suggested that environmental noise with $L_{Aeq,24h}$ values < 70 dB(A) do not cause hearing impairment in the large majority of people (> 95%), even in the case of life-time exposure. On the other hand, young children may be more vulnerable to noise induced hearing impairments than adults (Passchier-Vermeer & Passchier, 2000).

At high instantaneous sound levels, at a peak sound pressure level of 140 dB for adults and 120 dB for children, mechanical damage to the outer and the inner ear may occur (Passchier-Vermeer & Passchier, 2000).

Noise exposure may also cause tinnitus (ringing in the ears). It may be observed among teenagers exposed to high levels of recreational noise. Noise induced tinnitus may be temporary, lasting up to 24 hours after exposure, or it may be more permanent (Passchier-Vermeer & Passchier, 2000).

Even a hearing impairment of 10 dB averaged over 2,000 and 4,000 Hz may effect on the understanding of speech, whereas 30 dB hearing impairment is a noticeable handicap. (Passchier-Vermeer & Passchier, 2000).

2.2.2 Psychosocial effects

Psychosocial effects due to exposure to environmental noise that have been studied in epidemiologic investigations include annoyance, psychosocial well-being, and psychiatric hospitalization (Passchier-Vermeer & Passchier, 2000).

The main psychosocial effect from noise exposure is annoyance. Noise annoyance is a feeling of resentment, displeasure, discomfort, dissatisfaction, or offense when exposed to noise (Passchier-Vermeer & Passchier, 2000). Noise annoyance in populations is determined using questionnaires. Dose-effect relationships have been prepared for exposure to road traffic, railway, and aircraft noise (WG-HSEA, 2002). The effect is given as the percentage of the population annoyed and highly annoyed by a specific environmental noise. More information on noise annoyance is given in Section 3.

2.2.3 Noise-induced stress-related health effects

Reactions of humans to stressors may be psychologic (fear, depression, sorrow), behavioral (social isolation, aggression, addiction), or somatic (cardiovascular, gastrointestinal, respiratory illnesses). Many laboratory experiments have shown noise-induced temporal changes in the cardiovascular system. Some studies on possible long-term effects associated with noise exposure were carried out; for example stress-related cardiovascular disorders, the effects of noise exposure on the hormone and immune systems, effects from environmental noise on reproduction and development. Research on chronic effects of long term exposure to noise is complicated because it is almost impossible to control all the other factors effecting cardiovascular and biochemical changes and to obtain detailed information about past noise exposure (Passchier-Vermeer & Passchier, 2000).

2.2.3.1 Cardiovascular effects in adults

Environmental noise studies on changes in blood pressure and increased risk for ischemic heart disease in adults are mostly on road traffic noise. Mainly, the studies do not provide any results supporting the effect of noise exposure on mean diastolic and mean systolic blood pressure; on the other hand, an increase in the percentage of people with hypertension was noticed, including those who use medication for hypertension. The observation threshold for hypertension and for ischemic heart disease are L_{dn} value of 70 dB(A) for environmental noise exposure. The relative risks for hypertension and ischemic heart disease for exposure levels above the observation thresholds are estimated to be about 1.5 (Passchier-Vermeer & Passchier, 2000).

A few epidemiologic studies worked on biochemical and immunologic effects. Norepinephrine (a neurotransmitter that is secreted in response to stress) levels were found to be increased in women whose bedrooms faced busy streets (> 20,000 vehicles a day) and epinephrine (adrenalin) levels were also higher in women reporting high disturbances of communication and sleep under closed window conditions (Passchier-Vermeer & Passchier, 2000).

2.2.3.2 Cardiovascular effects in children

Studies showed significantly higher increase in systolic and diastolic blood pressure in children exposed to very high road traffic noise levels or aircraft noise levels. Overnight resting levels of epinephrine and norepinephrine increased significantly among children exposed to aircraft noise (Passchier-Vermeer & Passchier, 2000).

2.2.3.3 Effects on the unborn child

Data from older studies propose that small reductions in birthweight occur when pregnant women are exposed to high levels of aircraft noise, $L_{dn} > 62$ dB(A), although no new study supports these findings. It is found in some studies that mother's stress induced by exposure to noise during pregnancy may cause high-frequency hearing impairment in babies (Passchier-Vermeer & Passchier, 2000).

2.2.4 Sleep Disturbance

Sleep is a recovery process essential for humans to function properly. A good night's sleep is considered to be essential for good life quality. Noise interference during sleep may hinder brain restoration and cardiovascular system relief. Reduced sleep quality due to noise interferes with daytime functioning and can have adverse effects on mood next day and possibly on vigilance and cognitive performance (Passchier-Vermeer & Passchier, 2000).

Sleep quality can be measured by subjective and objective methods. Most common subjective methods are self-reporting using sleep logs and behavioral observations. Most common objective methods are electroencephalograph (EEG) recordings and actimetry; wearing watch-like actimeters for detecting movement (Passchier-Vermeer & Passchier, 2000).

Epidemiologic studies show that there is sufficient evidence for a causal relationship between exposure to night-time noise and changes in sleep pattern, awakenings, sleep stages, heart rate, subjective sleep quality, and mood the next day. Evidence for hormone levels and performance the next day is limited and for immune system it is inadequate. The relationship between the risk of awakening and exposure to night-time environmental noise is determined for single noise events, with indoor SEL values (Passchier-Vermeer & Passchier, 2000).

2.3 Directives on Environmental Noise

European Directive on environmental noise has led to implementation of many acoustical studies, especially noise mapping studies all over Europe. Although annoyance studies seem to be long-term objectives, directives are helping knowledge on noise annoyance build up rapidly and with specific norms. This section provides information on "Directive relating to the Assessment and Management of Environmental Noise" by European Parliament and Council (2002) and "Assessment and Management of Environmental Noise Directive" by Republic of Turkey Ministry of Environment and Forestry (2010).

2.3.1 European directive on the assessment and management of environmental noise

"Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise" was published in Official Journal of the European Communities on July 18th 2002. EU directives lay down certain end results that must be achieved in every Member State. National authorities need to adapt their laws to meet these goals, but they are free to decide how to do so.

Directive defines ‘annoyance’ as ‘the degree of community noise annoyance as determined by means of field surveys’. ‘Dose-effect relation’ is defined as ‘mean the relationship between the value of a noise indicator and a harmful effect’.

Article 1 states that the aim of this directive is to define a common approach intended to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. These three actions given below are put forth the be implemented in an orderly fashion:

1. Noise mapping: determination of exposure to environmental noise;

2. Public information: information on environmental noise and its effects is made available to the public;

3. Action plans: based upon noise-mapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good. According to the directive, action plans must include an evaluation of the estimated number of people exposed to noise and estimates in terms of the reduction of the number of people affected (annoyed, sleep disturbed, or other).

This directive applies to environmental noise caused by transport or industry, but does not apply to noise from domestic activities, noise at workplaces or inside transportation vehicles.

The directive states that dose-effect relations should be used to assess the effect of noise on populations. The dose-effect relations may represent ‘the relation between annoyance and L_{den} for road, rail and air traffic noise, and for industrial noise’ or ‘the relation between sleep disturbance and L_{night} for road, rail and air traffic noise, and for industrial noise’. If necessary, specific dose-effect relations may be used to present dwellings with special insulation against noise, dwellings with a quiet façade, different climates/different cultures, vulnerable groups of the population, tonal industrial noise or impulsive industrial noise.

2.3.1.1 Noise indicators

Noise indicators defined in this directive are L_{den}, L_{day}, $L_{evening}$ and L_{night}, representing overall, day period, evening period and night period annoyances respectively. The selected common noise indicators are L_{den}, to assess annoyance, and L_{night}, to assess sleep disturbance. It is also stated that Member States are allowed to use supplementary indicators in order to monitor or control special noise situations or use other noise indicators for acoustical planning and noise zoning.

Annex I of the directive defines L_{den}, L_{night} and supplementary noise indicators.

The day-evening-night level L_{den} in decibels (dB) is defined by the following formula:

$$L_{den} = 10 \log \frac{1}{24} \left[12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening}+5}{10}} + 8 * 10^{\frac{L_{night}+10}{10}} \right] \quad (2.7)$$

Where:

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

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

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

Timing of these periods are 07.00 to 19.00 for day, 19.00 to 23.00 for evening and 23.00 to 07.00 for night in local time. The Member States are allowed to change these hours if they provide the Commission with information.

ISO 1996-2 standard was revised in 2007 as ‘Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels’.

In this equation, “a year” is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances. Sound which is reflected from the façade is not taken into account for these calculations, which means a 3 dB correction is needed in case of measurement results.

The height for estimation of noise indicators for preparing noise maps is 4,0 ± 0,2 m above ground and at the most exposed façade. If measurement are to be made for noise mapping, other heights no less than 1,5 m above ground may be used, but measurement result should be corrected to an equivalent height of 4 m. For acoustical planning and noise zoning issues, other heights no less than 1,5 m above ground may be used.

In the cases given below, the directive states that, the use of supplementary noise indicators may be beneficial:

- The noise source under consideration operates only for a short time of the day or very limited time of the year,

- Very low average number of noise events exists;

- Low-frequency content of the noise is strong;

- Tonal components of the noise are strong;

- L_{Amax}, or SEL (sound exposure level) for night period protection in the case of noise peaks;

- Extra protection exists at a specific part of the year or the day;

- Multiple noise sources existing together;

- Quiet areas in open country;

- The noise has an impulsive character.

2.3.1.2 Assessment methods

Article 6 of the directive specifies that L_{den} and L_{night} noise indicator values should be determined by assessment methods defined in Annex II. According to Annex II, L_{den} and L_{night} values can be determined either by computation or by measurement at assessment positions. It states that only computation is applicable for predictions of future situations.

Until common computation methods for the determination of L_{den} and L_{night} are established by the Commission, either adaptation of existing national computation methods or interim computation methods recommended by the Commission may be used by Member States.

Recommended interim computation methods are as follows:

- For Industrial Noise: ISO 9613-2 (1996) 'Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation'. For noise-emission data, one of the following methods can be used for making measurements: ISO 8297 (1994) ‘Acoustics - Determination of sound power levels of multisource industrial plants for evaluation of sound pressure levels in the environment - Engineering method’; EN ISO 3744 (1995) ‘Acoustics - Determination of sound power levels of noise using sound pressure - Engineering method in an essentially free field over a reflecting plane’ (Revised in 2010); EN ISO 3746 (1995) ‘Acoustics - Determination of sound power levels of noise sources using an enveloping measurement surface over a reflecting plane’ (Revised in 2010).

- For Aircraft Noise: ECAC.CEAC Doc. 29 ‘Report on Standard Method of Computing Noise Contours around Civil Airports’, 1997. The segmentation technique referred to in section 7.5 of ECAC.CEAC Doc. 29 will be used.

- For Road Traffic Noise: The French national computation method ‘NMPB-Routes-96 (SETRA-CERTU-LCPCCSTB)’, referred to in ‘Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, Article 6’ and in the French standard ‘XPS 31-133’. For input data concerning emission, these documents refer to the ‘Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR 1980’.

- For Railway Noise: The Netherlands national computation method (Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 1996).

The Commission adopted a ‘Recommendation concerning the guidelines on the revised interim computation methods for industrial noise, aircraft noise, road traffic noise and railway noise, and related emission’ on 6 August 2003 (European Commision, 2003).

The European Commission decided to prepare Common Noise Assessment Methods (CNOSSOS-EU) for road, railway, aircraft and industrial noise in order to improve the reliability and the comparability of results across the EU Member States. A reference report was published in July 2012 (Kephalopoulos at al, 2012).

Regarding the interim measurement methods for L_{den} and L_{night}, if a Member State desires to use its own official measurement method, that method shall be adapted to the noise indicators and to long-term average measurements stated in ISO 1996-2: 1987 and ISO 1996-1: 1982. If a Member State has no measurement method, a method may be defined based on ISO 1996-2: 1987 and ISO 1996-1: 1982. Measurement data in front of a façade needs to be corrected by 3 dB to exclude the reflected contribution.

2.3.1.3 Annex II - Establishing Common Noise Assessment Methods

In 2008, the European Commission started the development of the common noise assessment methodological framework through the project 'Common Noise Assessment Methods in the EU' (CNOSSOS-EU). In 2015, Annex II: "Establishing Common Noise Assessment Methods According to Directive 2002/49/EC of the European Parliament and of the Council" (The European Commission, 2015) was revised in accordance with CNOSSOS-EU results. Member States are required to use these methods from 31 December 2018 onwards.

Annex describes the common EU methods for calculating exposure to different noise levels. They comprise a set of formulas and coefficients to be used to calculate noise levels at the façade of the buildings.

The noise indicators L_{den} and L_{night} are also used in this revision. Noise calculations shall be defined in the frequency range from 63 Hz to 8 kHz, in octave bands.

For the accuracy of input values, emission level of a source should have uncertainty of ± 2dB(A). If default values are used for input data, it should be only if real data is associated with disproportionately high costs.

For road traffic noise, source descriptions, reference conditions, rolling noise, propulsion noise, effect of the acceleration and deceleration of vehicles are effect of the type of road surface are defined.

Classification of vehicles has been changed from light and heavy vehicles, to five separate categories: 1) Light motor vehicles, 2) Medium heavy vehicles, 3) Heavy vehicles, 4) Powered two-wheelers and 5) Open category. Light motor vehicles include passenger cars, delivery vans ≤ 3,5 tons, SUVs, MPVs including trailers and caravans. Medium heavy vehicles include medium heavy vehicles, delivery vans > 3,5 tons, buses, motorhomes, etc. with two axles and twin tyre mounting on rear axle. Heavy vehicles include heavy duty vehicles, touring cars, buses, with three or more axles. Powered two-wheelers are divided into two categories, a) Two-, Three- and Four-wheel Mopeds and b) Motorcycles with and without sidecars, Tricycles and

Quadricycles. Open category is reserved for future needs such as electric or hybrid vehicles.

Each vehicle (category 1, 2, 3, 4 and 5) is represented by one single point source radiating uniformly into the 2-π half space, placed 0.05 m above the road surface.

Noise propagation for road sources is also provided in this Annex. The method provides the equivalent continuous sound pressure level at a receiver point at two types of atmospheric conditions; downward-refraction propagation conditions from the source to the receiver and homogeneous atmospheric conditions over the entire area of propagation. Upward-refraction propagation conditions are approximated by homogeneous conditions.

The temperature and humidity conditions are calculated according to ISO 9613-1:1996. Annex explains geometrical considerations, sound propagation model and calculation process.

Annex also demonstrates assigning noise levels and population to buildings.

Annex expresses that measurements should be performed in accordance with the principles of long term average measurements stated in ISO 1996-1:2003 and ISO 1996-2:2007.

Appendix F provides the database for most of the existing road noise sources to be used to calculate road traffic noise (The European Commission, 2015).

2.3.2 Turkish national directive on the assessment and management of environmental noise

Republic of Turkey was recognized as a candidate for full membership to European Union in 1999. As the negotiations still continue, Turkey is trying to keep up with the directives of European Union and its implementations.

"Assessment and Management of Environmental Noise Directive" (2002/49/EC), by Republic of Turkey Ministry of Environment and Forestry (2010) was published for this purpose. The first version of this Directive was published on July 1st 2005 in Official Gazette numbered 25862, the second version on March 7th 2008 with Gazette number 26809 and the third version on June 4th 2010 with Gazette number 27601. Although this is the current version of the Directive, on April 27th 2011 with 27917 numbered Gazette, some of the Articles were subjected to changes.

The objective of this directive is to ensure that necessary measures are taken to prevent disturbance of tranquility and peace of mind and physiological and psychological health of humans on account of exposure to environmental noise. To that end;

- Determination of exposure to environmental noise by using methods of assessment, through noise mapping, acoustic reports, and environmental noise assessment reports,

- Ensuring that information on environmental noise and its effects is made available to the public,

- Preparation and application of action plans, based upon the results of noise mapping, acoustic reports and environmental noise assessment reports, with a view to preventing and reducing environmental noise particularly where exposure levels can induce harmful effects on human health and where it is necessary to preserve environmental noise quality,

shall be implemented progressively.

This directive covers principles and criteria in relation to environmental noises which humans are exposed to particularly in areas of intensive population, in public parks or other quiet areas in agglomerations, in quiet areas in open country, and in schools, hospitals and other noise-sensitive areas, and in relation to damages caused by environmental vibration in buildings.

All aspects of the directive are very similar to Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Parts on noise indicators and assessment methods are exactly the same as given in the previous section.

2.4 Standards on Environmental Noise and Road Vehicle Noise

This section provides information on ISO 1996-2 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels (2007).

ISO 362-1 (2007), "Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 1: M and N categories" and ISO 362-2 (2009), "Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 2: L category" standards specify engineering methods for measuring the noise emitted by road vehicles. ISO 10844, “Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tires” standard specifies the essential characteristics of a test surface intended to be used for measuring vehicle and tire or road noise emissions.

2.4.1 ISO 1996-2:2007 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels

ISO 1996-2 “Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels” describes how sound pressure levels can be determined by direct measurement, by extrapolation, or by calculation, for evaluating environmental noise. The standard provides information on measurement uncertainty, instrumentation and calibration, source operation conditions for different source types, propagation in various weather conditions, the measurement procedure and evaluation of the results.

2.4.1.1 Road traffic source operation

The source conditions should represent the noise environment and should include a minimum number of noise events.

For measuring L_{eq} of road traffic, the number of vehicle pass-bys (heavy and light vehicles) should be counted during the measurement time interval. The average traffic speed should be measured and the type of road surface should be determined to decide if traffic conditions are representative. The standard uncertainty denoted by X in Table can be calculated by means of Equation 2.8 (ISO 1996-2, 2007) :

$$X \cong \frac{10}{\sqrt{n}} dB \tag{2.8}$$

Where n is the total number of vehicle pass-bys.

When L_E from individual vehicle pass-bys are used to calculate L_{eq}, the minimum number of vehicles per category shall be 30 (ISO 1996-2, 2007).

The maximum sound pressure level should be determined based on the SPL measured during at least 30 pass-bys. Within each vehicle category, maximum sound pressure levels differ due to individual differences among vehicles and variation in speed or driving patterns (ISO 1996-2, 2007).

2.4.1.2 Measurement uncertainty

The uncertainty of sound pressure levels depends on the sound source and the measurement time interval, the weather conditions, the distance from the source and the measurement method and instrumentation. Table 2.2 provides guidelines on estimating the measurement uncertainty (ISO 1996-2, 2007).

Table 2.2 : Overview of the measurement uncertainty for L_{Aeq} uncertainty (ISO 1996-2, 2007).

Standard uncertainty				Combined standard uncertainty	Expanded measurement uncertainty
Due to instrumentation [a]	Due to operating conditions [b]	Due to weather and ground conditions [c]	Due to residual sound [d]	σ_t	
1,0 dB	X dB	Y dB	Z dB	$\sqrt{1^2+X^2+Y^2+Z^2}$ dB	± 2,0 σ_t dB

[a] For IEC 61672-1:2002 class 1 instrumentation. If other instrumentation (IEC 61672-1:2002 class 2 or IEC 60651:2001/ IEC 60804:2000 type 1 sound level meters) or directional microphones are used, the value will be larger.
[b] To be determined from at least three, and preferably five, measurements under repeatability conditions (the same measurement procedure, the same instruments, the same operator, the same place) and at a position where variations in meteorological conditions have little influence on the results. For long-term measurements, more measurements are required to determine the repeatability standard deviation.
[c] The value varies depending upon the measurement distance and the prevailing meteorological conditions. A method using a simplified meteorological window is provided in Annex A (in this case Y = σm). For long-term measurements, it is necessary to deal with different weather categories separately and then combined together. For short-term measurement, variations in ground conditions are small. However, for long-term measurements, these variations can add considerably to the measurement uncertainty.
[d] The value varies depending on the difference between measured total values and the residual sound.

2.4.1.3 Weather conditions

The weather conditions should represent the noise exposure situation. The road surface should be dry and ground surface should not be covered with snow or ice or soaked with water. Sound pressure levels change with the weather conditions. For soft ground Equation 2.9 should be applied (ISO 1996-2, 2007).:

$$\frac{h_s + h_r}{r} \geq 0.1 \tag{2.9}$$

Where,

h_s is the source height;

h_r is the receiver height;

r is the distance between the source and receiver.

If the ground is hard, larger distances are acceptable.

During measurement, meteorological conditions should be noted or recorded. Measurements have large uncertainties if they are made at upwind of the source and therefore should not be used for short-term environmental-noise measurements (ISO 1996-2, 2007).

2.4.2 ISO 362 standard series, measurement of noise emitted by accelerating road vehicles

ISO 362-1 (2007), “Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 1: M and N categories” and ISO 362-2 (2009), “Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 2: L category” standards specify engineering methods for measuring the noise emitted by road vehicles of categories M, N, L3, L4 and L5 under typical urban traffic conditions. The specifications intend to reproduce the level of noise generated by the noise sources during normal driving in urban traffic (ISO 362-1, 2007).

2.4.2.1 Vehicle definitions

Category M is defined as, “power-driven vehicles having at least four wheels and used for the carriage of passengers”. This category includes, M1, with no more than eight seats in addition to the driver's seat; M2, with more than eight seats and a maximum mass not exceeding 5000 kg; and M3, with more than eight seats and a maximum mass exceeding 5000 kg (ISO 362-1, 2007).

Category N is defined as, “power-driven vehicles having at least four wheels and used for the carriage of goods”. This category includes, N1, with a maximum authorized mass not exceeding 3500 kg; N2, with a maximum authorized mass exceeding 3500 kg but not exceeding 12000 kg; and N3, with a maximum authorized mass exceeding 12000 kg (ISO 362-1, 2007).

Category L is defined as, “motor vehicles with fewer than four wheels”. Category L1 and L2 are mopeds. Category L3 includes vehicles with two wheels and an engine cylinder capacity greater than 50 cm^3 or maximum speed greater than 50 km/h. Category L4 is the same as Category L3, except the wheels are attached asymmetrically along the longitudinal vehicle axis. Category L5 includes three-wheeled motor vehicles with an engine cylinder capacity greater than 50 cm^3 or maximum speed greater than 50 km/h (ISO 362-2, 2009).

Reference points are defined for these vehicle categories for the purpose of defining measurement conditions on the test track. Reference point for Category L is the front end of the vehicle. Reference point for category M1 and N1 vehicles are as follows:

- for front engine vehicles, it is the front end of the vehicle;
- for mid-engine vehicles, it is the center of the vehicle;
- for rear engine vehicles, it is the rear end of the vehicle.

Reference point for category M2, M3, N2, and N3 vehicles are as follows:

- for front engine vehicles, it is the front end of the vehicle;
- for all other vehicles, it is the border of the engine closest to the front of the vehicle.

A target acceleration is defined as an acceleration at a partial throttle condition in urban traffic, derived from statistical investigations (ISO 362-1, 2007).

2.4.2.2 Measurement conditions

Sound pressure level shall be measured with a Class 1 sound level meter. The entire measurement system shall be checked with a sound calibrator. Measurements shall be carried out using the time weighting “F”, fast, and the “A” frequency weighting (ISO 362-1, 2007).

Temperature, wind speed and direction, relative humidity and barometric pressure shall be recorded during measurements. The tests shall not be carried out if the wind speed at microphone height exceeds 5 m/s (ISO 362-1, 2007).

The test site shall be substantially level. The test track construction and surface shall meet the requirements of ISO 10844. The test site dimensions are shown in Figure 2.9. Within a radius of 50 m around the centre of the track, the space shall be free of large reflecting objects such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials such as powdery snow or loose debris (ISO 362-1, 2007).

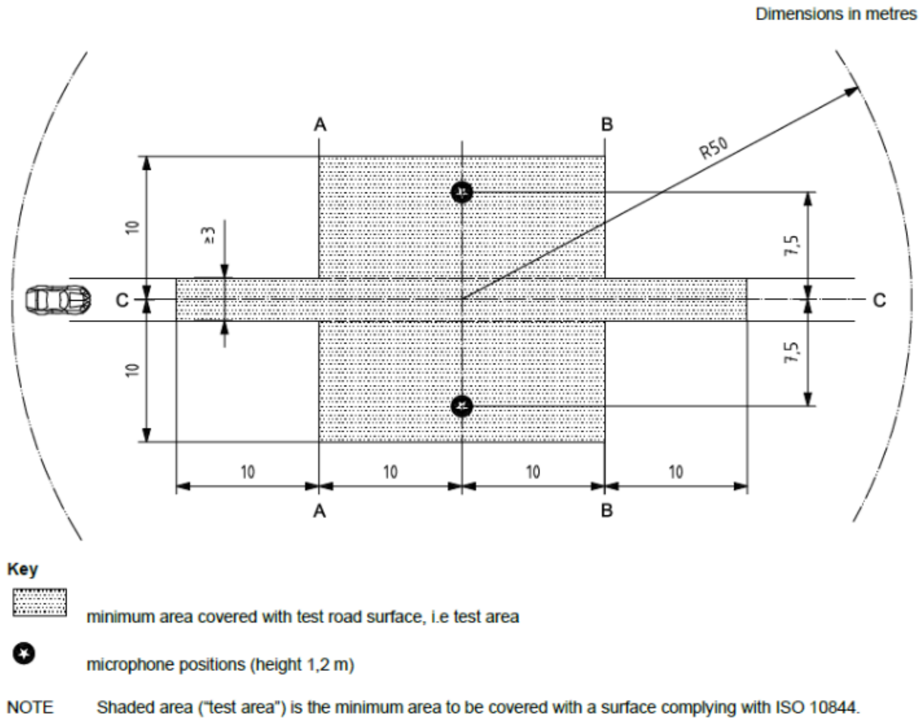


Figure 2.9 : Test site dimensions (ISO 362-1, 2007).

In the vicinity of the microphone, there shall be no obstacle that could influence the acoustical field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading (ISO 362-1, 2007).

The distance from the microphone positions on the microphone line PP' to the perpendicular reference line CC' (see Figure 1) on the test track shall be 7,5 m ± 0,05 m. The microphone shall be located 1,2 m ± 0,02 m above the ground level (ISO 362-1, 2007).

The background noise shall be measured for a duration of 10 s immediately before and after a series of vehicle tests. The measurements shall be made with the same microphones and microphone locations used during the test. The maximum A-weighted sound pressure level shall be reported. The background noise (including any wind noise) shall be at least 10 dB below the A-weighted sound pressure level produced by the vehicle under test. If the difference between the ambient sound pressure level and the measured sound pressure level is between 10 dB and 15 dB, in order to calculate the *j*th test result the appropriate correction shall be subtracted from the readings on the sound level meter, as given in Table 2.3 (ISO 362-1, 2007).

Table 2.3 : Correction applied to an individual measured test value (ISO 362-1, 2007).

Background sound pressure level difference to measured sound pressure level, in dB	10	11	12	13	14	greater than or equal to 15
Correction, in dB	0.5	0.4	0.3	0.2	0.1	0.0

2.4.2.3 Vehicle conditions

The vehicle shall be supplied as specified by the vehicle manufacturer. Before the measurements are started, the vehicle shall be brought to its normal operating conditions. The path of the centerline of the vehicle shall follow line CC' as closely as possible throughout the entire test, from the approach to line AA' until the rear of the vehicle passes line BB'. The test speed v_{test} shall be 50 km/h ± 1 km/h. The test speed shall be reached when the reference point is at line PP' (ISO 362-1, 2007).

2.4.2.4 Measurement uncertainty

The uncertainties are grouped as follows (ISO 362-1, 2007):

- variations expected within the same test laboratory and slight variations in ambient conditions found within a single test series (run-to-run);

- variations expected within the same test laboratory but with variation in ambient conditions and equipment properties that can normally be expected during the year (day-to-day);

- variations between test laboratories where, apart from ambient conditions, equipment, staff and road surface conditions will also be different (site-to-site).

If reported, the expanded uncertainty together with the corresponding coverage factor for the stated coverage probability of 80 % as defined in ISO Guide 98 (2008) shall be given (ISO 362-1, 2007).

2.4.2.5 Test report

The test report shall include the following information (ISO 362-1, 2007):

a) reference to this part of ISO 362;

b) details of the test site, site orientation, and weather conditions including wind speed and air temperature, wind direction, barometric pressure and humidity;

c) the type of measuring equipment, including the windscreen;

d) the maximum A-weighted sound pressure level typical of the background noise;

e) the identification of the vehicle, its engine, its transmission system, including available transmission ratios, size and type of tyres, tyre pressure, tyre production type, power, test mass, power-to-mass ratio, vehicle length and location of the reference point;

f) the transmission gears or gear ratios used during the test;

g) the vehicle speed and engine speed at the beginning of the period of acceleration, and the location of the beginning of the acceleration;

h) the vehicle speed (*v*PP', *v*BB') and engine rotational speed (*n*BB', *n*PP') at PP' and at end of the acceleration;

i) the method used for calculation of the acceleration;

j) the auxiliary equipment of the vehicle, where appropriate, and its operating conditions;

k) all valid A-weighted sound pressure level values measured for each test, listed according to the side of the vehicle and the direction of the vehicle movement on the test site (ISO 362-1, 2007).

2.4.2.6 Development of vehicle noise test procedure

The standards include detailed annexes on the technical background for the development of vehicle noise test procedures based on in-use operation in urban conditions. The procedure enables measurement of the actual level of noise due to vehicle emission in urban traffic.

The noise from different sources are subject to regulations with the goal of controlling the maximum noise in front of buildings. The noise in front of buildings due to road traffic noise depend on different factors (ISO 362-1, 2007):

a) the way cities are built (primarily the distance between living houses and roads);

b) the actual traffic on the roads (number of vehicles);

c) the road surface as a contributing factor to tire/road noise;

d) the sound path (noise transmission) control between the source and receiver (noise barriers, sound insulation, etc.);

e) the behaviour of drivers, which depends on

– speed limits (traffic laws),

– traffic density,

– road arrangement (traffic lights, corners, etc.),

– driving purpose (commuting, pleasure, commercial, etc.),

– enforcement of traffic laws, and

– the way the vehicle behaves as an acoustical source under these conditions (ISO 362-1, 2007).

A vehicle noise measurement procedure intended to describe the actual behavior should take the actual driving conditions into account. Because there are many different driving conditions, the choice of a “representative” driving condition is difficult.

Inquiries among dwellers along various streets show that noise disturbance happens mainly

– along urban main streets, and

– during vehicle acceleration transients.

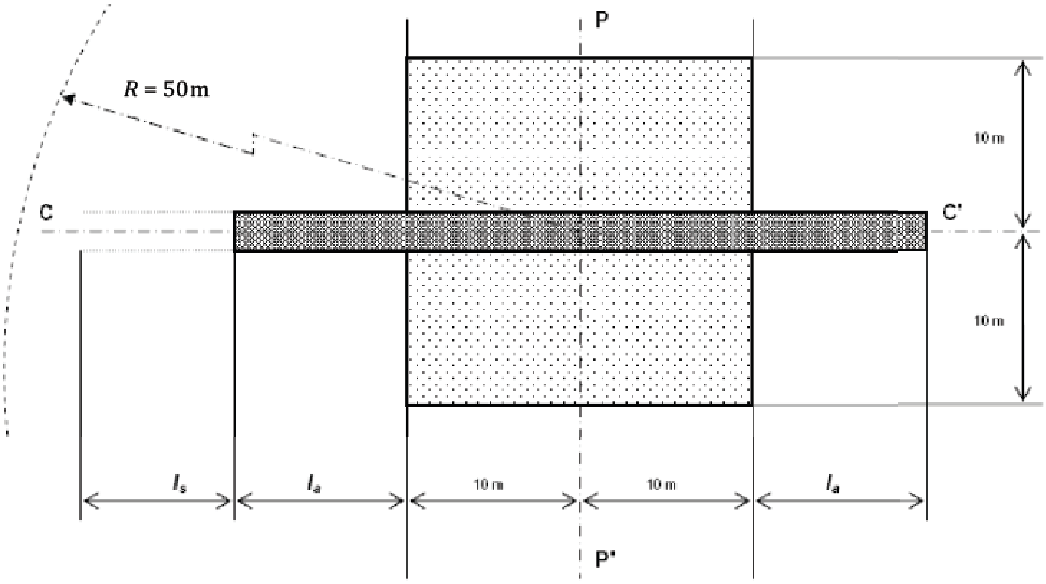
For the roads on which maximum allowed speed is 50 km/h, the mean traffic speed is 50 km/h on these main streets. Based on these statistics, it was decided to perform the test at 50 km/h, in conditions representing the noisiest realistic case on main streets (ISO 362-1, 2007).

2.4.3 ISO 10844 Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tires

ISO 10844, “Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tires” standard specifies the essential characteristics of a test surface intended to be used for measuring vehicle and tire or road noise emissions.

In general, the road surface parameters affecting the noise emission of vehicles are the texture and sound absorption characteristics. In order to minimize the variation in rolling sound emission and vehicle sound emission measurements made at different testing locations, it is necessary to specify the relevant surface properties and recommend carefully the properties of the materials, design, and construction of the test surface (ISO 10844, 2014).

The test track shall consist of two areas, a drive lane and a propagation area. The dimensions are given in Figure 2.10 and Table 2.4.



Key
*l*s construction run-up section
*l*a drive lane extension beyond propagation area
CC' drive lane centre line
PP' microphone line
light-grey area propagation area
dark-grey area with dotted line drive lane

Figure 2.10 : Size of the test track (ISO 10844, 2014).

Table 2.4 : Minimum drive lane extension length (ISO 10844, 2014).

Length	For testing tires, passenger cars, motorcycles, light duty vehicles, and trucks	For long vehicles with rear engine, having a distance of more than 10 m between the reference point and the front axle (reference point as defined in ISO 362‑1, 2007)
l_a	10 m	20 m (20 m is necessary only for the exit side (BB'))

For the stabilization of the laying process, a minimum length of *l*s = 60 m is recommended on at least one side. The propagation area shall extend at least 10 m from the center of the drive lane and at least 10 m at both sides of the line PP'. Within a radius of 50 m around the center of the track, the space shall be free of large reflecting objects such as fences, rocks, bridges, or buildings. Buildings outside the 50 m radius can have significant influence if their reflection focuses on the test track (ISO 10844, 2014).

Transverse irregularities of the test track and the propagation area shall be measured with the straightedge. Straightedge consists of a beam of 3.0 m in length and a wedge with 1-mm steps on the oblique side. The slope of the test track and the propagation area should be able to drain the water (ISO 10844, 2014).

The average of the values of the sound absorption in each one-third-octave band between 315 Hz and 1 600 Hz central frequency shall be less than or equal to 10 % on the propagation area surface. In the surface of the drive lane, it shall be less than or equal to 8 % (ISO 10844, 2014).

The surface of the drive lane shall be dense asphalt concrete and it shall have no elastic material (rubber, polyurethane, etc.) applied on the top layer or sub layers except for the modification of bitumen that is less than 1 % of the mass of the total mix. The test track is a test instrument and shall be protected from damage and be taken care of. The test track should be used only for noise measurements. Loose debris or dust which could significantly reduce the texture depth shall be removed from the surface (ISO 10844, 2014).

3. LITERATURE ON NOISE EVALUATION AND NOISE ANNOYANCE

Subjective evaluation of noise is quite complex and related to many disciplines such as acoustics, physiology, sociology, psychology and statistics (Kang, 2007). Noise annoyance studies require the subjective evaluation of noise. Noise annoyance is a feeling of resentment, displeasure, discomfort, dissatisfaction, or offense when noise interferes with someone's thoughts, feelings, or actual activities (Passchier-Vermeer & Passchier, 2000).

The European Parliament and The Council of The European Union (2002) defines noise annoyance as the degree of community noise annoyance as determined by means of field surveys. European Commission (2003) defines dose-effect relations as the relationship between the value of a noise indicator and a harmful effect. The properties of the noise indicator, the noise source and the environment are all effective in this relationship.

In this section, factors effective in noise annoyance and methods for evaluation of noise annoyance will be discussed.

3.1 Factors Effective in Noise Annoyance

Factors effective in noise evaluation and therefore noise annoyance may be studied in two headings; acoustic / physical factors and social / psychological / economic factors (Kang, 2007).

3.1.1 Acoustic / physical factors on noise annoyance

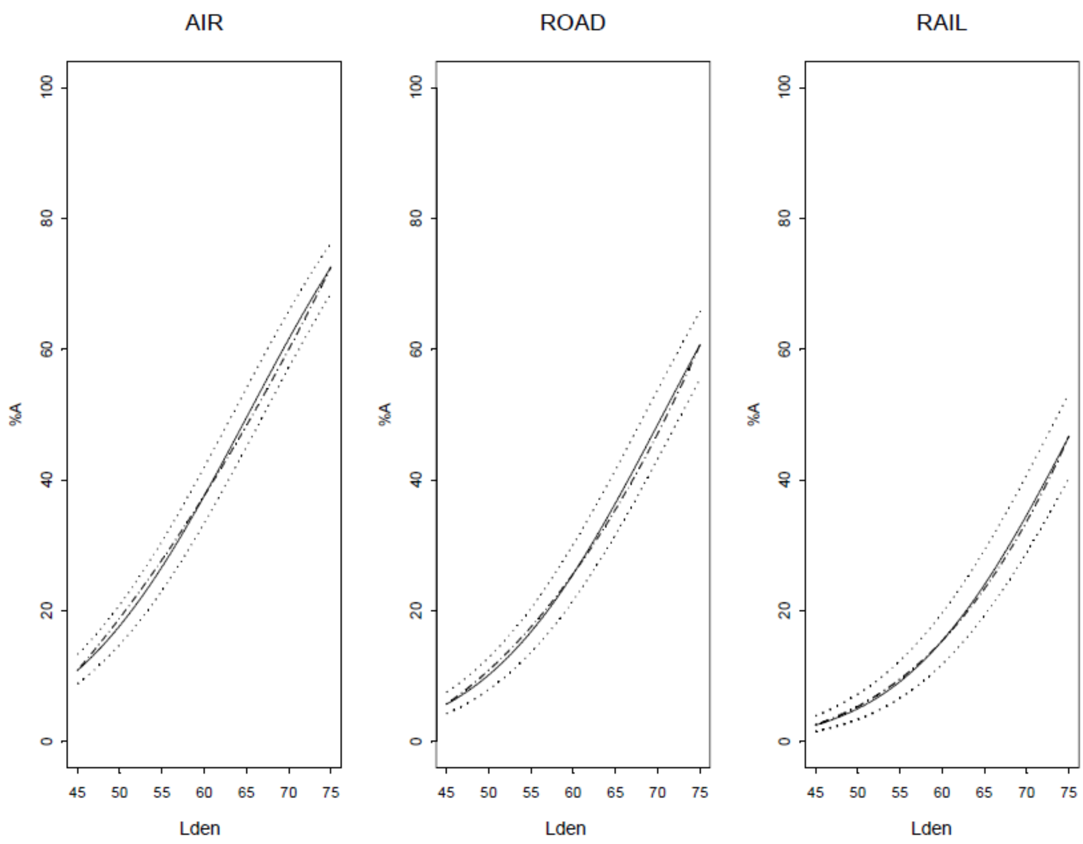
Sound levels, spectrum characteristics, environment and timing are the most commonly investigated factors of annoyance. Some of the other factors that affect annoyance may include regularity of events, maximum sound level, rise time, duration of occasional events, spectral distribution of energy and number and duration of quiet periods (Guski 1997).

3.1.1.1 Sound levels

Sound level is an important factor for evaluation of noise. Many researchers such as Schultz (1978), Kryter (1982), Miedema and Vos (1998), Arana and García (1998), Ali and Tamura (2003), Klæboe et al. (2004), worked on the relationship between annoyance and equivalent continuous sound level, L_{eq} (as cited in Kang, 2007). As a result of numerous studies over the years linking overall sound levels to noise annoyance, European Commission's Working Group published correlations between day–evening–night sound level L_{den} and noise annoyance for various environmental transportation noise types (WG-HSEA, 2002). The same working group also published correlation between L_{night} and sleep disturbance (WG-HSEA, 2004). The relations are given in Figure 3.1 and Figure 3.2. In Figure 3.1, the solid lines are the estimated curves, and the dashed lines are the polynomial approximations. The figure also shows the 95% confidence intervals (dotted lines) (WG-HSEA, 2002).

Kurra et al. (1999a; 1999b) presented a study on road, railway and aircraft noise levels and annoyance responses. With continuous road traffic and controlled numbers of railway and aircraft traffic, overall annoyance and activity disturbance were investigated. It was found that type of noise source is not highly deterministic for annoyance of reading activity, but that it is deterministic for annoyance of listening activity. Regarding overall annoyance at home, railway noise proved to be the leading noise source especially in Japan. Findings supported the opinion that L_{eq} = 45 dBA is an indoor noise limit which indicates a crossover between the source-specific annoyance lines. Correlation between activity disturbance and noise levels were high. The annoyance patterns for reading and listening activities were different from one another.

Namba et al. (1996) found that increase in number of acoustics events even with a constant energy summation, L_{eq}, causes the increase in annoyance (as cited in Kang, 2007). As concluded in WG-HSEA (2002) different types of noise, such as aircraft, road traffic, and railway noise, may each have different annoyance relationships even with constant sound level, L_{den}.



Polynomial approximations (WG-HSEA, 2002):
Road traffic: %A = 1.795*10^{-4} (L_{den}-37)^3 + 2.110*10^{-2} (L_{den}-37)^2+ 0.5353 (L_{den}-37)
Road traffic: %HA = 9.868*10^{-4} (L_{den}-42)^3 - 1.436*10^{-2} (L_{den}-42)^2+ 0.5118 (L_{den}-42)

Figure 3.1 : The percentage annoyed persons (%A) as a function of the noise exposure of the dwelling (L_{den}) (WG-HSEA, 2002).

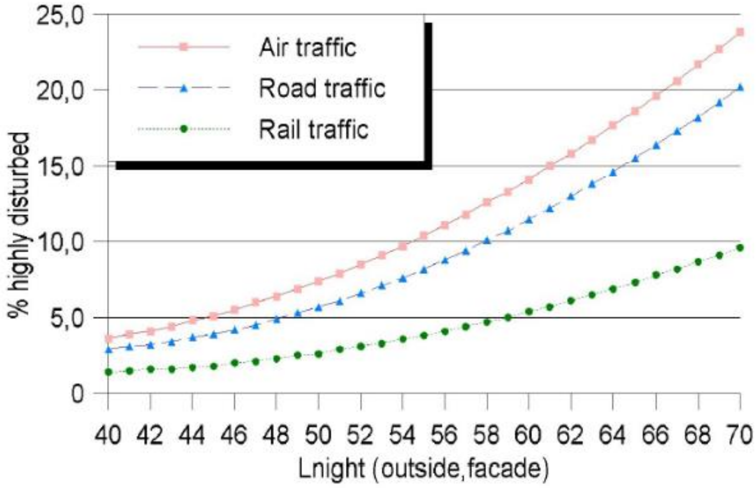


Figure 3.2 : Percentages of highly disturbed when exposed to rail and road traffic noise (WG-HSEA, 2004).

3.1.1.2 Spectrum characteristics

Spectrum characteristics of noise have been known to affect evaluation of noise.

Noise that includes tonal components, such as horn noise in traffic, may cause extreme annoyance (Phan et al, 2009).

Torija et al. (2011b), analyzed the relationship between traffic noise annoyance and acoustic indicators of overall indoor sound level. A reduced number of 1/3-octave bands (31.5–125 Hz, 315 Hz, and 630–2500 Hz) was found to be relevant for annoyance of road/railway traffic noise.

Persson Waye K. and Öhrström E. (2002) worked on wind turbine noise annoyance. Even though noise recordings of different wind turbines had the same equivalent noise levels, annoyance ratings were different. All recordings were analyzed for psycho-acoustic parameters, but none of the psycho-acoustic parameters (sharpness, loudness, roughness, fluctuation strength or modulation) could explain the differences in annoyance response.

Persson Waye and Rylander (2001) worked on homes exposed to noise from heat pump or ventilation installations and conducted surveys on noise annoyance. It was concluded that sounds that have dominant low frequency components are more annoying and A-weighted evaluation is inefficient in evaluating this. No significant differences in medical or psycho-social symptoms were found between the low-frequency noise exposed subjects and mid-frequency noise exposed subjects.

Di et al. (2011) investigated on subjective annoyance of low frequency noise, structure-borne noise from a heat pump, with and without additional sound. Adding frequency-modulated pure tones (15dB, central frequency 2000 Hz) and a modulation frequency (10 Hz) decreased subjective annoyance value.

Sattler and Rott (1996) concluded that elements of traffic (busses, cars, moped, trucks) may have different annoyance rates (as cited in Kang, 2007).

Versfeld and Vos, J. (2002) on the other hand, found that proportion of heavy vehicles in a continuous stream of road vehicles does not affect annoyance in a laboratory listening test.

Paunović et al. (2014) studied the association between noise annoyance and public transport by surveying 5861 adults in the city center of Belgrade. The results showed that the presence of public transport is a predictor of high noise annoyance. The combination of buses and trams at night proved to be the most annoying. The study demonstrated that the role of public transport on noise annoyance is independent from noise levels.

Ma and Yano (2004) investigated railway and road traffic noises at three noise levels with listening and calculation tasks. The disturbance during listening tests were different but there was not difference for task performance.

3.1.1.3 Environment

Although it was found that background noise has very little effect on overall annoyance (Fields 1998), annoyance in loud and quiet environments was found to have relationships with different socio-acoustic parameters (Paunovic et al., 2009).

On the other hand, Nguyen et al. (2011) concluded that although noise exposure was the same in Hanoi and Ho Chi Minh City, the aircraft annoyance was different because of the lower background noise level in Hanoi.

Rylander and Björkman (2002) researched effects of window orientation in dwellings on road traffic noise annoyance. Dose effect relationships showed that subjects living in flats which only face the street are more annoyed than the subjects which also have a quieter façade.

Öhrström et al. (2006) conducted socio–acoustic surveys to study the health effects of various soundscapes in residential areas. To survey results showed that access to quiet indoor and outdoor sections in dwellings decreased annoyance, improved sleep and contributed to physiological and psychological wellbeing. The study suggests that, $L_{Aeq,24h}$, road traffic noise at the most-exposed side should not exceed 60 dB, even if there is access to a quiet side in the dwelling, in order to protect 80% of people from annoyance.

Viollon et al. (2002) conducted audiovisual tests on listeners' judgements during different visual settings. The results showed that visual influence was significant and negative for sounds clips without human sounds; urban visual settings were perceived more unpleasant and more stressful. Bangjun, et al. (2003) found that, in the same acoustic environment, noise annoyance is higher if the noise source is visible.

Gidlöf-Gunnarsson & Öhrström (2007) concluded that availability to nearby green areas is important for people's well-being and daily behavior by reducing long-term noise annoyances and prevalence of stress-related psychosocial symptoms.

Nang (2011) found that several neighbourhood characteristics such as greenery and sea are able to decrease noise annoyance. Li et al. (2010) concluded that wetland parks and garden parks reduce noise annoyance better than grassy hills.

Morihara et al. (2004) compared the dose–response relationships between railway and road traffic noises in European and Japanese studies and questioned the difference in relationships. Although there are cultural factors, they concluded that distance from the noise source was an important factor in annoyance.

Klaeboe et al. (2000) worked on an integrated approach to assess the combined effects of noise and air pollution on annoyance in Oslo. Result showed that people are more likely to be annoyed by smell at the same air pollution level if traffic noise levels are higher. Similarly, people are more likely to be annoyed by noise at the same noise level if air pollution levels are higher.

3.1.1.4 Time

Seasons such as summer and winter (Recuero et al. 1996, as cited in Kang, 2007) and time of day such as day, evening and night (Vallet et al, 1996 as cited in Kang, 2007) may have an effect in annoyance. Directive 2002/49/EC (The European Parliament and of the Council, 2002) adds a penalty of 5 dB for evening and 10 dB for night, for calculating the day-evening-night level, L_{den}.

Noise annoyance during night is identified as sleep disturbance and is investigated extensively. Factors which effect sleep disturbance, such as bedroom location (Pirrera et al., 2014), time frames (Pirrera et al., 2014), number of events (Janssen et al., 2014), balcony design (Naish et al., 2012) and noise source types (Lee at al., 2010) have been studied. Health effects were studied under many heading such as objective and subjective sleep quality (Frei et al., 2014), mental health (Sygna et al., 2014), children's behavioral problems (Tiesler et al., 2013) and cardiovascular problems (Fyhri & Aasvang, 2010; Tonne et al., 2016).

Studies on relatively long-term changes in noise exposure showed interesting results. Fidell et al. (1998) concluded that a progressive drop of 1.5–3dB near an airport was hardly noticed over a long period. Another study on airports showed an increase of annoyance and an alteration of dose and effect curves over the years (Babisch et al, 2009).

Influence of time patterns on aircraft noise annoyance was investigated by Brooker (2010). It is stated that people benefit from Heathrow's regular and predictable alternation cycles. Ohshima and Yamada (2009) investigated on the effect of sound duration on the annoyance of helicopter noise. The sound signal durations were time compressed or expanded and results indicated that the effect of duration is significant.

3.1.2 Social / psychological / economic factors on noise annoyance

Relationship between noise annoyance and acoustic / physical factors were considered in studies and their effects were found to be a minority in dose effect relationships. Acoustic parameters were suggested to have about 33 percent (Guski, 1998) or 20 percent (Job, 1988) effect on annoyance evaluation. It may be concluded that, other factors, such as social, psychological or economic, are far more important than acoustic or physical factors in dose effect relationships.

Fields (1993) conducted an extensive study on effect of personal variables on noise annoyance in residential areas, using 136 social surveys. He investigated demographic variables, such as age, sex, social status, income, education, home ownership, dwelling type, length of residence and users of noise source. He concluded that these demographic variables studied do not have an important effect on annoyance. Miedema and Vos (1999) also investigated on demographic factors and used analyses of the original data from various previous field surveys. They concluded that the effects of demographic factors on noise annoyance are very small. They also found that gender has no effect and that age has some effect. There are many different studies on effect of personal factors on noise annoyance. Some of these give conflicting results on factors such as gender, marital status, family size, education level, time spend at home and type of occupancy (Kang, 2007). Some factors related to lifestyle, such as exposure to noise at work or opening of windows, were also found to effect annoyance (Kang, 2007).

Ryu and Jeon (2011) conducted a survey and a laboratory experiment which showed that noise sensitivity significantly influenced the annoyance level caused by both indoor and outdoor noise.

Nelson (1987) stated that in terms of attitude, there are six aspects which influence annoyance; fear, cause of noise, sensitivity to noise, type of activity, perception of neighborhood and perception of environment. If people fear their health is affected by a source, they may feel more annoyed.

Miedema and Vos (1999) argued that if people were economically dependent on the cause of noise, they might be less annoyed. They also stated that people with various levels of noise sensitivity had very different reactions to same levels of noise. The type of activity at the time of noise occurrence is important as well, such as talking, listening or concentrating. Negative of positive perception of the neighborhood also effects evaluation of noise.

Perceptions of environmental factors, such as light, air quality, smell, temperate or landscape also influence annoyance of noise (Nelson, 1987). Fields (1993) conducted an extensive study on effect of personal and situational variables on noise annoyance in residential areas. He concluded that the attitudinal variables such as fear of the source, feeling that noise annoyance is preventable, and noise sensitivity have an important effect on annoyance. Miedema and Vos (1999) also investigated on two attitudinal variables, noise sensitivity and fear of the noise source. They found that fear and noise sensitivity have a large impact on annoyance.

Fields (1993) also concluded that the number of hours residents are in their dwelling, the mode of interviewing and the ambient noise conditions in the neighborhood do not have an important effect on annoyance. There was weak support for the hypothesis that insulation of housing reduces annoyance.

WG-HSEA (2002) presented dose and effect relationships for transportation noise in Europe, but different cultures in the world may have different relationships. Phan et al. (2010) found that Vietnamese people are 5 dB more sensitive to noise than Europeans are. Kurra et al. (1999a) also demonstrated the importance of the cultural differences in noise annoyance studies. A study on road traffic noise in Japan and Sweden by Sato et al. (1998) concluded that various customs of the people living in different countries and in different types of housing, effect dose and effect relationships.

Numerous studies were made on economic effects of community noise, which correlated noise levels or noise annoyance usually with price of dwellings (Li et al, 2009). Some relationships between noise annoyance and price have been formed over the years.

3.1.3 Discussion

Considering factors which affect annoyance, sound levels present the most important relationship between the dose and the effect. Although A-weighted noise levels are commonly used in annoyance studies, there are many studies criticizing this and proposing other descriptors. This subject is still under consideration in current literature.

Spectrum characteristics of noise, especially low frequency and tonal components are known to affect annoyance. Even though types of road vehicles may not affect annoyance in a continuous stream of traffic (Versfeld and Vos, 2002), they may cause important variations in single event annoyance levels (Kang, 2007). The annoyance due to different vehicles may also differ according to activity (Ma and Yano, 2004). Tonal characteristics, for example horn sound; types of vehicles and activity disturbance are all subjects that should be considered when studying road traffic noise annoyance.

In terms of environment, window orientation, quiet façades, and visual settings are the most important factors which affect environmental noise annoyance. While quiet façades can be estimated through noise mapping, window orientation may be asked in questionnaires.

Years, seasons and time of day may affect environmental noise annoyance. 5 dB and 10 dB penalties for evening and night on Directive 2002/49/EC (The European Parliament and of the Council, 2002) may be studied further in terms of annoyance.

Although demographic factors, such as age, sex, social status, income, education, home ownership, dwelling type and length of residence have very small effect on annoyance (Fields, 1993; Miedema and Vos, 1999), they are still collected in the socio acoustic surveys to assess the distribution of respondents. Some factors related to lifestyle, such as exposure to noise at work or opening of windows, were found to effect annoyance (Kang, 2007).

In terms of attitude, the strongest factors are fear of the source, sensitivity to noise and type of activity (Fields, 1993; Miedema and Vos, 1999; Nelson, 1987). Fear of road traffic is quite low as it is encountered on a daily basis and is a part of everyone's daily routine. On the other hand, sensitivity to noise and type of activity may be studied further in order to assess road traffic annoyance.

Cultural differences are considered to be strong factors in noise annoyance studies. This subject should be studied further in every culture and every country.

3.2 Noise Annoyance Evaluation Methods

In this section, methods for noise evaluation and methods for noise annoyance are discussed.

3.2.1 Methods for noise evaluation

Scaling techniques of sound evaluation may be studied in two types of methods, unidimensional and multidimensional (Marquis-Favre et al, 2005).

3.2.1.1 Unidimensional method

Unidimensional method includes three main scales; category, discrimination and ratio. This method works on one acoustic variable and perceptual dimension of a stimulus sound. Category scale is the most common scale used for noise annoyance evaluation. It contains absolute judgments and has equal intervals of verbal or numerical scales. The discrimination scale uses paired comparison to evaluate relative annoyance of two acoustic stimuli. The ratio scale compares one stimulus to a reference stimulus, which is mostly white or pink noise. This may be studied in two parts, magnitude estimation and ratio production. The subject is asked to rate the stimulus with a number, relative to the reference, in magnitude estimation method; whereas in ratio production method, subject is required to adjust the stimulus to a point where it's evaluation is a fraction of the reference stimulus. These methods may also be merged to evaluate sound (Marquis-Favre et al, 2005).

3.2.1.2 Multidimensional method

Multidimensional method for sound evaluation involves various perception dimensions. Some of the methods used in multidimensional evaluation are semantic differential, selected description and estimation of similarities. Semantic differential method requires the subject to select a rating on a multiple scale given between two adjectives with opposite meaning. In selected description method, the subject is asked to choose most relevant adjectives for evaluation of a stimulus, from a list of descriptive adjectives. Estimation of similarities method compares the similar properties of two stimuli. The multidimensional techniques may be used together or be used with unidimensional techniques to evaluate noise annoyance (Kang, 2007).

3.2.1.3 Discussion

Multidimensional method for sound evaluation is the verbal assessment of sound, which is based on describing the sound, usually using adjectives. Multidimensional methods are used to assess sound from a soundscape point of view, not from an annoyance point of view. The objective in this study is to assess environmental noise annoyance using European Union’s noise mapping studies and noise annoyance studies, which are based on the Directive 2002/49/EC (The European Parliament and The Council of The European Union, 2002). Unidimensional method is more appropriate for assessing noise annoyance than multidimensional method.

Unidimensional method includes three main scales; category, discrimination and ratio. Category scale is the most common scale used for noise annoyance evaluation and it is appropriate for this study’s purposes. As it contains absolute judgments and has equal intervals of verbal or numerical scales, it provides clear annoyance results. Discrimination scale and ratio scale are used for comparing two stimuli. The ratio scale usually uses white or pink noise for comparison, which is not needed for environmental noise annoyance. The discrimination scale uses paired comparison to evaluate relative annoyance of two acoustic stimuli. Discrimination scale may be used in this study to compare the effects of traffic characteristics or environmental characteristics of two stimuli.

3.2.2 Methods for noise annoyance evaluation

In this section, noise annoyance studies from literature are discussed under the headings of evaluating noise annoyance using previous studies, using socio-acoustic surveys on site and using listening tests.

3.2.2.1 Evaluating noise annoyance using previous studies

Important researches were made, taking into account massive numbers of previous study results, in order to improve the methods of noise annoyance studies. These studies shape all the noise annoyance studies today. These researches are summarized and compared in this section.

Fields (1993) method

Fields (1993) conducted an elaborate study on the effect of personal and situational variables on noise annoyance in residential areas, using 136 social surveys which ask the respondents about their feelings about the environmental noise when they are at home. In the article, the findings on effects were classified as 'no important effect', 'an important effect which supports a hypothesis' or 'an important effect which is in the opposite direction to that hypothesized'. To determine whether an effect is important or not, the following six criteria were investigated, if any of them were met, the effect was labeled as 'important' (Fields, 1993):

- 3 dB: The difference in annoyance scores of the subgroups formed by the moderating variable is the equivalent of a 3-dB difference in noise exposure.

- Δ5%: There is at least a 5% difference between the percent annoyed in the subgroups of the moderating variable.

- $0.01r^2$: The moderating variable explains at least 1% of the variance in annoyance scores.

- $p < 0.05$: The relationship between the moderating variable and annoyance is statistically significant at $p < 0.05$.

- 3/4g: 3/4 of sample groups support a hypothesis in an analysis that compares annoyance scores between moderating variable groups within subareas.

- V_b: There is an unqualified verbal assertion of a relation between annoyance and the moderating variable (Fields, 1993).

The quality of the findings were analyzed in three aspects; measurement and analysis methods, survey sizes and methodological weaknesses. 22 hypotheses were studied under seven headings, which were demographic characteristics, attitudes, individualized noise exposure, ambient noise, interviewing method, change in noise environment and annoyance at low noise levels. The hypotheses were tested according to percent of findings and responses supporting the stated hypothesis, supporting no important effect and supporting opposite hypothesis. The results were evaluated by “balance of evidence”, checking if more than fifty percent of the findings and responses support the hypothesis or support having no important effect or support opposite hypothesis.

Fields et al. (1997) method

Fields et al. (1997) reported the guidelines produced by Community Response to Noise Team of ICBEN (The International Commission on the Biological Effects of Noise).

These guidelines were for reporting core information from community noise reaction surveys. In this study, over 360 acoustical and social surveys on environmental noise were examined. These survey studies differed from one another in many aspects, but all of them interviewed residents about their reactions to a noise source while living in their home. Noise exposure was measured or estimated and was compared to annoyance results. To improve comparability of these research results, guidelines for reporting core information from community noise reaction surveys were developed and minimal requirements were presented for three levels of publications. Level I is "Limited" for conference papers, Level II is "Basic" for journal articles and Level III is "Extended" for research reports. This study was used to form the technical specification ISO/TS 15666:2003 "Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys".

Miedema and Oudshoorn (2001) method

Miedema and Oudshoorn (2001) worked on annoyance relationships with exposure descriptors day-night level, DNL and day-evening-night level, DENL, using analyses of the original data from various previous field surveys. A model was presented on the dispersion of noise annoyance as a function of noise exposure. The model was fitted with polynomial curve, for road, railway and aircraft traffic separately. Annoyance percentages were presented with cutoff points: "highly annoyed" (cutoff at 72 on a scale of 0–100), "annoyed" (cutoff at 50 on a scale of 0–100), and "a little annoyed" (cutoff at 28 on a scale of 0–100). Confidence intervals were established.

Fields (2001) method

Fields et al. (2001) presented the work of Community Response to Noise Team of ICBEN (The International Commission on the Biological Effects of Noise). The work produced standardized general-purpose noise reaction questions for community noise surveys in nine languages. Standardized questions provided gathering of useful data to compare survey results from different cultures and countries. The goal was to design noise reaction questions with the following characteristics:

- Allow international comparisons between languages;

- Produce a reliable measure for general noise reaction in a residential environment;

- Provide transparent results;

- Provide a response scale compatible with statistical analysis;

- is likely to be used internationally;

- is suitable for all questionnaire methods.

After long years of research on existing surveys, wording of questions, answer scales and location of questions, two noise reaction questions were recommended. The 5-point verbal scale question was:

“Thinking about the last (…12 months or so…), when you are here at home, how much does noise from (…noise source…) bother, disturb, or annoy you; Extremely, Very, Moderately, Slightly or Not at all?"

The (0-10) point numeric scale question was:

“Next is a zero to ten opinion scale for how much (…source…) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last (…12 months or so…), what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by (…source…) noise?"

Figure 3.3 shows answer cards for recommend annoyance questions.

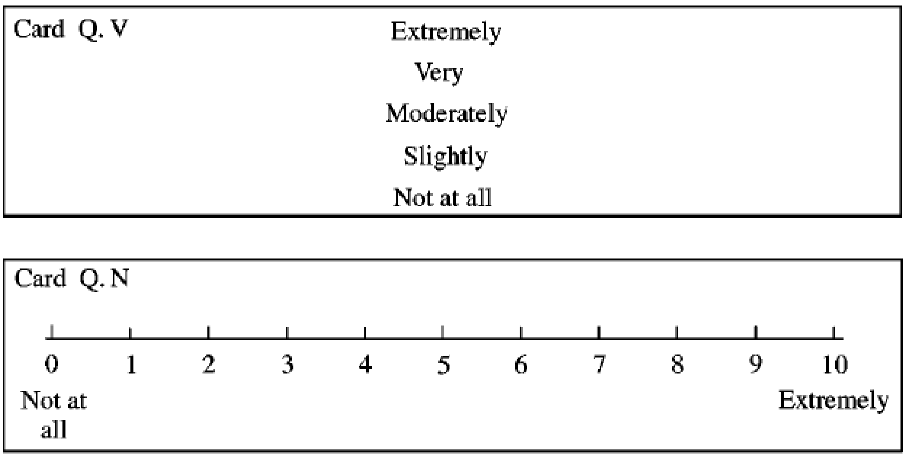


Figure 3.3 : Answer cards for recommend annoyance questions (Fields et al., 2001).

The paper also suggested guidelines to ensure the uniform administration of these questions:

- Ask all respondents both questions.

- Interviewers should not rephrase or explain questions, they should ask exactly as worded, to all respondents.

- Unless it conflicts with survey objectives, place the questions early in the questionnaire.

- Apply pretests and see if questions are perceived as repetitious. If that is the case, include appropriate instructions.

- Prepare written instructions for interviewers. (1) instruct interviewers to ask questions exactly as written, (2) train interviewers to respond to “I don't understand" with methods that do not require paraphrasing the question, (3) urge respondents to choose between the offered answers, (4) encourage all residents to answer these questions (new residents can be instructed to answer about only their recent period of residence), (5) provide interviewers with instructions for respondents who find the questions to be repetitious.

One of the nine languages this study provided questions for was Turkish. The questions were as follows. The 5-point verbal scale question was:

“Yaklaşık son (…12 ayı…) düşündüğünüzde, (…gürültü kaynağından…) gelen gürültü, burada evinizdeyken sizi ne kadar rahatsız etmektedir?” ‘Feci şekilde’, ‘Çok’, Orta derecede’, ‘Hafifçe’, ‘Hiç değil’?

The (0-10) point numeric scale question was:

“Şimdi, burada evinizdeyken (…kaynak…) gürültüsünün sizi ne kadar rahatsız ettiğini ‘sıfır’ ile ‘on’ arasında sayılarla gösteren bir görüş (veya kanaat) ölçeği verilmektedir. Eğer hiç rahatsız değilseniz ‘sıfır’ı seçiniz, eğer feci şekilde rahatsız iseniz ‘on’u seçiniz, bunların arasında iseniz ‘sıfır’ ile ‘on’ arasında bir sayı seçiniz. Yaklaşık son (…12 ayı…) düşünerek, (…kaynak…) gürültüsünden olan rahatsızlığınızı ‘sıfır’dan ‘on’a kadar hangi sayı en iyi gösterir?

This study (Fields et al., 2001) was used to form the technical specification ISO/TS 15666:2003 “Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys”.

Klæboe et al. (2004) method

Klæboe et al. (2004) explored exposure–effect relationships between the road traffic noise at the most exposed facade and the residents' reactions to road traffic noise. The study was based on five Norwegian socio-acoustic studies on 18 study areas from two cities (east Oslo in 1987, 1994 and 1996 and Drammen in 1998 and 1999) with almost 4000 total respondents. The survey questioned noise annoyance experienced right outside the apartment and when indoors. Although the wording of the questions were a little different form each other, they all asked firstly if people could hear the noise.

Exposure-effect relationships for all degrees of annoyance were estimated from ordinal logit models. Cumulative proportions were given for people experiencing different degrees of annoyance; does not hear, hears-not annoying, a little annoying, highly annoying; for different road traffic noise exposure values (L_{den}), for both indoor annoyance and annoyance when right outside apartment.

Discussion

Fields et al. (1997) method and Fields et al. (2001) method were both used to form the technical specification ISO/TS 15666: 2003 "Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys". These methods have been accepted worldwide and used ever since. Therefore, due to comparability, these methods should be used in this proposed methodology as well. Fields et al. (1997) method, Fields et al. (2001) method and therefore ISO/TS 15666 (2003) method will be used in this proposed methodology for information disclosure, standardized general-purpose noise reaction questions, 5-point verbal scale answers and (0-10) point numeric scale answers for socio-acoustic surveys.

Miedema and Oudshoorn (2001) method presented cutoff points for annoyance percentages: "highly annoyed" (cutoff at 72 on a scale of 0–100), "annoyed" (cutoff at 50 on a scale of 0–100), and "a little annoyed" (cutoff at 28 on a scale of 0–100). This study is the leading study on annoyance percentage cutoff points and is accepted and used worldwide, therefore it will be used in this proposed methodology.

3.2.2.2 Evaluating noise annoyance using ISO/TS 15666

ISO/TS 15666:2003 "Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys" is a technical specification, which provides guidance for socio-acoustic surveys and social surveys on noise, by providing questions, response scales, key aspects of conducting the survey, and reporting the results. This technical specification was formed by taking into consideration the works of Fields (Fields et al, 1997; Fields et al, 2001).

The scope of this technical specification is restricted to surveys conducted to obtain information about noise annoyance ‘at home’.

In this technical specification, ‘noise-induced annoyance’ is described as ‘one person’s individual adverse reaction to noise’. ‘Socio-acoustic survey’ is described as ‘social survey in which noise-induced annoyance is assessed and values of measured or calculated noise metrics are attributed to the subjects’ residential environment’.

Two types of questions are formulated; with verbal rating scale and numerical rating scale. Question with verbal rating scale is: ‘Thinking about the last (12 months or so), when you are here at home, how much does noise from (noise source) bother, disturb or annoy you? The verbal answers to be chosen from are: ‘Not at all?’, ‘Slightly?’, ‘Moderately?’, ‘Very?’, ‘Extremely?’. The question is also given in Turkish language as: ‘Yaklaşık son on iki ayı düşündüğünüzde, (gürültü kaynağından) gelen gürültü, burada evinizdeyken sizi ne kadar rahatsız etmektedir?’; with possible answers as: ‘Değil’, ‘Hafifçe’, ‘Orta derecede’, ‘Çok’, ‘Feci şekilde’.

Question with numerical rating scale gives an introduction first: ‘This uses a 0-to-10 opinion scale for how much (source) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose 0; if you are extremely annoyed choose 10; if you are somewhere in between, choose a number between 0 and 10.’ The question given is: ‘Thinking about the last (12 months or so), what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by (source) noise?’ The Turkish version of the introduction is ‘Şimdi, evinizdeyken (....) gürültüsünün sizi ne kadar rahatsız ettiğini “sıfır” ile “on” arasında sayılarla gösteren bir ölçek verilmektedir. Eğer hiç rahatsız değil seniz “sıfır”ı seçiniz, eğer feci şekilde rahatsız iseniz “on” u seçiniz, bunların arasında iseniz “sıfır” ile “on” arasında bir sayı seçiniz.’; whereas the question is: ‘Yaklaşık son 12 ayı düşünerek (......) gürültüsünden olan rahatsızlığınızı “sıfır”dan “on”a kadar hangi sayı en iyi gösterir?’.

This Technical Specification also provides additional specifications for the design of a noise annoyance questionnaire. According to these specifications, participants shall be asked both of the questions, question with verbal rating scale and question with numerical rating scale. Whether participants hear the noise or not should not be an exclusion question. Length of residence should also not be an exclusion question. Before the annoyance scale questions, participants should not be asked if they are annoyed or not, they should only use the verbal and numerical scales. The specifications also include instructions for interviews, on explaining the questions to participants if needed and encouraging participants to answer all questions even if repetitious. If show cards are used for verbal scale answers, they should be presented without numbers, placed one below the other. If show cards are used for numerical scale answers, they should be presented with each number in a box, placed next to each other, with 0 indicating “not at all” and 10 indicating “extremely”. Figure 3.4 shows exemplary show cards for both verbal and numerical scales.

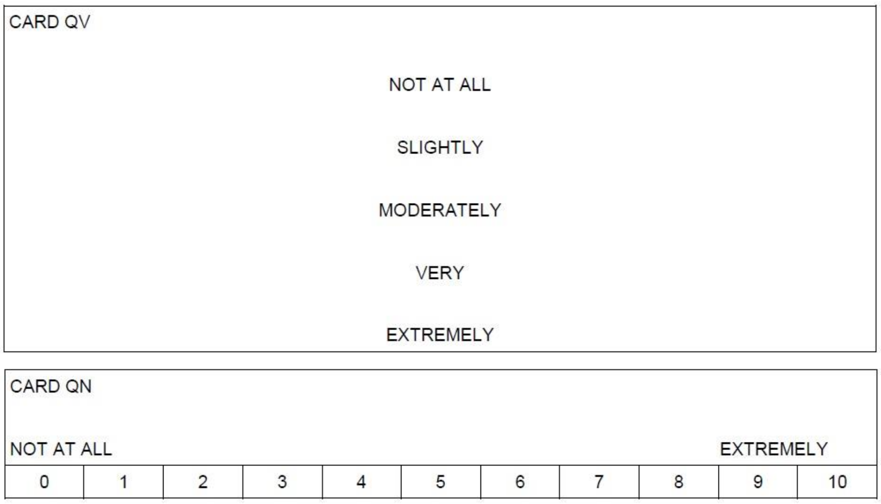


Figure 3.4 : Exemplary annoyance show cards for verbal (above, Card QV) and numerical (below, Card QN) scales (ISO/TS 15666, 2003).

According to the specifications for assessing the degree of annoyance, results of each question should be given as the frequency or cumulative distributions of the individual annoyance scores and if needed, results may also be given as mean or median annoyance score, or percentages of respondents who are annoyed to a certain degree. However, cut-off scores are not defined in this Technical Specification.

Annex A of the technical specification is informative documentation on rationale for wording and scaling of questions on annoyance. It is explained that the word 'noise' should be used instead of the word 'sound'. Why each word in the recommended questions are used is explained thoroughly. For scales, as noise is never found to be enjoyable, one pole of the scale should be extremely negative (extremely annoyed), and the other pole should be neutral (not at all annoyed).

Table 3.1 : Minimum specifications for reporting core information from social and socio-acoustical surveys in scientific reports (ISO/TS 15666, 2003).

Topic area	Item	Topic	Required information
Overall design	1	Survey date	Year and months of social survey
	2	Site location	Country and city of study sites
	3	Site selection	Any important, unusual characteristic of the study period or sites Map or description of study site locations relative to the noise source
	4	Site size	Rationale for site selection Site selection and exclusion criteria
	5	Study purpose	Number of study sites Number of respondents by site State original study goals
Social survey sample	6	Sample selection	Respondent sample selection method (probability, judgmental, etc.) Respondent exclusion criteria (age, gender, length of residence, etc.)
	7	Sample size and Quality	Response rate Reasons for non-response
Social survey data collection	8	Survey methods	Method (face-to-face, telephone, etc.)
	9	Questionnaire wording	Exact wording by primary questionnaire items (including answer alternatives)
	10	Precision of sample estimate	Number of responses for main analyses
Acoustical conditions	11	Noise source	Type of primary noise source (aircraft, road traffic, etc.) Types of noise source operations that are included or excluded Protocols to define the noise source (e.g. minimum level, operations, days of week)
	12	Noise metrics	Give the complete description of any noise metric reported, according to ISO 1996-1, ISO 1996-2, ISO 1996-3 or ISO 3891 (if applicable): - Provide $L_{Aeq,24h}$, L_{dn} and L_{den} (or L_{Aeq} by time-period) for all locations or - provide conversion rule(s) to estimate $L_{Aeq,24h}$, L_{dn} and L_{den} under the specific study conditions from the study's preferred metric - Discuss the adequacy of the conversion rule(s) - Provide impulse and/or tone corrections
	13	Time period	Hours of day represented by noise metric Period (months, years) represented by noise metric
	14	Estimation / measurement procedure	Estimation approach (modelling, measurement during sampled periods, etc.)
	15	Reference position	Nominal position relative to noise source and reflecting surfaces Present exposure (or give conversion rule) for noisiest façade, specifying whether reflections from the façade are taken into account or not
	16	Precision of noise estimate	Best information available on precision of noise exposure estimates
Basic dose / Response analysis	17	Dose/response relationships	Tabulation of frequency of annoyance ratings for each category of noise exposure

Table 3.1 introduces minimum specifications for reporting core information from social and socio-acoustic surveys in scientific reports.

Two types of questions are presented in this Annex, one being direct questions and the other being indirect questions. Direct questions are the prime measure for relationship between noise and annoyance. Examples of direct rating questions may be 'name the noise source' or 'respondents’ attitude towards the noise'. Indirect questions try to determine the hidden effects of noise and they can only be used to interpret how people feel about noise. They may be questions with no identified noise source or in which respondents report complaint actions or behavioral reactions. These questions are less related to noise exposure than direct questions and are more expensive to analyze. As open questions allow respondents to give their own answers, it is hard to compare results.

It is recommended to use both questions and scales of annoyance given in this technical specification because it is consistent with the most basic principles of increasing the reliability of psychometric measurements. The verbal scale is simple and clear, and applies to any degree of sophistication in any culture. The numerical scale controls the consistency of the respondent’s answer. It is also an asset in a multiracial society and in international work.

3.2.2.3 Evaluating noise annoyance using on site surveys

Many studies on noise annoyance has been made over the years with many different methods. A summary of some of the important works assessing annoyance for exposure to everyday noise (not recordings) are given in this section.

Arana and Garcia (1998) method

Arana and Garcia (1998) worked on the effects of environmental noise on the residents of Pamplona in Spain. A-weighted noise levels were measured and statistical noise levels were calculated over 24 hour periods in various residential areas of the city. Questionnaires were sent by the local councilor for Environment and Health, to residents who lived near the areas where the measurements took place. 496 questionnaires were completed. The questionnaire had questions on demographic data, residential environment and noise nuisance. Questions on traffic noise general annoyance and sleep interference had 5 point verbal rating scales. Correlations were calculated and results were graphed.

Klaeboe et al. (2000) method

Klaeboe et al. (2000) worked on an integrated approach to assess the combined effects of noise and air pollution on annoyance in Oslo. The annoyances studied were of exhaust smell, dust, feeling insecure in traffic and road traffic noise. Personal interviews were in 1987 and telephones interviews were made in years 1994 and 1996. Wording of the questions changed over the years. $L_{Aeq,24h}$ levels were calculated using Nordic calculation method of Public Road Directorate. Curves for probabilities of people being highly annoyed with road traffic noise by 24 h equivalent sound pressure levels were estimated.

Onuu (2000) method

Onuu (2000) presented a study on road traffic noise annoyance for 8 cities in South-Eastern Nigeria. Instantaneous and 24 hour noise measurements were made and noise descriptors such as L_{eq}, L_{dn}, L_{max} and L_{10} were determined. Questionnaire was made with people living or working near the measurement sites. Question on traffic noise annoyance had a 3 point verbal rating scale. Correlation of noise levels and annoyance levels were prepared.

Persson Waye and Rylander (2001) method

Persson Waye and Rylander (2001) worked on homes exposed to noise from heat pump or ventilation installations and conducted surveys distributed by mail, on noise annoyance. The aim was to assess annoyance, disturbance of rest and concentration, psycho-social symptoms and medical symptoms in relation to noise exposure. Almost half of the people were exposed to low frequency noise. The other half was exposed to mid frequency noise and they were used as a control group. Noise levels were measured indoors and logarithmic average noise levels (dBA, dBB, dBC), sound pressure levels and standard deviations of the measurements were calculated. The question on annoyance and the question on degree of disturbance of rest/relaxation and concentration had a four-graded scales. There were also five questions on perception of low frequency noise discomfort, such as "Is there any room in your home where you regularly experience: a pressure build-up on the ear drum, a vibrating feeling in your body, a vibrating feeling in your chest, a feeling of discomfort caused by a low pitch, humming sound or an unexplained feeling of discomfort?". The part on medical symptoms questioned nausea, headache, tension, irritation and unusual tiredness, with time frequencies of symptoms. The part on psycho-social symptoms questioned mental and physical tiredness, social interaction and feelings of contentedness and depression, including frequency and degree of symptoms. Results were used to form relationships for annoyance, noise sensitivity, discomfort and symptoms.

Rylander and Björkman (2002) method

Rylander and Björkman (2002) researched effects of window orientation in dwellings on road traffic noise annoyance. Noise measurements were made on the facades, L_{Aeq} and L_{max} values were determined. The mail survey included questions on demographic data, general sources of annoyance in the area, general satisfaction with the environment and a three graded scale question on noise annoyance. Different from other studies, subjects were asked if they noticed a particular noise source. Subjects were classified by location of windows: subjects living in flats only facing the street and subjects living in flats which also have windows not facing the street. Dose effect relationships were presented on the subject.

Sato et al. (2002) method

Social surveys were executed in Gothenburg, Sweden, and Kumamoto and Sapporo, Japan, to study cross-cultural differences in the community response to road traffic noise, using the same questionnaire and noise measurement method. In each city, 11 to 15 typical residential areas with detached houses and apartment houses, facing roads, were selected. The social surveys had 40 questions about environmental, housing and personal factors. The key questions were on road traffic noise annoyance, with answers on a five-point scale. The respondents were 1142 people from 18 to 75 years of age in Gothenburg, 837 people from 20 to 75 years of age in Kumamoto and 780 people from 20 to 75 years of age in Sapporo, which were randomly selected on a one-person-per-family basis (Sato et al., 2002).

After the questionnaires were completed, environmental noise and sound insulation measurements were made in each area. Environmental noise measurements were 24-h continuous noise measurements close to the roadside, the reference point. . The passing vehicles were manually counted during these times. Sound insulation measurements were made at 5, 10, 20 and 40-m points on the ground level from the reference point and at each floor level of apartment houses. The noise exposure for each house was determined using these data Community responses were compared on the basis of the dose-response relationships (Sato et al., 2002).

Bangjun et al. (2003) method

Bangjun et al. (2003) investigated the influence of the visibility of the source on noise annoyance. The study was conducted in a city park and a school building; they both had areas almost equally distanced from the road source, some seeing the source and some separated from the source by hedges. In the park, the study was conducted with stochastically selected tourists, park staff and nearby residents in between ages of 14 to 60, during a weekday and one weekend every month for one year. In the school buildings, 400 students of ages between 14 to 22 was carried out weekly, for almost 2 months (Bangjun et al., 2003).

The questionnaire answers on level of disturbance or annoyance were ‘not at all’, ‘slightly’, ‘moderately’, ‘very’, and ‘extremely’. These verbal scale of five degrees were considered to be typical fuzzy description and the appraisal of subjective annoying response was considered to be a fuzzy event. So the fuzzy mathematic method was applied to calculate the probability of noise annoyance to evaluate the influence of the visibility of the source on subjective noise annoyance (Bangjun et al., 2003).

Discussion

In studies evaluating noise annoyance using on site surveys, the most common aim is to assess the effects of environmental noise on the residents. Some of these studies assess the exposure inside the houses, some outside the houses, some in the workplaces and some in recreational spaces. In terms of environmental noise, there are studies on single noise source, multiple environmental noise sources and combined effects of noise and other effects such as air pollution. Some of the studies assess non-environmental noise, which is usually mechanical noise heard inside the houses.

The studies use noise measurement results or environmental noise calculation results for evaluating dose. Measurement of 24-hour continuous A-weighted noise levels and use of noise descriptors such as L_{eq}, L_{den}, L_{max} and L_{10} are quite common. Environmental noise calculation methods were given by Directive 2002/49/EC (the European Parliament and of the Council, 2002). Sound insulation measurements were also made in case the study aimed to evaluate the effects of façade sound insulation.

On-site questionnaires may be conducted through mail surveys, telephone interviews and personal interviews. Local authorities choose to use mail surveys throughout cities. The number of respondents in cities vary from 400 to 1000. In cases where districts or areas were studied, about 100 respondents were used.

The questionnaires usually had questions on demographic data, housing and environment and noise annoyance. Questions on noise annoyance had varying scales, for example 5 or 4 or 3 point verbal rating scales. Bodin et al.'s study (2012) compared the annoyance difference between two surveys, one was introduced broadly and the other clearly stated aim of investigating noise and health. It was found that although the stated aim and questions were different, the substantial difference came from the scales, 4-point and 5-point scales. On the other hand, ISO/TS 15666 (2003) provides 5-point verbal scale and (0-10) point numeric scale questions.

For results, correlation of noise levels and annoyance levels were prepared and dose effect relationships were presented.

The type of source investigated in this study is only road traffic noise. Although noise measurements are used in most of the studies, noise calculation methods are used in European Union countries and measurements are only used for validating calculation models. Even though mail surveys are usually used for citywide studies, personal interviews provide more accurate results in smaller studies, because surveyors can explain the questions if needed. The questionnaires usually had questions on demographic data, housing and environment and noise annoyance. The 5-point verbal scale and (0-10) point numeric scale questions from ISO/TS 15666 should be used to assess environmental noise annoyance. Dose effect relationships should be presented as results of socio-acoustic surveys.

3.2.2.4 Evaluating noise annoyance using listening tests

Many studies on noise annoyance have been made over the years with many different methods. A summary of some of the important works assessing annoyance for exposure to sound recordings, using listening tests are given in this section.

Kurra et al. (1999) method

Kurra et al. (1999a; 1999b) presented a study on road, railway and aircraft noise levels and annoyance responses. With continuous road traffic and controlled numbers of railway and aircraft traffic, overall annoyance and activity disturbance were investigated for 30 minutes each. Noise was simulated in an indoor laboratory environment and transmission loss of façade, acoustical properties of room and characteristics of loudspeakers were taken into account. The questions in the questionnaire were categorized as: (a) demographic characteristics; (b) previous experience with noise; (c) sensitivity to noise; (d) annoyance while reading; (e) annoyance while listening; (f) overall annoyance; (g) comparison of annoyances from three different noise sources. A 7-point category scale from "not at all" to "very much annoyed" was used. Noise clips had six different noise levels, 30, 35, 40, 45, 50 and 55 dBA. Overall annoyance was presented with individual values, group averages and correlation with noise levels. Activity disturbance was evaluated by writing ad listening activities.

Persson Waye and Öhrström (2002) method

Persson Waye and Öhrström. (2002) worked on wind turbine noise annoyance. Subjects were exposed to five different wind turbine noise recordings for 10 minutes and 3 minutes, which had L_{Aeq} = 40 dBA. Surveys assessed annoyance with 11 point scale and psycho-acoustic descriptors with six graded scale, as well as attitude towards wind turbines and noise sensitivity.

Versfeld and Vos (2002) method

Versfeld and Vos (2002) assessed A-weighted equivalent sound level as a predictor of the annoyance caused by road traffic consisting of various proportions of light and heavy vehicles. A laboratory study was conducted to examine the relationship between noise annoyance and the proportion of heavy vehicles in a mixture of trucks and passenger cars. Twenty normal-hearing subjects were asked to judge the annoyance caused by the sounds from a continuous stream of vehicles, assuming they were exposed to it at home on a regular basis. The number of passby events as well as the A-weighted equivalent sound level were kept constant. (Versfeld and Vos, 2002)

Viollon et al. (2002) method

Viollon et al. (2002) assessed how listener's judgments of a set of urban sound environments were affected by co-occurring visual settings. In artificial audiovisual environments, subjects rated eight urban sound environments (recordings) when they were associated with five visual settings (four color slides varying in degree of urbanization and a control condition with no slide), along two sound scales (Unpleasant–Pleasant and Stressful–Relaxing). In general, the more urban the visual setting, the more negative the sound ratings. However, this influence depended on the type of sound. It was marked for recordings which did not include human sounds (particularly strong for bird song and weaker for traffic noise), but was absent for all recordings which included human sounds (footsteps and voices) (Viollon et al., 2002).

Barbot et al. (2008) method

Study by Barbot et al. (2008) focused on aircraft sound perception. Fourteen different aircraft sounds were studied and corresponded to seven take offs and seven landings. Preference tests were carried out in order to assess the sound agreement using a seven-point scale, each stimulus being compared to a reference sound. For each pair, subjects had to justify their answer in their own words. Their descriptions were analyzed in a linguistic way. Dissimilarity tests were also carried out using the same stimuli. Four perceptual factors, which explain the distance between aircrafts sounds, were extracted thanks to INDividual multidimensional SCALing (INDSCAL) analysis. They corresponded to the temporal evolution of the sound level (one factor for the slope of the increase and another factor for the regularity of the increase) and to the timbre aspect (one factor for tonality and one factor for the texture of noise). The verbalisation helped to understand and interpret these dimensions. Objective classical criteria were tested to characterize these perceptual effects using correlations between objective and subjective measurements (Barbot et al., 2008).

Trollé et al. (2008) method

Trollé et al. (2008) worked on the influence of the independent variation of some structural parameters on the auditory perception of environmental noises transmitted through a window. The pane of glass in its frame was modelled as a thin baffled plate with viscoelastic boundary conditions; transmitted noises were then synthesized by convolving a binaurally recorded environmental noise to different calculated impulse responses of the plate involving so many different values of the structural parameters (structural damping factor and mounting conditions).

Stimuli were submitted to a jury of subjects pairwise who were asked to give dissimilarity and preference judgments. Analysis first allowed to identify the relevant auditory attributes that were likely used by the subjects in their differentiation task, and also focused on drawing up a preference ranking of the transmitted noises in order to provide recommendations for window structural modifications that could improve acoustic comfort in inner spaces (Trollé et al., 2008).

Lavandier et al. (2011) method

Lavandier et al. (2011) focused on perceived activity disturbance evaluated by participants who are subjected to the repetition noise of current aircraft and modified aircraft in regard to tonal quality. Six 20-min sound sequences were created combining two variables: number of aircraft (N1 with six aircraft and N2 with 10 aircraft plus one sequence without aircraft N0) and tonality (sequences with current aircraft, sequences with +5 dB-amplified tonality and sequences with -5 dB-attenuated tonality). For all sequences, the equivalent sound level and the peak level of the loudest event are constant, except for the sequence without aircraft. Sixty-three subjects, attending two different sequences in one session, rated on a category scale the level of activity disturbance due to the noise environment when carrying out memory and concentration tasks. The order of presentation was controlled as an additional variable in the variance analyses (Lavandier et al., 2011).

Torija et al. (2011) method

Torija et al. (2011a; 2011b; 2012) studied urban soundscapes to predict level and temporal-spectral composition of sound pressure in urban sound environments. As part of the study, relationship between road and railway noise annoyance and overall indoor sound exposure was investigated with listening tests.

The listening tests were conducted in a living room of a house. Transportation noise was played on two loudspeakers and a subwoofer placed outdoors, 3 m from the façade, and not seen from inside. The noise exposure stimuli all lasted 10 min, and consisted of two or four passages of the same train type at the same distance and speed, or alternatively, of highway/road traffic noise.

During listening tests, participants continued daily activities. The house was located in a quiet area. A hundred participants were selected as representative of the Dutch population. All experimental sounds were recorded in the field using two microphones, spaced about 10 m from each other. Participants were asked to assess annoyance on a relative scale (e.g. if one is twice as much annoyed by a subsequent stimulus, one had to use twice the previous number), with zero if they were not annoyed at all by the sound.

Zimmer et al. (2008) method

In Zimmer et al.'s study (2008), participants rated a number of sounds before, after, and while performing a cognitively demanding memory task in a laboratory situation.

The task consisted of memorizing, and later reproducing, a visually presented sequence of digits while being exposed to irrelevant sound chosen to produce different degrees of disruption.

The rating scale was thirteen categories ranging from 'not annoying at all' to 'extremely annoying.' The judgments were collected immediately before, after, and concomitant to, the memory task. The visual stimuli to be memorized on each trial were a random permutation of the digits 1–9, displayed sequentially in the center of a computer monitor. In addition to silence, serving as a baseline condition, four auditory stimuli of 14 s were used as a background in the memory task. Twenty-five subjects participated in each of the two experiments. The sounds had a duration of approximately 10 min in the second experiment, in order to study exposure duration.

Discussion

The listening tests are designed to analyze the effects of specific aspects of noise on humans. Listening tests are almost always conducted in a controlled indoor laboratory environment. The sources investigated in the studies presented here are usually transportation noise sources (road, railway, and aircraft). On the other hand, wind turbines, nature sounds and human sounds have been studied as well.

Some of the environmental sound recordings have been filtered for façade or window sound transmission. Placing loudspeakers outside a façade and listening from inside is also an applied method.

The scales used vary widely, from 5, 7 and 11 category scales to numerous relative scales, which compare sounds to each other or a reference sound. The disturbances studied are usually overall disturbance but listening tests are also a good way to study activity disturbance. The activities may be on memory or concentration, writing and listening, while being exposed to sound clips.

The number of participants in listening tests change from 25 to 100. In cases with more than thirty or forty participants, the participants evaluate noises together in one room, reproduced through loudspeakers. In cases where headphones are used, the number of participants are about 25 and evaluate noises on their own, one by one.

In this study, the source is road traffic and many different aspects of road traffic noise may be studied by listening tests. Listening test is conducted in a controlled indoor laboratory environment. Sound recordings may be filtered for façade sound transmission. The 5-point verbal scale and (0-10) point numeric scale questions from ISO/TS 15666 may be used to assess environmental noise annoyance. Both overall disturbance and activity disturbance may be studied using listening tests. Using a loudspeaker requires a room designed for this purpose. Using headphones only requires a quiet environment, but number of participants are usually limited because of timing concerns.

3.2.2.5 General discussion on noise annoyance methods

Evaluating noise annoyance using previous studies provided the standards in this field. Fields et al. (1997) method and Fields et al. (2001) method were both used to form the technical specification ISO/TS 15666:2003 "Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys". Miedema and Oudshoorn (2001) method presented cutoff points for annoyance percentages: "highly annoyed" (cutoff at 72 on a scale of 0–100), "annoyed" (cutoff at 50 on a scale of 0–100), and "a little annoyed" (cutoff at 28 on a scale of 0–100). These cutoff points are accepted and used worldwide, therefore it will be used in this proposed methodology.

ISO/TS 15666 (2003) method will be used in this proposed methodology for information disclosure, standardized general-purpose noise reaction questions, 5-point verbal scale answers and (0-10) point numeric scale answers for socio-acoustic surveys.

The type of source investigated in this study is only road traffic noise. Noise calculation methods are used in European Union countries and measurements are only used for validating calculation models. On-site surveys are used for determining dose effect relationships, following ISO/TS 15666 (2003) method. The questionnaires have questions on demographic data, housing and environment and noise annoyance.

Listening tests may be used to investigate many different aspects of road traffic noise. Listening test is conducted in a controlled indoor laboratory environment. Sound recordings may be filtered for façade sound transmission. The 5-point verbal scale and (0-10) point numeric scale questions from ISO/TS 15666 may be used to assess noise annoyance. Both overall disturbance and activity disturbance may be studied using listening tests.

On-site surveys are a healthy and accurate way of determining overall annoyance. Listening tests are useful in investigating different aspects noise annoyance, but the responses to short term doses may yield different results than on-site surveys. It would be favorable to validate listening test results using on-site survey results.

4. APPROACH FOR DEVELOPING ROAD TRAFFIC NOISE ANNOYANCE PREDICTION MODEL

The approach for developing a road traffic noise annoyance prediction model is explained in this section. Preparing noise maps, socio-acoustic surveys, façade insulation analysis, sound recordings, sound clips, listening tests and annoyance prediction model are the main steps of this approach. Objectives and flowchart of approach and detailed descriptions for each step are presented in the following sections.

4.1 Objectives and Limitations of Approach

The main objective of "Assessment and Management of Environmental Noise (2002/49/EC)" Directive (The European Parliament and The Council of The European Union, 2002) is to define a common approach intended to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. To that end, the following actions are to be implemented: noise mapping, informing the public and action planning. Noise maps and action plans are created by calculation techniques, through noise assessment methods, with simulation software. Noise measurements are only used for verification of the model. Quality of data input is crucial in accuracy of noise maps.

The term, 'annoyance' is defined in the Directive as 'the degree of community noise annoyance as determined by means of field surveys. L_{den}, L_{day}, $L_{evening}$ and L_{night} are defined as noise indicators for annoyance or for sleep disturbance, during the time period they are assigned to. Dose-effect relations should be established for L_{den} and L_{night}. It is stated in the Directive that each action plan should contain estimates in terms of the reduction of the number of people annoyed and sleep disturbed.

The first round of noise mapping in EU, in 2007, proved that due to quality of input data, noise maps may have a local uncertainty as large as 5 dB. The first round of action planning in EU, in 2008, showed that although noise maps are very effective in determining hot spots, they do not function accurately in quiet areas and areas in between which are called gray areas. In these quiet and gray areas, the lack of defining minor noise sources and lack of identifying perceived noise cause insufficient understanding of noise annoyance (Licitra, 2012).

Although the main purpose of the Directive and of noise control studies all over the world is to reduce harmful effects of noise, including annoyance, the implementation is focused on and led by noise levels, not annoyance. As explained in the previous sections, many studies have shown that the recommended indicators do not reflect many aspects of annoyance (Kang, 2007; Persson Waye & Rylander, 2001; Phan et al., 2009). Including all sources, major and minor, into the models, eliminating noise indicators and focusing on perceived noise would be start in accurately assessing annoyance. Using annoyance prediction models instead of noise prediction models would provide cost effective action plans which focus on decreasing annoyance levels, not noise levels. Planning actions against annoyance is be easier to organize because the model helps to understand the factors which effect annoyance levels.

The objective of this approach is to develop a local road traffic noise annoyance prediction model by means of noise maps, socio-acoustic surveys, façade sound insulation, sound recordings, sound clips and listening tests. Using all of these methods together, provides detailed information on noise sources, urban propagation conditions and people’s responses to certain types of noise heard inside their homes, which help to create an accurate model. Using this approach, authorities can develop their own annoyance prediction models, taking into account characteristics of traffic, urban development and population.

The aim of a local annoyance model is taking all of the data collected for noise mapping, improving it and transforming it into noise annoyance data directly. With this model, there is no need for inaccurate noise levels, time consuming noise mapping simulation and expensive field surveys. The local road traffic noise annoyance prediction model may be easily used in areas with similar demographics and built environment characteristics.

There are some limitations to this approach:

- The model is only for road traffic noise sources, but further studies may be used to implement the approach for other noise sources.

- This approach is for general noise annoyance and not sleep disturbance, because this study does not include awakening, motility or health effects (WG-HSEA, 2004).

- This approach is to be used only in urbanized areas.

- Meteorological effects are not taken into account because attenuation is assumed zero in urban conditions.

4.2 Flowchart of Approach

The steps of this approach are presented in detail using flowchart in Figure 4.1.

The main steps are noise maps, socio-acoustic surveys, façade insulation analysis, sound recordings, sound clips, listening tests and annoyance prediction model.

Figure 4.2 presents the flowchart of noise map process.

Figure 4.3 shows the flowchart of socio-acoustic survey process.

Figure 4.4 presents the flowchart of façade sound insulation process.

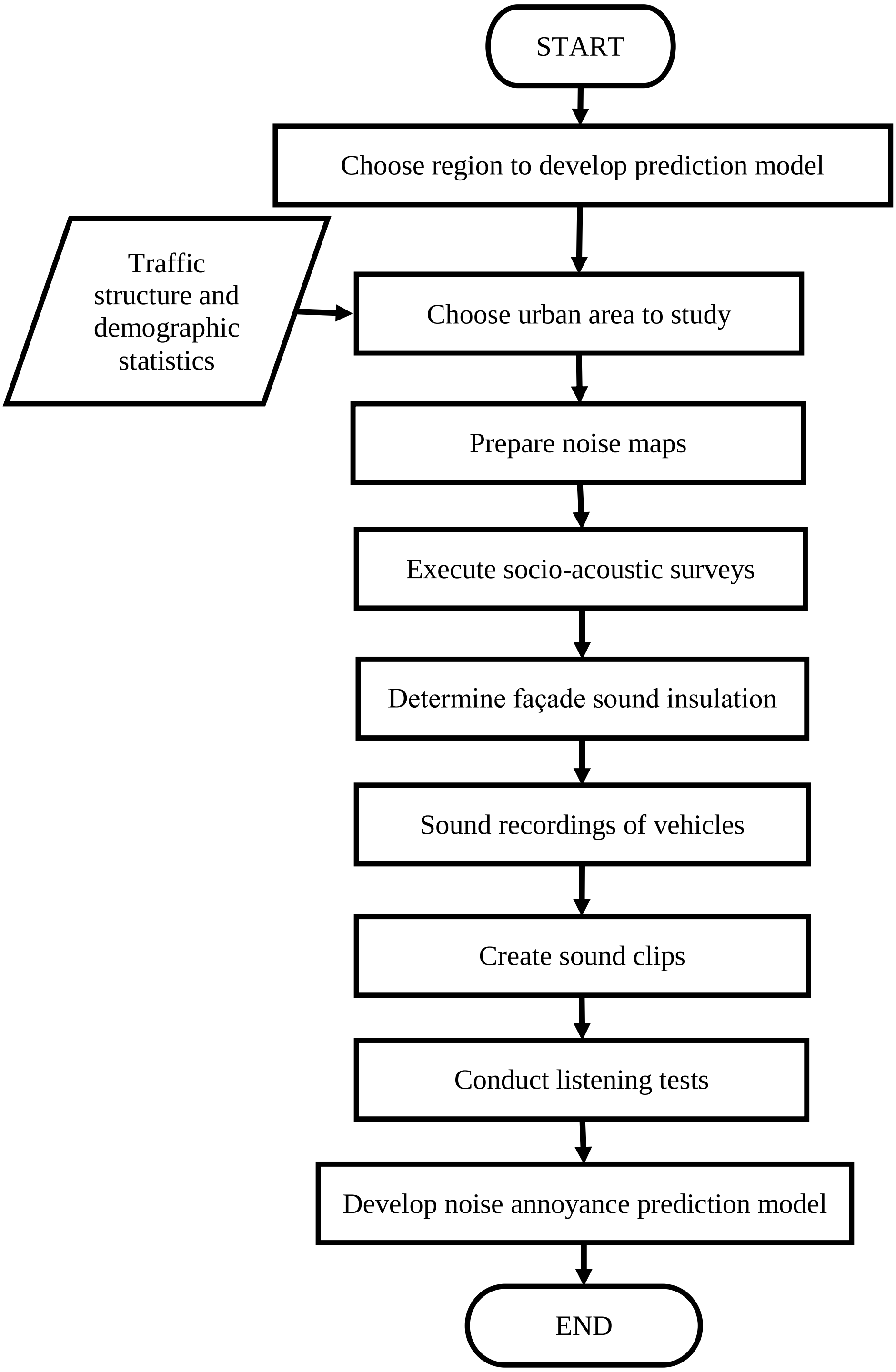


Figure 4.1 : Flowchart for steps of the approach.

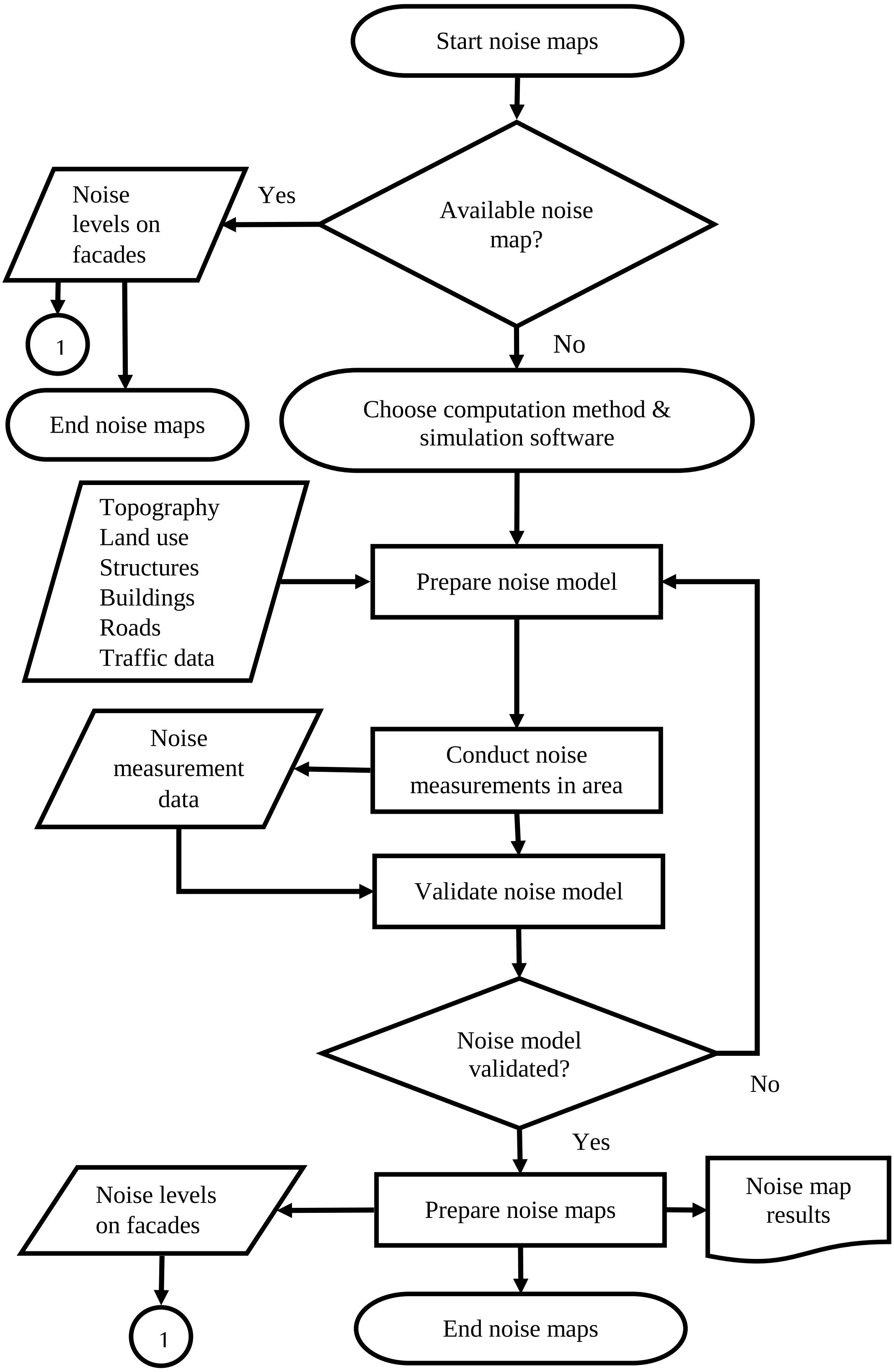


Figure 4.2 : Flowchart for noise map process.

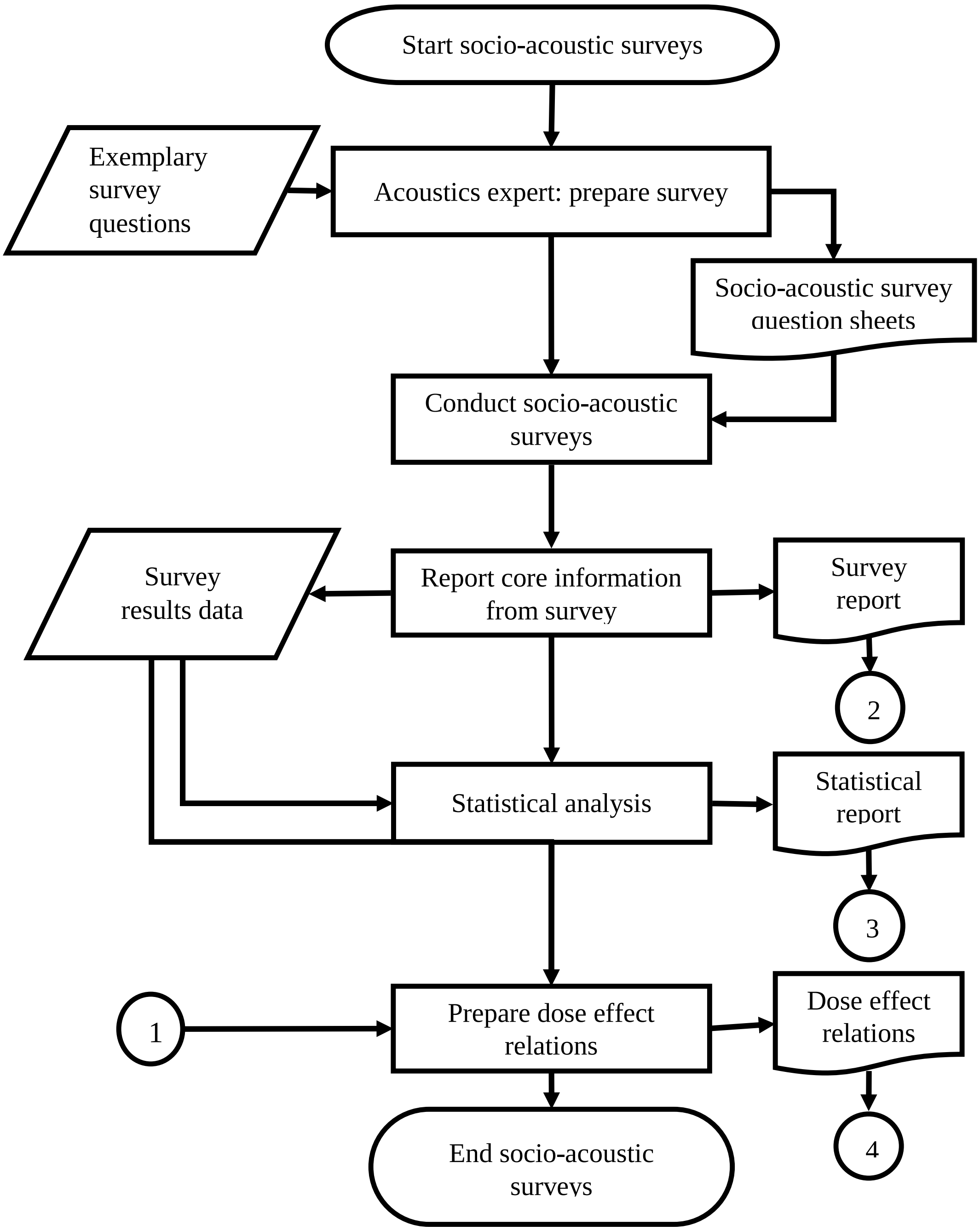


Figure 4.3 : Flowchart for socio-acoustic survey process.

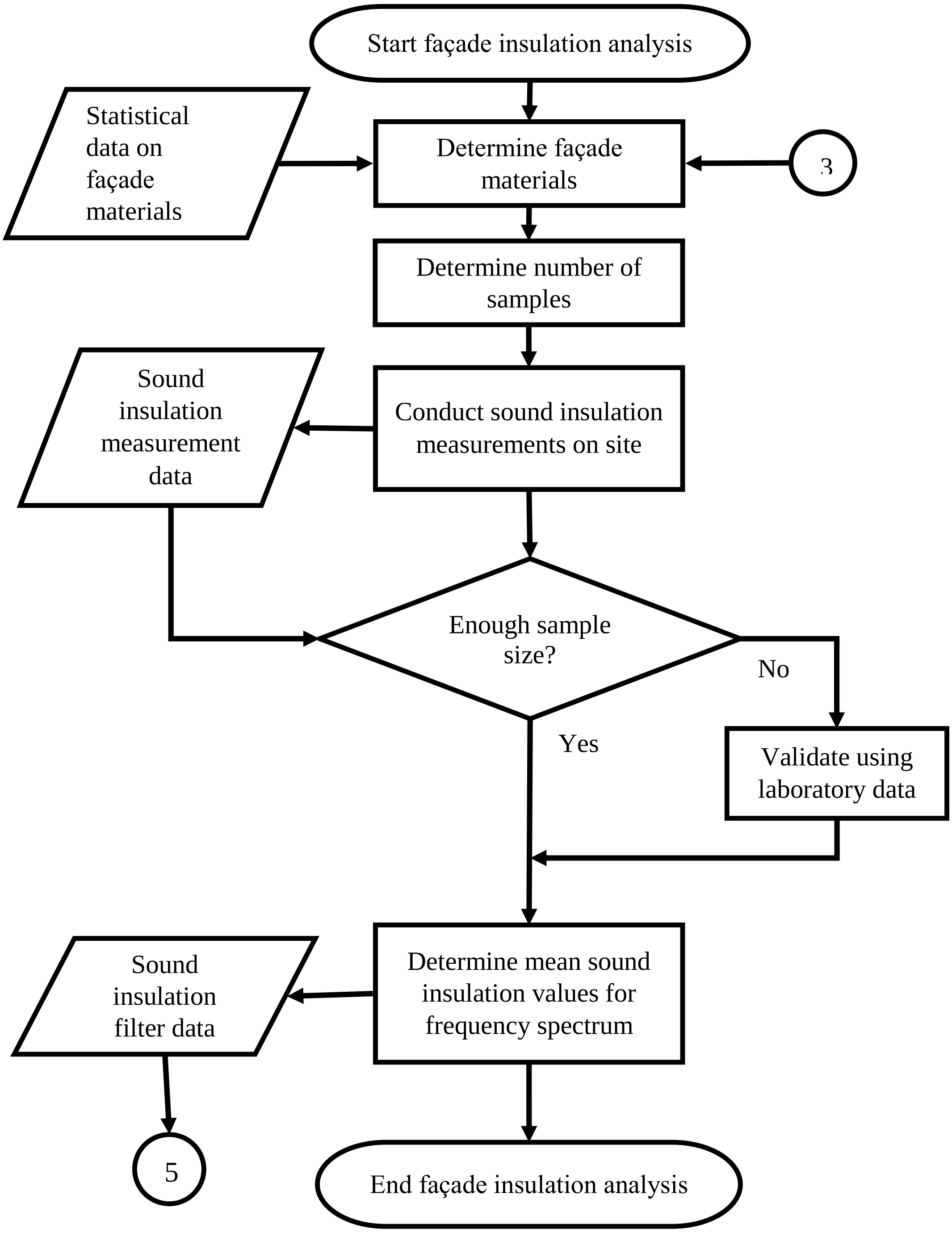


Figure 4.4 : Flowchart for façade sound insulation process.

Figure 4.5 shows the flowchart of sound recording process.

Figure 4.6 presents the flowchart of sound clips process.

Figure 4.7 shows the flowchart of listening test process.

Figure 4.8 presents the flowchart of annoyance prediction model process.

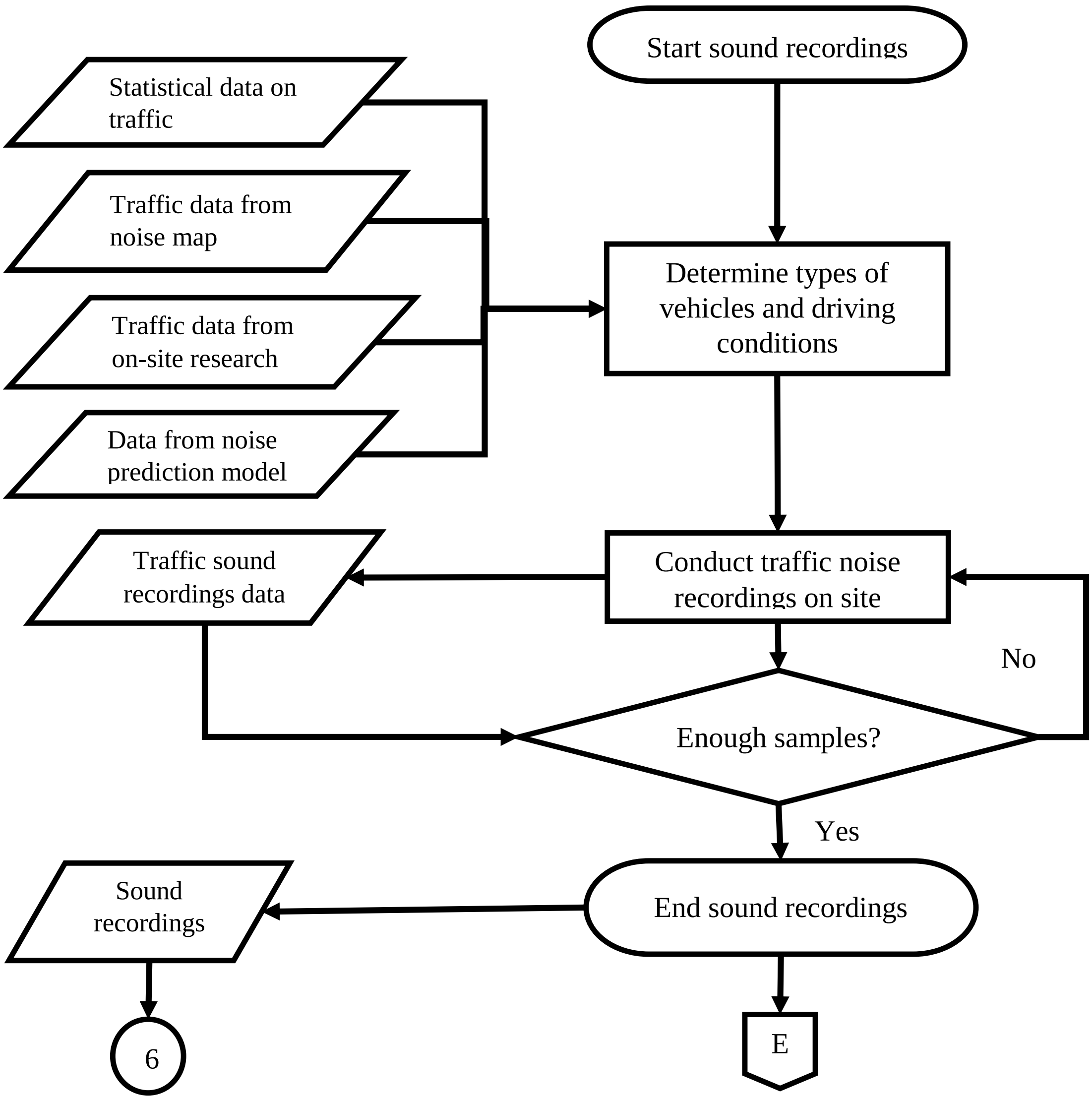


Figure 4.5 : Flowchart for sound recording process.

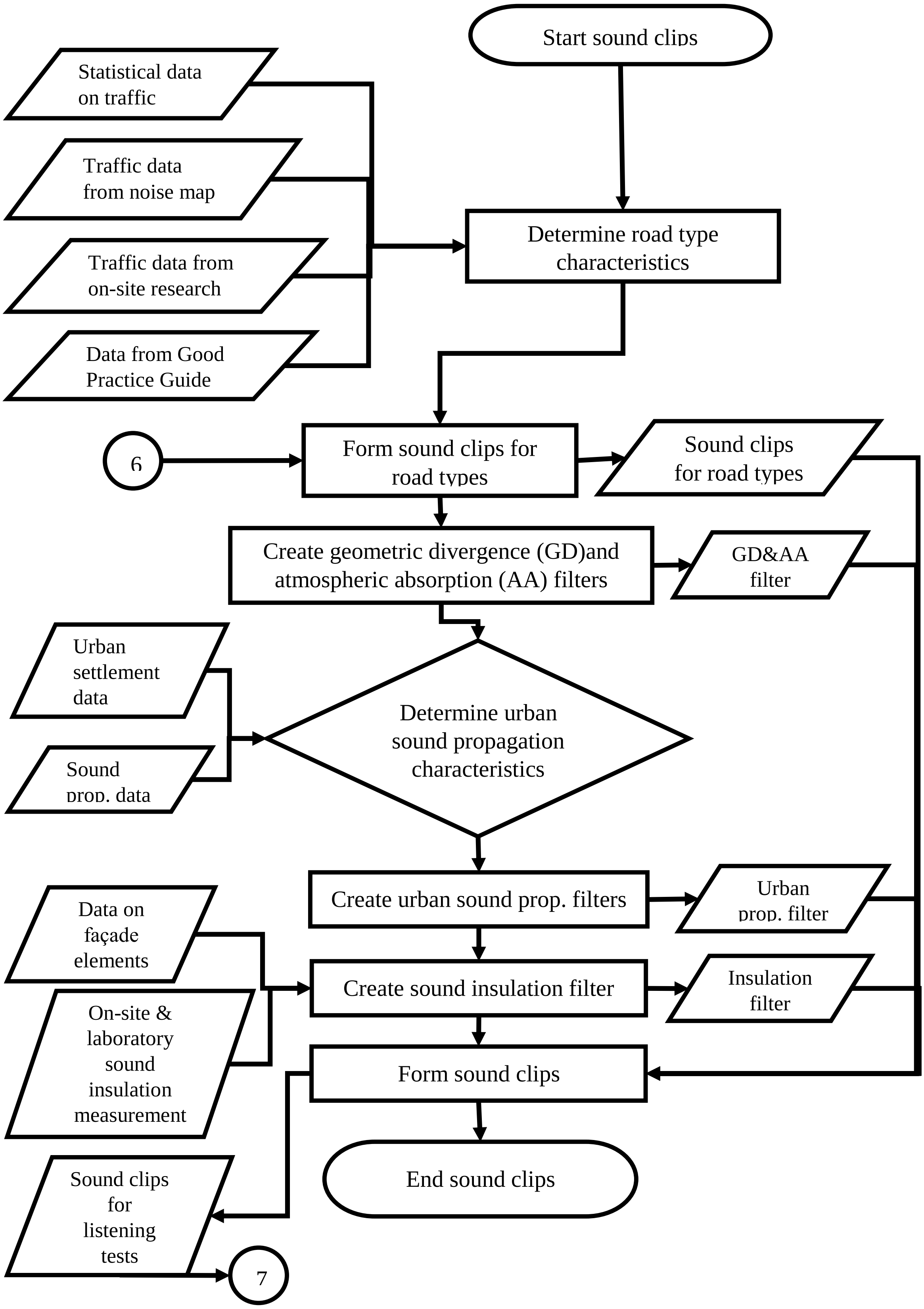


Figure 4.6 : Flowchart for sound clips process.

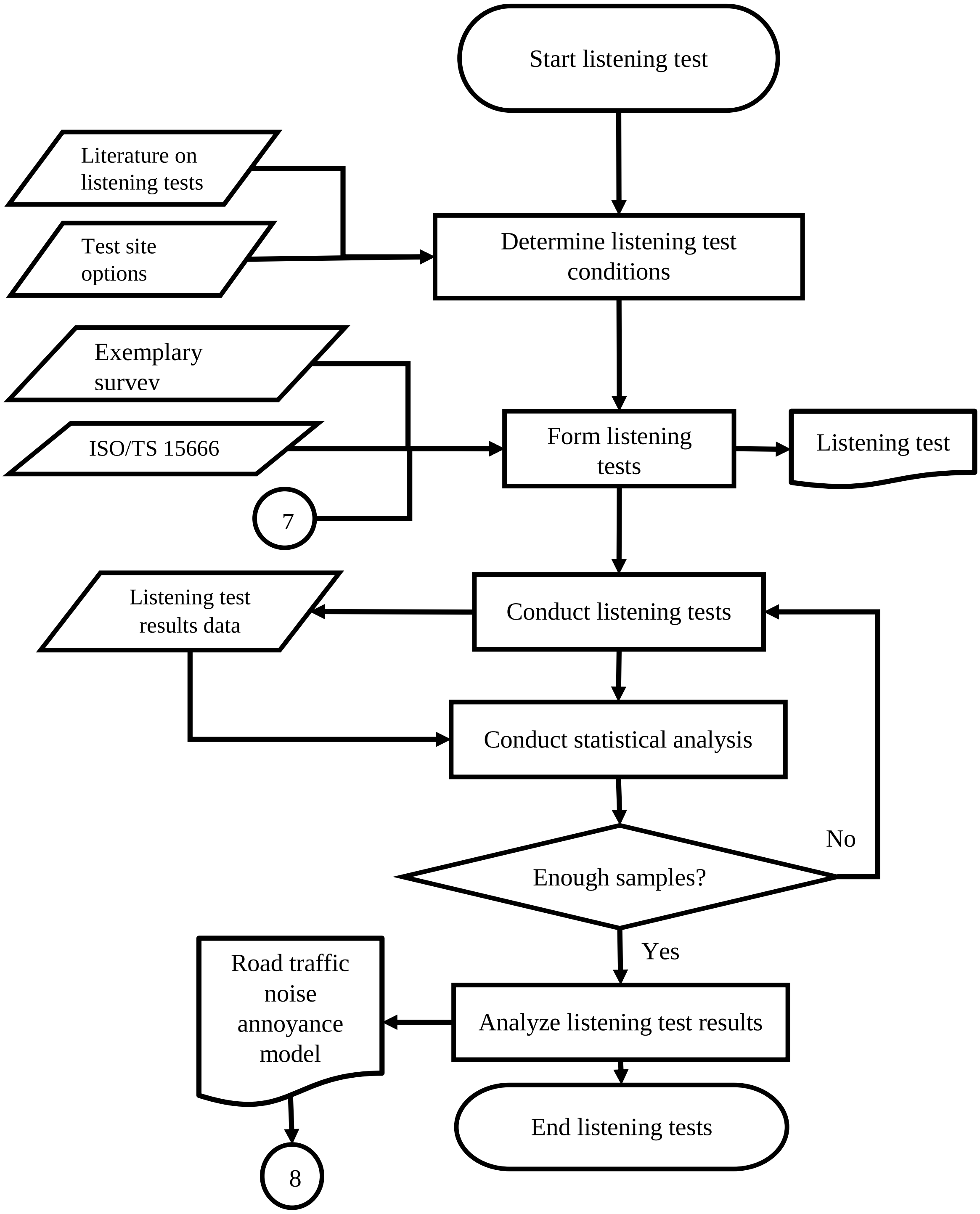


Figure 4.7 : Flowchart for listening test process.

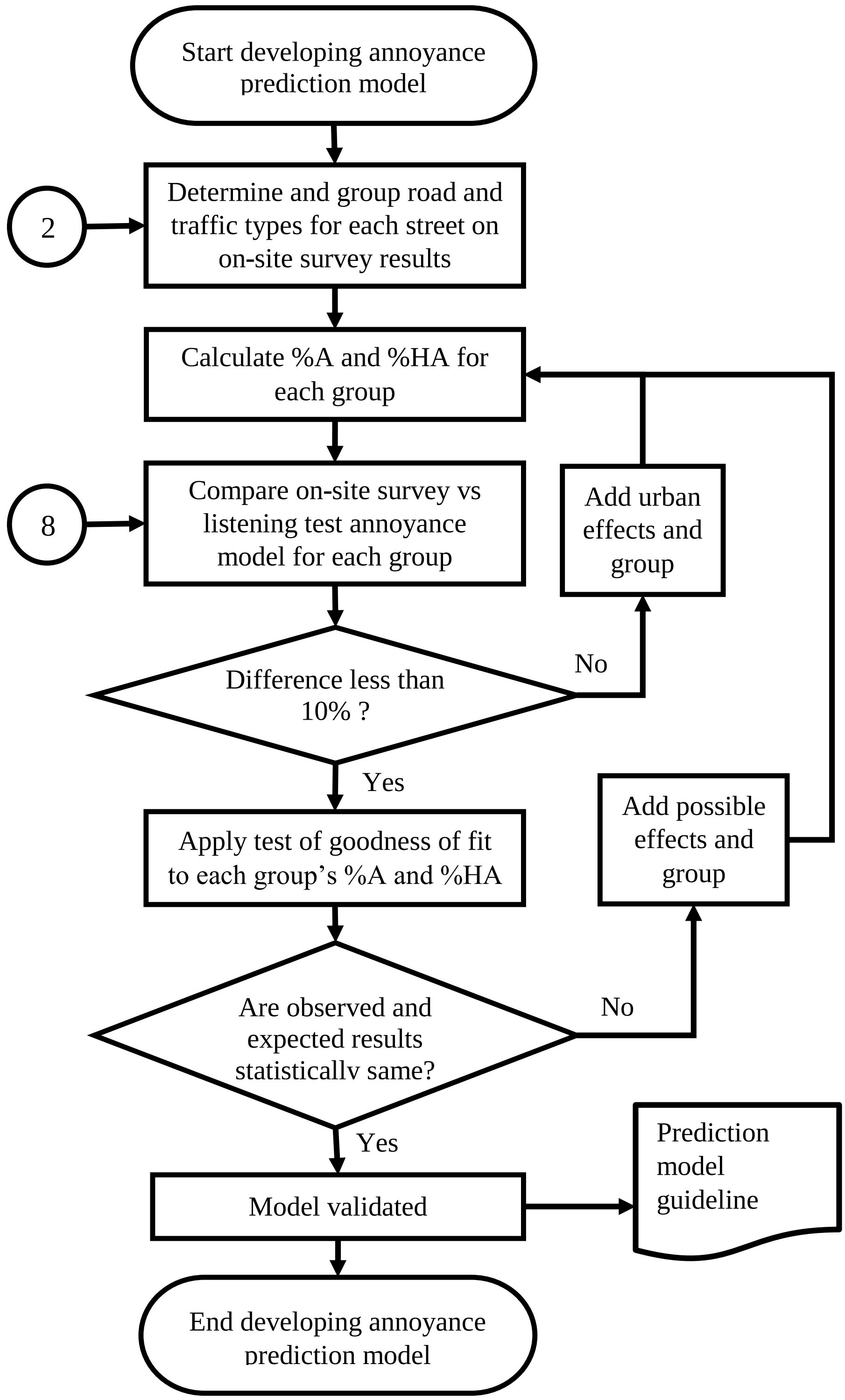


Figure 4.8 : Flowchart for developing annoyance prediction model process.

4.3 Preparing Noise Maps

Strategic noise mapping is introduced in "Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise" as a tool of acoustic planning (The European Parliament and The Council of The European Union, 2002). It is stated in the Directive that Member States shall prepare strategic noise maps (for all agglomerations with more than 250 000 inhabitants, major roads with more than six million vehicle passages a year, major railways with more than 60 000 train passages per year and major airports) until 30 June 2007. Member States should also prepare strategic noise maps for all agglomerations with more than 100 000 inhabitants, major roads with more than three million vehicle passages a year, major railways with more than 30 000 train passages per year and major airports with more than 50 000 movements until 30 June 2012. Member States have prepared noise maps according to this European Directive and national legislations. For this work, available noise maps in Member States may be used if needed.

For areas which do not have available noise maps, or for non-member countries, technique for noise mapping is briefly explained below.

4.3.1 Choosing computation method and simulation software

Directive states that national computation methods may be applied, provided that they are adapted to the definitions of the indicators set out in Annex I (The European Parliament and The Council of The European Union,2002).

For Member States that have no national computation method or for those that are willing to change their computation method, the French national computation method 'NMPB-Routes-96 (SETRA-CERTU-LCPCCSTB), (NMPB-Routes-96, 1995) is recommended for road traffic noise. For emission input data, 'Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, (CETUR, 1980)' is referred.

The French road traffic noise prediction model was revised in 2008. French standard AFNOR NF S 31-133 was revised in late 2010. European Commission published a revision of the Environmental Noise Directive on 19 May 2015. The revision is on

Annex II of the Environmental Noise Directive, which describes the common EU methods for calculating exposure to different noise levels (CNOSSOS-EU, 2012). It includes formulas and coefficients to be used to calculate noise levels at the façade of the buildings. This revision should be implemented by the member states by the end of 2018. Road traffic noise assessment method is revised in Annex II.

"Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure" (WG-AEN, 2006) is a helpful Position Paper which provides discussions and recommendations on noise source, noise propagation and receiver related issues.

Simulation software for estimation of environmental noise should be able to work with the computation method chosen. Software should provide noise indicators given in Annex I of the Directive (The European Parliament and The Council of The European Union, 2002). The outputs of the software should meet the minimum requirements for strategic noise mapping given in Annex IV of the Directive.

4.3.2 Choosing area to be studied

The area to be mapped should represent the traffic structure and urban structure of the country/city to be studied. Urban areas should be chosen, rural areas are not acceptable for this approach. The area should be chosen using statistics on buildings, traffic and demographic data.

4.3.3 Collecting noise mapping data

The data given below should be collected on site or obtained from credible sources:

- Topography of land (elevation contour lines or/and elevation points, acoustic properties of land components)
- Land use
- Structures (geographic data on walls, bridges etc.)
- Buildings (geographic data, shape and size data, height and number of floors, number of residents)
- Roads (geographic data, number of lanes, surface type, road junctions, bridges, traffic lights, parking)

- Traffic (yearly average on: types of vehicles, number of vehicles per hour, average traffic speed, traffic flow characteristics)
- Noise measurements (at key points for validating the noise model)

Good Practice Guide (WG-AEN, 2006) should be used for details in collecting data. Collecting data on types of vehicles is important in further steps of this approach.

4.3.4 Validating noise map

Noise maps may be validated by noise level measurements. Long-term measurements can be compared to yearly average noise levels calculated in noise maps. Short-term measurements can be compared to selected circumstances, such as favorable noise propagation and certain traffic flow conditions. Short-term measurement validation can be projected to annual average of noise emission and propagation. If discrepancies between measurement and calculations are smaller than 1 dB, the model is considered to be sufficient. Corrections should be made in the model if larger differences occur (Licitra, 2012). Noise level measurements on site should be made according to ISO 1996-2 (2007) as explained in Chapter 2.

4.3.5 Noise map outputs

Noise maps should supply the output data listed below:

- Presentation of existing road traffic noise situation at a height of 4 m in 5 dB ranges in terms of noise indicators,
- Presentation of existing road traffic noise situation at building façades in terms of noise indicators,
- The estimated number of people, dwellings, schools and hospitals in the area that are exposed to specific values of a noise indicator.

4.4 Executing Socio-Acoustic Surveys

Socio-acoustic surveys is the method advised by the EU to determine environmental noise annoyance. “ISO/TS 15666:2003 Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys” standard provides the necessary guidelines for this method.

4.4.1 Socio-acoustic survey exemplary questions

"ISO/TS 15666:2003 Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys" standard includes the wording of annoyance questions in many languages. If the wording exists in language of concern, this wording should be used; if not, an acoustics expert should translate them.

Figure 4.9, Figure 4.10 and Figure 4.11 give three pages of an exemplary socio-acoustic survey which may be used in this study. Page 1 asks questions which determine if the subject is competent to attend this survey. Pre-criteria for conducting the surveys are minimum 12 months of residency in the related dwelling, lack of any hearing problems and being in the age range of 18 to 65. If necessary, the age range may be altered due to area's demographics.

Page 2 includes the survey questions. Under the heading of 'personal information', gender, age, education level, duration of residence, time and period spend at home during day, noise sensitivity and noise annoyance at workplace are investigated with 8 questions. Under the heading of 'noise annoyance', traffic noise annoyance at home, for all day and only night periods are investigated in verbal and numerical scales. Also under the same heading, most annoying traffic elements and annoyance during daily activities are inquired by multiple-answer questions. In the last part of the survey, room positions in regards to main road, open windows during night and main wall elements are questioned.

Page 3 is the data sheet for addresses. These addresses are needed for comparing survey results to noise map results and preparing dose-effect relations.

Page 1

SOCIO-ACOUSTIC SURVEY
On road traffic noise annoyance

Dear resident,
This survey is …(explain source of study)… studying human response to road traffic noise.
Interviews are conducted by ………….
By answering the following questions, you will be making a big contribution to this research/project/study. Thank you for your support.

Pre-questions:

A.1. Do you live in this residence?
Yes (1) → Continue
No (2) → End the interview

A.2. Have you lived in this residence more than 12 months?
Yes (1) → Continue
No (2) → End the interview

A.3. Do you have any hearing problems?
Yes (1) → End the interview
No (2) → Continue

A.4. Age of respondent ……….. (DO NOT INTERVIEW < 18 YEARS AND >65 YEARS)
(1) → 18-35 (2) → 36-50 (3) → 51-65

If the respondent is suitable to these criteria, please continue with the main form and later fill the address form.

Figure 4.9 : Page 1 of exemplary socio-acoustic survey.

Page 2

Date of interview: ……/……/………… Survey no: …………...

SOCIO-ACOUSTIC SURVEY
On road traffic noise annoyance

PERSONAL INFORMATION

1) Gender: ☐Female ☐Male

2) Age: ………

3) Educational Level:

☐Primary School ☐Secondary School ☐High School ☐Graduate ☐Postgraduate

4) How many years have you lived at your current address?………

5) How many hours do you spend at home during the day? ………

6) What is your home-staying period? (more than one answer can be chosen)

☐ Day (7am-7pm) ☐ Evening (7pm-11pm) ☐ Night (11pm-7am)

7) Are you generally sensitive to noise?

☐ Not sensitive ☐ Somewhat sensitive ☐ Highly sensitive

8) Are you annoyed by the noise at your workplace?

☐ I do not work ☐ Not annoyed ☐ Annoyed

NOISE ANNOYANCE

9) Thinking about the last 12 months, when you are here at home, how much does noise from **road traffic** bother, disturb or annoy you?

☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely?

10) Thinking about the last 12 months, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by **road traffic noise**?

Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

11) Thinking about the last 12 months, during **sleep at night**, how much does noise from **road traffic** bother, disturb or annoy you?

☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely?

12) Thinking about the last 12 months, during **sleep at night**, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by **road traffic noise**?

Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

13) Which element of road traffic noise is the most annoying for you? (one or more answer)

☐ Cars ☐ Trucks ☐Buses ☐ Minibuses ☐ Motorcycles ☐ Horns ☐Not specific

(Please add or remove any road traffic element if needed)

14) During which of the activities below are you more disturbed by the traffic noise? (one or more answer)

☐ Concentrating (Reading, Working, Studying) ☐ Conversing ☐ Watching TV ☐ Resting ☐ Sleeping ☐ Other…………….………

15) Which room or rooms overlook the street in which there is the major road noise? (one or more answer)

☐ Living room ☐ Bedroom ☐ None ☐ Other ……….

16) Do you sleep with your windows open?

☐ Yes, during summer and winter ☐Yes, only in summer ☐No

17) What is the main wall element of your façade?

☐Brick ☐Aerated concrete ☐ I do not know ☐Other ……….

(Please add or remove any wall element if needed)

Thank you for attending.

Figure 4.10 : Page 2 of exemplary socio-acoustic survey.

Page 3

SOCIO-ACOUSTIC SURVEY
On road traffic noise annoyance
DATA SHEET FOR ADDRESS

No of survey	District	Street	No	Floor

Figure 4.11 : Page 3 of exemplary socio-acoustic survey.

Surveys should be prepared by an expert in the area of acoustics, who has experience in the area. The expert should choose the possible annoying road traffic elements and possible main wall elements in the area.

4.4.2 Reporting socio-acoustic surveys

Socio-acoustic survey should be reported with at least the information asked for in Table 3.1.

4.4.3 Conducting socio-acoustic surveys on site

If possible, apply socio-acoustic surveys by face-to-face interviews, in the houses of the respondents. If it is not possible, mail surveys may also be applied. Surveys should be conducted by simple random sampling method in the residences in the area which is noise mapped. Apply the surveys to all residents in the area if possible.

4.4.4 Statistical analysis of socio-acoustic surveys

The questionnaire results should be subjected to statistical analysis in order to determine relations between factors affecting annoyance. Answers of noise annoyance questions should be evaluated by comparing them to the receiver noise levels calculated in front of the most exposed façade of the subject's floor.

The statistical values given below should be calculated from the survey results and reported:

- Sample size (N)
- Confidence levels (min 95%) and error values of survey
- Reliability statistics on annoyance questions
- Determination of parametric tests or non-parametric tests
- Pearson or Spearman's correlation coefficients (for determining relationships between variables of the questionnaire) and level significance

4.4.5 Forming dose-effect relations

The aim is to produce dose-effect relations to describe the percentage of Annoyed and Highly Annoyed people as a function of L_{den} and Sleep Disturbed and Highly Sleep Disturbed people as a function of L_{night} indicators.

Four annoyance questions with verbal and numerical scales are used to measure noise annoyance of L_{den} and L_{night}. These different scales are converted and analyzed in a 100 scale. On the verbal scale, “not at all” is converted to 0, “slightly” to 25, “moderately” to 50, “very” to 75 and “extremely” to 100. On the numerical scale, 0 is 0, 1 is converted to 10, 2 to 20 and so on. For analyzing percentage of people annoyed (%A) and percentage of people highly annoyed (%HA) the cutoff points on a 100 scale are 50 for %A and 72 for %HA. Polynomial trend lines should be given with algorithms (WG-HSEA, 2006).

L_{den} and L_{night} values are calculated by the placement of single receivers into the noise mapping simulation model. The receivers are placed in front of the most exposed façade of the buildings at questionnaire subjects’ floors, so that a proper correspondence with receivers’ positions are set. Compare dose-effect relations to ones provided by the European Commission (2003) and determine the possible reasons for dissimilarities.

4.5 Determining Façade Sound Insulation

In this approach, average façade sound insulation in the area is determined by measurements and used for filtering environmental noise to be heard inside dwellings.

4.5.1 Determination of façade elements

Any available data may be used for determination of most common façade elements in the area. Statistical data or data from literature, results of socio-acoustic survey on-site (question on main wall element) and visual data of the area may be used. Façade elements commonly used in the area should be presented with percent of application in total number of buildings and ratio in whole façade area.

4.5.2 Determination of sample buildings for façade measurements

In this approach, road traffic noise in the area is used as sound source according to ISO 140-5 (1998). Background noise level should be at least 10 dB higher than equivalent sound pressure level in receiver room. Minimum $L_{Aeqtraffic}$ level should be determined taking into consideration these factors. The number of buildings which fulfil this requirement should be determined from the noise map at hand. Façade sound insulation measurements should be made in all of these buildings if possible. If it is no possible, a sample size should be statistically determined with 95% confidence and 5% error level. If it is not possible achieve this sample size, then a way of validation, such as laboratory measurement data or data from similar previous studies may be used.

4.5.3 Sound insulation measurements on site

During the implementation of this of this approach, ISO 140-5 (1998) standard was active for measurement of façade sound insulation. Towards the end of this study, ISO 16283-3 (2016) superseded ISO 140-5. In this part, both of these similar standards are explained.

4.5.3.1 Façade sound insulation measurements with ISO 140-5

ISO 140-5 "Acoustics — Measurement of sound insulation in buildings and of building elements — Part 5: Field measurements of airborne sound insulation of façade elements and façades" (1998) specifies the rules for airborne sound insulation field measurements of façade elements and façades.

ISO 140-5 presents two method series, which are element methods and global methods, for measurement of the airborne sound insulation of façade elements and whole façades, respectively. The sound source may be a loudspeaker or actual traffic (road, railway or air traffic) for both methods.

The global methods intend to estimate the outdoor/indoor sound level difference under actual traffic conditions. They provide the real reduction of a façade in a given place relative to a position 2 m in front of the façade and evaluate the performance of a whole façade, including all flanking paths. For the purposes of this approach, sound reduction index of each façade element is not needed, sound reduction index of whole façades is demanded. Using actual traffic as sound source is the preferred and the most accurate method to estimate the global sound insulation of a façade. The result cannot be compared with that of laboratory measurements.

Standardized level difference, $D_{tr,2m,nT}$ is the level difference, in decibels, corresponding to a reference value of the reverberation time in the receiving room when traffic noise is used as the sound source. The equation is:

$$D_{tr,2m,nT} = D_{tr,2m} + 10\log\left(\frac{T}{T_0}\right) dB \tag{4.1}$$

where,

$D_{tr,2m,nT}$: standardized level difference (source traffic noise), dB

$D_{tr,2m}$: level difference (source traffic noise), $D_{tr,2m} = L_{1,2m} - L_2$, dB

$L_{1,2m}$: outdoor sound pressure level 2 m in front of the façade, dB

L_2 : the space and time averaged sound pressure level in the receiving room, dB

T : reverberation time in the receiving room, s

T_0 : reference value of the reverberation time, T_0 = 0,5 s

When road traffic is used a source for measurements, sound is incident on the test specimen from different directions and with varying intensity. Therefore, the level difference is obtained from the equivalent sound pressure levels measured on both sides of the test specimen.

Measurements should be made in one-third-octave bands, at least from 100 Hz to 3150 Hz. The measurement time should include at least 50 passing vehicles. Equivalent sound pressure levels should be measured simultaneously on two sides of the test specimen because measurements may be affected by possible fluctuations in traffic. Quiet periods which traffic noise does not exceed the background noise by more than 10 dB should be avoided.

For the source measurements, the microphone should be placed outside the façade, in the middle of the façade, 2,0 (± 0,2) m away from the plane of the façade and 1,5 m above the floor of the receiving room. Because of uncontrolled interference effects, systematic errors will occur, particularly at low frequencies.

At least five microphone positions should be used in the receiving room to obtain the average sound pressure level. Minimum separating distances are 0.7 m between microphone positions, 0.5 m between any microphone position and room boundaries or objects in the room and 1 m between any microphone position and the sound source.

Background noise level (L_b) should be measured in the receiving room. The background level should be at least 6 dB (and preferably more than 10 dB) below the level of the signal and background noise combined. If the difference in levels is smaller than 10 dB but greater than 6 dB, calculate corrections to the signal level according to equation:

$$L = 10\log\left(10^{L_{sb}/10} - 10^{L_b/10}\right) \tag{4.2}$$

where,

L : the adjusted signal level, in decibels;

L_{sb} : the level of signal and background noise combined, in decibels;

L_b is the background noise level, in decibels.

If the difference in levels is less than or equal to 6 dB in any of the frequency bands, use the correction 1,3 dB, corresponding to a difference of 6 dB and indicate in the measurement report.

For measurement of reverberation time, the minimum number of decay measurements required for each frequency band is six: at least one loudspeaker position and three microphone positions with two readings in each case.

The precisions of the global road traffic methods are not known.

4.5.3.2 Façade sound insulation measurements with ISO 16283-3

ISO 16283-3 (2016) Acoustics - Field measurement of sound insulation in buildings and of building elements Part 3: Façade sound insulation, has replaced ISO 140-5 (1998). ISO 16283 differs from ISO 140 series in that (a) it applies to rooms in which the sound field can or cannot approximate to a diffuse field, (b) it clarifies how operators can measure the sound field using hand-held devices, and (c) it includes additional guidance.

Mainly the standard is very similar to ISO 140-5 (1998). It contains the same element and global methods, using loudspeaker or actual traffic noise as sources. The global road traffic method provides the real sound insulation of a façade 2 m in front of the façade. This method is the preferred method when the aim of the measurement is to evaluate the performance of a whole façade, including all flanking paths, relative to nearby roads. The results cannot be compared to laboratory measurements.

Standardized level difference using traffic noise as sound source is Dtr,2m,nT, as given in Equation 4.1. The procedures for measuring indoor and outdoor sound pressure levels, background noise and reverberation time in global road traffic method are the same as those defined in ISO 140-5 (1998).

Procedures for conducting low-frequency measurements are defined in detail. The low-frequency procedure shall be used for the 50 Hz, 63 Hz, and 80 Hz one-third octave bands in the receiving room when its volume is smaller than 25 m^3. This procedure requires additional measurements of the sound pressure level in the corners of the receiving room.

Correction for the signal level for background noise is the same as the procedure given in Equation 4.2.

The uncertainty of the measurement result shall be determined in accordance with the method given in ISO 12999-1.

4.5.4 Calculation and validation of façade sound insulation filter

If it is not possible to execute all façade sound insulation measurements on site, then laboratory measurements or other available on-site measurements may be used for validation of data, given that the elements are known to have similar properties as the façade elements on site. Calculate the mean sound insulation values for frequency spectrum and determine sound insulation filter data to be applied to sound clips which will be formed later in the approach.

If laboratory measurements (ISO 10140-2, 2010) of single elements are used for validation, the equation below may be used for calculating sound insulation of composite façade (Barron, 2003).

$$R_{façade} = 10\log\left(\frac{A_{façade}}{\frac{1}{10^{R_{wall}/10}}A_{wall} + \frac{1}{10^{R_{window}/10}}A_{window}}\right) \tag{4.3}$$

where,

$R_{façade}$: Sound reduction index of composite façade, dB;

R_{wall}: Sound reduction index of wall, dB;

R_{window}: Sound reduction index of window, dB;

$A_{façade}$: Area of composite façade, $A_{wall} + A_{window}$, m^2;

A_{wall}: Area of wall, m^2;

A_{window}: Area of window, m^2.

EN 12354-1 (2000) provides relation between sound insulation quantities as given in the Equation:

$$D_{nT} = R + 10\log\frac{0{,}32\,V}{S_s} \tag{4.4}$$

where,

D_{nT} : Standardized level difference, dB ;

R : Sound reduction index, dB ;

V : Volume of receiving room, m^3 ;

S_s: Area of separating element , m^2.

In this case, S_s is the façade area and V / S_s is equal to depth of room. This equation can be used for transforming laboratory values into on-site values and comparing them.

4.6 Sound Recordings of Common Vehicles

In this approach, for traffic sound recordings, most common types of vehicles are determined by statistical information, driving conditions are determined by data from noise maps, noise prediction models and/or on-site research. Sound recordings are conducted in a similar approach to traffic noise measurement standards. The test tracks are to be constructed according to the standards. If that is not possible, available roads in the rural areas which comply with the standards may be used.

4.6.1 Determining vehicles and driving conditions

Available statistical data may be used to determine the most common types of vehicles which may be used in recording vehicle sounds in traffic conditions. Driving conditions may be determined by using data from noise maps, noise prediction model and/or on-site research.

Traffic noise prediction model NMPB-Routes-96 (1995) is advised by the Directive (EU Parliament and Council, 2002). In this model, given traffic flow types are fluid continuous, pulsed continuous, pulsed accelerating and pulsed decelerating. The traffic flows may be categorized the same way, for compatibility.

In “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure”, (WG-AEN, 2006) the roads are classified as dead-end roads, service roads, collective roads, small main roads and main roads. The same classification is used in this approach for compatibility purposes.

Annex A of ISO 362-1 (2007) gives the technical background for development of vehicle noise test procedure based on in-use operation in urban conditions. In the annex, the distribution of vehicle speed in urban traffic is examined and driving behavior is recorded on actual urban routes. Speed, acceleration and gears are statistically examined in urban driving conditions. Standard recommends vehicle speed and acceleration for the measurement to be determined according to real urban traffic conditions, so that vehicle emission in urban traffic may be portrayed correctly. An on-site study by driving through the area at different times during the day can be used to reveal the driving patterns.

All the data collected about vehicles and driving conditions should be examined and most common vehicle types and driving conditions for each road type should be determined. Traffic sound recordings should be made for each type of vehicle, for all possible driving conditions (traffic flow type, speed or acceleration, road slope, road surface), separately. If there are other dominant traffic elements such as horn noise, these may also be recorded.

4.6.2 Conducting traffic sound recordings

ISO 362-1 (2007), ISO 362-2 (2009) and ISO 10844 (2014) standards are used as guidelines in traffic sound recordings.

The test track construction and surface requirements are given in ISO 10844 (2014). The geometry of the proposed test track altered according to this approach is given in Figure 4.12. Within a radius of 50 m around the center of the track, the space shall be free of large reflecting objects such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials (ISO 362-1, 2007).

In the vicinity of the microphone, there should be no obstacle that could influence the acoustical field and no person can remain between the microphone and the noise source. The distance from the microphone positions on the microphone line PP' to the perpendicular reference line CC' on the test track should be 7.5 m ± 0.05 m. The microphone shall be located about 1.2 m above the ground level. The path of the centerline of the vehicle should follow line CC' as closely as possible throughout the entire test, from the approach to line AA' until the rear of the vehicle passed line BB'. For accelerations and decelerations, the test speed is reached when the reference point was at line PP' (ISO 362-2, 2007). For fluid continuous traffic flow recordings, test speed is constant from AA’ to BB’. Reference points of road vehicles are defined according to engine positions, which is mostly the front end of vehicles (ISO 362-1, 2007).

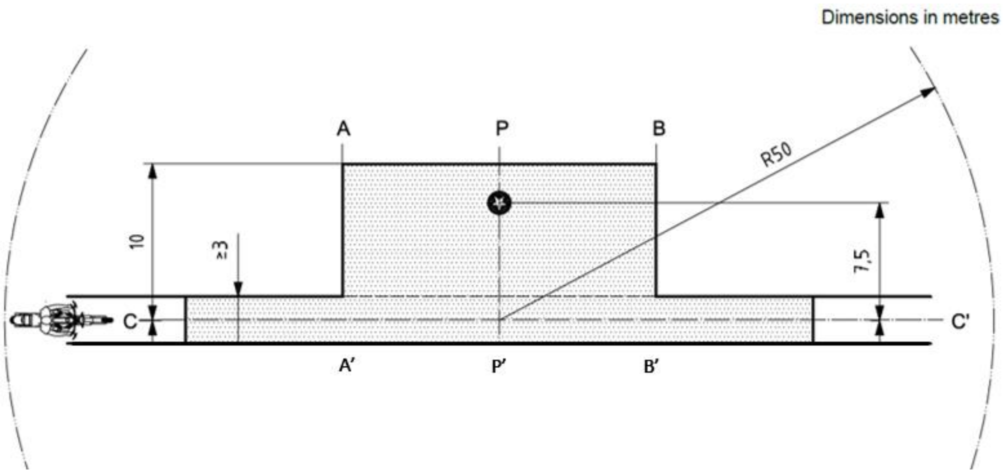


Figure 4.12 : Test site dimensions

The test track is a test instrument and shall be protected from damage and be taken care of. If it is possible, the test track should be used only for noise measurements. It should be kept clear from loose debris or dust during measurements (ISO 10844, 2014).

The background noise is measured before and after recordings. The recordings are made with the same microphones and microphone locations used during the test. The background noise should at least 10 dB below the A-weighted sound pressure level produced by the vehicle under test (ISO 362-1, 2007).

ISO 362 standard series recommend vehicle speed and acceleration for the measurement to be determined according to real urban traffic conditions, so that vehicle emission in urban traffic may be portrayed correctly. Inquiries among dwellers along various streets show that noise disturbance happens mainly along urban main streets, and during vehicle acceleration transients (ISO 362-1, 2007). According to ISO 362-1 (2007), the behavior of drivers depends on speed limits (traffic laws), traffic density, road arrangement (traffic lights, corners, etc.), driving purpose (commuting, pleasure, commercial, etc.), enforcement of traffic laws, and the way the vehicle behaves as an acoustical source under these conditions.

4.7 Creating Sound Clips

The sound clips are formed with the purpose of helping to develop a road traffic noise annoyance model. The sound clips should each simulate a traffic noise situation possible to hear inside houses in the area under consideration. First, road types and characteristics are determined to create the traffic noise heard 7.5 meters from road sources (ISO 10844, 2014). Then, sound propagation characteristics for the urban area are investigated and used for creating and applying sound propagation filters to sound clips. To simulate the traffic noise heard inside the houses, sound insulation values are applied as sound filters. All of these steps finally create the sound clips to use in the listening tests.

4.7.1 Determining road type characteristics

Road types in the area should be determined. Characteristics which influence traffic noise emission are, traffic volume, types of vehicles, traffic speed, traffic flow type and road surface. European Commission’s Good Practice Guide for Strategic Noise Mapping (WG-AEN, 2006) proposes some default values for traffic flow volume, these values may be adapted to the area under consideration. If the area already has a road classification system, that may also be used. Statistics of road motor vehicles may also be used. The on-site research recommended by Annex A of ISO 362-1 (2007) can be used to determine traffic conditions. After using all of the possible data, traffic flow for all roads in the area should be determined and grouped. In order to use this data in sound clips, road traffic volumes should be adjusted from one hour to the length of the sound clips. The length of the sound clips may be between 10 seconds and one minute, but the roads with the lightest traffic volume should be considered when making this choice.

4.7.2 Generating sound propagation filters

The sound clips represent different types of roads and traffic flow characteristics recorded at 7.5 meters from road sources, in open space conditions. Some common examples of urban sound propagation should be calculated and applied as filters to sound clips at hand, in order to simulate traffic sounds in the city. Filters for geometric divergence and atmospheric absorption can be created from literature. Filters for urban condition examples may be calculated with noise mapping software or by internationally accepted methods of sound propagation.

4.7.2.1 Geometric divergence and atmospheric absorption

Filters for geometric divergence and atmospheric absorption may be created from literature. Geometric divergence for line sources is attenuation of 3 dB for doubling of distance. Because the sound recordings are conducted 7.5 m away from source, geometric divergence filter values for double distances such as 15 m and 30 m can be used. The same principle is applied for atmospheric absorption using sound absorption values from ISO 9613-1 (1993).

4.7.2.2 Urban sound propagation

Environmental noise prediction model recommended by the Directive, NMPB-Routes-96 (1995), may be used to assess all types of sound propagation in the settlement types.

Various noise propagation conditions may be simulated in noise mapping software, both in open space conditions and in urban conditions. The difference between the two conditions are to be used to create sound propagation filters, which are used on sound clips, in order to simulate traffic sounds in city conditions.

Urban sound propagation filters include attenuation due to ground effect and diffraction.

4.7.2.3 Sound insulation filters

Environmental noise annoyance focuses on environmental noise perceived inside houses. In order to simulate this effect, the sound clips are filtered by façade sound insulation values, determined by on-site measurements explained in the previous section.

4.8 Conducting Listening Tests

For the listening tests, questions and sound clips are prepared, tests are conducted in laboratory conditions and results are analyzed.

4.8.1 Questionnaire forms for listening tests

Listening test questions are prepared in parts. Pre-criteria questions determine if the participant is competent to attend the survey. The first part of the listening tests include the same questions as the on-site socio-acoustic survey conducted in the area. The second part of the survey inquire into the annoyance of sound clips. Figure 4.13, Figure 4.14 and Figure 4.15 give the parts of the listening test.

Pre-criteria for conducting the surveys are; minimum 12 months of residency in Besiktas District, lack of any hearing problems and being in the age range of 18 to 65. If necessary, the age range may be altered due to area's demographics.

In Part 1 of the listening test, personal information and environmental noise annoyance are questioned. Under the heading of 'personal information', gender, age, education level, duration of residence, time and period spend at home during day, noise sensitivity and noise annoyance at workplace are investigated. Under the heading of 'noise annoyance', traffic noise annoyance at home, for all day and only night periods are investigated in verbal and numerical scales. Wording of these questions and verbal and numerical scales are given in ISO/TS 15666 (2003). Also under the same heading, most annoying traffic elements and annoyance during daily activities are inquired using multiple-answer questions. Room positions in regards to main road, open windows during night and main wall elements are also questioned.

Part 2 of the listening test inquired about how much the sound clips bother, disturb or annoy the participants in verbal and numerical scales (Table 1). Wording of these questions are similar to questions given in ISO/TS 15666 (2003). Verbal and numerical scales are the same as scales used in Part 1 and ISO/TS 15666 (2003).

Part 2 is divided into four sub-parts to provide breaks if necessary. In sub-parts 1 and 2, wording of the questions do not change. The question is; "Imagining you are resting at home, how much does the sound clip you listened to, bother, disturb or annoy you?". In sub-part 3, a time frame is given in each question, such as day time (07-19), evening time (19-23) or night time (23-07). In sub-part 4, the activity changes from resting to reading. A short magazine article is read by participants. The article is divided in two parts, first part is read in quiet, while the second part is read with exposure to traffic noise. If the result of the 14^{th} question in the socio-acoustics surveys show other types of activity as most disturbing, those activities may be preferred in this part.

TRAFFIC NOISE ANNOYANCE LISTENING TEST
Dear participant,
This listening test is …(explain source of study)…
By answering the following questions, you will be making a big contribution to this research/project/study. Thank you for your support.
Personal information of participants will not be shared with third parties.
Please read and sign the Consent Form before you begin.

Pre-questions:

A.1. Do you live in …. (district, city)?
Yes (1) → Continue
No (2) → End the interview

A.2. Have you lived in this residence more than 12 months?
Yes (1) → Continue
No (2) → End the interview

A.3. Do you have any hearing problems?
Yes (1) → End the interview
No (2) → Continue

A.4. Age of respondent ……….. (DO NOT INTERVIEW < 18 YEARS AND >65 YEARS)
(1) → 18-35 (2) → 36-50 (3) → 51-65

If the respondent is suitable to these criteria, please continue.

Figure 4.13 : Exemplary Pre-criteria questions in the listening test.

PERSONAL INFORMATION

1) Gender: ☐Female ☐Male

2) Age: ………

3) Educational Level:

☐Primary School ☐Secondary School ☐High School ☐Graduate ☐Postgraduate

4) How many years have you lived at your current address?………

5) How many hours do you spend at home during the day? ………

6) What is your home-staying period? (more than one answer can be chosen)

☐ Day (7am-7pm) ☐ Evening (7pm-11pm) ☐ Night (11pm-7am)

7) Are you generally sensitive to noise?

☐ Not sensitive ☐ Somewhat sensitive ☐ Highly sensitive

8) Are you annoyed by the noise at your workplace?

☐ I do not work ☐ Not annoyed ☐ Annoyed

NOISE ANNOYANCE

9) Thinking about the last 12 months, when you are at home, how much does noise from **road traffic** bother, disturb or annoy you?

☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely?

10) Thinking about the last 12 months, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by **road traffic noise**?

Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

11) Thinking about the last 12 months, during **sleep at night**, how much does noise from **road traffic** bother, disturb or annoy you?

☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely?

12) Thinking about the last 12 months, during **sleep at night**, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by **road traffic noise**?

Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

13) Which element of road traffic noise is the most annoying for you? (one or more answer)

☐ Cars ☐ Trucks ☐Buses ☐ Minibuses ☐ Motorcycles ☐ Horns ☐Not specific

(Please add or remove any road traffic element if needed)

14) During which of the activities below are you more disturbed by the traffic noise? (one or more answer)

☐ Concentrating (Reading, Working, Studying) ☐ Conversing ☐ Watching TV ☐ Resting ☐ Sleeping ☐ Other………….………

15) Which room or rooms in your house overlook the street in which there is the major road noise? (one or more answer)

☐ Living room ☐ Bedroom ☐ None ☐ Other ……….

16) Do you sleep with your windows open?

☐ Yes, during summer and winter ☐Yes, only in summer ☐No

17) What is the main wall element of your façade?

☐Brick ☐Aerated concrete ☐ I do not know ☐Other ……….

(Please add or remove any wall element if needed)

Figure 4.14 : Exemplary Part 1 questions in the listening test.

Part 2, Sub-part 1 and Sub-part 2
XX) Imagining you are resting at home, how much does the sound clip you listened to, bother, disturb or annoy you? ☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely? XX) Imagining you are resting at home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

Part 2, Sub-part 3 (the question asks for only one time frame)
XX) Imagining you are resting at home, during day time (07-19) / evening time (19-23) / night time (23-07) , how much does the sound clip you listened to, bother, disturb or annoy you? ☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely? XX) Imagining you are resting at home, during day time (07-19) / evening time (19-23) / night time (23-07) , what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

Part 2, Sub-part 4
XX) Imagining you are reading at home, how much does the sound clip you listened to, bother, disturb or annoy you? ☐ Not at all? ☐ Slightly? ☐ Moderately? ☐ Very? ☐ Extremely? XX) Imagining you are reading at home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? Not at all Extremely

0	1	2	3	4	5	6	7	8	9	10

Figure 4.15 : Exemplary Part 2 questions in the listening test.

4.8.2 Executing listening tests

Pilot listening tests are executed if possible, to identify the possible problems. Some explanatory phrases and warnings may be added to the listening test as a result of the pilot study. The listening tests are conducted as face-to-face interviews with at least 40 people between the ages of 18 and 65, who live in or around the related area. The listening tests are executed in a laboratory, where background noise is always monitored.

Headphones should be used to listen to sound clips. All participants should sign a consent form and they should be warned to stop the test if they felt any auditory problem. The investigator asks the questions, turn on the sound clips and type the answers of the participants; so that the participants can concentrate on the sound clips. 30 second breaks are given between each sound clip to ensure concentration and a fresh perception. Participants are free to express any opinions they have about the sound clips and the listening test.

4.8.3 Analyzing listening test and building annoyance model

Listening test results are statistically analyzed; Cronbach's alpha is computed for reliability and correlation coefficients are calculated for factors affecting annoyance.

Verbal and numerical scales are used for sound clip annoyance questions. These different scales are converted and analyzed on a 100 scale. On the verbal scale, "not at all" is converted to 0, "slightly" to 25, "moderately" to 50, "very" to 75 and "extremely" to 100. On the numerical scale, 0 is 0, 1 is converted to 10, 2 to 20 and so on. For analyzing percentage of people annoyed (%A) and percentage of people highly annoyed (%HA) the cutoff points on a 100 scale are 50 for %A and 72 for %HA (WG-HSEA, 2002). On the verbal scale, cutoff point of 50 for %A referred to points 50, 75 and 100, which are "moderately", "very" and "extremely" respectively. Cutoff point of 72 for %HA referred to points 75 and 100, which are "very" and "extremely" respectively. %A is associated with the total number of responses for 5, 6, 7, 8, 9 and 10 (from 50 to 100 on the 100 scale) on the numerical scale, whereas %HA is associated with the total number of responses for 8, 9 and 10 (from 80 to 100 on the 100 scale) on the numerical scale.

Annoyance levels for each simulated traffic sound clip is examined for number of people annoyed and highly annoyed within the whole group of respondents, in order to calculate percentage of people annoyed (%A) and percentage of people highly annoyed (%HA). Averages of verbal and numerical scale results are used. %A and %HA levels for each sound clip are then compared to others with similar properties to build a listening test annoyance model.

4.9 Developing A Noise Annoyance Prediction Model

The prediction model should be developed using the annoyance model derived from the listening tests as base. It should be validated using the on-site socio-acoustic surveys. It should then be presented as a guideline on how to apply the prediction model.

4.9.1 Developing prediction model base

The foundation of the prediction model is the annoyance model derived from the listening tests. This annoyance model provides dose-effect relationships between traffic conditions (dose) and noise annoyance (effect). The traffic conditions are defined by road types, flow types, average vehicle speeds, road slope and surface. Adjustments such as urban sound propagation conditions, horns, specific vehicles or specific situations may also be used in addition to traffic conditions. The noise annoyance expressed in these relationships are the same as defined by the Directive (The European Parliament and The Council of The European Union, 2002).

4.9.2 Validating prediction model base

The listening test sound clips are short-termed, therefore their effect is not the same as noise annoyance experienced in long term inside residents' houses. In order to correct and/or validate the model derived from listening tests, results from on-site socio-acoustic surveys should be used.

The results from socio-acoustic surveys should be examined step by step.

Step one: Each survey result should be matched with the street on its address (provided by the address given in survey). The type of the road and traffic properties (flow, speed, road slope and surface) should be determined for each of these streets. Each survey result with the same type of road and traffic property should be grouped. Each of these groups should be analyzed to determine %A and %HA, within each group. The answer scales should be converted to a 100 scale. For analyzing percentage of people annoyed (%A) and percentage of people highly annoyed (%HA) the cutoff points on a 100 scale are 50 for %A and 72 for %HA (WG-HSEA, 2002). The %A and %HA of each group should be compared to %A and %HA of listening tests. If the difference between on-site (socio-acoustics surveys) and laboratory (listening test) results are mostly more than 10%, go to step two.

Table 4.1 : An example of a study table for grouping survey results.

	Street Address				Road type					Road				
Survey No	District	Street	Build. No	Floor No	Dead-end	Service	Collective	Small main	Main	Surface	Slope	Annoyance response	Urban propagation	Main road (if needed)

Step two: Each survey point on map should be checked for similar relations to urban propagation conditions studied in this research. These might be streets affected by noise from main roads or street canyons, or any other urban effect studied. An example of a study table is given in Table 4.1. The survey results should be grouped according to this point of view. The %A and %HA for each group should be calculated and compared to listening test model. If the difference between on-site (socio-acoustics surveys) and laboratory (listening test) results are mostly more than 10%, go to step three. If the results are similar, try statistical verification.

Step three: Each survey point on map should be examined for any other possible unexpected sound situation: such as unexceptionally quiet or noisy streets, or extreme use of horn, a type of vehicle, traffic lights, speed bumps, or extremely high slopes, or different road surfaces. These effects might be recorded, measured of simulated if needed, for better understanding of the situation. These effects that might be occurring on the street address or around it, such as parallel roads or perpendicular roads should be determined.

Statistical verification: A “test of goodness of fit” establishes whether or not an observed frequency distribution differs from a theoretical distribution. Test of goodness of fit is made by Pearson's chi-squared test. To perform this test, the total of observed an expected must be equal. To execute the test in the percentage of annoyed people, percentage of non-annoyed people should also be calculated. An example is given in Table 4.2.

Looking at the results of the Pearson's chi-squared test, P-value is important in determining if the results are different from each other or not.

Statistical significance (or a statistically significant result) is accomplished when a p-value is less than the significance level (α, alpha). By conventional criteria, significance level is 0.05. So if the P-value is more than 0.05, the expected and observed results are considered to be statistically not different, so the same.

Table 4.2 : Input example for Pearson's chi-squared test, for %A listening test result 25%, %A on-site survey result 28%.

	Category	Expected	Observed
1	Annoyed	25	28
2	Not-annoyed	75	72

Trying all possible percentages on Pearson's chi-squared test showed that difference between expected and observed percentages may be up to 10%. Using this information as a pre-test in each step is convinient.

The model can be considered to be validated when all the possible survey groups are validated.

Some situations considered in the listening tests might be unavailable in the on-site surveys or have very few number of surveys. In that case, these situations cannot be validated.

4.9.3 Forming prediction model

The prediction model should be formed using the validated situations. Non- validated situations may not be used for the final prediction model. Each possible type of situation should coincide with the relevant %A and %HA values.

4.9.4 Presenting prediction model

The final model should be presented with guidelines on how to use the prediction model created. The guidelines should provide information on limitations of the model and on how to determine the types of roads, traffic conditions, urban propagation conditions and any other effects considered. The guidelines should provide dose-effect relationships between traffic conditions (dose) and noise annoyance (effect).

5. IMPLEMENTATION OF THE APPROACH FOR DEVELOPING ROAD TRAFFIC NOISE ANNOYANCE PREDICTION MODEL IN ISTANBUL-BESIKTAS DISTRICT

In this section, the approach for developing road traffic noise annoyance prediction model is implemented in Turkey, Istanbul, Besiktas district. Noise maps, socio-acoustic surveys, façade insulation analysis, sound recordings, sound clips, listening tests and annoyance prediction model steps are all carried out for the center of Besiktas district.

Turkey is a candidate for EU membership and in this process, EU directives and regulations are being applied into Turkey's legislative system. "Assessment and Management of Environmental Noise (2002/49/EC)" Directive (The European Parliament and The Council of The European Union, 2002) was adopted to Turkey with the same name (In Turkish: Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği) (Republic of Turkey Ministry of Environment and Forestry, 2010).

Istanbul is the most populated city in Turkey, with a population of 14,377,018, according to ABPRS (Address Based Population Registration System) records for end of 2014. Besiktas, one the oldest districts, is one of the 39 districts in Istanbul, with a population of 118,793 (ABPRS, 2014). The center of Besiktas district is Barbaros Avenue, which connects the Bosphorus to the traffic node of Zincirlikuyu. In the middle of Barbaros Avenue, D-100 connection road connects this area to the Bosphorus Bridge. The aerial photograph is given in Figure 5.1.

More than 30 million vehicles pass annually in Barbaros Avenue, with a traffic trend nearly constant throughout the year. The examined area is chosen taking into account the high number of vehicles, diversity of vehicle types, the heterogeneous characteristics of land use and the presence of residential areas, densely populated (Badino et al., 2012).

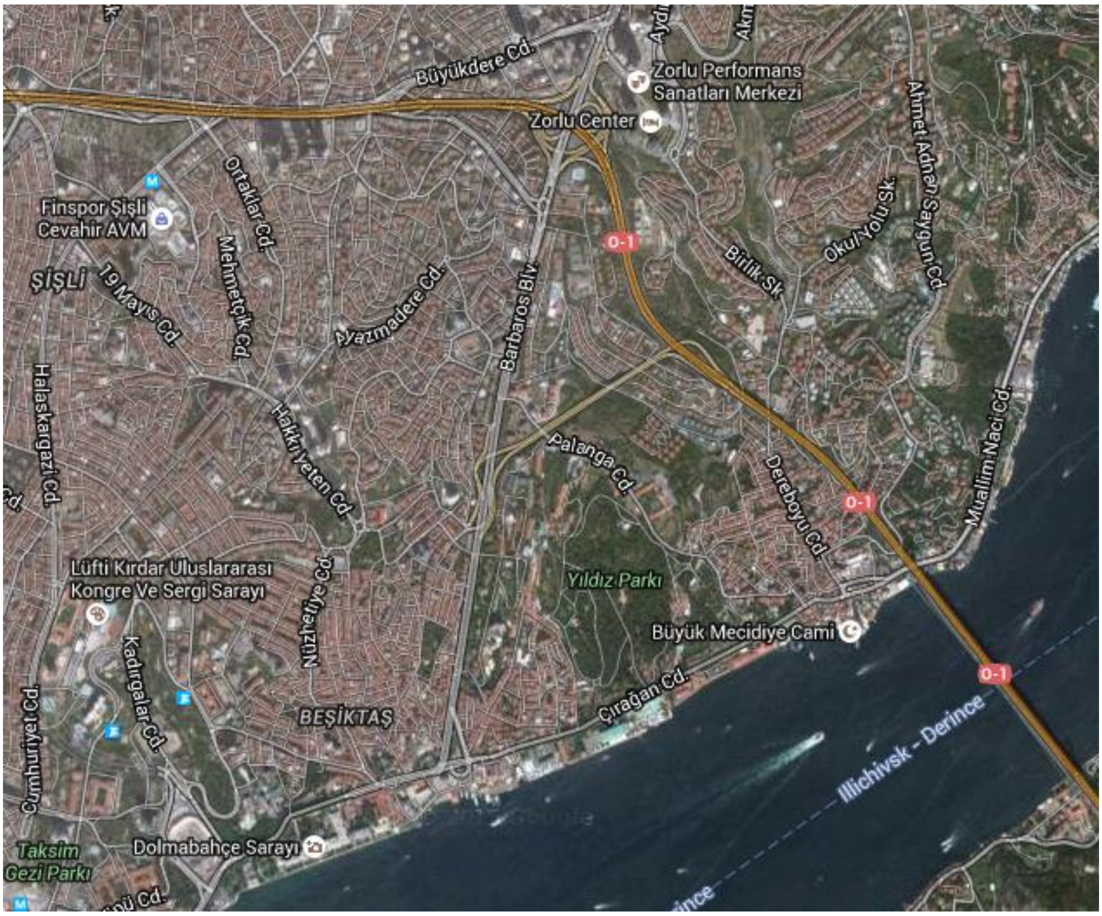


Figure 5.1 : Aerial photograph for central Besiktas (GoogleMaps).

5.1 Preparing Road Traffic Noise Map for Besiktas

A road traffic noise map around Barbaros Avenue in Besiktas District was prepared by A. Badino and M. Ascigil-Dincer in 2010 (Badino et al., 2012).

5.1.1 Computation method and simulation software for Besiktas noise map

Turkey has no national computation method, so French national computation method 'NMPB-Routes-96 (SETRA-CERTU-LCPCCSTB), (NMPB-Routes-96, 1995) was used, as recommended by the Directive (The European Parliament and The Council of The European Union, 2002). For emission input data, 'Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, (CETUR, 1980)' was used.

Annex II revision of the Environmental Noise Directive (CNOSSOS-EU, 2012) was not used in this study because the revision was published in 2015.

5.1.2 Choosing simulation software

Soundplan 6.5 was used for simulating the noise environment. Inputs and outputs of the software are compatible with requirements of the Directive.

5.1.3 Collecting data in Besiktas

Barbaros Avenue is a straight road, 2.3 km long. It is formed by 2 carriageways, one for each direction, divided by a central reservation 4 m wide. Each carriageway has 3 lines. The width of each line is 3 m. The route starts next to ferryboats station of Besiktas, almost 5 m above sea level and finishes at a height of 118 m above sea level. The slope is 4% between the beginning and the middle of Barbaros and it is 1.8% between the middle and the end.

Concerning the traffic flow, the sensors (Traffic Control Center, 2010) placed in Barbaros Avenue have counted more than 30 million of vehicle passages per year. The average number of vehicles is 43,000 per 24 hours in sea direction and 40,000 per 24 hours in Zincirlikuyu direction. The traffic changes significantly in the middle of Barbaros Avenue, due to the intersection with D-100 Connection Road. 3 different traffic flows are taken into account in Zincirlikuyu direction, whereas 4 traffic flows are considered in sea direction. The annual average number of vehicles per hour in each section is shown in Table 5.1, divided in the 3 day periods: day (7.00 a.m. – 7.00 p.m.), evening (7.00 p.m. – 11.00 p.m.) and night (11.00 p.m. – 7.00 p.m.).

The percentage of heavy vehicles, in respect to the total number of vehicles, changes in the different road sections of Barbaros Avenue, because few heavy vehicles go to or come from D-100 Connection Road. More than 80% of heavy vehicles are buses of the public transportation; there are few trucks, and buses of private transportation. The public buses have different sizes: simple, double and with 2 floors. The light vehicles are motorcycles and mainly cars. There is also another type of vehicle for the public transportation, the minibus. The percentage of minibuses in Barbaros Avenue is about 3.5% of light vehicles.

In Zincirlikuyu direction the heavy vehicles have a low speed in the first and second section due to the high slope; the speed increases in the third section where the slope is smaller. In sea direction the speed is low in the third and specially in the fourth section, because there is the connection of Barbaros Avenue with Besiktas Street, regulated by a traffic light. In general the speed is high when the traffic is smooth-flowing. The annual average values can reach 95 km/m for light vehicles and 80 km/h for heavy vehicles.

Table 5.1 : Annual average values of traffic flow of Barbaros Avenue (Badino et al., 2012).

Direction	Road section	Total vehicles [veh/h]			Percentage of heavy vehicles [%]		
		day	evening	night	day	evening	night
Zincirlikuyu	Section 1	3573	2466	1024	2.3	2.3	2.1
	Section 2	4558	3167	1250	2.2	2.3	2.2
	Section 3	2667	1773	665	2.9	2.8	3.2
	Section 4	4312	2943	970	1.8	1.7	2.2
	Average	3778	2587	977	2.3	2.3	2.4
Sea	Section 1	4574	3783	1468	2.4	2.6	3.1
	Section 2	3292	2700	1095	2.6	2.6	3.4
	Section 3	4334	3049	1077	1.9	2.3	3.4
	Average	4067	3177	1213	2.3	2.5	3.3

Table 5.2 : Annual average values of the traffic flow of the road sources (Badino et al., 2012).

Street name	Direction	Total vehicles [veh/h]			Percentage of heavy vehicles [%]		
		day	evening	night	day	evening	night
D-100	to Barbaros Av.	1317	1692	836	2.0	1.6	1.0
Connection	from Barbaros Av.	1535	1016	649	1.5	2.3	1.0
Ciragan	both directions	1966	1945	1212	3.0	2.5	2.0
Besiktas	to Barbaros Av.	2671	2732	1653	4.3	3.5	3.0
	from Barbaros Av.	3114	2553	1571	3.5	3.2	2.2

Other main roads, connected to Barbaros Avenue and with similar traffic flows, are considered in the traffic noise map, because their contribution in terms of number of vehicles and emitted noise levels cannot be neglected. These roads are: Besiktas Street, Ciragan Street and D-100 Connection Road.

The traffic flows of these three roads, considered in the modeling and shown in Table 5.2, are annual average values, divided in the 3 day periods. In each road the vehicle passages per year are more than 6 million. The percentage of heavy vehicles is high along Besiktas Street, whereas it is very low in D-100 Connection Road.

Secondary roads, whose traffic flow varies in function of the traffic flow of Barbaros Avenue, are also taken into account. Most of them have only one lane and the number of vehicles per hour is very low if compared to the main roads and to Barbaros Avenue. Even though the noise levels are lesser than the noise levels generated by the main roads, it has been decided to take into account 30 secondary roads because they are connected to Barbaros Avenue and they can influence the answer of the resident people to the annoyance. Some of these roads have been paved with cobblestone. Other sources, connected to road traffic and taken into account in the traffic noise map, are the traffic signals, the bus stops and the parking.

The land use is quite different between left and right side of Barbaros Avenue: on the right side of Barbaros Avenue, the area is less dense and land is greener than on the left side. In the right side there are different military areas, the campus of Yildiz Technical University and behind it the big Park of Yildiz. The residential buildings are concentrated in the area near Ciragan Street and in the Mediko Village. There are few commercial buildings and the offices are placed in the upper part of Barbaros Avenue. In the left side the commercial buildings are mainly in the area of Besiktas, whereas the offices are further north.

The contour line L_{den} = 55 dB(A) is defined considering the noise propagation of Barbaros Avenue in free field without the presence of buildings or other constructions or noise sources, as suggested by the European Commission working group. Only the digital ground morphology, the ground absorbing characteristics and the two road traffic sources, corresponding to the two carriageways of Barbaros Avenue, are introduced in the numerical model. Once the area to be mapped is defined, the other road sources, the buildings, the bus stops, the parking, the traffic lights, are inserted into the model (Badino et al., 2012).

5.1.4 Validating Besiktas traffic noise map

For validating the noise map in Besiktas district, sound pressure level measurements on site were compared to calculated levels in simulation software. The measurements are made according to ISO 1996-2, for road traffic, during appropriate weather conditions. Receiver points are chosen to support favorable sound propagation conditions of downward sound-ray curvature.

Table 5.3 : The comparison of measured levels and calculated levels (Badino, 2012).

Position	L_{day} (10.00 a.m. - 11.00 a.m.) [dB(A)]		
	Calculated level	Measured level	Difference
1P	63.4	62.3	1.1
2P	66.8	65.5	1.3
3P	78.6	78.9	-0.3
4P	78.8	78.5	0.3
5P	70.5	69.0	1.5
6P	74.0	72.2	1.8
7P	68.8	67.0	1.8

Position	L_{night} (11.00 p.m. - 00.00 a.m.) [dB(A)]		
	Calculated level	Measured level	Difference
8P	79.0	78.4	0.6
9P	75.8	74.6	1.2

Nine 60 minutes long sound pressure level measurements were made with B&K 2260 Investigator Sound Level Meter. In the month of October, 7 measurements during the daytime at the same hour (10 a.m.-11.00 a.m.) and 2 measurements during the nighttime at the same hour (11.00 p.m.-0.00 a.m.) were taken. The microphone was placed at 1.5 m above the ground surface. October traffic values were inserted into the noise map model and levels were calculated for single receivers 1.5 m above ground. The reflection order was 3, for accuracy.

Noise measurement points and levels are given in Figure 5.2. The comparison of measured levels and calculated levels are given in Table 5.3. The average difference between measured and calculated levels is 1.1 dB, which proves a verified noise map.

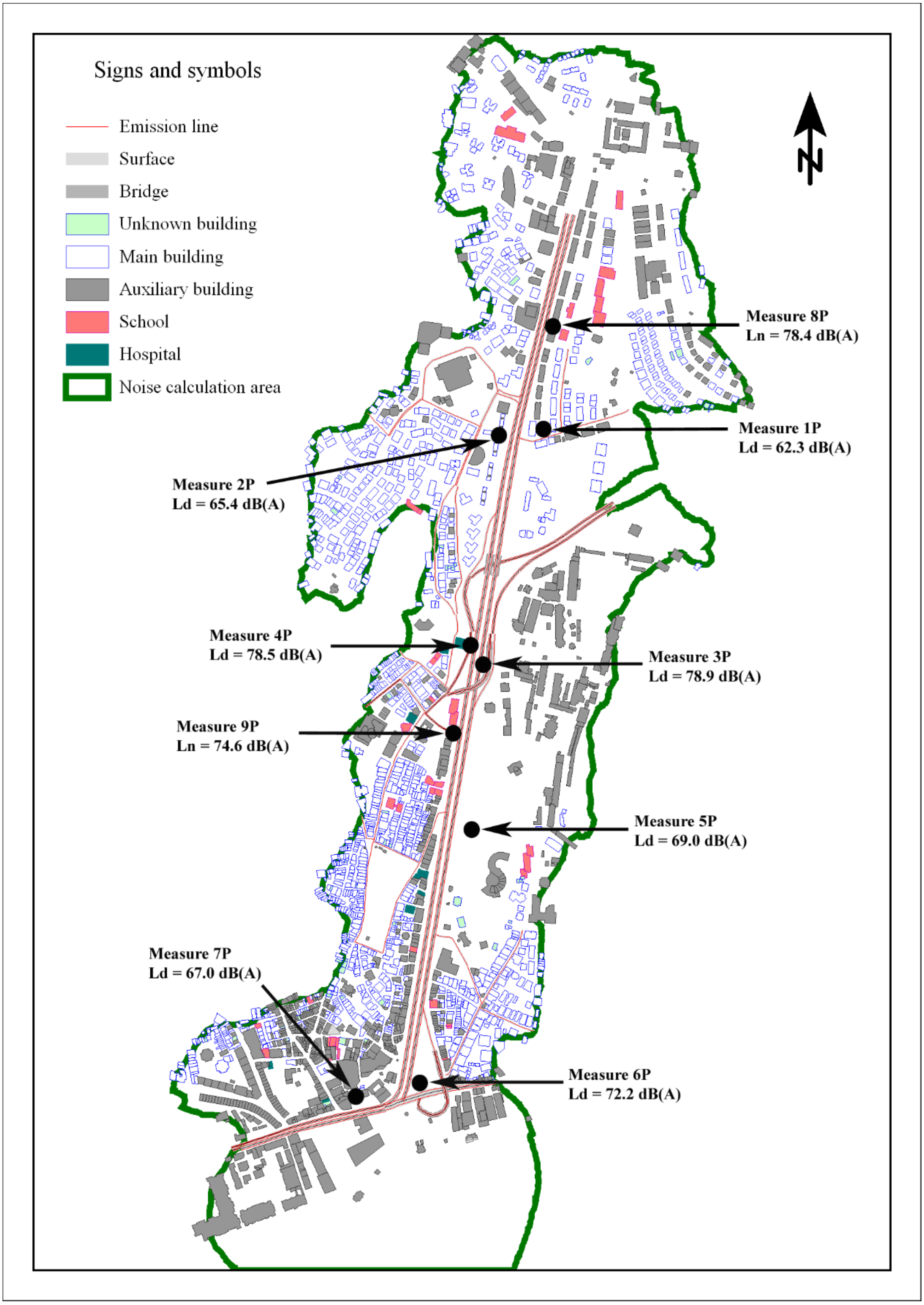


Figure 5.2 : Traffic noise measurements for validation of noise model (Badino, 2012).

5.1.5 Noise map outputs

The noise propagation map at a height of 4 m, as required by the European Directive 2002/49/EC was prepared both for L_{den} (Figure 5.3) and L_{night} (Figure 5.4), as well as the noise façade maps and the maps in agreement with Annex VI of European Directive 2002/49/EC. This map shows the number of residential buildings, hospitals, schools affected by the different values of L_{den} and L_{night} by means of chromatic scales. Figure 5.5 and Figure 5.6 present the façade noise maps for L_{den} and L_{night}. Loudest façade and quiet façade are marked.

Below, clarification on the signs and symbols in the noise map legends are given.

Emission line: Center axis of road.

Unknown building: A building in which the function of the building is not known.

Main building: A residential building.

Auxiliary building: A commercial or depot building.

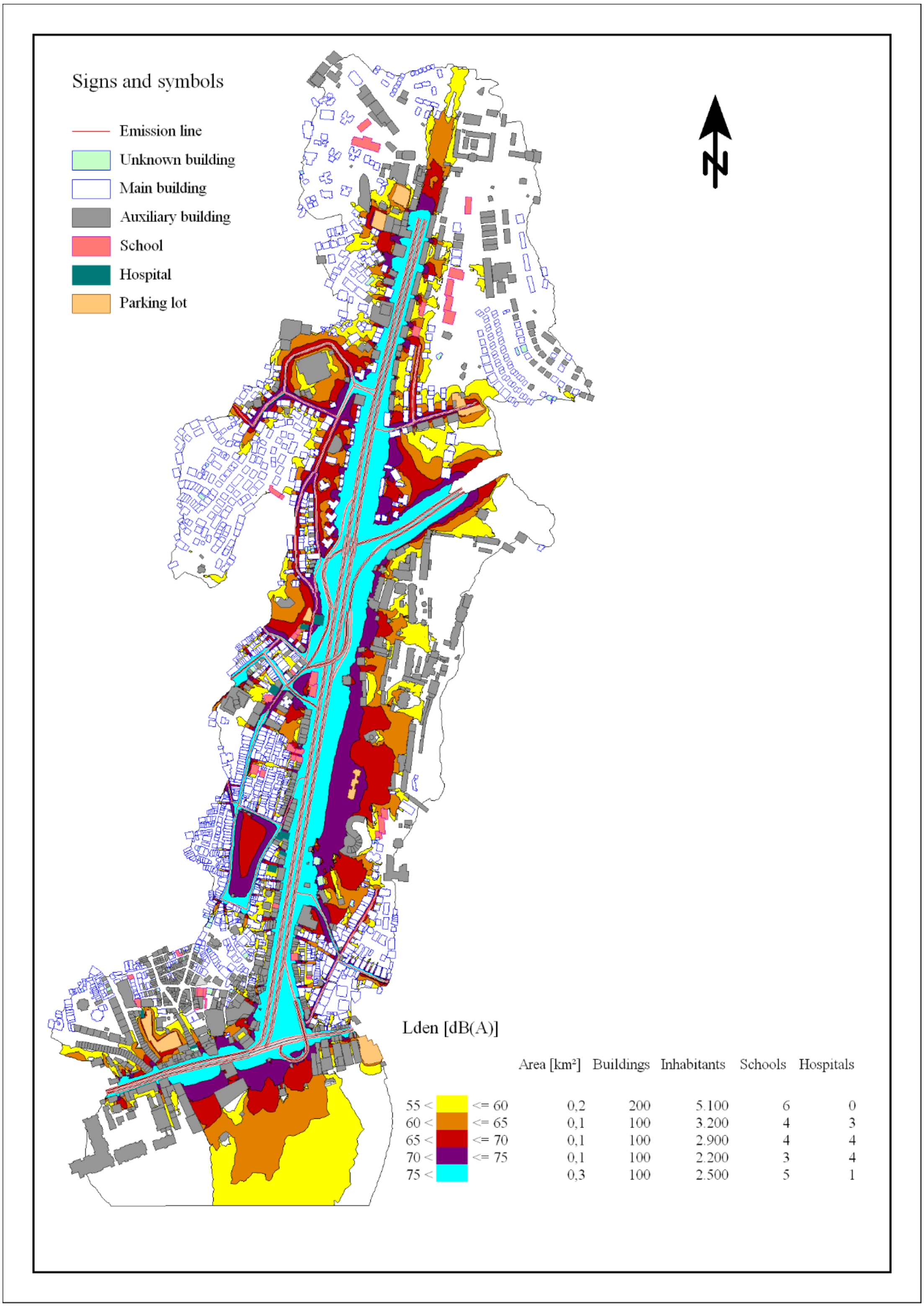


Figure 5.3 : L_{den} traffic noise map of Barbaros Avenue and surronding area at 4 m above the ground (Badino et al., 2012).

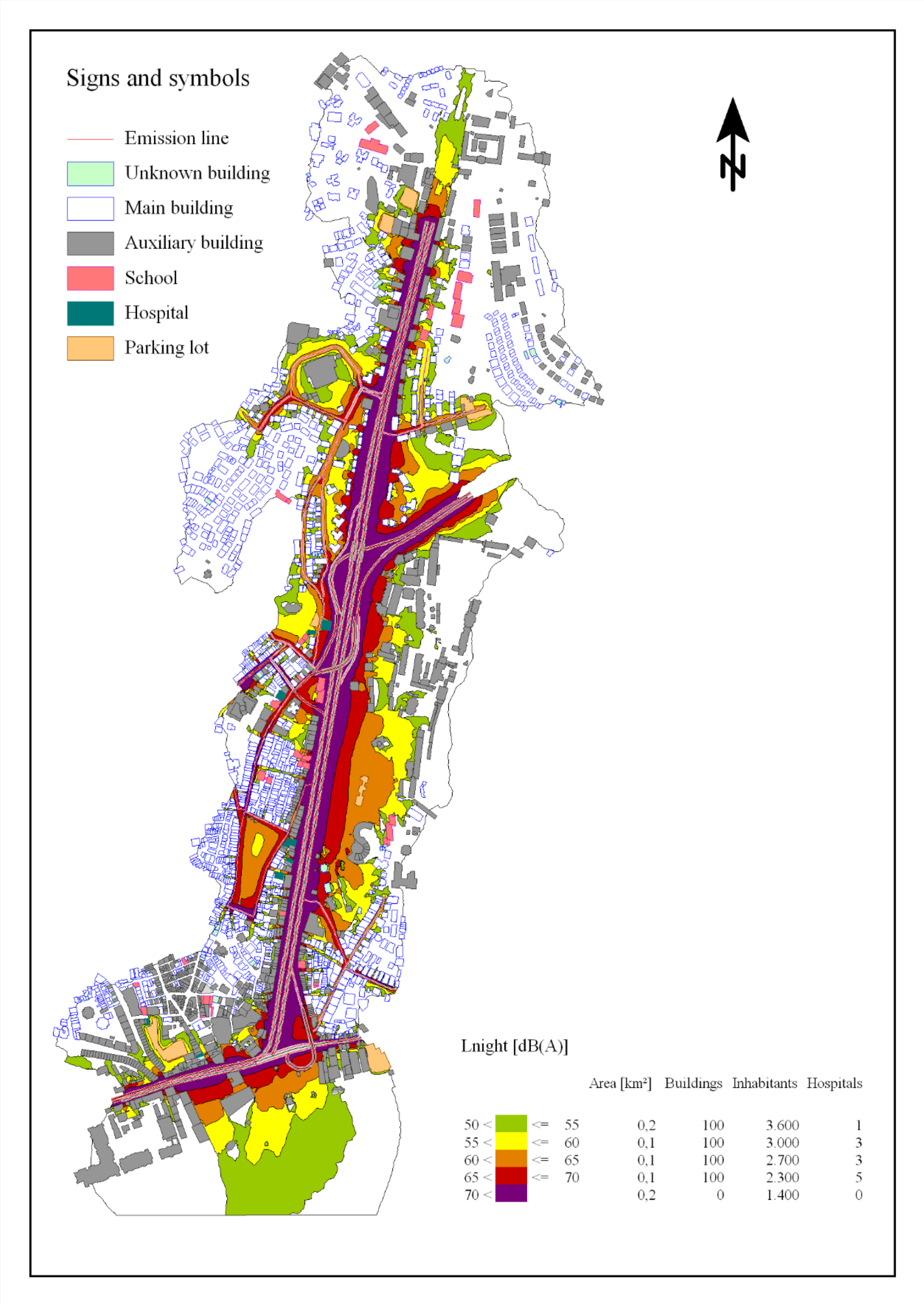


Figure 5.4 : L_{night} traffic noise map of Barbaros Avenue and surronding area at 4 m above the ground (Badino et al., 2012).

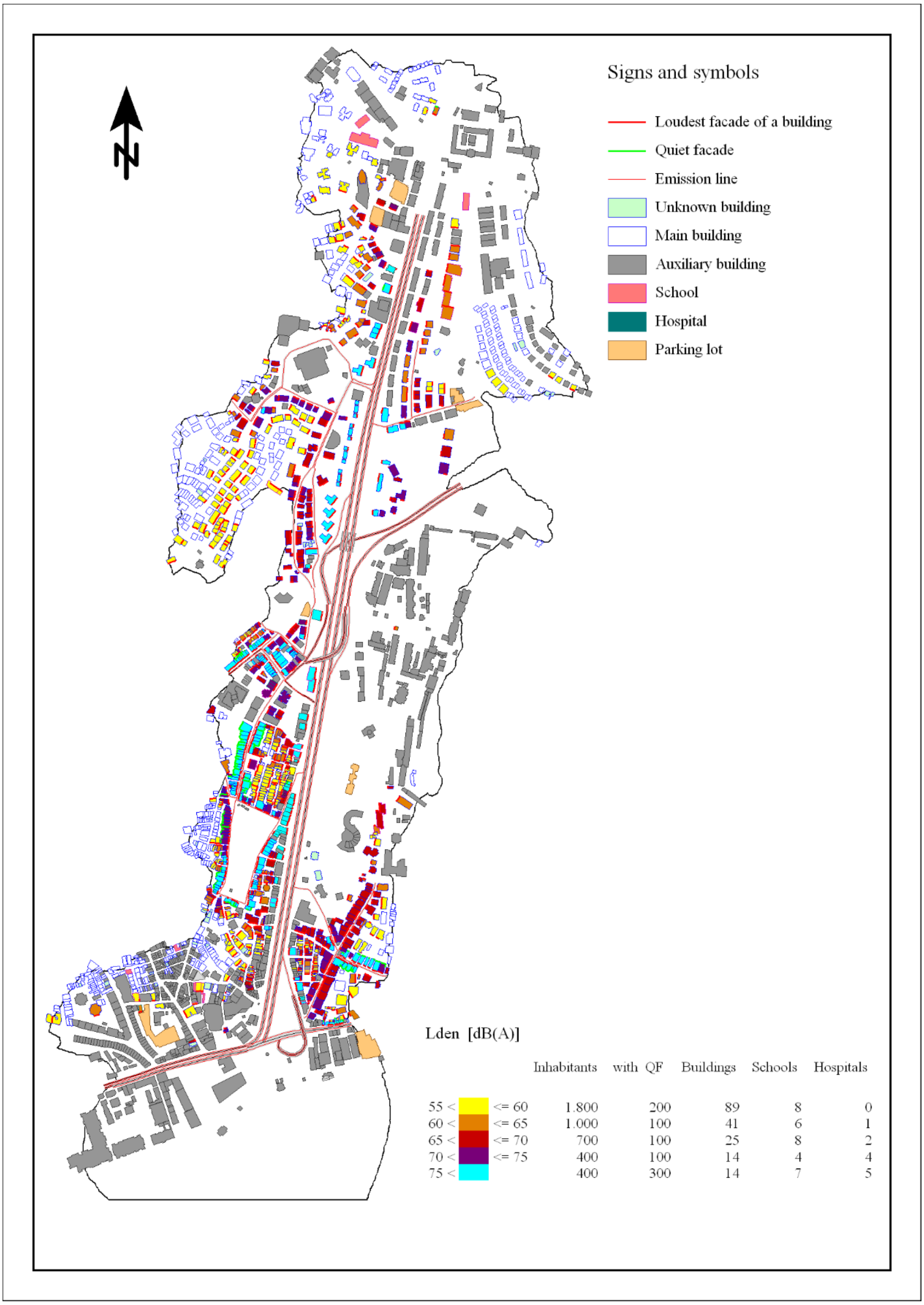


Figure 5.5 : L_{den} facade noise map of Barbaros Avenue (Badino et al., 2012).

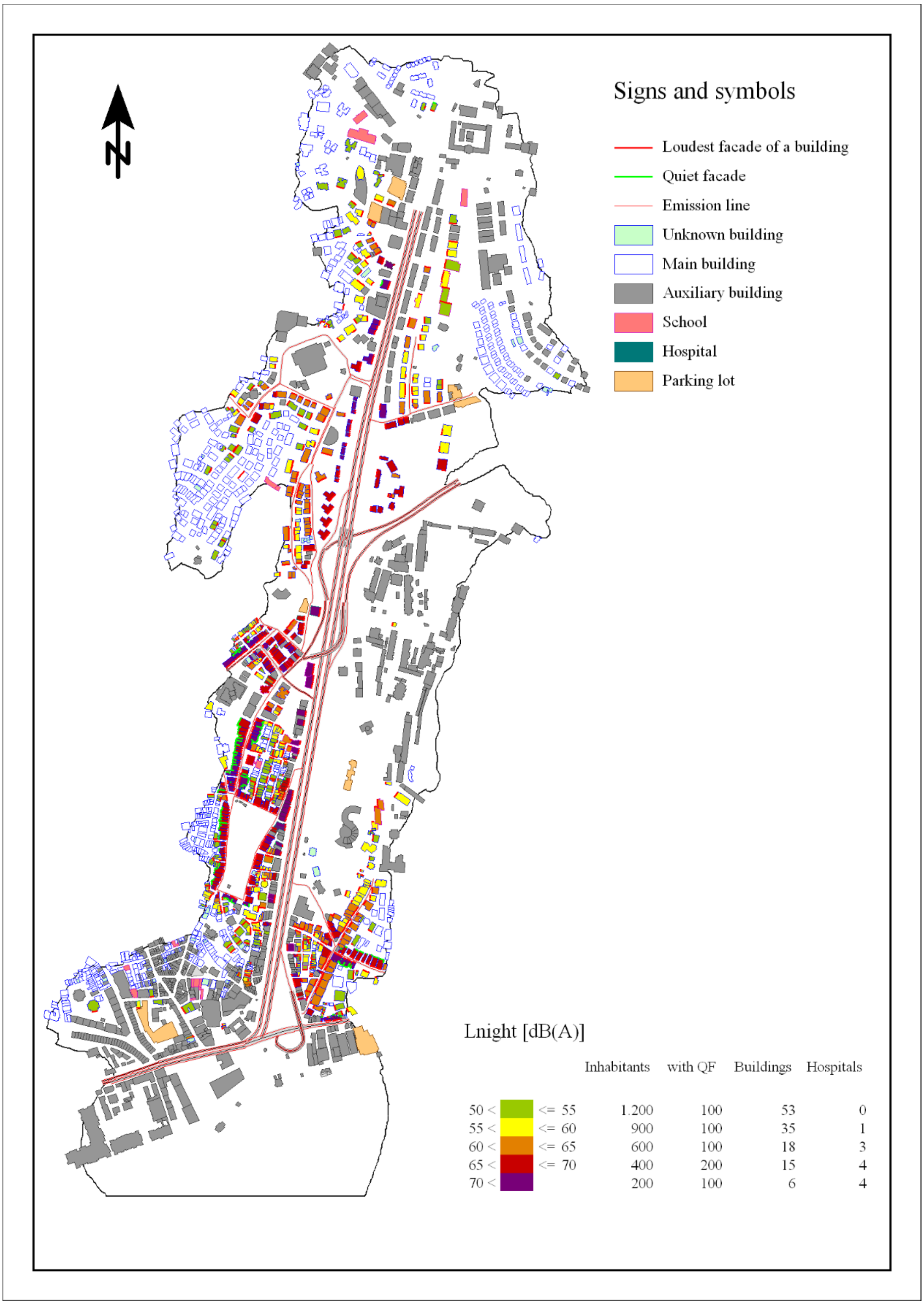


Figure 5.6 : L_{night} facade noise map of Barbaros Avenue (Badino et al., 2012).

5.2 Executing Socio-Acoustic Surveys in Besiktas

A socio-acoustic survey was designed for assessing traffic noise annoyance around Barbaros Avenue. In the area, there are 435 buildings which are affected by L_{den} > 55 dBA traffic noise. 183 face-to-face interviews were conducted by simple random sampling method in the residences from November 2011 to February of 2012.

5.2.1 Socio-acoustic survey questions

Three pages of the socio-acoustic survey which were used in this study are the same as Figure 4.9, Figure 4.10 and Figure 4.11. Page 1 asks questions which determine if the subject is competent to attend this survey. Pre-criteria for conducting the surveys are minimum 12 months of residency in the related dwelling, lack of any hearing problems and being in the age range of 18 to 65.

Page 2 includes the survey questions. Under the heading of 'personal information', gender, age, education level, duration of residence, time and period spend at home during day, noise sensitivity and noise annoyance at workplace are investigated with 8 questions. Under the heading of 'noise annoyance', traffic noise annoyance at home, for all day and only night periods are investigated in verbal and numerical scales. Also under the same heading, most annoying traffic elements and annoyance during daily activities are inquired by multiple-answer questions. In the last part of the survey, room positions in regards to main road, open windows during night and main wall elements are questioned.

Page 3 is the data sheet for addresses. These addresses are needed for comparing survey results to noise map results and preparing dose-effect relations.

5.2.2 Reporting Besiktas socio-acoustic surveys

Socio-acoustic survey in Besiktas is reported in Table 5.4.

Table 5.4 : Socio-acoustical survey report for Besiktas.

Topic area	Item	Topic	Information
Overall design	1	Survey date	From November 2011 to February 2012
	2	Site location	Turkey, Istanbul, Besiktaş district, around Barbaros Avenue
	3	Site selection	

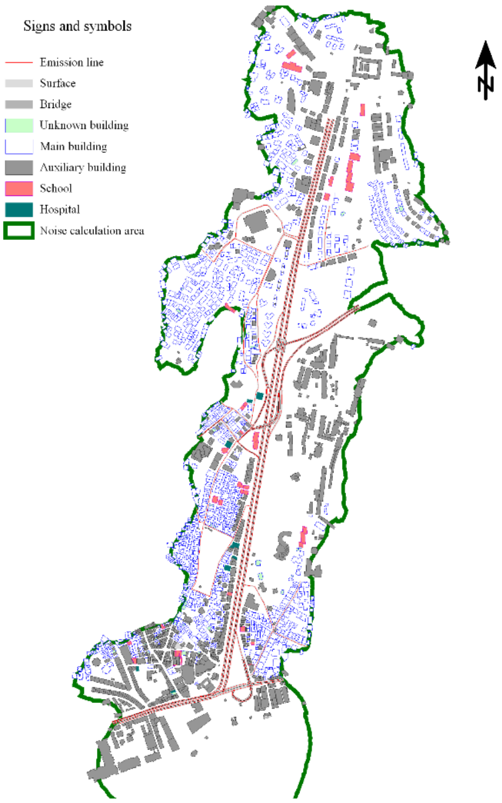


Table 5.4 (continued):

	Item	Topic	Information
	4	Site size	The site was formed around Barbaros Avenue, in Besiktas District. Buildings affected by L_{den}>55 dB were selected.
	5	Study purpose	Main study goal is assessing road traffic noise annoyance in Besiktas District, inside dwellings.
Social survey sample	6	Sample selection	Respondents chosen by: simple random sampling method. Respondent exclusion criteria: length of residence (min 12 months), age (no less than 18, no more than 65) and hearing problems.
	7	Sample size and Quality	Out of 435 buildings affected by L_{den} > 55 dBA traffic noise, 183 surveys could be conducted. Most residents chose not to reply.
Social survey data collection	8	Survey methods	Method: face-to-face.
	9	Questionnaire wording	Figure 4.9, Figure 4.10 and Figure 4.11
	10	Precision of sample estimate	As 183 surveys have been completed in 435 buildings, survey results have 95% confidence with 5.5% error. Reliability statistics on annoyance questions showed the questionnaire to be reliable, as Cronbach's Alpha is 0.827. Also, Item-Total Statistics showed that each annoyance question increases reliability.
Acoustical conditions	11	Noise source	Type of primary noise source: road traffic.
	12	Noise metrics	L_{den} and L_{night}.
	13	Time period	Day: 07:00-19:00 Evening: 19:00-23:00 Night: 23:00-07:00 Year 2010-2011.
	14	Estimation / measurement procedure	Modelling by computation method NMPB - Routes – 96 , simulation by Soundplan 6.5.
	15	Reference position	The receivers on façades were placed at 0.01 m from the façades and reflections on the façades were not considered.
	16	Precision of noise estimate	The average difference between calculated levels (on simulation software) and measured levels (on site) is 1.1 dB.
Basic dose / Response analysis	17	Dose/response relationships	Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12

5.2.3 Statistical analysis of socio-acoustic surveys

Personal data collected from the participants were analyzed. The respondents were 40% male and 60% female. Their age groups were 18-25 (21%), 26-35 (22%), 36-45 (12%), 46-55 (16%), 56-65 (29%). Their education level ranged: postgraduate (10%), graduate (35%), high school (33%), secondary school of 8 years of education (10%) and primary school of 5 years of education (11%), only 1 subject is illiterate. Among the residents interviewed, 7% identified themselves to be non-sensitive to noise, 45% somewhat sensitive and 48% highly sensitive to noise.

The questionnaire results were analyzed statistically. As 183 surveys were completed in 435 buildings, survey results had 95% confidence with 5.5% error. Reliability statistics on annoyance questions showed the questionnaire to be reliable, as Cronbach's Alpha is 0.827. Also, Item-Total Statistics showed that each annoyance question increases reliability. Although the data is homogenous, statistical analysis proved that non-parametric tests need to be used for the data at hand. Evaluations were made for determining relationships between variables of the questionnaire using Spearman's correlation. Table 5.5 gives Spearman's correlations for the variables. All the correlations have 183 sample size (N) and they all have 2-tailed 0.01 level significance, except those that are marked, which have 0.05 level significance.

"Sleep disturbance" has a low correlation with "bedroom facing main road" and "disturbed by traffic noise during sleep activity" with correlation coefficients r_s=0.397 and 0.389 respectively. "Education level" has a low correlation with "noise sensitivity at workspace" with correlation coefficient r_s=0.436, meaning people with higher education are more disturbed by noise at workplace. People who are disturbed by bus noise are also disturbed by car and minibus noise with correlation coefficients r_s=0.407 and 0.541 respectively. "Disturbed by traffic noise during conversing" has low correlations with "disturbed by traffic noise during concentrating" and "disturbed by traffic noise during watching TV" with correlation coefficients r_s=0.304 and 0.365.

Kruskal-Wallis-H Test showed that at α=0.01 level of significance, there is a difference in median and mean sleep disturbance for both verbal and numerical scales according to bedroom placement. This concludes that in cases where the bedroom faces the main road, statistically, people are more annoyed at night.

Most annoying traffic noises are in decreasing order: horn, motorcycle, truck, car, minibus (a Turkish version) and bus (Figure 5.7). Daily activities most disturbed by traffic noise in decreasing order were: resting, sleeping, concentrating, watching TV and conversing (Figure 5.8).

Table 5.5 : Spearman 's correlations for socio-acoustical survey in Besiktas.

Variable 1	Variable 2	Correlation Coefficient
Day-evening-night annoyance	Sensitivity	0.273
Day-evening-night annoyance	L_{den}	0.217
Sleep disturbance	Sensitivity	0.286
Sleep disturbance	Bedroom facing main road	0.397
Sleep disturbance	Disturbed by traffic noise during sleep activity	0.389
Sleep disturbance	Age	0.182 *
Sensitivity	Age	0.265
Sensitivity	Years lived in the house	0.186 *
Sensitivity	Hours spent at home	0.190
Age	Disturbed by traffic noise during watching TV	0.236
Education level	Noise sensitivity at workspace	0.436
Education level	Disturbed by traffic noise during concentrating	0.196
Bedroom facing main road	Disturbed by traffic noise during sleep activity	0.255
Disturbed by bus noise	Disturbed by car noise	0.407
Disturbed by bus noise	Disturbed by minibus noise	0.541
Disturbed by traffic noise during conversing	Disturbed by traffic noise during concentrating	0.304
Disturbed by traffic noise during conversing	Disturbed by traffic noise during watching TV	0.365

* Correlation is significant at the 0.05 level (2-tailed). All other correlations are significant at the 0.01 level (2-tailed).

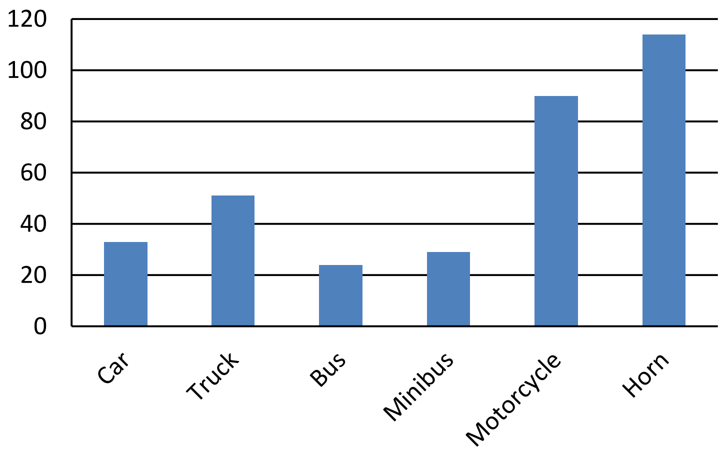


Figure 5.7 : Most annoying traffic noises according to on-site surveys.

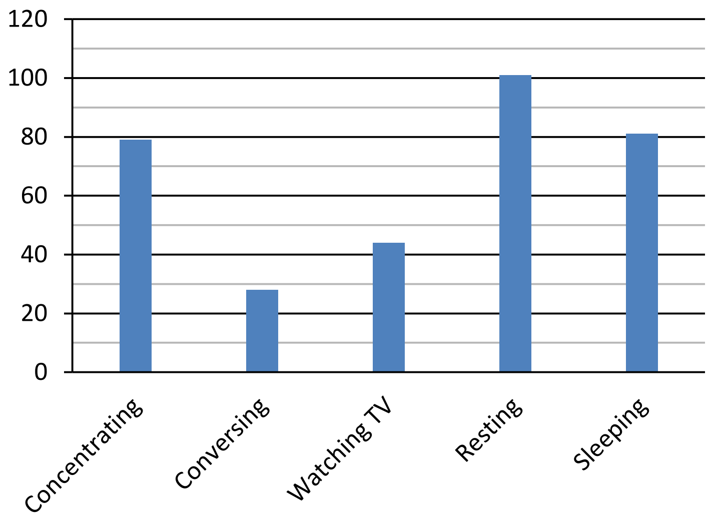


Figure 5.8 : Daily activities most disturbed by traffic noise according to on-site surveys .

5.2.4 Dose-effect relations for traffic noise in Besiktas

Verbal and numerical scales were converted and analyzed in a 100 scale. On the verbal scale, “not at all” is converted to 0, “slightly” to 25, “moderately” to 50, “very” to 75 and “extremely” to 100. On the numerical scale, 0 is 0, 1 is converted to 10, 2 to 20 and so on. For analyzing percentage of people annoyed (%A) and percentage of people highly annoyed (%HA) the cutoff points on a 100 scale are 50 for %A and 72 for %HA. The analyses are made at 5 dB(A) ranges. Each range was ±2.5 dB, for example: 57.5 dB ≤ 60 dB range < 62.5 dB.

Figure 5.9 and Figure 5.10 of L_{den} traffic noise levels for %A and %HA respectively in Besiktas area clearly show a very different curve than European Commission’s (E.C.) recommended algorithms. Between the 55-75 dB(A) range, annoyance is higher than E.C.’s curve. E.C.’s curve has been found to be an understatement in some other studies as well. Starting from 70 dB(A), the curve shows characteristics of an asymptotic curve and annoyance stays almost the same as L_{den} dB(A) noise levels increase. These characteristics apply both to %A and %HA values. The idea that an annoyance curve would include a lower and an upper asymptote is being used in recently proposed algorithms (Badino et al., 2012). Another possibility is that the number of surveys in highly exposed areas are too low in assessing the %A and %HA accurately.

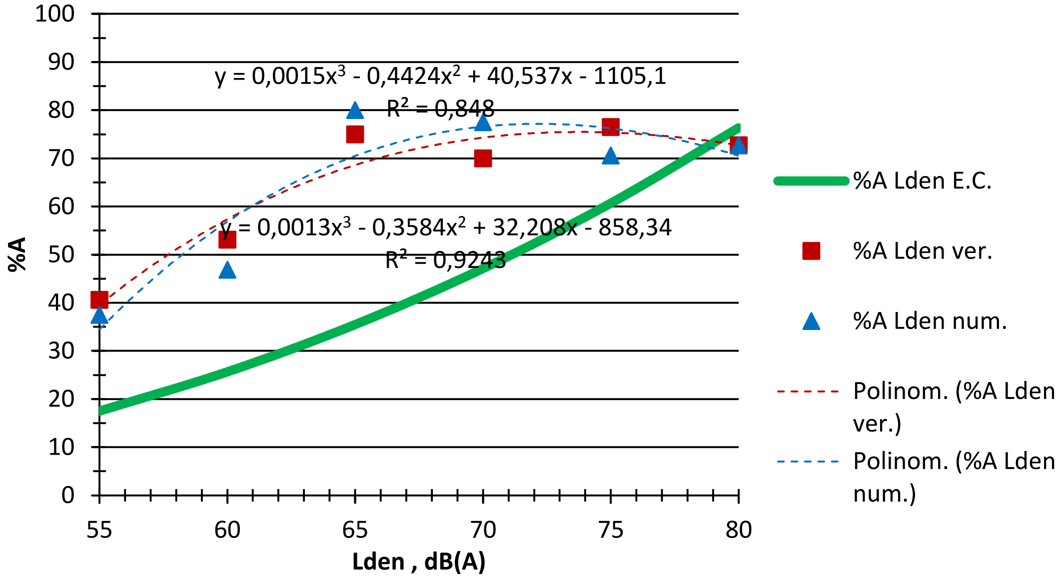


Figure 5.9 : %A graph for L_{den} (Badino et al., 2012).

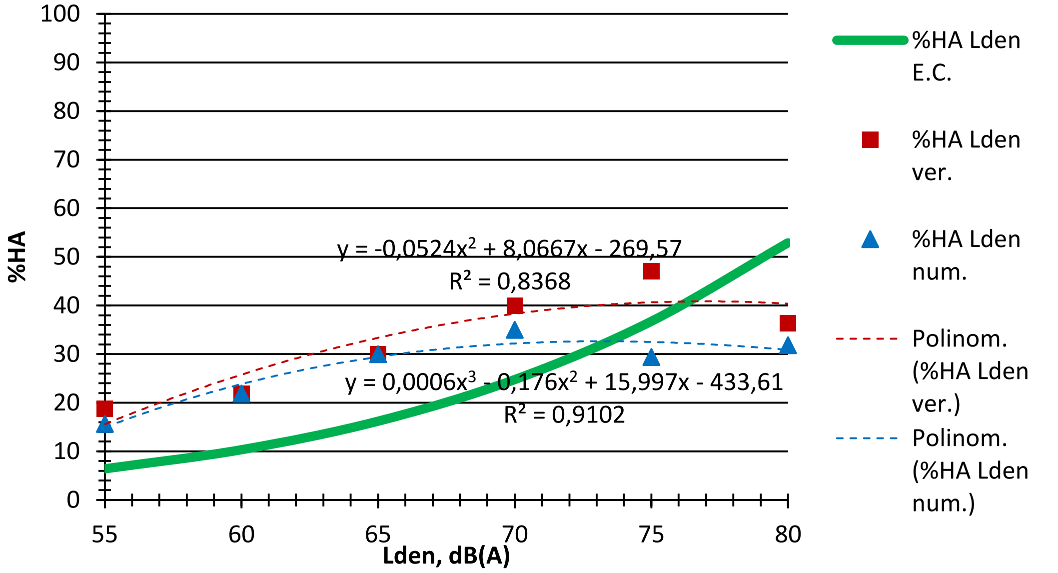


Figure 5.10 : %HA graph for L_{den} (Badino et al., 2012).

Figure 5.11 and Figure 5.12 of L_{night} traffic noise levels for %SD and %HSD respectively in Besiktas area also show a different curve than European Commission's recommended algorithms. At all noise ranges, which is 50 to 70 dB(A) in this case, annoyance is higher than E.C.'s curve. Starting at about 65 dB(A), %SD curve of the numerical scale shows characteristics of an asymptotic curve, percentage of sleep disturbed stays almost the same as L_{night} noise levels increase. On the other hand, starting from 65 dB(A), %HSD curve shows decreasing characteristics, annoyance seems to decay as L_{night} noise levels increase (Badino et al., 2012).

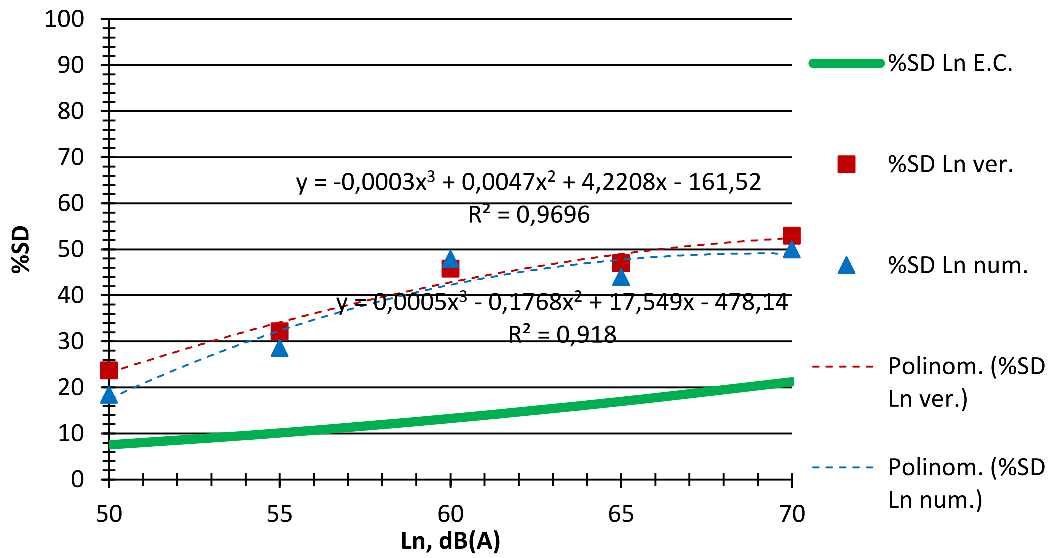


Figure 5.11 : %SD graph for L_n (Badino et al., 2012).

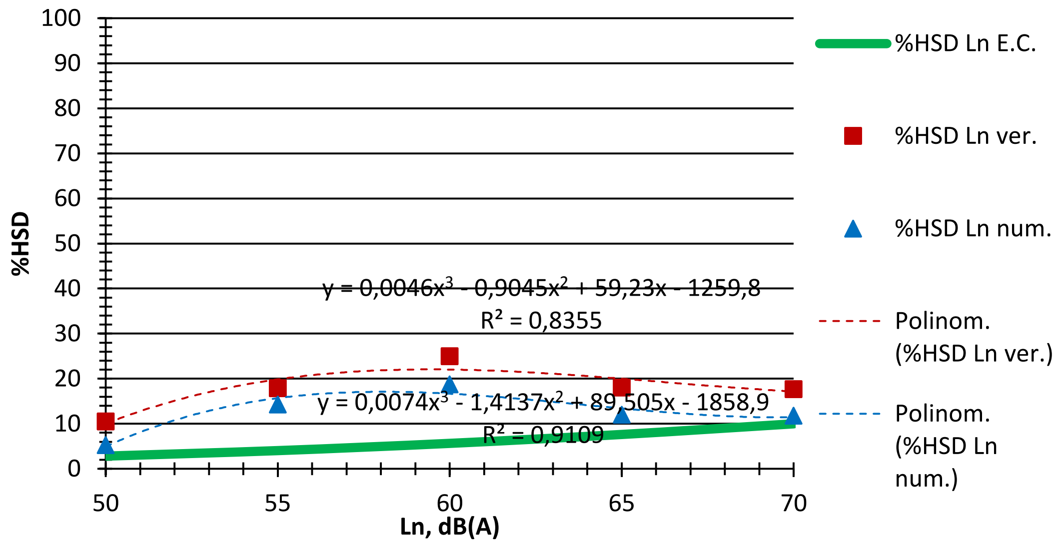


Figure 5.12 : %HSD graph for L_n (Badino et al., 2012).

The decrease in %HSD curve after 60 dB(A) may be explained by the characteristics of traffic flow. People who are exposed to L_{night} > 60 dB(A) live near Barbaros street and are exposed to a continuous traffic overnight. The people who are exposed to L_{night} ≤ 60 dB live away from Barbaros street and they are exposed to a low continuous traffic noise. But these people are also exposed to individual vehicle passes throughout the night, some of which take place on cobblestone paved streets. The noise on these streets tend to pulsate and impulse noise tends to be more annoying than continuous noise, so the effect of noise level on annoyance is likely to be higher than expected. Also, it is known that for sleep disturbances, when single events such as passing vehicles come into play, the equivalent noise level becomes unreliable when used alone. Instead, the emergence of the isolated events from the background noise becomes more important (Badino et al., 2012).

5.3 Determining Façade Sound Insulation in Besiktas

Façade sound insulation to be used for filtering was determined in the area by determining façade elements, executing sound insulation measurements on site and validating them.

5.3.1 Façade elements in Besiktas

Surveys were one of the ways to determine types of façade elements. One of the survey questions was: "What is the main wall element of your façade?" The answer choices were, "brick", "aerated concrete", "I do not know" and "other". These answer choices were chosen by means of experience in construction in the area. 65% of the respondents did not know the main wall element of their façades. 29% of the respondents chose "brick" and remaining 6% chose "aerated concrete". No respondent suggested "other" wall elements. Only 35% of the respondents had knowledge of the main façade element, so the data was insufficient and not statistically significant. But the data at hand suggests that 80% of the buildings have brick and 20% have aerated concrete as their main façade wall element.

Observation was a way to determine the ratio of façade building elements. Observations were made in surveyed buildings. The observations showed that almost all buildings have double glazed windows. The observations from façade photographs also showed that the façades have a combination of 45% transparent (window) and 55% opaque (wall).

Turkish Statistical Institute (TurkStat) is responsible for collecting and disseminating the data that display the social and economic structure of Turkey. Building permit statistics through dynamic search application in TurkStat webpage provides data on wall material for each municipality for years between 2002 and 2013 (TurkStat, 2014a). The results showed that 86.6% of buildings and 87.4% of the flats in Besiktas district were built using brick in the last 12 years (Table 5.6). These statistical values supported the questionnaire results.

Table 5.6 : Building permit statistics on main wall material in Besiktas district, 2002-2013 totals (TurkStat, 2014a).

	Total	Brick	Stone	Aerated concrete	Concrete block	Light Panel	Other
Number of buildings	719	623	2	77	3	4	10
Percent of buildings	100,0%	86,6%	0,3%	10,7%	0,4%	0,6%	1,4%
Number of flats	5784	5057	2	495	5	35	190
Percent of flats	100,0%	87,4%	0,0%	8,6%	0,1%	0,6%	3,3%

5.3.2 Number of façade sound insulation samples in Besiktas

ISO 140-5 (1998) standard was used for making sound insulation measurements on site. Original traffic noise was used as sound source. Background noise level should be at least 10 dB higher than equivalent sound pressure level in receiver room. Sound insulation experience from literature showed that $L_{Aeqtraffic}$ should be at least 65 dBA in order to provide this condition.

L_{day} and $L_{evening}$ values determined on noise maps are higher than L_{night} values. The average and standard deviation of differences between these values and L_{den} values are given in Table 5.7. L_{day} and $L_{evening}$ values are almost the same. Therefore, buildings which have L_{day} or $L_{evening}$ values above 65 dB may be used.

Number of buildings in the area which have Lday or Levening over 65 dB is 28. 24 measurements need to be made for statistically significant results. Unfortunately, only 18 measurements could be made in these buildings.

Table 5.7 : Average and standard deviation of differences between L_{day} , $L_{evening}$, L_{night} values and L_{den} values.

	$L_{den} - L_{day}$	$L_{den} - L_{evening}$	$L_{den} - L_{night}$
Average	4,4	4,8	7,2
Standard deviation	0,4	0,3	0,3

5.3.3 Façade sound insulation measurements on site

For sound level measurements in front of the façade and in receiver room, busiest hours of traffic were chosen. For background noise, two different measurements were made. First, a quiet room which is not exposed to traffic noise was chosen. Second, the receiver room was measured for background noise at a silent hour, when the traffic is minimum. Measurement of reverberation time, was made during silent hour. Locations of measurement sites are given in Figure 5.14. Figure 5.13 gives results of façade sound insulation measurements on 18 sites.

Table 5.8 gives the weighted standardized level difference ($D_{tr,2m,nT,w}$) values of all 18 measurements on site. Table 5.9 gives the average standardized level difference ($D_{tr,2m,nT}$) values between 100 Hz and 3150 Hz. The average weighted standardized level difference ($D_{tr,2m,nT,w}$) is 32 dB.

Table 5.8 : Weighted standardized level difference values of site measurements.

Site number	1	2	3	4	5	6	7	8	9
$D_{tr,2m,nT,w}$	30	35	36	29	30	26	35	31	29
Site number	10	11	12	13	14	15	16	17	18
$D_{tr,2m,nT,w}$	33	34	31,0	33,0	25,0	33,0	33,0	28,0	35,0

Table 5.9 : Average standardized level difference values between 100 Hz and 3150 Hz.

Frequency, Hz	100	125	160	200	250	315	400	500
$D_{tr,2m,nT}$, dB	27,2	25,6	23,8	22,1	22,7	24,6	26,6	27,8
Frequency, Hz	630	800	1000	1250	1600	2000	2500	3150
$D_{tr,2m,nT}$, dB	29,5	30,4	32,0	33,9	34,9	35,7	36,1	35,8

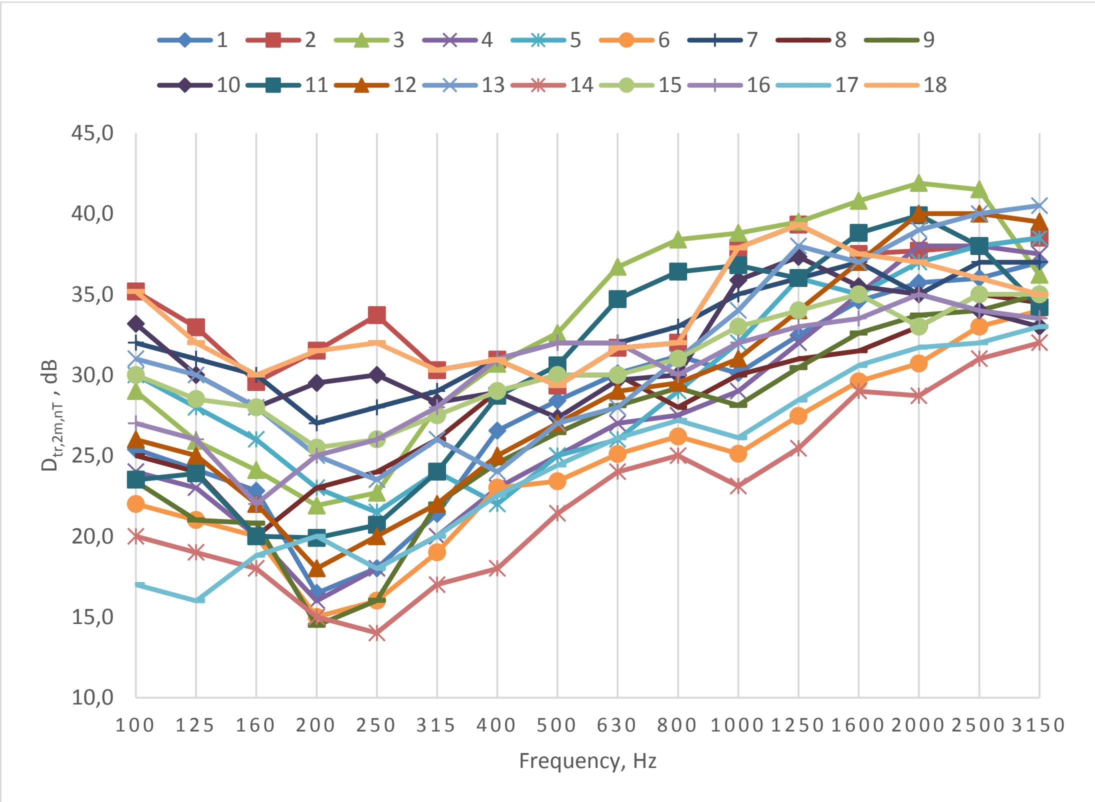


Figure 5.13 : Results of façade sound insulation measurements on 18 sites.

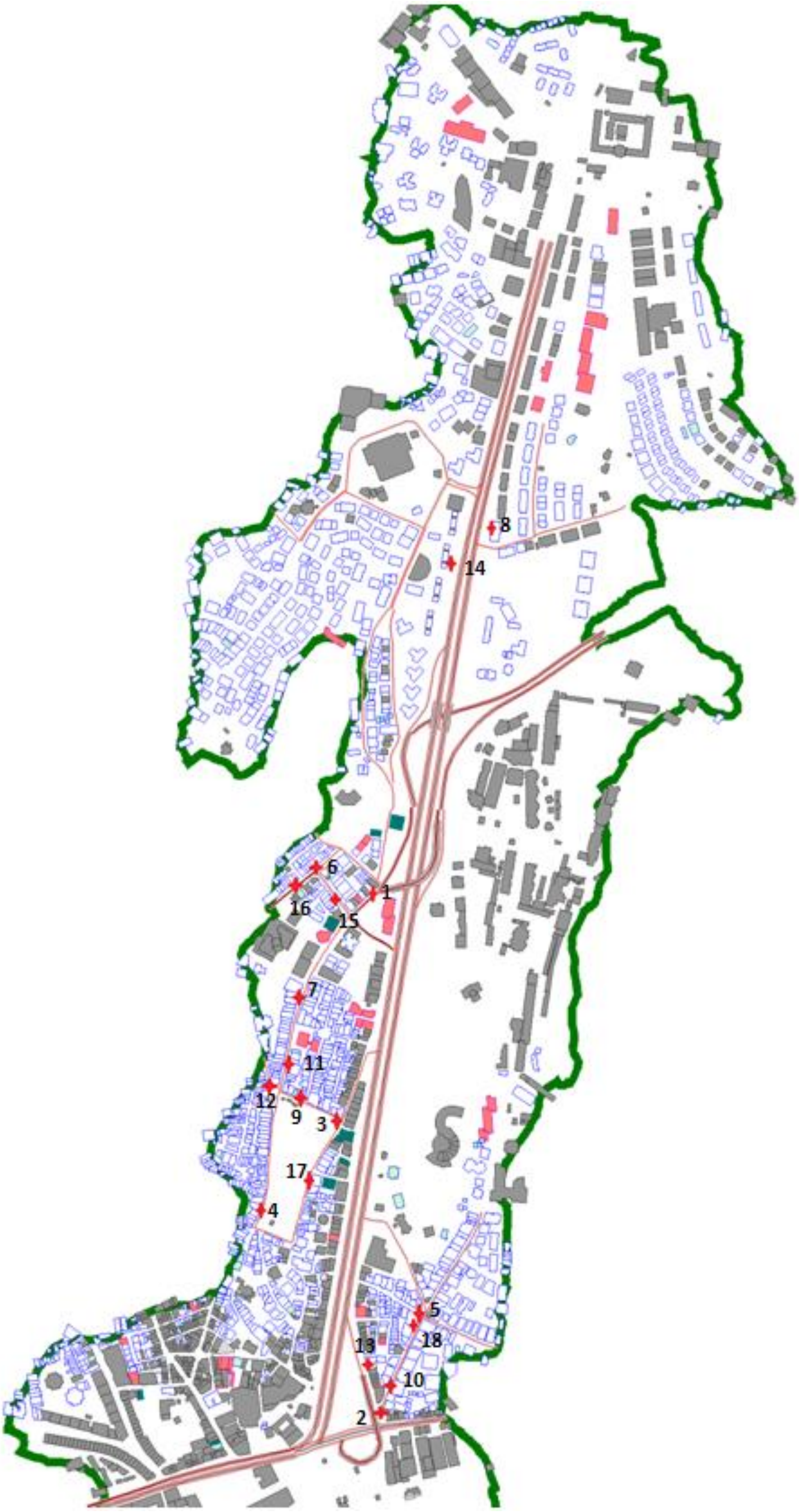


Figure 5.14 : Locations of residences where the façade sound insulation measurements took place.

5.3.4 Validation of façade sound insulation in Besiktas

Although 24 on site measurements needed to be made, only 18 measurements could be performed. For validation of site measurements, laboratory measurements made with traditional Turkish materials were used (Ascigil Dincer & Yilmaz Demirkale, 2015; Yilmaz et al., 2012).

Laboratory airborne sound insulation measurements were made according to ISO 10140-2 (2010) standard for brick walls and double glazed windows commonly used in Turkey. The sound reduction index values of measured 19 cm thick brick, measured double glazed window (4 mm glass, 16 mm cavity, 4 mm glass) and calculated composite façade are given in Table 5.10. Composite façade consists of 55% 19 cm thick brick wall and 45% double glazed window. Equation 4.3 was used to calculate composite façade sound reduction index. Equation 4.4 was used to calculate composite façade standardized level difference. The average depth of measured rooms on site is 4.2 m. According to Equation 4.4, 1.3 dB was added to all façade sound reduction index values.

Table 5.10 : Façade sound reduction index values

Frequency	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150
R_{Brick}	34,7	35,8	40,1	39,1	36,4	36,7	38,4	39,9	40,4	40,9	39,5	39,9	40,8	41,7	44,5	48,1
R_{Window}	26,3	22,7	20,7	18,4	19,4	24,9	27,7	29,7	34,4	36,5	38,1	39,1	40,8	42,3	39,5	32,9
$R_{Façade}$	29,0	25,9	24,1	21,9	22,7	28,0	30,7	32,6	36,7	38,4	38,8	39,5	40,8	41,9	41,5	36,2
$D_{nT,Façade}$	30,3	27,2	25,4	23,2	24	29,3	32	33,9	38	39,7	40,1	40,8	42,1	43,2	42,8	37,5

5.3.5 Determining sound insulation values

The data from surveys suggest that 80% of the buildings in the area have brick as the main façade element. The statistical values of the last 12 years show that 86% of the buildings have brick as the main façade element. Using these data, it is reasonable to choose brick as the main component in sound insulation calculations. Figure 5.15 shows the comparison of sound reduction index values measured on site and calculated from laboratory measurements. Measured and calculated values show similar acoustical characteristics. Site measurements represent a realistic case of construction problems. Measured values are chosen to be representative of sound insulation.

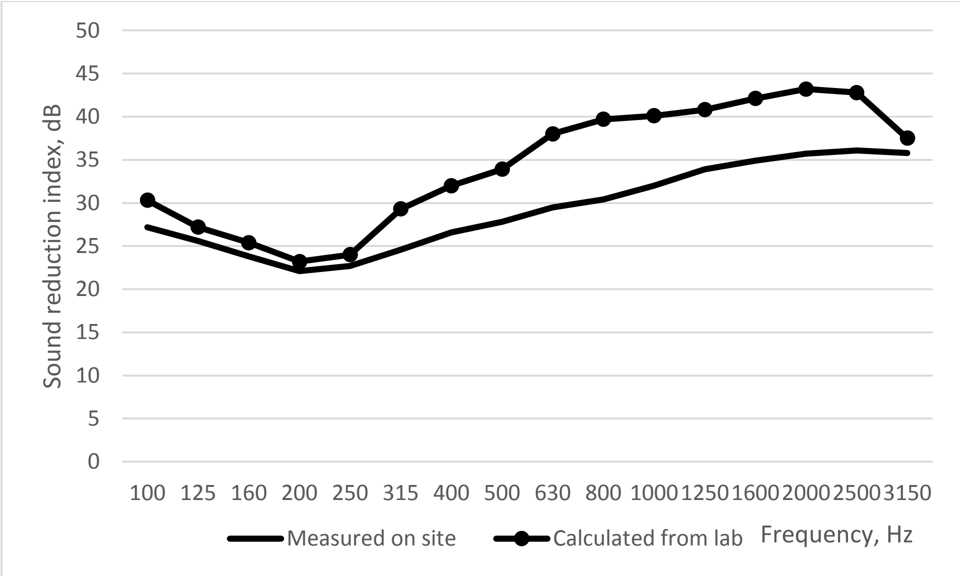


Figure 5.15 : Comparison of sound reduction index values measured on site and calculated from laboratory measurements.

5.4 Sound Recordings of Common Vehicles in Besiktas

The road traffic sound recordings were made using the most common vehicles in Istanbul city and the possible driving behaviors in the area under consideration.

5.4.1 Determining most common vehicles

Turkish Statistical Institute is responsible for collecting and disseminating the data which display the social and economic structure of Turkey. The publication “Road Motor Vehicle Statistics 2012”, includes statistics of the road motor vehicles such as, the current number of the vehicles according to their types, trademarks, fuel type and model years by the end of year 2012. Vehicle definitions given in this publication are as follows:

> Vehicle: Used on roads for transporting passengers, livestock and goods. Those driven by mechanical power are called motor vehicles while those propelled by human or animal power are referred to as non-motor vehicles.
>
> 1. Passenger vehicle: Is a motor vehicle designed to carry passengers, cars and minibuses, buses and motorcycles cycles fall into this category.
>
> 1.1 Car: A motor vehicle intended for the transport of passengers and seating not more than eight persons (including the driver).That which carries passengers in return for a fare as determined either by a taximeter or a fixed rate is called a Taxi Cab. That which charges fares on a passenger

basis is called a Dolmus (or shared) cab. All others not falling in any of these categories and not subject to the Motor Vehicles Code 237, are called private cars.

1.2 Minibus: Passenger road motor vehicle, seating between eight and fourteen persons (excluding drivers).

1.3 Bus: Road motor vehicle designed for the transport of passengers having at least fifteen seats. Trolley buses are also included in this category.

1.4 Motorcycle: Two-wheeled or three-wheeled road motor vehicles with or without sidecar. (ATV'S are also included)

1.5 Moped: Any two-wheeled or three-wheeled road vehicles with an internal combustion engine having a cylinder capacity not to exceed 50 cc. and a maximum design speed not exceeding 50 km (30 miles) per hour.

2. Cargo motor vehicle: Is a motor vehicle designed to carry merchandise. Motorcycles, small trucks and trucks fall into this category.

2.1 Small truck: Road motor vehicles designed to carry goods, to a maximum laden permissible weight of vehicle not exceeding 3 500 kg.

2.2 Truck: Road motor vehicles designed to carry goods, exceeding 3 500 kg laden in weight.

2.3 Road tractor: Road motor vehicles designed to houl trailer and semi-trailers not carrying goods.

2.4 Land vehicle: Road motor vehicle designed to carry persons and goods, four-wheeled road vehicle.

2.5 Tricycle: If three-wheeled motorcycle is designed to carry goods not persons, it is called carrier tricycle.

3. Other vehicles: Are motor vehicles designed for miscellaneous purposes. Special purpose vehicles, road construction and work machinery fall into this category.

3.1 Special purpose vehicles: Road motor vehicles designed for a special purpose to carry persons or goods and to haul and lift broken down vehicles, such as fire engines, ambulances, hearses, research vehicles, mobile libraries, tow truck etc.

3.1.1 Fire vehicle: Motor vehicles are used for fights fire which been special device.

3.1.2 Street sprinkler: Motor vehicles are used for sprays water.

3.1.3 Ambulance: Motor vehicle which has medical facilities and transport patients to the hospital.

3.1.4 Rescue vehicle: Motor vehicle which wrecks or tears down or removes vehicle.

3.1.5 Caravan: Motor vehicle which mobile home, trailer home.

3.1.6 Disabled vehicle: Motor vehicles are used by handicapped person.

3.1.7 Armored vehicle: Protected vehicle which used for get to security.

3.2 Road and Work machinery: Tractors with plates or metal wheels, harvesters, road construction machinery and similar machinery used in agriculture, industry, public works, national defense, and used by services and work of other institutions. These machinery are not designed to carry people, animals or goods.

3.2.1 Tractor: Motor vehicles are used for agricultural which can pull a trailer or a semi-trailer under certain condition. (Turkish Statistical Institute, 2013)

With the aim of the collection and development of regional statistics, socio-economic analysis of regions and establishing statistical database to be compared with European Union Regional Statistics System, information and data is presented in the scope of Statistical Regions with Level 1, Level 2 and Level 3. These statistical regions are determined by population, geography, regional development plans, basic indicators of statistics and socio-economic analysis of regions. Istanbul city is a Level 1 statistical region on its own, with the code TR1. Level 2 and Level 3 of statistical region TR1 are also the city of İstanbul.

Table 5.11, Table 5.12, Table 5.13, Table 5.14, Table 5.15 and Table 5.16 give detailed information on the statistics road motor vehicles in Istanbul. In all motor vehicles, gasoline and diesel type fueled vehicles are leading. Considering that LPG fueled vehicles have gasoline engines, 2012 statistics show almost half and half distribution of gasoline and diesel engines. Renault is the most common trademark in terms of cars, small trucks, trucks, buses and minibuses. Honda is the most common trademark for motorcycles. Most common engine size of cars is 1600 cc. Most common engine size of cars is 1600 cc with 38.3%. The most common public transportation bus is Otokar Kent 290 LF with 29.4% (Url-1).

The most common trademarks were used for sound recordings. The cars used for sound recordings were diesel fueled Renault and gasoline fueled Ford with engine size 1600 cc. These cars were also used to record horn sounds. Other vehicles used were, Honda motorcycle, Otokar Kent public transportation bus, Iveco minibus (blue minibus common in Besiktas area) and Renault Midlum Truck.

Table 5.11 : Number and percent of all road motor vehicles sorted by type of fuel in Istanbul, for years 2008-2012 (Turkish Statistical Institute, 2013).

Type of fuel	2008	2009	2010	2011	2012
Gasoline #	1.266.113	1.227.782	1.171.541	1.129.963	1.109.418
Gasoline %	47,1%	45,1%	41,9%	38,6%	36,2%
Diesel #	1.095.365	1.162.184	1.280.598	1.446.154	1.593.030
Diesel %	40,8%	42,7%	45,8%	49,4%	52,0%
LPG #	216.817	240.431	259.032	275.992	294.150
LPG %	8,1%	8,8%	9,3%	9,4%	9,6%
Unknown #	107.461	90.806	83.065	75.541	68.867
Unknown %	4,0%	3,3%	3,0%	2,6%	2,2%
Total #	2.685.756	2.721.203	2.794.236	2.927.650	3.065.465

Table 5.12 : Number and percent of vehicles in Istanbul, sorted by type, at the end of year 2012 (Turkish Statistical Institute, 2013).

Total	Car	Small truck	Motorcycle	Truck
3.065.465	2.009.777	575.846	206.631	126.745
	65,6%	18,8%	6,7%	4,1%
	Bus	Minibus	Tractor	Special purpose vehicles
3.065.465	62.475	56.034	21.878	6.079
	2,0%	1,8%	0,7%	0,2%

Table 5.13 : Number and percent of road motor vehicles in Istanbul, sorted by trademark (10 most common), at the end of year 2012 (Motorcycles, special purpose vehicles and tractors are excluded) (Turkish Statistical Institute, 2013).

Total	Renault	Ford	Fiat	Volkswagen	Hyundai
2.830.877	435.469	280.634	272.341	239.377	180.784
	15,4%	9,9%	9,6%	8,5%	6,4%
	Opel	Tofaş	Mercedes	Toyota	Peugeot
	155.953	122.433	122.414	118.675	104.656
	5,5%	4,3%	4,3%	4,2%	3,7%

Table 5.14 : Number and percent of motorcycles in Istanbul, sorted by trademark (5 most common), at the end of year (Turkish Statistical Institute, 2013).

Total	Honda	Mondial	Mz	Yamaha	Asya
206631	52113	28075	15611	11214	8364
	25,2%	13,6%	7,6%	5,4%	4,0%

Table 5.15 : Number and percent of tractors in Istanbul, sorted by trademark (5 most common), at the end of year 2012 (Turkish Statistical Institute, 2013).

Total	Massey Ferguson	New Holland	Fiat	Universal	Steyr
21878	4973	3391	2479	773	684
	22,7%	15,5%	11,3%	3,5%	3,1%

Table 5.16 : Distribution of cars registered to the traffic by engine size, 2011 – 2013 (Turkish Statistical Institute, 2014b).

	2011		2012		2013	
Engine Size	Number of cars	(%)	Number of cars	(%)	Number of cars	(%)
Total	602 248	100	565 791	100	654 905	100
-1300	119 252	19,8	109 022	19,3	134 173	20,5
1301 - 1400	128 513	21,3	120 088	21,2	109 114	16,7
1401 - 1500	104 292	17,3	91 928	16,2	113 401	17,3
1501 - 1600	173 819	28,9	195 083	34,5	250 916	38,3
1601 - 2000	53 404	8,9	37 541	6,6	34 966	5,3
2001+	13 142	2,2	9 900	1,8	10 785	1,6
Unknown	9 826	1,6	2 229	0,4	1 550	0,2

5.4.2 Determining most common driving conditions

Driving conditions were determined by using data from noise maps, noise prediction model and on-site research.

Average speed (km/h) data used in road modelling of noise maps in Besiktas district (Badino et al., 2012) was taken into consideration. The average speed for Barbaros Avenue in north direction received from radars was between 55 and 70 km/h for day, 60 and 65 km/h for evening, 75 and 80 km/h for night. The average speed for Barbaros Avenue in south direction received from radars was between 50 and 80 km/h for day, 50 and 85 km/h for evening, 65 and 95 km/h for night. The average speed for small main roads and collecting roads received from radars was between 40 and 50 km/h. The average speed for service roads and dead-end roads determined on-site were between 30 and 40 km/h.

Traffic flow types of fluid continuous, pulsed continuous, pulsed accelerating and pulsed decelerating were used as advised in NMPB-Routes-96 (1995).

The roads were classified as dead-end roads, service roads, collective roads, small main roads and main roads as advised in Good Practice Guide (WG-AEN, 2006).

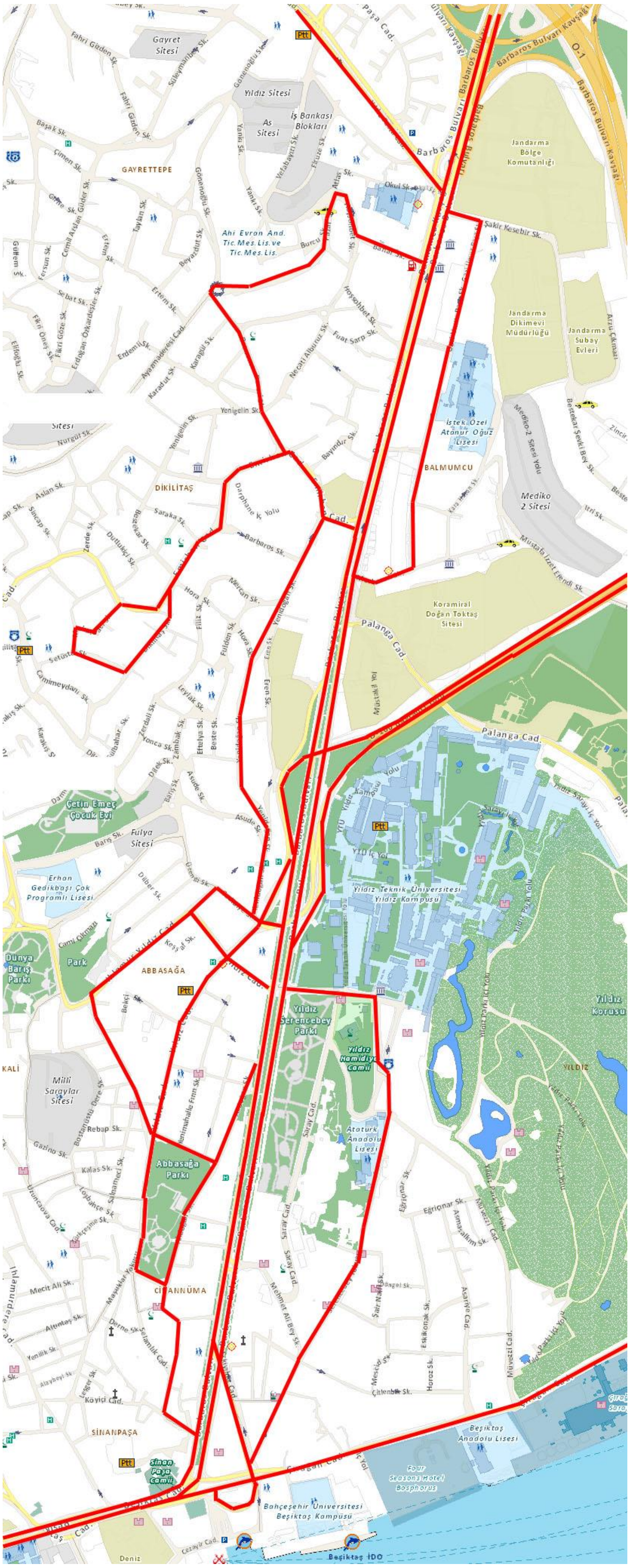


Figure 5.16 : The route for the on-site study driving through the area.

As it was advised in Annex A of ISO 362-1 (2007), an on-site study by driving through the area (Besiktas) at different times during the day was used to reveal the driving patterns. On Barbaros Avenue, traffic flow was mostly fluid continuous during daytime and nighttime, it was mostly pulsed continuous during evening. Pulsed accelerating and pulsed decelerating traffic flows were existent due to traffic lights. For fluid continuous traffic flow, speed during daytime ranged from 50 to 80 km/h, while speed during nighttime ranged from 70 to 100 km/h. Traffic flow during evening hours was pulsed continuous, mostly stopping and starting in traffic. Average speed of heavy vehicles were between 30 km/h and 50 km/h. The route for the on-site study driving through the area is given in Figure 5.16.

For roads other than Barbaros, the average speed values from on-site study were consistent with data from noise map models. The traffic flow was fluid continuous for service roads and dead-end roads at all times. For small main roads and collective roads, traffic flow was mostly fluid continuous during daytime and nighttime, it was mostly pulsed continuous during evening. Pulsed accelerating and pulsed decelerating traffic flows were existent due to traffic lights and junctions.

Slope of roads were categorized as, horizontal (slope between: $0\% \leq p \leq 2\%$), rising or falling slope (slope between $2\% \leq p \leq 6\%$) (Wölfel et al. 2003).

5.4.3 Recording vehicle sounds

It is stated in ISO 10844 (2014) that the test track should be used only for noise measurements, but it was not possible to build a test track for this study. Available roads around the city were used as tracks for this study. Information on the sound recording conditions are given in Table 5.17. Recording equipment were binaural microphone, data acquisition board and a laptop. Cars and motorcycles were recorded at a site where various road slopes and road surfaces were available. The site where bus, minibus and truck were recorded was chosen because it contained various road slopes and heavy vehicles and minibuses were not banned on this road. All tracks were in vast areas, with no large reflecting objects within a radius of 50 m. Meteorological data was taken from Meteorological General Directorate and background noise was also recorded.

Table 5.17 : Sound recording conditions.

Title	Information
Measuring equipment	MESA BMH.I-H42 binaural microphone, 01dB dB4 acquisition board, dBFA software, Dell Latitude Laptop
Recording for cars and motorcycle	
Date and time:	Between August 31st 2014 23:00 and September 1st 2014 02:00
Test site:	Istanbul, Kucukcekmece District, Soyak Olimpiyakent housing development

Weather:	18.2ºC temperature, 5 km/h SSW wind, 60% humidity
Vehicle types:	Car: Ford Focus, gasoline fueled with engine size 1600 cc. Car: Renault Fluence diesel fueled with engine size 1500 cc. Motorcycle: Honda CBF 150, with engine size 150 cc.

Average background noise:

Hz	50	100	125	160	200	250	315	400	500
L_{eq}	24,4	25,9	23,4	21,6	19,8	16,4	14,7	15,9	16,3
630	800	1000	1250	1600	2000	2500	3150	4000	5000
14,8	13,4	16,3	15,8	14,8	13,4	12,2	11,4	10,4	8,7

Recording for minibus, bus and truck	
Date and time:	Between September 7th 2014 23:00 and September 8th 2014 02:00
Test site:	Istanbul, Kartal District, Samandira 2 Koprulu Kavsak

Table 5.17 (continued) :	
Title	**Information**
Weather:	16.5ºC temperature, 6 km/h NNE wind, 55% humidity
Vehicle types:	Bus: Otokar Kent public transportation bus Minibus: Iveco blue minibus Truck: Renault Midlum truck
Average background noise:	(see below)

Hz	50	100	125	160	200	250	315	400	500
L_{eq}	20,5	22,3	19,2	18,4	16,9	14,7	9,8	12,9	12,5
630	800	1000	1250	1600	2000	2500	3150	4000	5000
9,3	8,4	8,2	6,6	7,1	7,3	6,8	6,1	5,3	4,7

The recordings took place on only one side of the road, 7.5 m from vehicle's travel path. For each sound recording, a vehicle was driven at a specific speed or acceleration, with a specific traffic flow type, on a road with a specific slope and surface. Diesel and gasoline fueled cars were driven with speeds of 30, 50, 70 and 100 km/h. At 50 km/h, sounds were recorded with driving patterns fluid continuous, pulsed continuous, pulsed accelerating and pulsed decelerating. Vehicles driven on various road slopes, level (slope between: 0% ≤ p ≤ 2%), rising and falling (slope between 2% ≤ p ≤ 6%) were also recorded. Road surfaces used were smooth asphalt and paving stones. Cars were also used for recording horn sounds.

Motorcycle, minibus, bus and truck were driven and recorded in a similar way but with fewer variations. Driving speeds were 30 and 50 km/h; the same driving patterns and road slopes were used. The road surface was only smooth asphalt because it is not possible for these vehicles to be driven on streets with paving stones in Besiktas area. All recordings were conducted late at night to keep the background noise and other pass-by vehicles at a minimum.

5.5 Creating Sound Clips for Besiktas

The sound clips each simulated a traffic noise situation possible to hear inside houses in Besiktas area. Road types and characteristics were determined to create the traffic noise heard 7.5 meters from road sources. To simulate the traffic noise heard inside the houses in various urban conditions, urban sound propagation filters and façade sound insulation filters were used. Sound clips were formed with a duration of 20 seconds. This value coincides with the road types explained in the next part of this study.

5.5.1 Determining road type characteristics in Besiktas District

Characteristics which influence traffic noise emission of the main roads, such as traffic volume, types of vehicles, traffic flow type and road surface had already been determined in detail for the noise map model. The main road, Barbaros Avenue, is a north-south dual carriageway with three lanes on each side, going through a highly populated urban area and is monitored by radars which record number and speed of light and heavy vehicles. The annual average traffic flow per hour to north and to south was calculated from radar data for day, evening and night. To use these traffic data in this study, the hourly data was transformed in 20 seconds data, by a division of 180. Table 5.18 gives average traffic volume on Barbaros Avenue adjusted to 20 seconds; light vehicles include cars (gasoline and diesel fueled), motorcycles, and minibuses. Statistics of road motor vehicles in Istanbul show that 52% of vehicles have diesel fueled motors and 46% of vehicles have gasoline fueled motors, almost half and half. (TurkStat, 2013b) A traffic flow count on Barbaros Avenue proved about 4% of light vehicles to be minibuses and about 4% of light vehicles to be motorcycles. Heavy vehicles are actually the number of long vehicles (3 times the length of cars) counted by the radar system by Istanbul Metropolitan Municipality, therefore heavy vehicles are buses in this case. Other heavy vehicles such as trucks, TIRs or oil tankers are only allowed to work in urban areas between 22:00 and 06:00. So, trucks can only be added to night time traffic flow. Minibuses work between 05:00 and 02:00, but they do not have a schedule. Buses work between 06:00 and 00:00. As a result of all this input, detailed traffic volume data for a total of both sides of Barbaros Avenue adjusted to 20 seconds, in order to simulate the main road, is given in Table 5.19.

There are many secondary roads around Barbaros Avenue and their traffic flow information have been included in noise map model. But preparing sound clips for each road would not be efficient, therefore, the secondary roads were grouped. European Commission’s Good Practice Guide for Strategic Noise Mapping (WG-AEN, 2006) proposes some default values for traffic flow volume, as given in Table 5.20. The road types in this table can be used for grouping roads around Barbaros Avenue. The traffic volumes of secondary roads determined in the previous noise map were grouped in this study. Average and standard deviation values of traffic volume of road types around Barbaros Avenue are also given in Table 5. Average values for daytime are very close to default values of roads proposed by WG-AEN, so these values were used. 0 adjusts traffic volumes of road types for one hour into traffic volumes for 20 second sound clips to simulate secondary roads.

Table 5.18 : Average traffic volume on Barbaros Avenue adjusted to 20 seconds (rounded).

	Barbaros Av. (to north)		Barbaros Av. (to south)	
	Light veh.	Heavy veh.	Light veh.	Heavy veh.
Day	12	0.5	13	0,5
Evening	12	0.5	11	0.5
Night	7	0.25	6	0.25

Table 5.19 : Traffic volume in 20 seconds for a total of both sides of Barbaros Avenue.

	Car (Gasoline)	Car (Diesel)	Motorcycle	Minibus	Bus	Truck
Main road (Barbaros Avenue) Day & Evening	10	10	2	2	1	0
Main road (Barbaros Avenue) Night	6	6	1	0	0	1

Table 5.20 : Proposed default values for traffic volume (WG-AEN, 2006) and average and standard deviation values of traffic volume of road types around Barbaros Avenue.

Road type (WG-AEN, 2006)	Traffic volume		
	day	evening	night
Dead-end roads	175	50	25
Service roads (mainly used by residents living there)	350	100	50
Collecting roads (collecting traffic from service roads and leading it to & from main roads)	700	200	100
Small main roads	1400	400	200
Main roads	Must undertake traffic counts.		
Road types around Barbaros Av.	Traffic volume		
	day	evening	night
Dead-end roads	166 ± 45	150 ± 41	79 ± 22
Service roads	365 ± 55	327 ± 52	176 ± 23
Collecting roads	730 ± 175	616 ± 126	331 ± 81
Small main roads	1349 ± 154	1079 ± 123	615 ± 70

Table 5.21 : Traffic volume in 20 seconds for secondary roads.

	Car (Gasoline)	Car (Diesel)	Motorcycle	Minibus	Bus	Truck
Dead-end roads	0	1	0	0	0	0
Service roads	1	1	0	0	0	0
Collecting roads	2	2	0	0	0	0
Small main roads	3	4	1	0	0	0

The number of vehicles given in Table 5.19 and Table 5.21 were used to form the sound clips from traffic sound recordings. The number of vehicles needed for each type of road were distributed as evenly as possible on a 20 seconds long empty sound clip, on the software Audacity. On the secondary road sound clips, where the number of vehicles are low, each vehicle's passing can be heard almost individually. On main road sound clips, where the number of vehicles are high, the passing of cars are not noticeable individually, but the passing of motorcycle, minibus, bus and truck are noticeable.

The summary of the conditions considered for each road is given below:

- Dead-end roads & service roads
    - Speed: 30 km/h
    - Flow: fluid continuous
    - Surface: smooth asphalt & paving stones
    - Source and receiver distance: 3.75 m
    - Slope: Level, falling, rising
- Collective roads & Small main roads
    - Speed: 30 km/h & 50 km/h
    - Flow types :
        - fluid continuous
        - pulsed continuous
        - pulsed accelerating
        - pulsed decelerating
    - Surface: smooth asphalt
    - Source and receiver distance: 3.75 m for Collective roads & 7.5 m for Small main roads
    - Effects: motorcycle passing & horn sounds

- Main roads
    - Speed: 50 km/h & 70 km/h
    - Flow types :
        - fluid continuous
        - pulsed continuous
        - pulsed accelerating
        - pulsed decelerating
    - Surface: smooth asphalt
    - Source and receiver distance: 30m
    - Effects: horn sounds

After forming the base of the sound clips, filters were applied.

5.5.2 Creating and applying sound propagation filters

The sound clips formed represent different types of roads and traffic flow characteristics recorded at 7.5 meters from road sources, in open space conditions. Some common examples of urban sound propagation are calculated and applied as filters to sound clips at hand, in order to simulate traffic sounds in the city. Filters for geometric divergence and atmospheric absorption were created from literature. Filters for urban condition examples were calculated with noise mapping software.

5.5.2.1 Geometric divergence and atmospheric absorption

Because the sound recordings were conducted 7.5 m away from source, geometric divergence and atmospheric absorption filter values for double distances such as 15 m and 30 m were used. Sound absorption values (ISO 9613-1, 1993) are calculated for 14 ºC, which is the yearly average temperature in Istanbul (MGM, 2014), and 50% relative humidity. Figure 5.17 shows filter values for a total of geometric divergence and atmospheric absorption to be applied for simulating different distances from source.

Right and left channel wave form (dB) and spectrogram log(f) from Audacity software for some single vehicle sound recordings and some street sound clips are given in Appendix A.

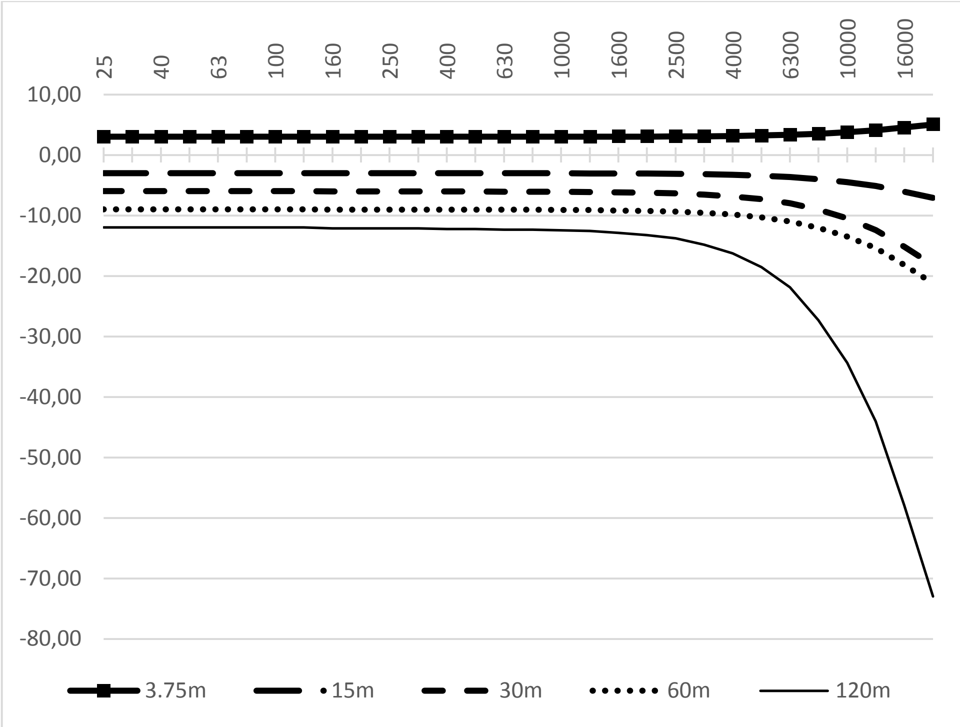


Figure 5.17 : Filter values for a total of geometric divergence and atmospheric absorption to be applied for simulating different distances from source.

5.5.2.2 Urban sound propagation in Besiktas District

Map around Barbaros Avenue in Besiktas was studied for common urban settlements and these settlements were grouped regarding sound propagation. Urban settlement conditions considered were:

a. Sound propagation from main road to perpendicular narrow streets

b. Sound propagation from main road to second row of buildings through detached buildings

c. Sound propagation from main road to second row of buildings through attached buildings

d. Sound propagation from main road to second row of buildings through narrow opening

e. Sound propagation in a street canyon

Examples of these settlements were simulated in noise mapping software, Soundplan 6.5. Single receivers were placed at possible façades. The simulations were executed two times for each receiver, (1) for open space, with no buildings and (2) for urban conditions, with buildings. In the simulation, the topography was excluded, so the road and the buildings were all set at zero height. The height of the buildings were identical to real height of the buildings in the area. All the point receivers had the same height, 150 cm. Noise levels were calculated using NMPB Routes 96 (1995) method. The traffic data of the main parallel roads were identical. Number of light vehicles per hour was 2160, number of heavy vehicles per hour was 90. Velocity of light vehicles was 70 km/h, velocity of heavy vehicles was 50 km/h. The traffic was smooth-flowing and the road surface was asphalt concrete. This traffic data was similar to that used in listening test sound clips.

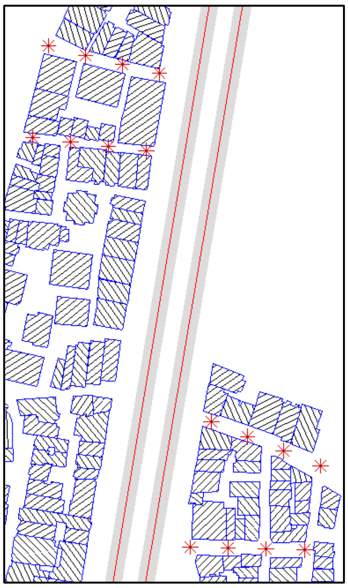


Figure 5.18 : Map around Barbaros Avenue and receivers (❋) for simulation of sound propagation: Narrow streets perpendicular to main road.

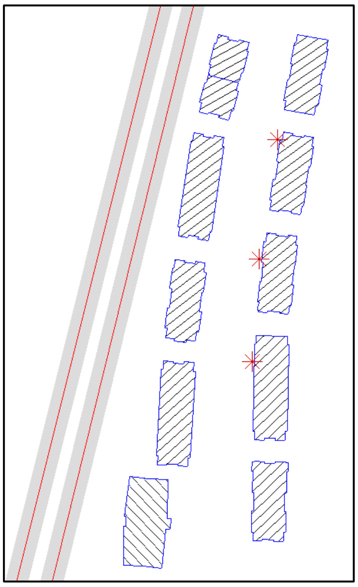


Figure 5.19 : Map around Barbaros Avenue and receivers (❋) for simulation of sound propagation: Second row of buildings behind detached buildings.

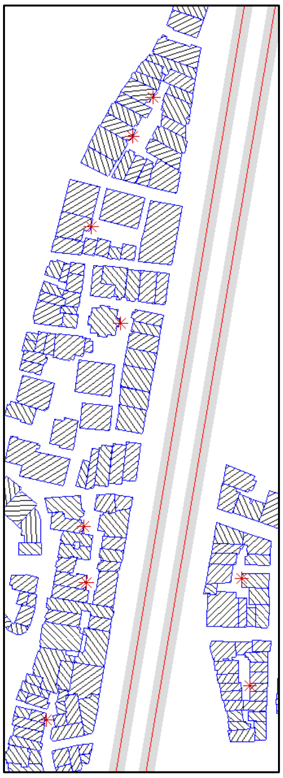


Figure 5.20 : Map around Barbaros Avenue and receivers (❋) for simulation of sound propagation: Second row of buildings behind attached buildings.

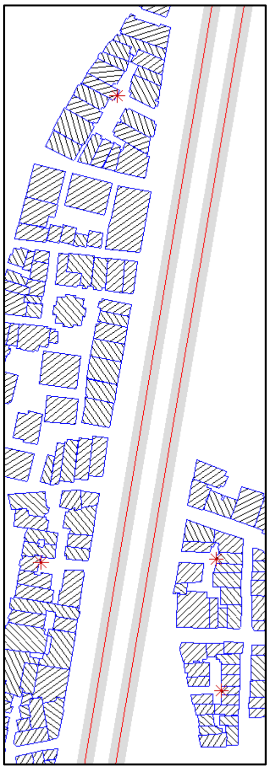


Figure 5.21 : Map around Barbaros Avenue and receivers (❋) for simulation of sound propagation: Second row of buildings behind a narrow opening.

Maps used for simulation and receiver points are given in Figure 5.18, Figure 5.19, Figure 5.20, Figure 5.21 and Figure 5.22. Figure 5.23 and Figure 5.24 show the filters calculated using the difference between open space conditions and urban conditions. Simulation calculation on single point receivers are given in Appendix B.

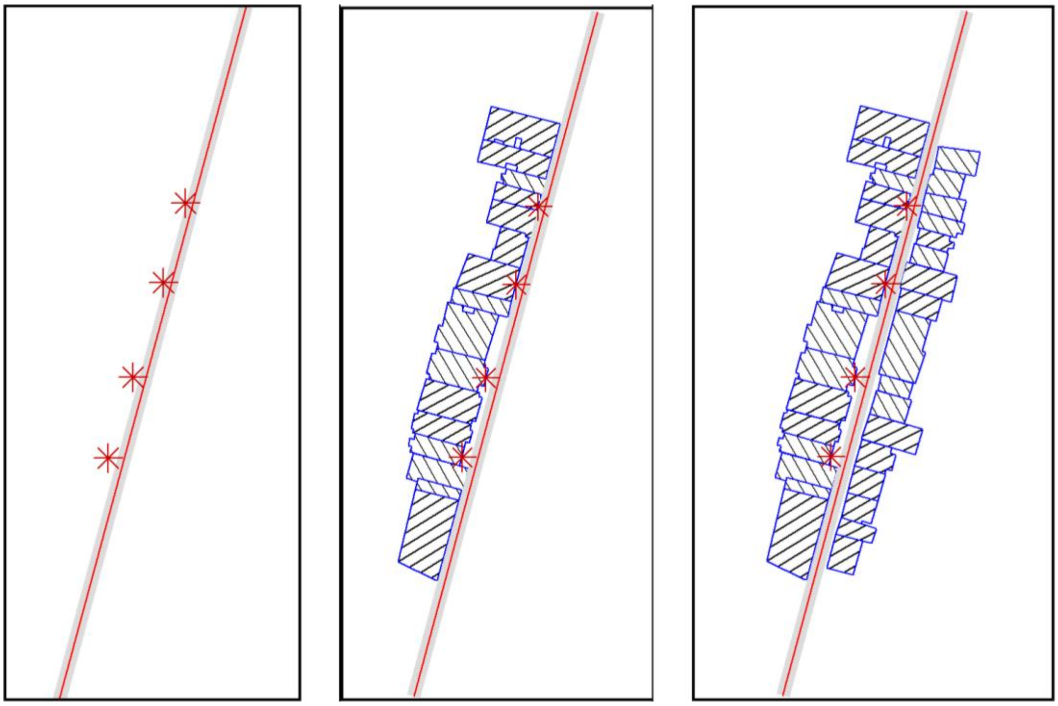


Figure 5.22 : Map around Barbaros Avenue and receivers (✱) for simulation of sound propagation: Open space, attached buildings on one side and attached buildings on both sides (street canyon).

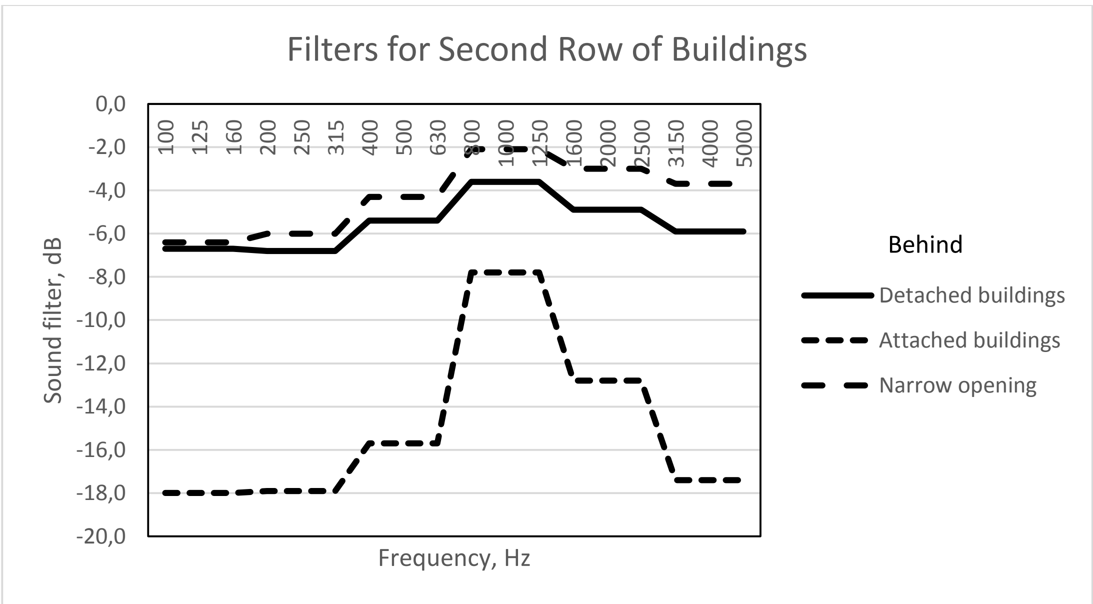


Figure 5.23 : Sound filter for second row of buildings behind detached buildings, behind attached buildings and behind a narrow opening.

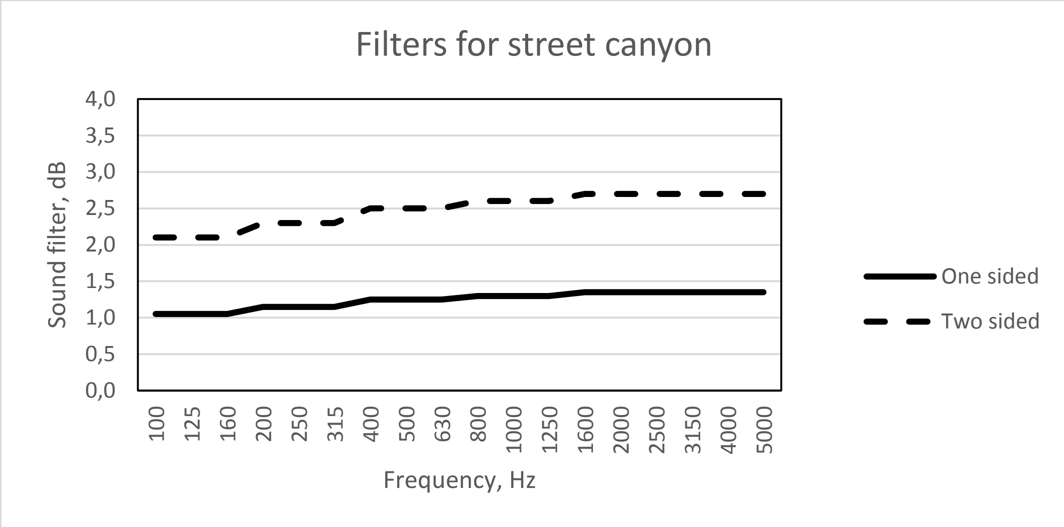


Figure 5.24 : Sound filter for narrow streets forming a street canyon, for attached buildings on only one side and attached buildings on both sides

5.5.3 Sound insulation filters for Besiktas District

Façade sound insulation analysis for Besiktas District is explained in Section 5.3.

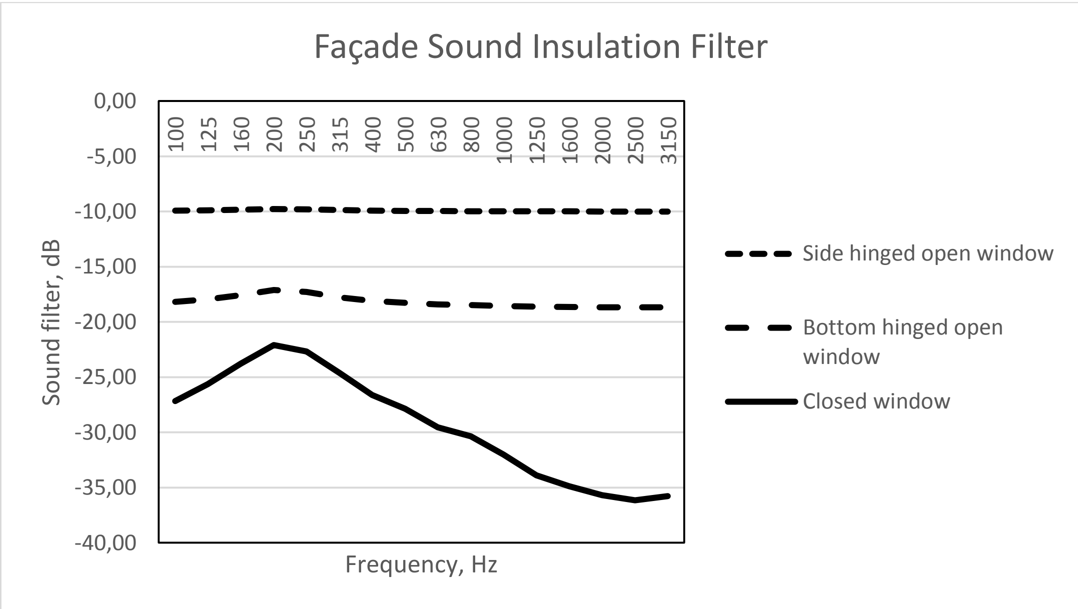


Figure 5.25 : Sound insulation filters for closed, side hinged open and bottom hinged open window conditions.

Results of laboratory sound insulation measurements (ISO 10140-2, 2010) for local building elements were received from a research study (Ascigil Dincer & Yilmaz Demirkale, 2015; Yilmaz et al., 2012) for validation of on-site measurements. Laboratory sound insulation values of 145 mm thick plastered brick wall and most common double glazed window were used to calculate sound insulation of a commonly used façade in the area, using Equation 4.3. The resulting values validated the measurements on-site. Therefore, results of measurements on-site were selected to filter the sound clips.

Calculation techniques for composite walls were used to simulate the noise heard inside the house when a window is open. For a full open window (side hinged), a bedroom with façade dimensions 4 m x 3 m (12 m^2) and a window of 0.8 m x 1.5 m (1.2 m^2) was considered. For a partially open window (bottom hinged), the same dimensions were also considered. Figure 5.25 shows sound insulation filters for closed, side hinged open and bottom hinged open window conditions.

5.6 Implementation of Listening Tests

For the listening tests, questionnaires and sound clips were prepared, tests were conducted in laboratory conditions to 40 respondents and results were analyzed. The listening tests were executed in December 2014, in Istanbul Technical University, Faculty of Architecture, Building Physics and Environmental Control Laboratory, where background noise was always monitored.

5.6.1 Listening test sound clips

20 seconds long sound clips were created to simulate the sound heard inside houses and to evaluate environmental noise annoyance. Each sound clip represents a road type with a specific speed of vehicles and traffic flow, on a specific road slope and surface. All of these traffic and road characteristics are present in the area under consideration. The information on the number of vehicles for each road was given in Table 5.19 and 0. Filter for geometric divergence and atmospheric absorption was applied for possible source-receiver distances. Effect of motorcycle passing and horn sounds during pulsed flow, which are found to be annoying in the socio-acoustics survey results, were also investigated. Urban sound propagation filters were applied to main road sound clips, canyon effect filters were applied to secondary roads. Façade sound insulation filter was applied to all sound clips, except two main road sound clips were used for side hinged and bottom hinged open window façade insulation. In sub-part 4, the effect of daily concentrating activity was investigated with a reading activity. The questions given in Figure 4.13, Figure 4.14 and Figure 4.15 were used. The description of the sound clips are given in Table 5.22, Table 5.23 and Table 5.24.

Table 5.22 : Descriptions of sound clips in listening test, Sub-part 1.

	Noise emission																			Noise propagation												Factors of annoyance					
	Traffic speed				Traffic flow volume						Traffic flow type				Road slope			Road surface		Geo.div. & Atm.abs. (Filter)						Urban propagation (Filter)						Time of day			insulation (Filter)		
Label	30 km/h	50 km/h	70 km/h	110 km/h	Dead-end road	Service road	Collective road	Small main road	Main road (day)	Main road (night)	Fluid continuous	Pulsed continuous	Pulsed accelerating	Pulsed decelerating	Level ≤2%	Rising >2% upward	Falling >2% downward	Smooth asphalt	Paving stones	3.75 m	7.5 m	15 m	30 m	60 m	120 m	From main road to narrow	Behind detached buildings	Behind attached buildings	Behind a narrow opening	One sided canyon street	Canyon street	Day	Evening	Night	Façade insulation	Open window (side hung)	Open window (bottom hung)
Sub-part 1																																					
Dead-end 30 4m	X				X						X				X			X		X												X			X		
Dead-end 30 4m Rise Stone	X				X						X					X			X	X												X			X		
Service 30 4m	X					X					X				X			X		X												X			X		
Service 30 4m Rise	X					X					X					X		X		X												X			X		
Service 30 4m Fall	X					X					X						X	X		X												X			X		
Service 30 4m Rise Stone	X					X					X					X			X	X												X			X		
Service 30 4m Fall Stone	X					X					X						X		X	X												X			X		
Service 30 4m CanyonS	X					X					X				X			X		X										X		X			X		
Service 30 4m CanyonD	X					X					X				X			X		X											X	X			X		
Collective 30 4m	X						X				X				X			X		X												X			X		
Collective 50 4m		X					X				X				X			X		X												X			X		
Collective wMc 50 4m		X					X				X				X			X		X												X			X		
Collective Pulsed 4m							X					X			X			X		X												X			X		
Collective Pulsed wH 4m							X					X			X			X		X												X			X		
Collective Acc 4m		X					X						X		X			X		X												X			X		
Collective Dec 4m		X					X							X	X			X		X												X			X		
Collective Acc 8m		X					X						X		X			X			X											X			X		
Collective Acc 15m		X					X						X		X			X				X										X			X		
Collective 30 4m Rise	X						X				X					X		X		X												X			X		
Collective 30 4m Fall	X						X				X						X	X		X												X			X		
Collective 50 4m CanyonS		X					X				X				X			X		X										X		X			X		
Collective 50 4m CanyonD		X					X				X				X			X		X											X	X			X		
Collective 50 4m woF		X					X				X				X			X		X												X					
Small main 50 8m		X						X			X				X			X			X											X			X		
Small main wMc 50 8m		X						X			X				X			X			X											X			X		
Small main Acc 8m		X						X					X		X			X			X											X			X		
Small main Acc 15m		X						X					X		X			X				X										X			X		
Small main Acc 30m		X						X					X		X			X					X									X			X		

wMc: with Motorcycle, one of the cars was replaced by a motorcycle. wH: with Horn, horn sounds are added.

Table 5.23 : Descriptions of sound clips in listening test, Sub-part 2.

	Noise emission																			Noise propagation												Factors of annoyance					
	Traffic speed				Traffic flow volume						Traffic flow type				Road slope			Road surface		Geo.div. & Atm.abs. (Filter)						Urban propagation (Filter)						Time of day			insulation (Filter)		
Label	30 km/h	50 km/h	70 km/h	110 km/h	Dead-end road	Service road	Collective road	Small main road	Main road (day)	Main road (night)	Fluid continuous	Pulsed continuous	Pulsed accelerating	Pulsed decelerating	Level ≤2%	Rising >2% upward	Falling >2% downward	Smooth asphalt	Paving stones	3.75 m	7.5 m	15 m	30 m	60 m	120 m	From main road to narrow streets	Behind detached buildings	Behind attached buildings	Behind a narrow opening	One sided canyon street	Canyon street	Day	Evening	Night	Façade insulation	Open window (side hung)	Open window (bottom hung)
Sub-part 2																																					
Main - day 50 15m		X							X		X				X			X				X										X			X		
Main - day 70 15m			X						X		X				X			X				X										X			X		
Main - day Pulsed 15m									X			X			X			X				X										X			X		
Main - day wH Pulsed 15m									X			X			X			X				X										X			X		
Main - day Acc 15m		X							X				X		X			X				X										X			X		
Main - day Acc 30m		X							X				X		X			X					X									X			X		
Main - day Acc 60m		X							X				X		X			X						X								X			X		
Main - day Acc 120m		X							X				X		X			X							X							X			X		
Main - day Acc Narrow 20m		X							X				X		X			X				X				X						X			X		
Main - day Acc Narrow 40m		X							X				X		X			X				X				X						X			X		
Main - day Acc Narrow 60m		X							X				X		X			X				X				X						X			X		
Main - day Acc Narrow 80m		X							X				X		X			X				X				X						X			X		
Main - day Acc 15m bDb		X							X				X		X			X				X					X					X			X		
Main - day Acc 15m bAb		X							X				X		X			X				X						X				X			X		
Main - day Acc 15m bNo		X							X				X		X			X				X							X			X			X		
Main - day Acc 15m oWS		X							X				X		X			X				X										X				X	
Main - day Acc 15m oWB		X							X				X		X			X				X										X					X
Main - day Acc 15m woF		X							X				X		X			X				X										X					

wH: with Horn, horn sounds are added.

Table 5.24 : Descriptions of sound clips in listening test, Sub-part 3&4.

	Noise emission																			Noise propagation												Factors of annoyance					
	Traffic speed				Traffic flow volume						Traffic flow type				Road slope			Road surface		Geo.div. & Atm.abs. (Filter)						Urban propagation (Filter)						Time of day			insulation (Filter)		
Label	30 km/h	50 km/h	70 km/h	110 km/h	Dead-end road	Service road	Collective road	Small main road	Main road (day)	Main road (night)	Fluid continuous	Pulsed continuous	Pulsed accelerating	Pulsed decelerating	Level ≤2%	Rising >2% upward	Falling >2% downward	Smooth asphalt	Paving stones	3.75 m	7.5 m	15 m	30 m	60 m	120 m	From main road to narrow streets	Behind detached buildings	Behind attached buildings	Behind a narrow opening	One sided canyon street	Canyon street	Day	Evening	Night	Façade insulation	Open window (side hung)	Open window (bottom hung)
Sub-part 3																																					
Main - day 70 15m (D)			X						X		X				X			X				X												X	X		
Main - day 70 15m (E)			X						X		X				X			X				X											X		X		
Main - day 70 15m (N)			X						X		X				X			X				X										X			X		
Main - night 70 15m			X							X	X				X			X				X												X	X		
Main - night wMb 70 15m			X							X	X				X			X				X												X	X		
Main - night 110 15m				X						X	X				X			X				X												X	X		
Main - night Acc 15m		X								X			X		X			X				X												X	X		
Main - night 70 Rise			X							X	X					X		X				X												X	X		
wMb: with Minibus.																																					
Sub-part 4																																					
Main - day 70 15m - READING			X						X		X				X			X				X										X			X		

5.6.2 Listening test results and annoyance model for Besiktas

Listening test results were statistically analyzed and were examined for factors effecting annoyance. Cronbach's alpha was computed for annoyance questions and it proved that the survey had a good reliability by $\alpha = 0.704$.

Spearman Correlation results showed some moderate correlations. In terms of annoyance, women were more sleep disturbed and older people were more annoyed and more sleep disturbed. People whose bedrooms overlooked the street were more annoyed. In terms of activity annoyance, men were more annoyed while concentrating; older people and more educated people were more annoyed while resting. Correlation coefficients are given in Table 5.25.

Most annoying reported traffic elements were horns and motorcycles. Annoyance during daily activities were highest for resting and concentrating. These results on traffic elements and daily activities are similar to the results of the on-site survey.

Table 5.25 : Spearman 's correlations for listening tests.

Variable 1	Variable 2	Correlation Coefficient
Noise annoyance	Age	0.432
Noise annoyance	Bedroom overlooking road	0.482
Sleep disturbance	Gender	0.529
Sleep disturbance	Age	0.449
Gender	Sensitivity	0.395*
Gender	Traffic element: Truck	0.491
Gender	Activity: Concentrating	0.491
Age	Activity: Resting	0.830
Education	Activity: Resting	0.453

* Correlation is significant at the 0.05 level (2-tailed). All other correlations are significant at the 0.01 level (2-tailed).

Annoyance levels of respondents for each simulated traffic sound clip was analyzed to calculate percentage of people annoyed (%A) and percentage of people highly annoyed (%HA). Averages of verbal and numerical scale results were used.

Annoyance results from listening tests are given in Table 5.26. For easy expression and comprehension, some factors which effect annoyance in a similar way were united. Traffic which had pulsed decelerating flow had almost the same annoyance response as fluid continuous flow. So, pulsed decelerating flow is not mentioned in the results. Traffic on a falling slope had almost the same annoyance response as traffic on level slope. So, falling slope is not mentioned in some of the results.

Figure 5.26 shows the %A and %HA results for secondary roads. For dead-end and service roads, on-site studies proved that traffic flow type is almost always fluid continuous and road surface may vary, smooth asphalt or paving stones. Rising slope and road surface (paving stones) were extremely effective in annoyance levels of dead-end and service roads, increasing annoyance up to 65%.

Table 5.26 : Annoyance results from listening tests.

Label	**%A**	**%HA**
Sub-part 1		
Dead-end 30 4m	5,0%	0,0%
Dead-end 30 4m Rise Stone	65,0%	37,5%
Service 30 4m	7,5%	0,0%
Service 30 4m Rise	50,0%	17,5%
Service 30 4m Fall	7,5%	0,0%
Service 30 4m Rise Stone	67,5%	37,5%
Service 30 4m Fall Stone	22,5%	10,0%
Service 30 4m CanyonS	15,0%	5,0%
Service 30 4m CanyonD	17,5%	5,0%

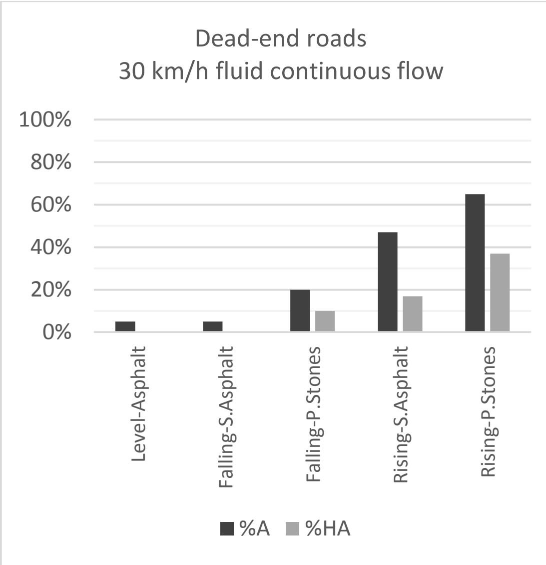
Table 5.26 (continued):		
Label	**%A**	**%HA**
Collective 30 4m	10,0%	0,0%
Collective 50 4m	27,5%	5,0%
Collective wMc 50 4m	37,5%	10,0%
Collective Pulsed 4m	35,0%	10,0%
Collective Pulsed wH 4m	50,0%	20,0%
Collective Acc 4m	45,0%	25,0%
Collective Dec 4m	25,0%	2,5%
Collective Acc 8m	45,0%	25,0%
Collective Acc 15m	35,0%	12,5%
Collective 30 4m Rise	45,0%	20,0%
Collective 30 4m Fall	12,5%	0,0%
Collective 50 4m CanyonS	37,5%	15,0%
Collective 50 4m CanyonD	37,5%	15,0%
Collective 50 4m woF	35,0%	10,0%
Small main 50 8m	25,0%	10,0%
Small main wMc 50 8m	40,0%	15,0%
Small main Acc 8m	55,0%	30,0%
Small main Acc 15m	50,0%	22,5%
Small main Acc 30m	45,0%	17,5%
Sub-part 2		
Main - day 50 15m	45,0%	7,5%
Main - day 70 15m	60,0%	12,5%
Main - day Pulsed 15m	65,0%	15,0%
Main - day Pulsed wH 15m	85,0%	30,0%
Main - day Acc 15m	70,0%	30,0%
Main - day Acc 30m	57,5%	17,5%
Main - day Acc 60m	40,0%	10,0%
Main - day Acc 120m	20,0%	0,0%
Main - day Acc Narrow 20m	70,0%	30,0%
Main - day Acc Narrow 40m	50,0%	20,0%
Main - day Acc Narrow 60m	37,5%	12,5%
Main - day Acc Narrow 80m	25,0%	0,0%
Main - day Acc 15m bDb	40,0%	10,0%
Main - day Acc 15m bAb	2,5%	0,0%
Main - day Acc 15m bNo	5,0%	2,5%
Main - day Acc 15m oWS	90,0%	52,5%
Main - day Acc 15m oWB	100,0%	67,5%
Main - day Acc 15m woF	70,0%	30,0%
Sub-part 3		
Main - day 70 15m (D)	60,0%	12,5%
Main - day 70 15m (E)	67,5%	17,5%
Main - day 70 15m (N)	65,0%	17,5%
Main - night 70 15m	60,0%	20,0%
Main - night wMb 70 15m	80,0%	30,0%
Main - night 110 15m	72,5%	30,0%
Main - night Acc 15m	85,0%	35,0%
Main - night 70 Rise	92,5%	37,5%
Sub-part 4		
Main - day 70 15m -Reading	42,5%	2,5%

Figure 5.26 c and d show annoyance results for collective and small main roads. Traffic flow type, speed and slope varies on these road types and are important in assessing annoyance. Surfaces for these types of roads are always asphalt concrete. Falling slopes are considered to have the same effect as fluid continuous flow. Rising slopes and accelerating flow provide the highest increase in annoyance levels. In cases where pulsed flow causes use of horns, %A increased by 15% and %HA increased by 10%.

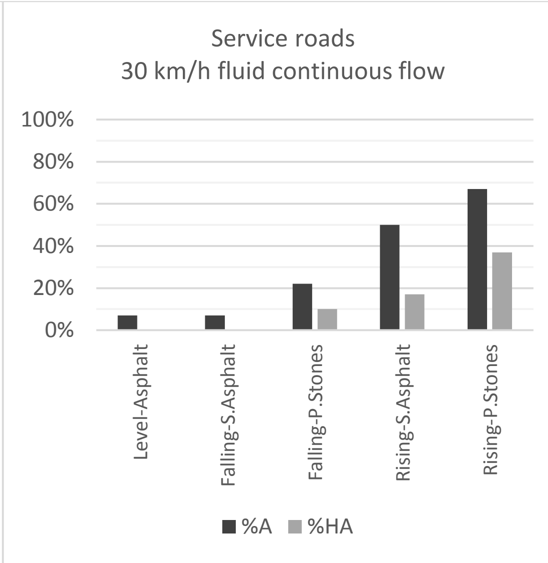
Freitas et al. (2012) executed listening tests for road traffic noise, using different road surfaces, car speeds and traffic densities, and expressed the results in cumulative graphs. In that study, cobblestone pavement induced the highest rate of annoyance; dense asphalt and open asphalt rubber pavement annoyed people almost the same. Vehicle speed and traffic density were effective in determining annoyance.

Some roads were commonly used by courier motorcycles. Listening test results showed that, when 15% of the light vehicle traffic volume is replaced by motorcycles, 15% increase in %A and 5% increase in %HA was spotted. Nilsson (2007) found that annoyance increases when traffic noises have stronger low frequency content. Analysis of the sound clips showed that source-receiver distance and source characteristics are the main reasons of variation in the spectrum, therefore motorcycles and heavy vehicles recorded at the close range provided strong low frequency content. Paviotti et al. (2012) demonstrated that in motorcycle and scooter annoyance, masking by an increased general traffic is effective in reducing annoyance. In this study, masking effect was not specifically investigated but during sound clips of secondary road types, almost all the participants expressed their motorcycle annoyance verbally. No mention of motorcycles were made by the participants during main road sound clips.

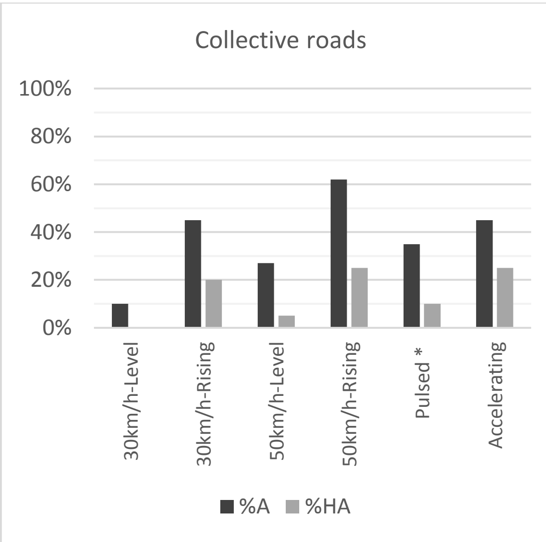
The effect of the insulation filter spectrum was also investigated. A flat filter (same level throughout the spectrum) with the same dBA level as the façade sound insulation was created and applied. For a collective road, using the façade filter with a flat spectrum increased %A by 12.5% and %HA by 5%.



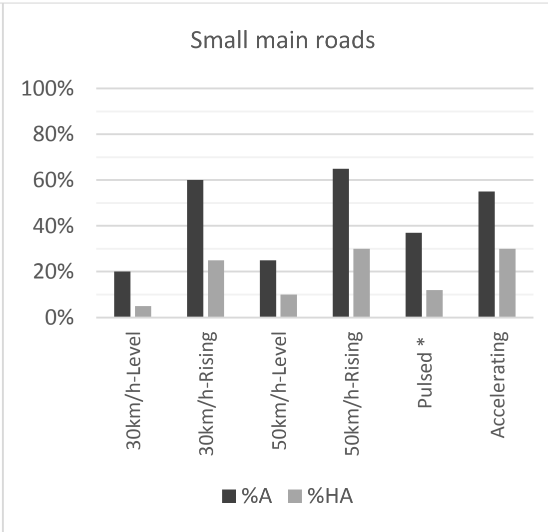
a. Dead-end roads, 30 km/h speed and fluid continuous traffic flow



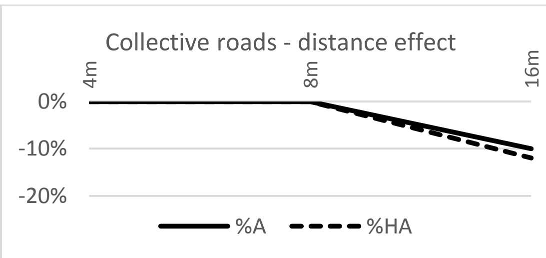
b. Service roads, 30 km/h speed and fluid continuous traffic flow



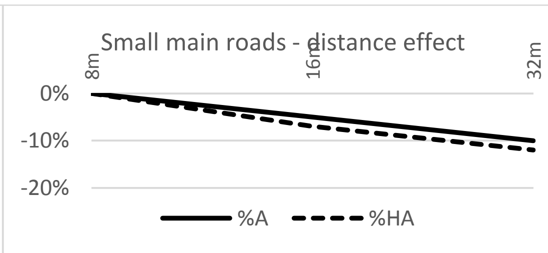
c. Collective roads



d. Small main roads



e. Source to receiver distance effect for collective roads



f. Source to receiver distance effect for small main roads

*Horns used during pulsed flow increases %A by 15% and %HA by 10%.

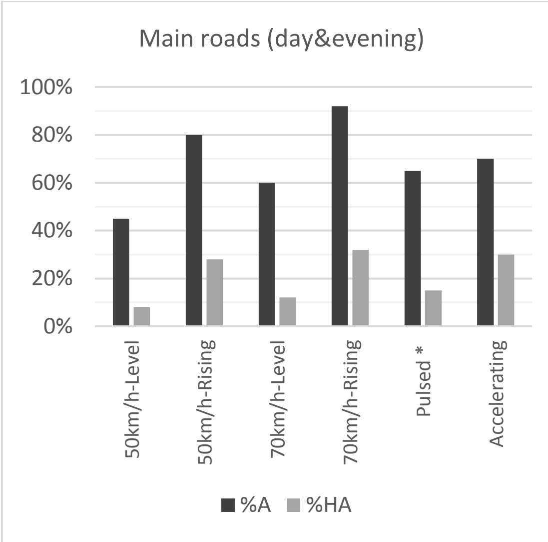
Figure 5.26 : Traffic noise annoyance model for secondary roads in Besiktas area.

Studies on-site and on maps showed that source receiver distance did not change significantly for dead-end and service roads. For collective and small main roads, the effects of source receiver distance were investigated for possible distances. The negative effects of distance may be added to traffic annoyance levels to reach a final annoyance level. Evaluation of canyon effect in secondary roads showed that it may increase %A by 10% and %HA by 5%.

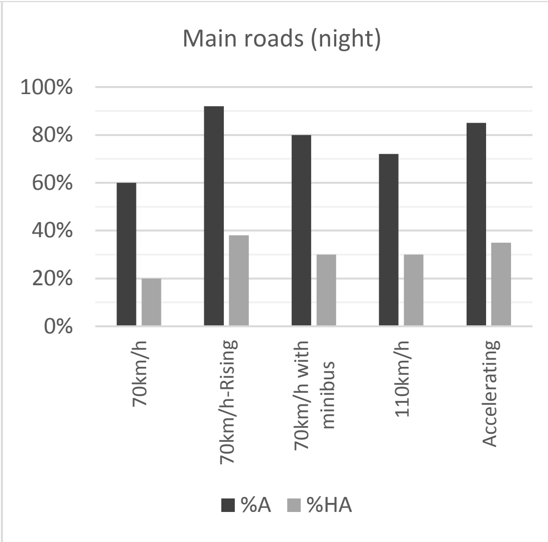
Figure 5.27 shows the %A and %HA results for main roads. Traffic flow type, speed and slope varies on these road types and are important in assessing annoyance. Surfaces for these types of roads are always asphalt concrete. Falling slopes are considered to have the same effect as level slopes. Rising slopes provide the highest increase in annoyance levels. In cases where pulsed flow causes use of horns, %A increased by 20% and %HA increased by 15%. Main road at night traffic was investigated in a similar way, but the respondents were asked to imagine they are listening to the sound clip a night. Traffic flow at night was also investigated including one minibus in 20 seconds, to take into account the time frame when minibuses work at night. The effect of the minibus on annoyance levels is quite valuable, increasing %A by 20% and %HA by 10%. The effects of source receiver distance were investigated for possible distances for the main roads. The negative effects of distance may be added to traffic annoyance levels to reach a final annoyance level.

Evaluation of urban propagation effects for sound propagation from main road to second row of buildings through attached buildings, through detached buildings, through narrow openings, and from main road into perpendicular narrow streets showed substantial decreases in annoyance levels.

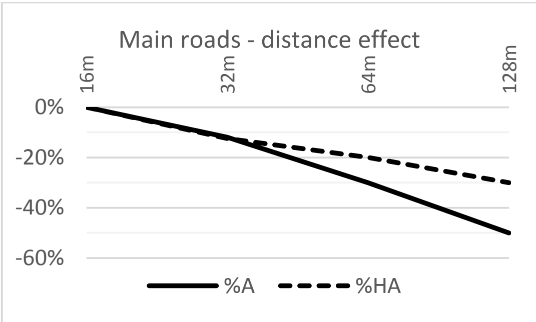
The Directive (EU Parliament and Council, 2002) defines noise indicator L_{den} as average levels during daytime, evening, and night-time, and applies a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night. The effect of time was investigated, using one of the main road sound clips, three times, by asking the respondents how much they are annoyed during day time (07-19), evening time (19-23), and night time (23-07). The results showed insignificant differences, about 5% increase for evening and night. %A increased 7.5% for evening and 5% for night, %HA increased 5% both for evening and night.



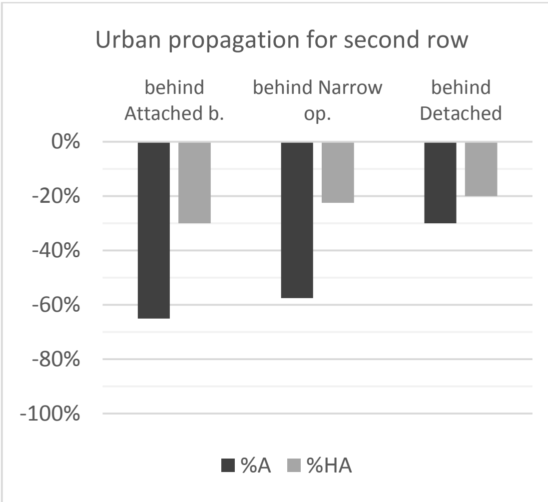
a. Main roads (day and evening)



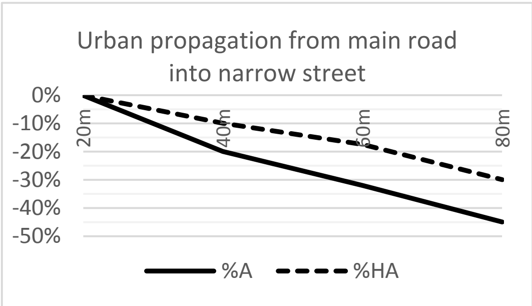
b. Main roads (night)



c. Source to receiver distance effect for main roads



d. Urban propagation effects for second row buildings on main roads



e. Urban propagation effects for narrow streets perpendicular to main roads

*In cases where pulsed flow causes use of horns, %A increased by 20% and %HA increased by 15%.

Figure 5.27 : Traffic noise annoyance model for main roads in Besiktas area.

Comparing closed window, partly open (bottom hinged) window and fully open (side hinged) window for main road revealed 20 and 30 % increase in %A and about 25 and 35 % increase in %HA, respectively.

The reading activity proved to result in 17.5% less annoyance in %A and 10% less annoyance in %HA compared to resting activity disturbance. This result coincides with on-site and laboratory survey results on annoyance during daily activities.

For main roads, the comparison between using a real sound insulation spectrum and a flat sound insulation spectrum showed no difference between the two conditions. On the other hand, it proved an important effect in secondary roads. This condition shows that the effect of the spectrum façade filter may vary for different road types.

5.7 Developing Road Traffic Noise Annoyance Prediction Model in Besiktas District

A road traffic noise annoyance prediction model was developed for Besiktas District and it can also be used for other areas with similar traffic and urban conditions.

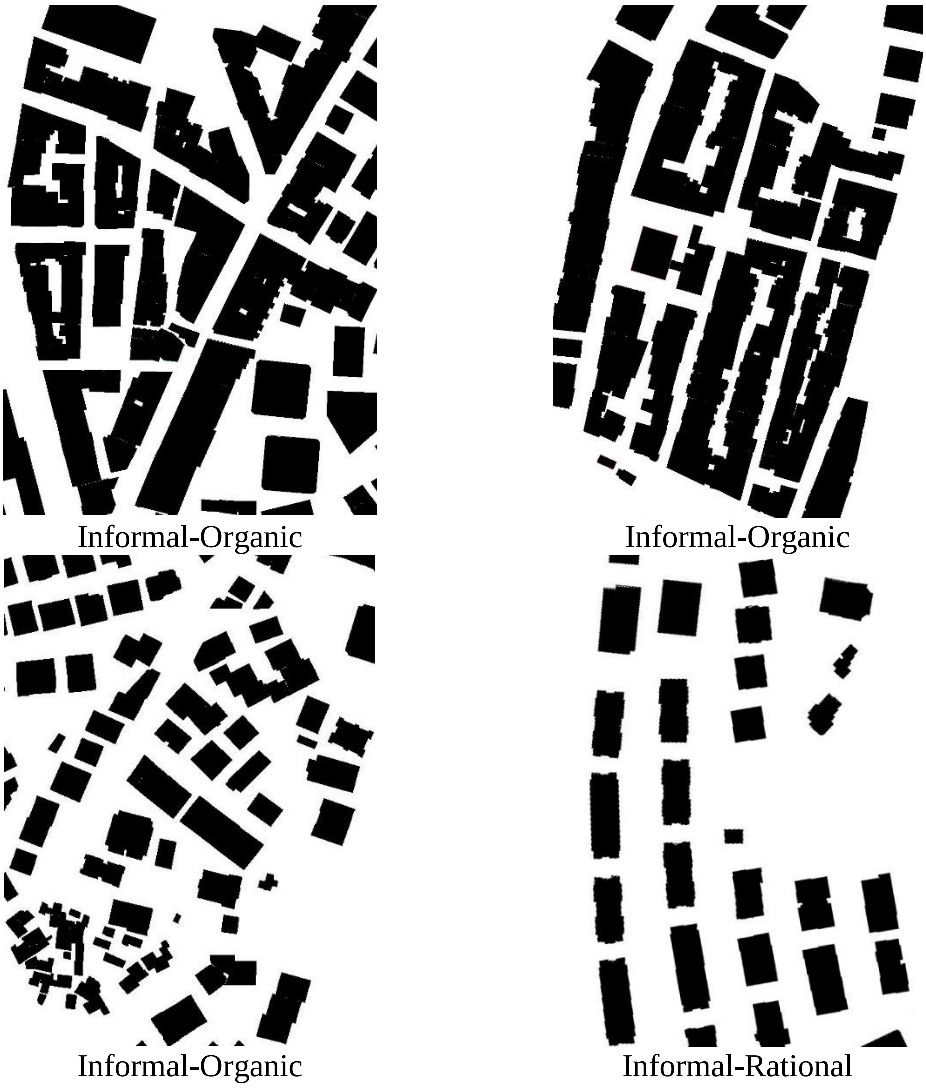


Figure 5.28 : Urban development types considered in Besiktas area.

The traffic conditions are similar throughout Istanbul city and most of the major cities in Turkey. The most common vehicle types were determined from Istanbul city statistics. All secondary and main roads can be classified. Average speed, traffic flow types, road slope and surface types are similar throughout Istanbul. Before applying this model to another area, traffic volume and distribution for main roads would have to be checked. The urban development types considered in this model are “Informal-Organic” and “Informal-Rational” are shown in Figure 5.28. These types of urban development are similar to many districts in Istanbul city. Gated community areas would not fit into this urban development classification.

5.7.1 Development of road traffic noise annoyance prediction model base for Besiktas District

The base of the road traffic noise annoyance prediction model is the annoyance model developed in Section 5.6.2, through listening tests, shown by Figure 5.26 and Figure 5.27.

5.7.2 Validation of road traffic noise annoyance prediction model in Besiktas District

The results of the on-site surveys were used for validating the road traffic noise annoyance prediction model in Besiktas District. In addition to 183 surveys made on-site (presented in Section 5.2), 58 additional surveys were executed in a slightly larger area, adding up to a total of 241 on-site surveys. The area for 183 surveys was defined by L_{den}>55 dBA, on a map including all roads and buildings. The larger area in which all 241 surveys were executed was defined by L_{den}>55 dBA, on a map including only Barbaros Avenue as source and without any buildings. The area was also the calculating area of the noise map. All 241 survey results were used for validation.

Each survey result was matched with the street on its address information. The type of the road was determined for each street. All streets were grouped according to road type. Each group was analyzed to determine %A and %HA. The answer scales were converted to a 100 scale. Percentage of people annoyed (%A) was determined with cutoff point 50 and percentage of people highly annoyed (%HA) was determined with cutoff point 72 (WG-HSEA, 2002). The %A and %HA of each group was compared to %A and %HA of listening tests. The difference between on-site (socio-acoustics surveys) and laboratory (listening test) results were more than 10% in all cases. The %A and %HA for road types showed no visible pattern.

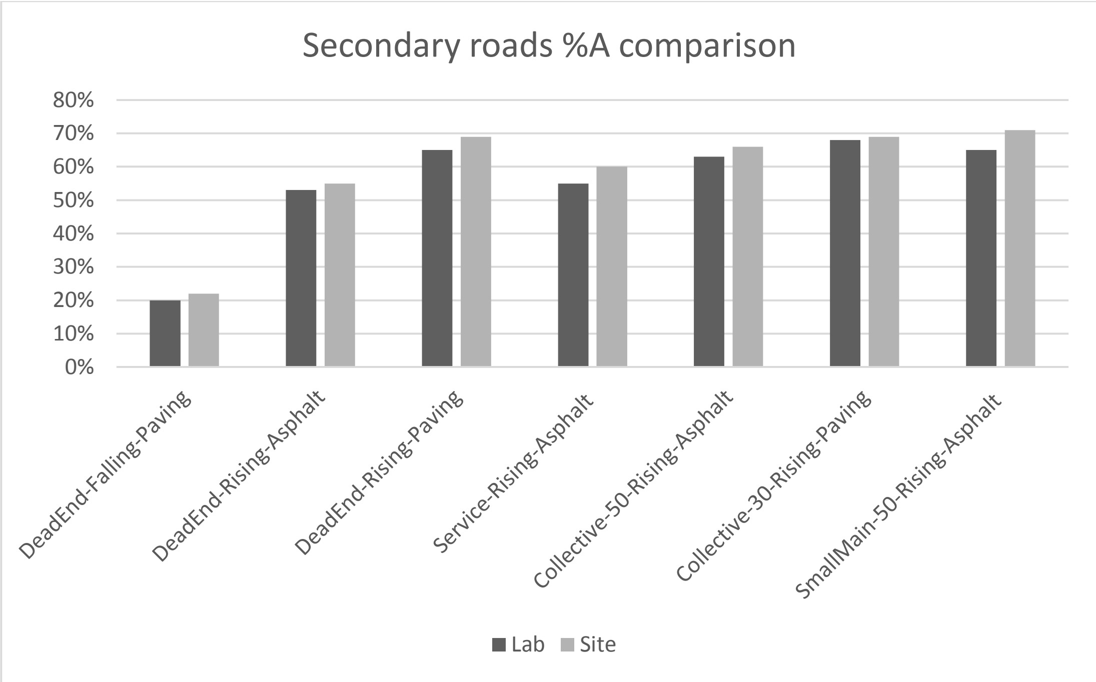


Figure 5.29 : Comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results on %A of secondary roads for traffic noise annoyance prediction model in Besiktas.

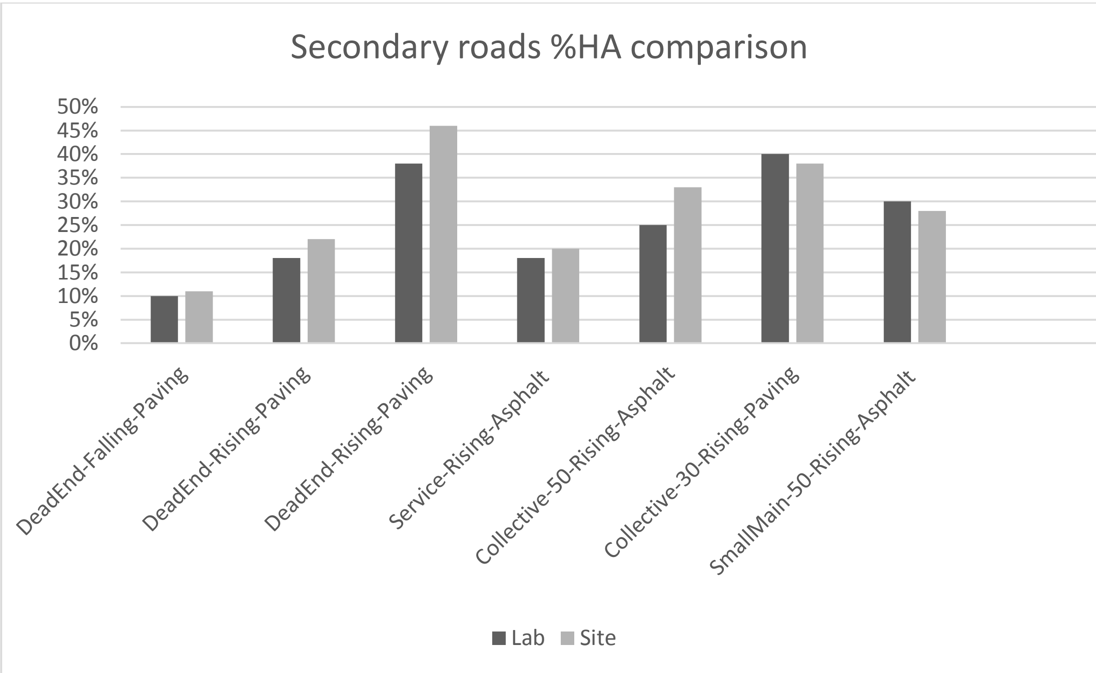


Figure 5.30 : Comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results on %HA of secondary roads for traffic noise annoyance prediction model in Besiktas.

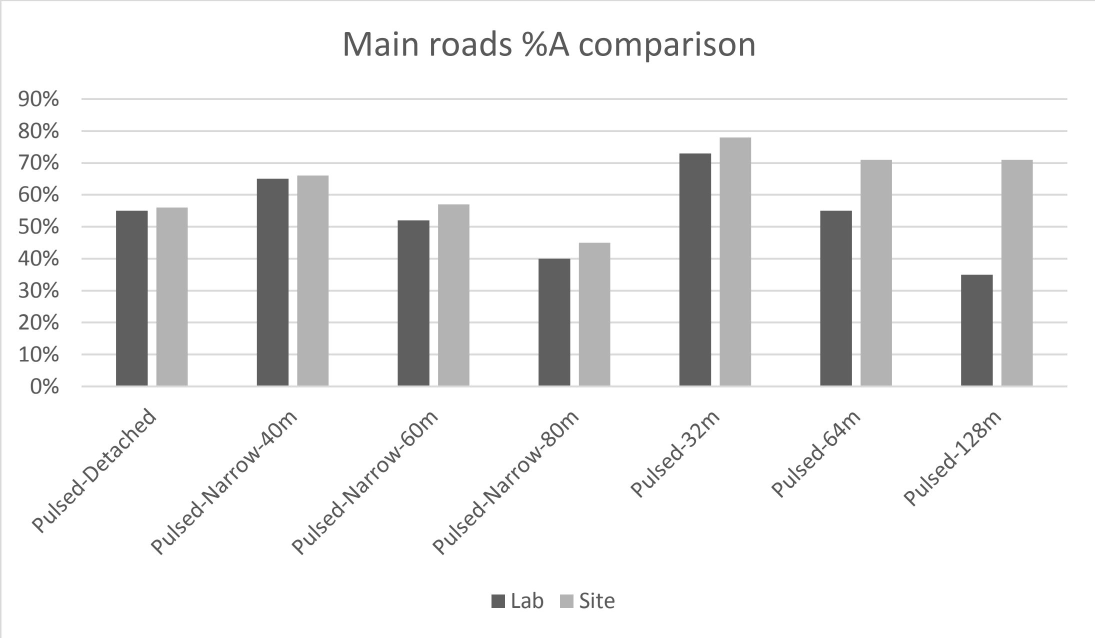


Figure 5.31 : Comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results on %A of main roads for traffic noise annoyance prediction model in Besiktas.

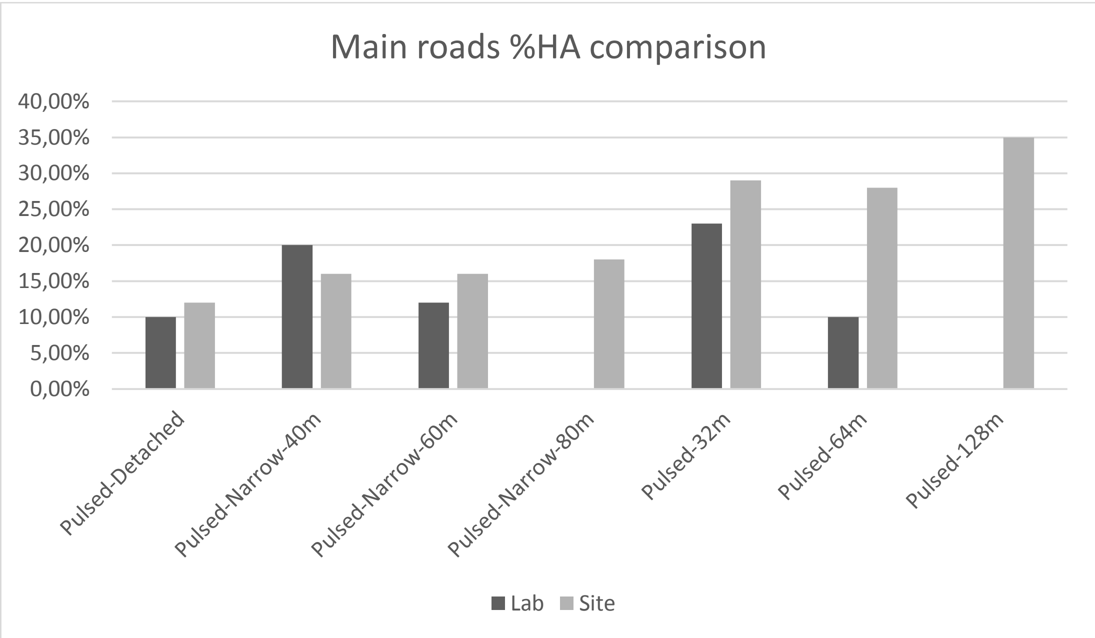


Figure 5.32 : Comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results on %HA of main roads for traffic noise annoyance prediction model in Besiktas.

Each survey point was checked on map for similar relations to urban propagation conditions studied in this research; streets affected by noise from main roads and street canyons. The survey results were grouped from this point of view. The %A and %HA for each group was calculated and compared to listening test annoyance model. The difference between on-site (socio-acoustics surveys) and laboratory (listening test) results were mostly more than 10%, but it was observed that a pattern was beginning to form. The groups of on-site surveys are given in Appendix C.

Each survey point was examined on map for any other possible unexpected sound situations. The problematic places were streets perpendicular to near dead-end and service roads which had stone paved road surfaces. Grouping these perpendicular streets showed a pattern. This sound situation was simulated in SoundPlan 6.5 for a better understanding.

The results of the comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results are graphed in Figure 5.29, Figure 5.30, Figure 5.31 and Figure 5.32.

Table 5.27 : Comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results on %A and %HA and the "test of goodness of fit" results (Pearson's chi-squared test), for traffic noise annoyance prediction model in Besiktas.

Name	Road	Speed	Flow	Slope	Surface	Dist.	Urban	Sam. size	Lab %A	Lab %HA	Site %A	Site %HA	Chi-sq %A	P %A	Chi-sq %HA	P %HA
Falling-Paving	Dead-end	30	Fluid	Falling	Paving	4m	No	9	20%	10%	22%	11%	0.250	0.6171	0.111	0.7389
Rising-Asphalt	Dead-end	30	Fluid	Rising	Asphalt	4m	No	9	53%	18%	55%	22%	0.161	0.6886	1.084	0.2978
Rising-Paving	Dead-end	30	Fluid	Rising	Paving	4m	No	13	65%	38%	69%	46%	0.703	0.4017	2.716	0.0993
Rising-Asphalt	Service	30	Fluid	Rising	Asphalt	4m	No	10	55%	18%	60%	20%	1.010	0.3149	0.271	0.6027
50-Rising-Asphalt	Collective	50	Fluid	Rising	Asphalt	8m	No	6	63%	25%	66%	33%	0.386	0.5344	3.413	0.0647
30-Rising-Paving	Collective	30	Fluid	Rising	Paving	8m	No	13	68%	40%	69%	38%	0.046	0.8303	0.170	0.6803
50-Rising-Asphalt	Small Main	50	Fluid	Rising	Asphalt	8m	No	7	65%	30%	71%	28%	1.582	0.2084	0.190	0.6625
Pulsed-DETACH	Main	50	Pulsed	Level	Asphalt	16m	Detached	19	55%	10%	56%	12%	0.040	0.8407	0.444	0.5050
Pulsed-NARROW -40m	Main	50	Pulsed	Level	Asphalt	40m	Narrow	18	65%	20%	66%	16%	0.044	0.8339	1.000	0.3173
Pulsed-NARROW -60m	Main	50	Pulsed	Level	Asphalt	60m	Narrow	12	52%	12%	57%	16%	1.002	0.3169		
Pulsed-NARROW -80m	Main	50	Pulsed	Level	Asphalt	80m	Narrow	22	40%	0%	45%	18%	1.042	0. 3074		
												16-18 Chi-sq 0.271 P 0.6027				
Pulsed-32m	Main	50	Pulsed	Level	Asphalt	32m	Distance	14	73%	23%	78%	29%	1.268	0.2601	2.033	0.1539
Pulsed-64m	Main	50	Pulsed	Level	Asphalt	64m	Distance	7	55%	10%	71%	28%				
Pulsed-128m	Main	50	Pulsed	Level	Asphalt	128 m	Distance	14	35%	0%	71%	35%				
											78-71 Chi-sq 2.855 P 0.0911	29-35 Chi-sq 1.748 P 0.1861				

The comparison between on-site (socio-acoustics surveys) and laboratory (listening test) results and the "test of goodness of fit" results (Pearson's chi-squared test) are given in Table 5.27. The survey groups with sample size 5 or under have been eliminated in these analyses.

Figure 5.29 compares on-site to laboratory %A results for secondary roads. The dead-end roads paved with stones had 9 survey samples for falling slope and 13 samples for rising slope on-site. %A for dead-end road with paving stone surface and falling slope is 20% in laboratory and 22% on site. %A for dead-end road with paving stone surface and rising slope is 65% in laboratory and 69% on site. Dead-end road with rising slope and asphalt surface with 9 on-site samples had 53% %A in laboratory and 55% on site. Only one type of service road has more than 5 survey samples (10 samples) on site. %A for service road with smooth asphalt surface and rising slope is 55% in laboratory and 60% on site. For collective roads with rising slopes, there were 6 survey samples for smooth asphalt surface and 13 samples for paving stone surface. %A for collective road with smooth asphalt surface and rising slope is 63% in laboratory and 66% on site. %A for collective road with paving stone surface and rising slope is 68% in laboratory and 69% on site. For small main roads, there were only samples (7) with rising slopes and smooth asphalt surface. %A for small main road with smooth asphalt surface and rising slope is 65% in laboratory and 71% on site. Test of goodness of fit proved all of the comparisons to be not statistically different, so on-site results from socio-acoustic surveys can be accepted for prediction model.

Figure 5.30 compares on-site to laboratory %HA results for secondary roads. The dead-end roads paved with stones had 9 survey samples for falling slope and 13 samples for rising slope on-site. %HA for dead-end road with paving stone surface and falling slope is 10% in laboratory and 11% on site. %HA for dead-end road with paving stone surface and rising slope is 38% in laboratory and 46% on site. Dead-end road with rising slope and asphalt surface with 9 on-site samples had 18% %HA in laboratory and 22% on site. Only one type of service road has more than 5 survey samples (10 samples) on site. %HA for service road with smooth asphalt surface and rising slope is 18% in laboratory and 20% on site. For collective roads with rising slopes, there were 6 survey samples for smooth asphalt surface and 13 samples for paving stone surface. %HA for collective road with smooth asphalt surface and rising slope is 25% in laboratory and 33% on site. %HA for collective road with paving stone surface and rising slope is 40% in laboratory and 38% on site. For small main roads, there were only 7 samples with rising slopes and smooth asphalt surface. %HA for small main road with smooth asphalt surface and rising slope is 30% in laboratory and 28% on site. Test of goodness of fit proved all of the comparisons to be not statistically different, so on-site results from socio-acoustic surveys can be accepted for prediction model.

Figure 5.31 compares on-site to laboratory %A results for main roads. Sound propagating from main road to second row of buildings behind detached buildings has 19 samples. %A for detached buildings effect is 55% in laboratory and 56% on site. Sound propagating from main road to perpendicular narrow streets has a total of 52 samples. They are grouped according to distance from main road: 40 m distance with 18, 60 m distance with 12, and 80 m distance with 22 samples. %A for narrow streets effect are 65%, 52% and 40% in laboratory and 66%, 57% and 45% on site, for 40 m, 60 m and 80 m distances from main road, respectively. Test of goodness of fit proved all of these comparisons to be the same, so on-site results from socio-acoustic surveys can be accepted for prediction model.

The survey receivers which are exposed to direct noise from the main road are 35. In the laboratory tests, geometric divergence and atmospheric attenuation were applied and sound clips for 32 m, 64 m and 128 m distance from the main road were formed. %A are 73%, 55% and 35% in laboratory conditions, respectively. But the on-site results from socio-acoustic surveys gave %A to be 78%, 71% and 71%. In this case, test of goodness of fit proved only 32 m distance to be the same, in comparing laboratory and on-site results. But when the three results from socio-acoustic surveys (78%, 71%, 71%) were compared within themselves, test of goodness of fit proved these three results to be the same. This demonstrates that distance does not apply as a factor effecting annoyance on main roads. This may be because of the visual effect of seeing the main road.

There is another set of data which is not graphed here, because it was not anticipated during listening test studies. On the on-site surveys, there are 23 samples on streets perpendicular to service roads with paving stone surface. %A is 34% and %HA is 17% for these survey samples. These samples did not fit into any of the other groups. This proves that sound propagation should be investigated for secondary roads as well.

Figure 5.32 compares on-site to laboratory %HA results for main roads. Sound propagating from main road to second row of buildings behind detached buildings has 19 samples. %HA for detached buildings effect is 10% in laboratory and 12% on site. Test of goodness of fit proved this comparisons to be the same, so on-site results from socio-acoustic surveys can be accepted for prediction model.

Sound propagating from main road to perpendicular narrow streets has a total of 52 samples. They are grouped according to distance from main road: 40 m distance with 18, 60 m distance with 12, and 80 m distance with 22 samples. %A for narrow streets effect are 20%, 12% and 0% in laboratory and 16%, 16% and 18% on site, for 40 m, 60 m and 80 m distances from main road, respectively. In comparing laboratory and on-site results, test of goodness of fit proved only 40 m distance to be the same. But when the three results from socio-acoustic surveys (16%, 16%, 18%) were compared within themselves, test of goodness of fit proved these three results to be the same. This may be because of the relationship between answering scales and cutoff point. People who answer “very” in verbal scale answer 7 or 8 in numerical scale. HA% cutoff point at 72% eliminates people who answer 7 in numerical scale but includes people who answer “very” in verbal scale, which causes problematic results.

The survey receivers which are exposed to direct noise from the main road are 35. In the laboratory tests, geometric divergence and atmospheric attenuation were applied and sound clips for 32 m, 64 m and 128 m distance from the main road were formed. %A are 23%, 10% and 0% in laboratory conditions, respectively. But the on-site results from socio-acoustic surveys gave %A to be 29%, 28% and 35%, respectively. In this case, in comparing laboratory and on-site results, test of goodness of fit proved only 32 m distance to be the same. But when the three results from socio-acoustic surveys (29%, 28%, 35%) were compared within themselves, test of goodness of fit proved these three results to be the same. This demonstrates that distance does not apply as a factor effecting annoyance on main roads. This may be because of the visual effect of seeing the main road.

Percentage of people annoyed in laboratory conditions is always lower than percentage of people annoyed in on-site conditions. The difference is between 1% and 6% (3.3 ±1.8). Percentage of people highly annoyed in laboratory conditions is usually lower than percentage of people highly annoyed in on-site conditions. The difference is between -4% and 8% (2.3 ±4.0). The reasons for this might be the difference between short-term and long-term effects and the visual effect of seeing the road.

5.7.3 Forming road traffic noise annoyance prediction model for Besiktas District

The on-site survey results grouped and validated according to listening test results are used to form the prediction model. Invalidated results are not used in the model. The prediction model is given in Table 5.28.

Table 5.28 : %A and %HA results for for traffic noise annoyance prediction model.

Name	Road	Speed	Flow	Slope	Surface	Dist.	Horn	Urban	%A	%HA
Dead-end - Falling-Paving	Dead-end	30	Fluid	Falling	Paving	4m	no	No	22%	11%
Dead-end - Rising-Asphalt	Dead-end	30	Fluid	Rising	Asphalt	4m	no	No	55%	22%
Dead-end - Rising-Paving	Dead-end	30	Fluid	Rising	Paving	4m	no	No	69%	46%
Service - Rising-Asphalt	Service	30	Fluid	Rising	Asphalt	4m	no	No	60%	20%
Collective - 50-Rising-Asphalt	Collective	50	Fluid	Rising	Asphalt	8m	no	No	66%	33%
Collective - 30-Rising-Paving	Collective	30	Fluid	Rising	Paving	8m	no	No	69%	38%
SmallMain - 50-Rising-Asphalt	SmallMain	50	Fluid	Rising	Asphalt	8m	no	No	71%	28%
Main - Pulsed-Detach	Main	50	Pulsed	Level	Asphalt	16m	yes	Detached	56%	12%
Main - Pulsed-Narrow-40m	Main	50	Pulsed	Level	Asphalt	40m	yes	Narrow	66%	16%
Main - Pulsed-Narrow-60m	Main	50	Pulsed	Level	Asphalt	60m	yes	Narrow	57%	12%
Main - Pulsed-Narrow-80m	Main	50	Pulsed	Level	Asphalt	80m	yes	Narrow	45%	8%
Main - Pulsed-AllDistances	Main	50	Pulsed	Level	Asphalt	All	yes	Distance	78%	29%

5.7.4 Presenting road traffic noise annoyance prediction model for Besiktas District

Road traffic noise annoyance prediction model for Besiktas District is presented in this section. With this presentation, the model may be used in other similar areas.

Step one: Check model compatibility

Traffic distrubution	Main road traffic volume should be checked.
	A. If the area is in Istanbul city, the vehicle disrubution is the same, model is compatible.
	B. If the area is not in Istanbul city, vehicle distrubution statistics should be checked.
Urban development	**A.** If the area is “Informal-Organic” and “Informal-Rational”, the model is compatible.
	B. If the area has gated communities, a new model should be developed.

Step two: Gather data

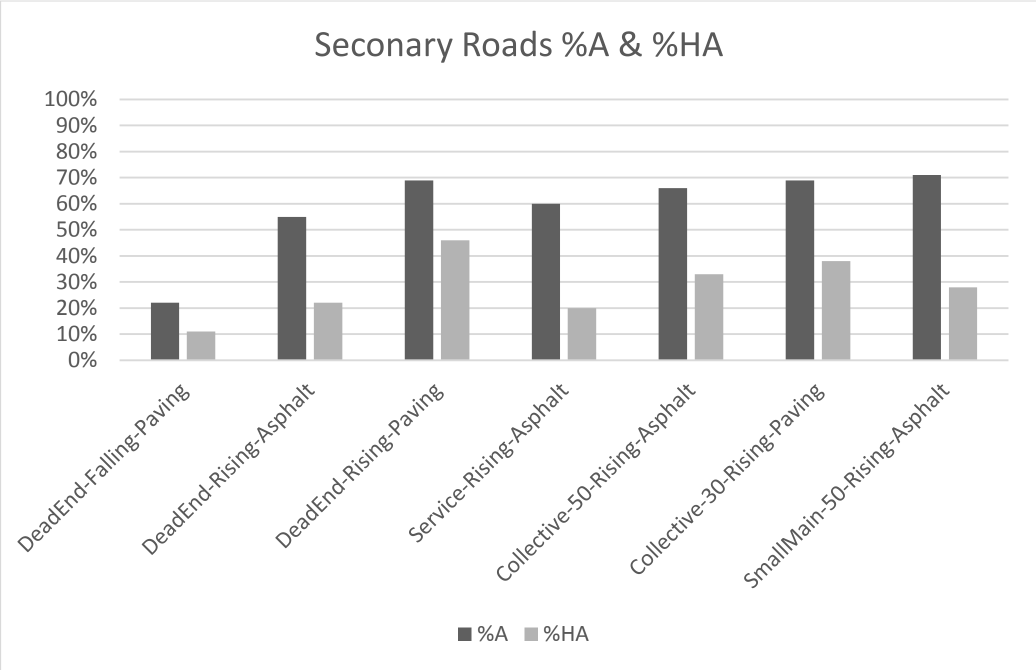
A: If a noise mapping study exists, existing data collected for noise mapping can be used.
B: If there is no noise mapping data, the data given below should be collected on site or obtained from credible sources (WG-AEN, 2006): - Topography of land (elevation contour lines or/and elevation points, acoustic properties of land components) - Structures (geographic data on walls, bridges etc.) - Buildings (geographic data, shape and size data, use, height and number of floors, number of residents) - Roads (geographic data, number of lanes, surface type, road junctions, bridges, traffic lights, parking) - Traffic (yearly average on: types of vehicles, number of vehicles per hour, average traffic speed, traffic flow characteristics)

Step three: Determine the types of roads in the area

A: If the municipality or traffic directorate has a classification on roads in the area, that information can be used.
B: Roads can be classified according to the traffic flow volume given below:

Road type	Traffic volume in 1 hour
Dead-end roads	180
Service roads	360
Collecting roads	720
Small main roads	1440
Main roads	2160 + 90 (HV)

Step four: Determine road types types for each street and average distances from buildings to center of roads and associate with %A and %HA from graphs



Step five: Calculate number of people annoyed and highly annoyed by using number of residents in each building or on each street

6. CONCLUSIONS

In this study, an approach to create local road traffic noise annoyance prediction model is presented. The annoyance prediction model uses use all the information collected for noise mapping as input, and provides annoyance levels as a direct output, taking into account physical and non-physical factors. Using this approach, authorities can develop their own annoyance prediction models, taking into account characteristics of traffic, urban development and population. This approach eliminates noise indicators, which have questionable reliability.

The approach to develop the model includes well-known methods such as noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings and listening tests. Using all of these methods together, provides detailed information on noise sources, urban propagation conditions and people's responses to certain types of noise heard inside their homes, which help to create an accurate model.

The prediction model proposed in this study improves collected traffic data to include all roads; eliminates the need to calculate and validate noise maps and conduct expensive socio acoustics surveys on-site; calculates number of people annoyed and highly annoyed directly. The factors effecting annoyance, such as type of vehicle, spectrum characteristics, tonal components and type of activity, are included. The revision on Environmental Noise Directive (The European Commission, 2015) endorses the decision to include different types of vehicles and differentiate between cars & motorcycles and buses & trucks.

6.1 Discussion on the Approach

The approach to develop road traffic noise annoyance prediction model uses various steps to create an accurate model, which takes into account almost all of the factors effecting annoyance.

Table 6.1 compares current EU annoyance determination technique to proposed approach.

Table 6.1 : Comparison of current EU annoyance determination technique and proposed approach.

	Current EU technique	***Proposed aprroach***	***Comment***
Steps	Noise map Socio acoustics surveys – – – Dose-effect relations development	Noise map Socio acoustics surveys Façade sound insulation Sound recordings and clips Listening tests Prediction model development	Proposed approach has more steps. Simplification of façade insulation and sound recordings might be useful.
Parameters	Input data : - Topography of land - Structures - Buildings - Main Roads - Traffic for main roads	Input data : - Topography of land - Structures - Buildings ***- All Roads*** ***- Traffic for all roads*** ***- Façade insulation*** ***- Sound recordings***	Most input data is already present in Europe. Input data for all roads is needed. Façade insulation and sound recordings data might be simplified.
	Sound propagation : - Meteorological conditions - Geometric divergence - Atmospheric absorption - Ground effect - Diffraction	Sound propagation : ***- Meteorological conditions assumed zero in city blocks scale*** - Geometric divergence - Atmospheric absorption - Ground effect - Diffraction	Sound propagation parameters are included in both cases.
	Acoustic/physical factors : - Sound levels - Type of noise source - – - – - – - – - Time - – Social/ psychological factors (in local applications)	Acoustic/physical factors : - Sound levels - Type of noise source ***- Type of vehicle*** ***- Spectrum characteristics*** ***- Tonal components*** ***- Type of activity*** - Time ***- Façade sound insulation*** Social/ psychological factors (in local applications)	Proposed approach includes almost all of the factors effecting annoyance.
Accuracy	Verified noise map Socio acoustics surveys on-site General annoyance – In action plans: good for hot spots, insufficient for quiet areas.	Verified noise map ***Data from socio acoustics surveys on-site & data from listening tests verified by each other*** General annoyance ***Specific annoyance*** In action plans: ***accurate for almost all types of conditions***	The proposed approach is more accurate in terms of surveys, annoyance and action plan use.

To ensure accuracy, proposed approach has twice the number of steps as the current EU annoyance technique. Simplification of the approach might be useful for implementation. Noise map and socio acoustic survey process exists in both the current EU annoyance technique and the proposed approach.

Façade sound insulation process might be simplified using various methods. Sound insulation of façades might be determined through literature and converted to on-site values through conversion factors. In this study, the effect of using a flat spectrum filter for façade sound insulation instead of a real insulation spectrum proved to have no effect on annoyance for main roads and a little effect for secondary roads. Using weighted value filters might be investigated further. Minimum façade sound insulation values of national legislations might be incorporated into the approach. All of these methods might be investigated in future studies to simplify the process without decreasing the accuracy of the approach.

A traffic sound recordings and clips database might be formed throughout Europe to eliminate this step.

Simplification of façade sound insulation and sound recordings steps will result in only having one extra step, on listening tests, in the proposed approach. This one extra step will help annoyance studies to be much more accurate on so many levels, such as surveys, annoyance and action planning and include many parameters effecting annoyance.

The approach may be simplified over time, in order to make it easier for authorities to apply the approach and develop local prediction models.

6.2 Discussion on the Developed Model

Table 6.2 and Table 6.3 compare current EU annoyance determination technique to proposed annoyance prediction model.

Using an accurate annoyance prediction model provides cost effective action plans which focus on decreasing annoyance levels, and not only noise levels. Planning actions against annoyance will be easier to organize because the model helps to understand the factors which effect annoyance levels. Adding the model as a module into the simulation software would provide a very efficient way of determining annoyance levels and controlling them.

Table 6.2 : Comparison of current EU annoyance determination technique and proposed annoyance prediction model.

	Current EU annoyance determination technique	*Proposed annoyance prediction model*	*Comments*
Steps	Collect data - Topography of land - Structures - Buildings - Main Roads - Traffic for main roads	Collect data - Topography of land - Structures - Buildings ***- All Roads*** ***- Traffic for all roads***	Data for all roads should be collected.
	–	***Analyze data for comparability to model***	Proposed annoynace model has less steps.
	Calculate noise map	–	
	Verify noise map	–	
	Conduct surveys on-site	–	
	Calculate %A & %HA	Calculate %A & %HA	
Parameters	Input data : - Topography of land - Structures - Buildings - Main Roads - Traffic for main roads	Input data : - Topography of land - Structures - Buildings ***- All Roads*** ***- Traffic for all roads***	Data for all roads should be collected.
	Sound propagation : - Meteorological conditions - Geometric divergence - Atmospheric absorption - Ground effect - Diffraction	Sound propagation : ***- Meteorological conditions assumed zero in city blocks scale*** - Geometric divergence - Atmospheric absorption - Ground effect - Diffraction	Sound propagation parameters are included in both cases.
	Acoustic/physical factors : - Sound levels - Type of noise source - – - – - – - – - Time - – Social/ psychological factors (in local applications)	Acoustic/physical factors : - Sound levels - Type of noise source ***- Type of vehicle*** ***- Spectrum characteristics*** ***- Tonal components*** ***- Type of activity*** - Time ***- Façade sound insulation*** Social/ psychological factors (in local applications)	Proposed approach includes almost all of the factors effecting annoyance.
Input	Topography of land Structures Buildings Main Roads Traffic for main roads Measurements for verification Survey data	Topography of land Structures Buildings ***All Roads*** ***Traffic for all roads*** – –	Data for all roads should be collected. Proposed annoynace model has less input steps.
Out put	Noise maps	–	%A & %HA in both cases.
	%A & %HA	%A & %HA	

Table 6.3 : Comparison current EU annoyance determination technique to proposed annoyance prediction model.

	Current EU annoyance determination technique	***Proposed annoyance prediction model***	***Comments***
Economy	Collect data for main roads Conduct socio acoustics surveys on-site In action plans: run different scenarios to reduced noise and then calculate annoyance Almost impossible to apply without software	Collect data for ***all roads*** – In action plans: ***predict reduced noise annoyance directly*** May be applied ***without software***	The proposed model is much more affordable.
Time consumption	Collect data for main roads Calculate noise map Verify noise map Conduct socio acoustics surveys on-site In action plans: run different scenarios to reduced noise and then calculate annoyance	Collect data for ***all roads*** ***Analyze data*** – – In action plans: ***predict reduced noise annoyance directly***	The proposed model is much less time consuming.
Technology	Noise mapping software exists Almost impossible to apply without software	Prediction models may be added as ***modules*** into noise mapping software ***May be applied without software***	Technology may be applied.
Accuracy	Verified noise map Socio acoustics surveys on-site General annoyance – In action plans: good for hot spots, insufficient for quiet areas.	– ***Data from socio acoustics surveys on-site & data from listening tests verified by each other*** General annoyance ***Specific annoyance*** In action plans: ***accurate for almost all types of conditions***	The proposed approach is more accurate in terms of surveys, annoyance and action plan use.

In this thesis, the approach is implemented to create an annoyance prediction model in the urban area of Besiktas in Istanbul city of Turkey, for road traffic noise. All the steps of the approach, noise maps, socio-acoustic surveys, sound insulation measurements, sound recordings, sound clips and listening tests are used to develop and to validate the model.

Implementation of the proposed approach resulted in the following:

- This approach is successful in developing an accurate local road traffic noise annoyance prediction model.
- Façade sound insulation should be considered in annoyance studies.
- Road types (WG-AEN, 2006) are useful in creating a road traffic noise annoyance prediction model.
- In order to obtain accurate results, noise mapping studies should consider all roads as sources, not only main roads. Although noise maps only consider main roads, main roads are not the only sources of annoyance.
- Urban sound propagation conditions should be considered for all types of roads, not only main roads. Even roads with low traffic volume can cause annoyance in nearby streets.
- Unusual source receiver locations are important variants in noise annoyance.
- Traffic elements such as horns and motorcycles, which are disregarded in noise mapping are very effective in determining annoyance.
- Visual contact to the main roads may eliminate the effect of geometric divergence.
- Even if the roads have extremely low traffic volume (such as dead-end roads), road surface and slope may result in annoyance levels equal to roads with highest traffic volumes (such as main roads).
- Percentage of people annoyed in laboratory conditions is always lower than percentage of people annoyed in on-site conditions. The reasons for this might be the difference between short-term and long-term effects and the visual effect of seeing the road.
- The difference between laboratory and on-site results on percentage of people highly annoyed are high. The reason might be the uncoordinated answer scales.
- In order to create an accurate model, each type of road should have enough samples of on-site surveys.

6.3 Further research

Further research on the subject may be on applying a similar approach to different transportation sources, such as railway and aircraft noise.

An approach for sleep disturbance may also be developed.

The simplification of this approach, without accuracy reduction will be useful for authorities in implementation.

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APPENDICES

APPENDIX A: Right and left channel wave form (dB) and spectrogram log(f) for some single vehicle sound recordings and some street sound clips

APPENDIX B: Soundplan simulation software calculations for sound propagation

APPENDIX C: On-site survey result groups for validation of prediction model

APPENDIX A : Right and left channel wave form (dB) and spectrogram log(f) for some single vehicle sound recordings and some street sound clips

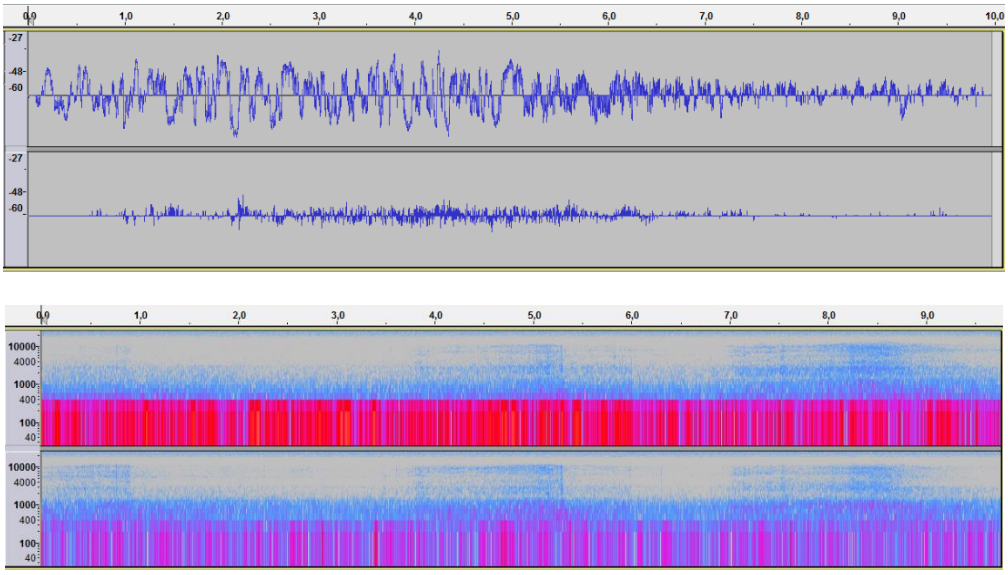

Figure A.1 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Car (Diesel fueled) –Smooth asphalt surface – Level slope – Pulsed continuous flow – 30 km/h

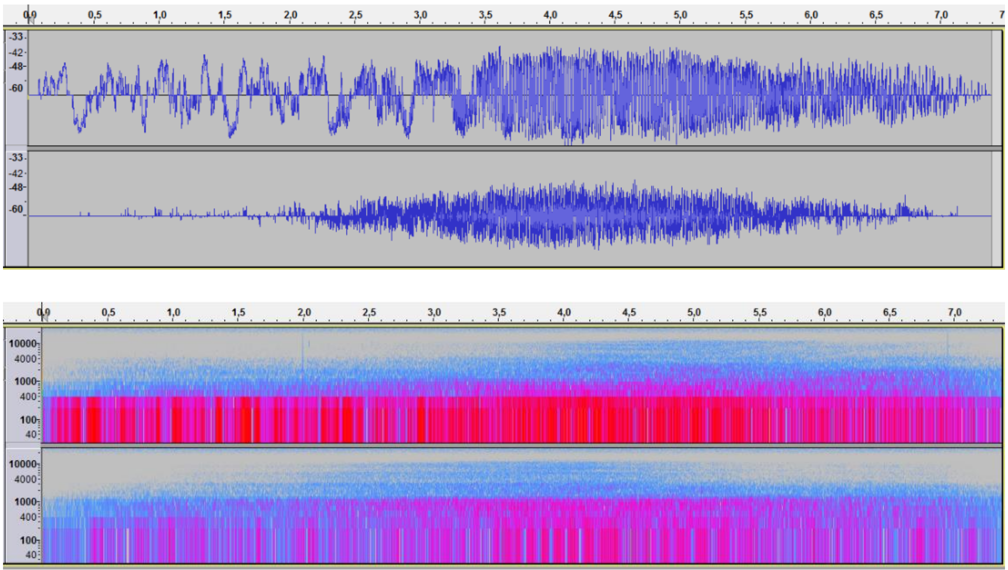

Figure A.2 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Car (Gasoline fueled) –Smooth asphalt surface – Level slope – Pulsed accelerating – 50 km/h

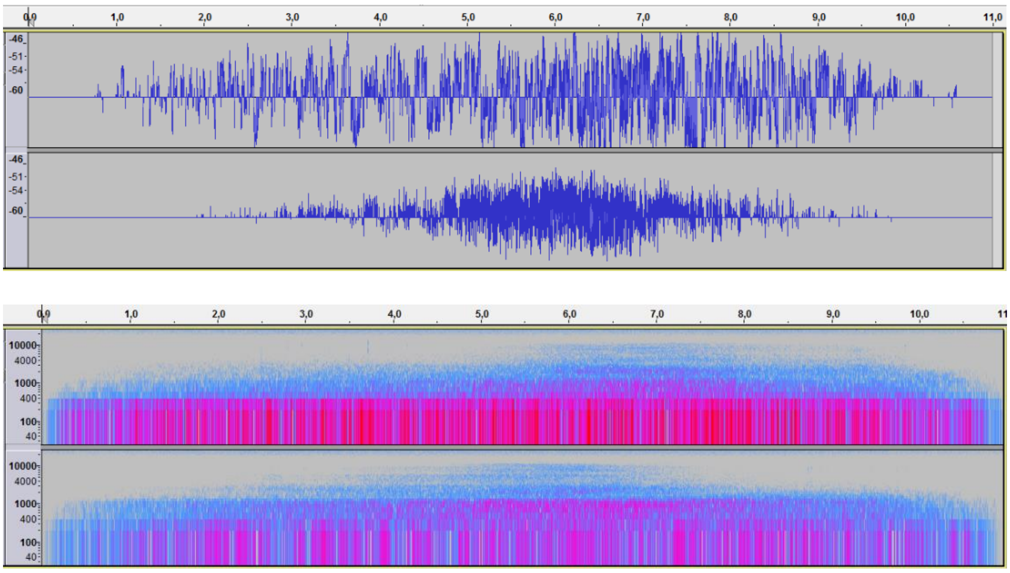

Figure A.3 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Car (Gasoline fueled) –Smooth asphalt surface – Level slope – Fluid continuous – 50 km/h

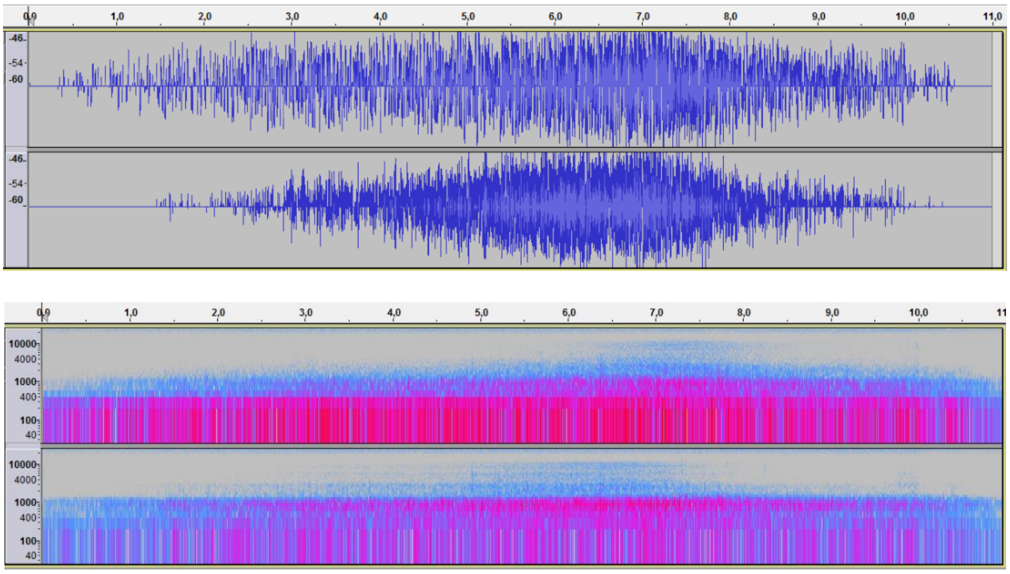

Figure A.4 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Car (Gasoline fueled) – Paving stones – Rising slope – Fluid continuous – 30 km/h

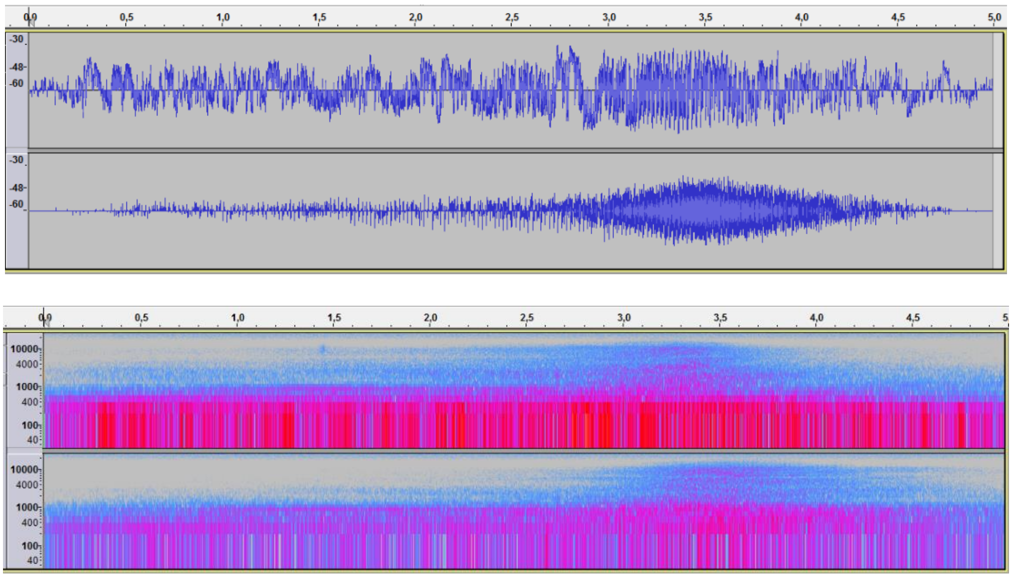

Figure A.5 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Motorcycle –Smooth asphalt surface – Level slope – Fluid continuous – 50 km/h

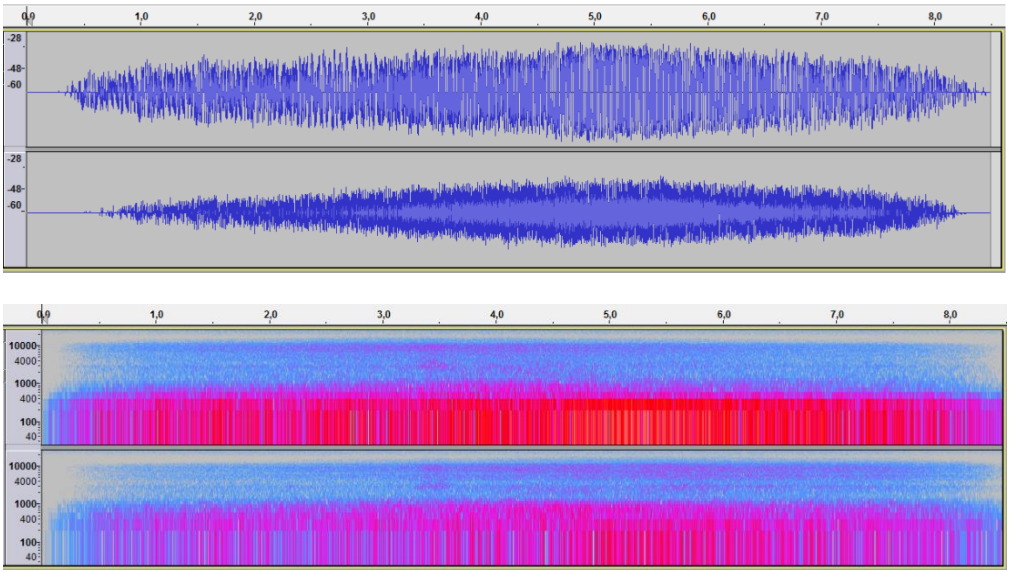

Figure A.6 : Right and left channel wave form (dB) and spectrogram log(f) for single vehicle sound recording: Bus –Smooth asphalt surface – Level slope – Fluid continuous – 50 km/h

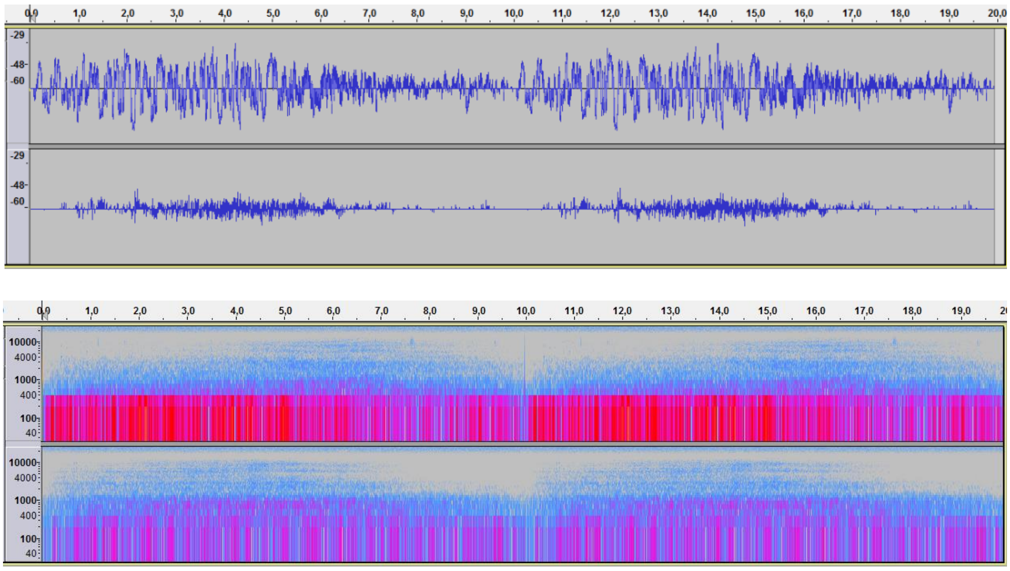

Figure A.7 : Right and left channel wave form (dB) and spectrogram log(f) for street sound clips without filter: Service road (1 gasoline and 1 diesel fueled car) – Smooth asphalt surface – Level slope – Fluid continuous flow – 30 km/h – 7.5m distance

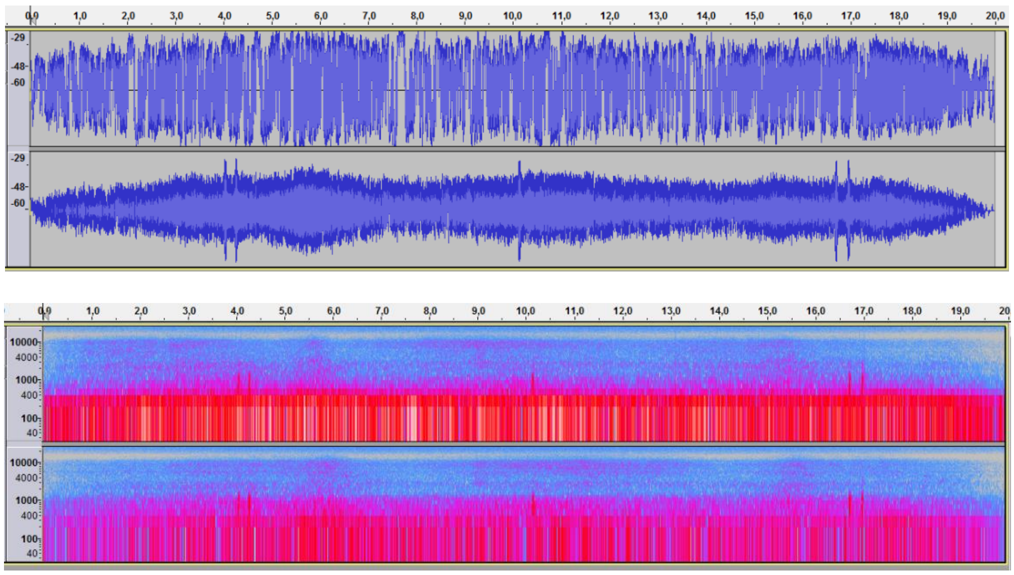

Figure A.8 : Right and left channel wave form (dB) and spectrogram log(f) for street sound clips without filter: Main road (10 gasoline and 10 diesel fueled cars, 2 motorcycles, 2 minibuses, 1 bus) –Smooth asphalt surface – Level slope – Pulsed continuous flow –7.5m distance – with horns

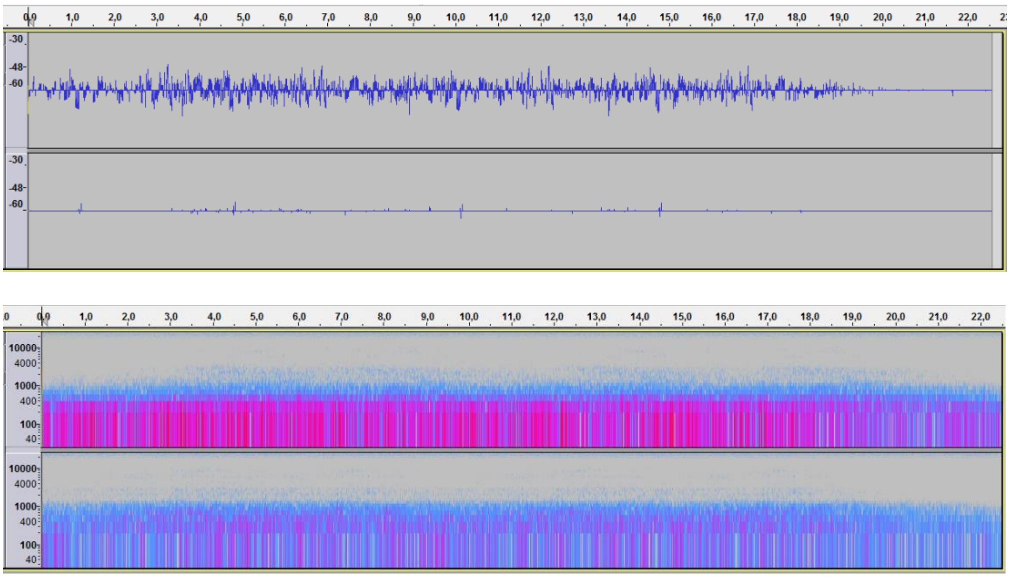

Figure A.9 : Right and left channel wave form (dB) and spectrogram log(f) for street sound clips with sound insulation filter: Service road (1 gasoline and 1 diesel fueled car) –Smooth asphalt surface – Level slope – Fluid continuous flow – 30 km/h – 7.5m distance

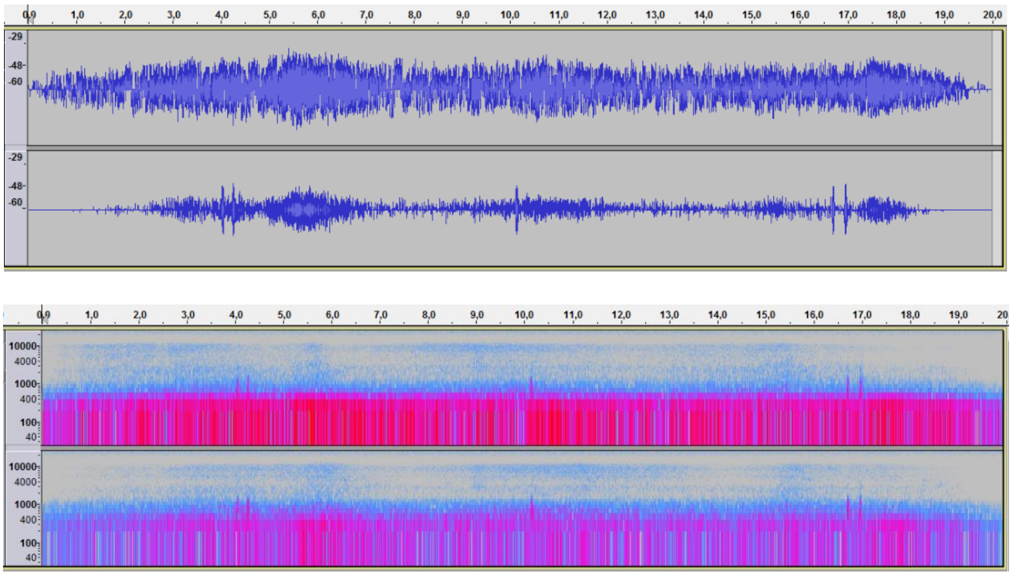

Figure A.10 : Right and left channel wave form (dB) and spectrogram log(f) for street sound clips with geometric divergence, atmospheric absorption and sound insulation filters: Main road (10 gasoline and 10 diesel fueled cars, 2 motorcycles, 2 minibuses, 1 bus) –Smooth asphalt surface – Level slope – Pulsed continuous flow –30m distance – with horns

APPENDIX B : Soundplan simulation software calculations for sound propagation

Sound propagation from main roads into perpendicular narrow streets

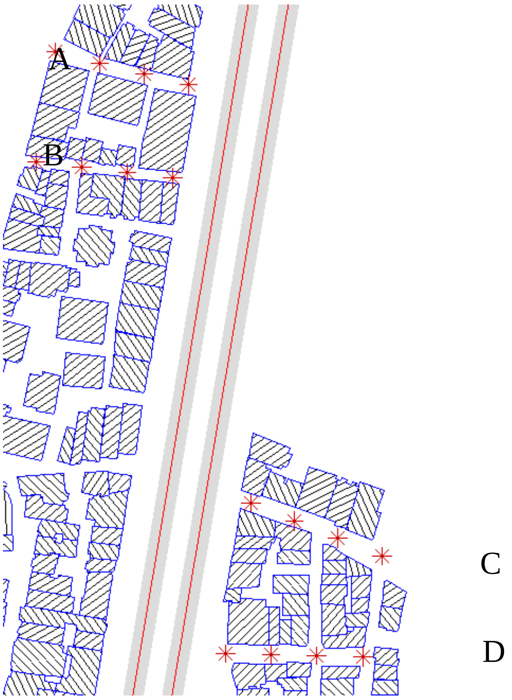

Figure B.1 : Map of area around Barbaros Avenue and receivers, for simulation of sound propagation into narrow streets.

Table B.1 : Simulated A weighted equivalent traffic noise levels for receivers in area with no buildings (open space)

R	Distance from road (m)	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	20	71,5	54,7	54,7	54,7	58,6	58,6	58,6	61,5	61,5	61,5	63,1	63,1	63,1	53,7	53,7	53,7	42,9	42,9	42,9
A	40	65,2	51,1	51,1	51,1	55,1	55,1	55,1	57,4	57,4	57,4	50,3	50,3	50,3	36,3	36,3	36,3	27,1	27,1	27,1
A	60	62,2	49,0	49,0	49,0	52,9	52,9	52,9	54,3	54,3	54,3	40,2	40,2	40,2	29,4	29,4	29,4	20,3	20,3	20,3
A	80	59,4	47,4	47,4	47,4	51,3	51,3	51,3	50,1	50,1	50,1	33,6	33,6	33,6	24,9	24,9	24,9	15,5	15,5	15,5
B	20	71,5	54,7	54,7	54,7	58,7	58,7	58,7	61,5	61,5	61,5	63	63	63	53,6	53,6	53,6	42,8	42,8	42,8
B	40	65	51,1	51,1	51,1	55	55	55	57,2	57,2	57,2	48,6	48,6	48,6	35,6	35,6	35,6	26,5	26,5	26,5
B	60	62	49	49	49	52,9	52,9	52,9	53,9	53,9	53,9	39	39	39	29	29	29	19,9	19,9	19,9
B	80	59,3	47,4	47,4	47,4	51,3	51,3	51,3	49,7	49,7	49,7	33,1	33,1	33,1	24,8	24,8	24,8	15,3	15,3	15,3
C	20	71,5	54,7	54,7	54,7	58,7	58,7	58,7	61,5	61,5	61,5	63,1	63,1	63,1	53,6	53,6	53,6	42,8	42,8	42,8
C	40	65,2	51,1	51,1	51,1	55,1	55,1	55,1	57,4	57,4	57,4	50,1	50,1	50,1	36,2	36,2	36,2	27,1	27,1	27,1
C	60	62,1	49	49	49	52,9	52,9	52,9	54,2	54,2	54,2	39,8	39,8	39,8	29,2	29,2	29,2	20,1	20,1	20,1
C	80	59,4	47,4	47,4	47,4	51,3	51,3	51,3	50	50	50	33,5	33,5	33,5	24,9	24,9	24,9	15,4	15,4	15,4
D	20	71,5	54,7	54,7	54,7	58,6	58,6	58,6	61,5	61,5	61,5	63,2	63,2	63,2	54,0	54,0	54,0	43,1	43,1	43,1
D	40	65,2	51,0	51,0	51,0	55,0	55,0	55,0	57,4	57,4	57,4	50,5	50,5	50,5	36,4	36,4	36,4	27,3	27,3	27,3
D	60	62,2	48,9	48,9	48,9	52,8	52,8	52,8	54,4	54,4	54,4	40,8	40,8	40,8	29,6	29,6	29,6	20,5	20,5	20,5
D	80	59,2	47,3	47,3	47,3	51,2	51,2	51,2	50,5	50,5	50,5	34,2	34,2	34,2	25,1	25,1	25,1	15,7	15,7	15,7

Table B.2 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings (urban conditions)

R	Distance from road (m)	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	20	71,4	54,4	54,4	54,4	58,5	58,5	58,5	61,4	61,4	61,4	63,0	63,0	63,0	53,7	53,7	53,7	43,0	43,0	43,0
A	40	60,2	43,6	43,6	43,6	48,8	48,8	48,8	52,3	52,3	52,3	48,3	48,3	48,3	39,4	39,4	39,4	32,4	32,4	32,4
A	60	53,9	37,8	37,8	37,8	42,2	42,2	42,2	46,1	46,1	46,1	41,0	41,0	41,0	36,8	36,8	36,8	30,0	30,0	30,0
A	80	49,3	34,3	34,3	34,3	38,2	38,2	38,2	39,7	39,7	39,7	38,0	38,0	38,0	34,3	34,3	34,3	27,0	27,0	27,0
B	20	70,9	53,6	53,6	53,6	57,6	57,6	57,6	60,5	60,5	60,5	62,8	62,8	62,8	53,7	53,7	53,7	43,2	43,2	43,2
B	40	57,6	41,1	41,1	41,1	46	46	46	49,4	49,4	49,4	46	46	46	39,1	39,1	39,1	32,4	32,4	32,4
B	60	52,4	36,7	36,7	36,7	40,8	40,8	40,8	43,8	43,8	43,8	40,6	40,6	40,6	36,9	36,9	36,9	30,1	30,1	30,1
B	80	49,5	34,3	34,3	34,3	38,3	38,3	38,3	39,6	39,6	39,6	38,7	38,7	38,7	35,1	35,1	35,1	27,9	27,9	27,9
C	20	70,9	53,6	53,6	53,6	57,7	57,7	57,7	60,7	60,7	60,7	62,7	62,7	62,7	53,7	53,7	53,7	43,1	43,1	43,1
C	40	59,7	43	43	43	48,4	48,4	48,4	51,8	51,8	51,8	47,7	47,7	47,7	39,6	39,6	39,6	32,8	32,8	32,8
C	60	53,2	38,2	38,2	38,2	42,2	42,2	42,2	45,1	45,1	45,1	40	40	40	35,9	35,9	35,9	29	29	29
C	80	49,6	35,5	35,5	35,5	39,4	39,4	39,4	40,1	40,1	40,1	37	37	37	33,4	33,4	33,4	26,3	26,3	26,3
D	20	71,8	54,8	54,8	54,8	58,9	58,9	58,9	62,0	62,0	62,0	63,2	63,2	63,2	54,0	54,0	54,0	43,2	43,2	43,2
D	40	62,4	46,6	46,6	46,6	51,3	51,3	51,3	54,7	54,7	54,7	49,8	49,8	49,8	39,9	39,9	39,9	32,8	32,8	32,8
D	60	54,7	39,9	39,9	39,9	44,0	44,0	44,0	46,8	46,8	46,8	40,5	40,5	40,5	36,1	36,1	36,1	29,5	29,5	29,5
D	80	51,8	36,8	36,8	36,8	41,3	41,3	41,3	43,5	43,5	43,5	38,3	38,3	38,3	34,5	34,5	34,5	27,4	27,4	27,4

Table B.3 : Average traffic noise level difference between open space and urban (with no buildings and with buildings) for different distances from road

Distance from road (m)	Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
20m	-0,2	0,4	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,4	-0,4	-0,4	-0,2	-0,2	-0,2	0,1	0,1	0,1	0,2	0,2	0,2
40m	-5,2	1,6	-7,5	-7,5	-7,5	-6,4	-6,4	-6,4	-5,3	-5,3	-5,3	-1,9	-1,9	-1,9	3,4	3,4	3,4	5,6	5,6	5,6
60m	-8,6	0,8	-10,8	-10,8	-10,8	-10,6	-10,6	-10,6	-8,8	-8,8	-8,8	0,6	0,6	0,6	7,1	7,1	7,1	9,5	9,5	9,5
80m	-9,3	1,1	-12,2	-12,2	-12,2	-12,0	-12,0	-12,0	-9,4	-9,4	-9,4	4,4	4,4	4,4	9,4	9,4	9,4	11,7	11,7	11,7

Table B.4 : Average traffic noise level difference for doubling of distance (with buildings)

Distance from road (m)	Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
From 20 to 40m	-11,3	1,4	-10,5	-10,5	-10,5	-9,6	-9,6	-9,6	-9,1	-9,1	-9,1	-15,0	-15,0	-15,0	-14,3	-14,3	-14,3	-10,5	-10,5	-10,5
From 40 to 80m	-9,9	1,1	-8,4	-8,4	-8,4	-9,3	-9,3	-9,3	-11,3	-11,3	-11,3	-10,0	-10,0	-10,0	-5,2	-5,2	-5,2	-5,5	-5,5	-5,5
All	-10,6	1,4	-9,4	-9,4	-9,4	-9,4	-9,4	-9,4	-10,2	-10,2	-10,2	-12,5	-12,5	-12,5	-9,7	-9,7	-9,7	-8,0	-8,0	-8,0

Sound propagation from main road to second row of buildings behind detached buildings

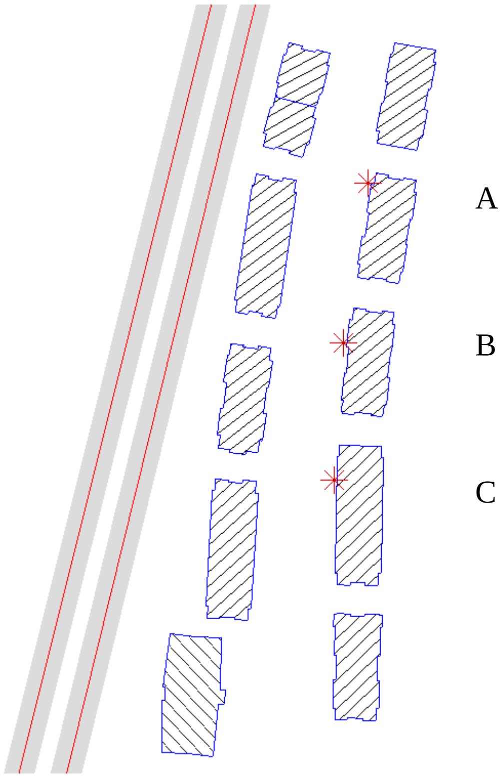

Figure B.2 : Map of area around Barbaros Avenue and receivers, for simulation of diffracted sound by detached buildings.

Table B.5 : Simulated A weighted equivalent traffic noise levels for receivers in area with no buildings (open space)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	65,2	50,4	50,4	50,4	54,4	54,4	54,4	55,5	55,5	55,5	50,1	50,1	50,1	52,1	52,1	52,1	50,3	50,3	50,3
B	64,1	49,9	49,9	49,9	53,8	53,8	53,8	53,7	53,7	53,7	48,0	48,0	48,0	51,3	51,3	51,3	49,6	49,6	49,6
C	62,8	49,1	49,1	49,1	53,0	53,0	53,0	51,9	51,9	51,9	45,9	45,9	45,9	49,6	49,6	49,6	48,5	48,5	48,5

Table B.6 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings (urban conditions)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	59,6	44,0	44,0	44,0	47,9	47,9	47,9	49,9	49,9	49,9	46,1	46,1	46,1	47,1	47,1	47,1	44,6	44,6	44,6
B	58,5	43,1	43,1	43,1	47,0	47,0	47,0	48,4	48,4	48,4	44,5	44,5	44,5	46,5	46,5	46,5	43,6	43,6	43,6
C	57,0	42,1	42,1	42,1	46,0	46,0	46,0	46,6	46,6	46,6	42,7	42,7	42,7	44,8	44,8	44,8	42,5	42,5	42,5

Table B.7 : Average traffic noise level difference between open space and urban (with no buildings and with buildings)

Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
-5,7	0,1	-6,7	-6,7	-6,7	-6,8	-6,8	-6,8	-5,4	-5,4	-5,4	-3,6	-3,6	-3,6	-4,9	-4,9	-4,9	-5,9	-5,9	-5,9

Sound propagation from main road to second row of buildings behind attached buildings

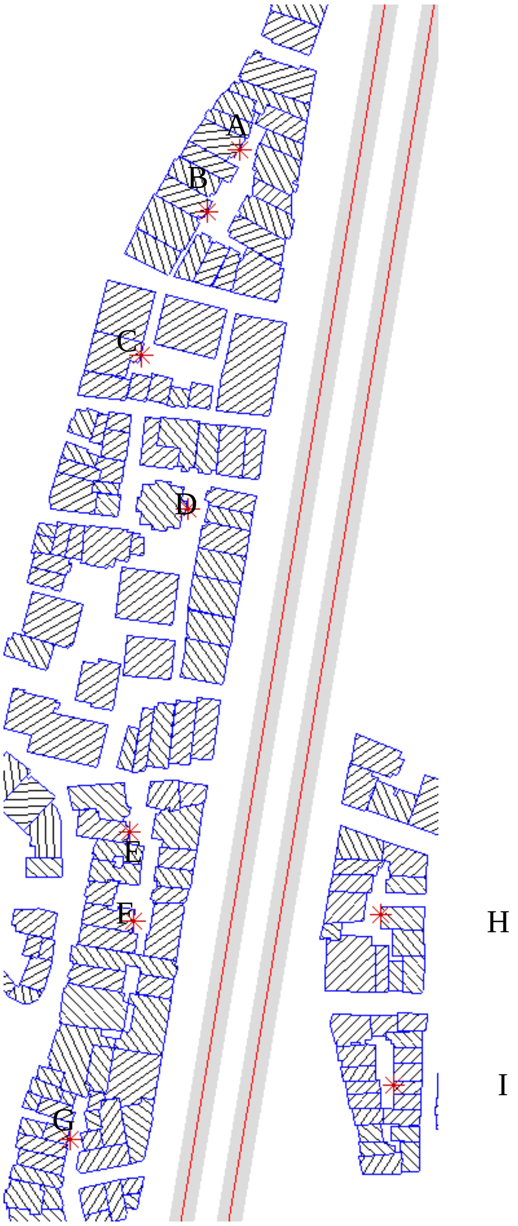

Figure B.3 : Map of area around Barbaros Avenue and receivers, for simulation of diffracted sound by attached buildings.

Table B.8 : Simulated A weighted equivalent traffic noise levels for receivers in area with no buildings (open space)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	66,0	50,8	50,8	50,8	54,7	54,7	54,7	56,1	56,1	56,1	51,1	51,1	51,1	52,4	52,4	52,4	50,6	50,6	50,6
B	64,2	49,9	49,9	49,9	53,8	53,8	53,8	54,2	54,2	54,2	48,3	48,3	48,3	50,6	50,6	50,6	49,4	49,4	49,4
C	61,6	48,6	48,6	48,6	52,5	52,5	52,5	50,0	50,0	50,0	43,7	43,7	43,7	47,7	47,7	47,7	47,2	47,2	47,2
D	66,1	51,3	51,3	51,3	55,2	55,2	55,2	55,9	55,9	55,9	51,1	51,1	51,1	53,7	53,7	53,7	51,1	51,1	51,1
E	66,1	51,1	51,1	51,1	55,1	55,1	55,1	56,5	56,5	56,5	51,6	51,6	51,6	52,8	52,8	52,8	50,9	50,9	50,9
F	67,8	52,1	52,1	52,1	56,1	56,1	56,1	58,2	58,2	58,2	55,0	55,0	55,0	54,7	54,7	54,7	52,3	52,3	52,3
G	64,8	49,9	49,9	49,9	53,8	53,8	53,8	55,2	55,2	55,2	50,2	50,2	50,2	51,6	51,6	51,6	49,7	49,7	49,7
H	67,6	52,0	52,0	52,0	56,0	56,0	56,0	58,0	58,0	58,0	54,6	54,6	54,6	54,5	54,5	54,5	52,2	52,2	52,2
I	64,1	49,7	49,7	49,7	53,6	53,6	53,6	54,2	54,2	54,2	48,4	48,4	48,4	50,7	50,7	50,7	49,3	49,3	49,3

Table B.9 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings (urban conditions)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	51,5	32,7	32,7	32,7	36,9	36,9	36,9	40,0	40,0	40,0	42,9	42,9	42,9	39,5	39,5	39,5	33,2	33,2	33,2
B	50,0	31,5	31,5	31,5	35,5	35,5	35,5	38,4	38,4	38,4	41,4	41,4	41,4	38,0	38,0	38,0	31,5	31,5	31,5
C	49,3	30,8	30,8	30,8	34,9	34,9	34,9	37,9	37,9	37,9	40,7	40,7	40,7	37,2	37,2	37,2	30,4	30,4	30,4
D	51,2	32,2	32,2	32,2	36,4	36,4	36,4	39,6	39,6	39,6	42,6	42,6	42,6	39,3	39,3	39,3	33,0	33,0	33,0
E	52,4	33,6	33,6	33,6	37,7	37,7	37,7	40,9	40,9	40,9	43,8	43,8	43,8	40,4	40,4	40,4	34,1	34,1	34,1
F	52,9	34,3	34,3	34,3	38,2	38,2	38,2	41,2	41,2	41,2	44,3	44,3	44,3	41,0	41,0	41,0	34,8	34,8	34,8
G	50,0	31,7	31,7	31,7	35,4	35,4	35,4	38,4	38,4	38,4	41,4	41,4	41,4	38,1	38,1	38,1	31,8	31,8	31,8
H	53,1	34,4	34,4	34,4	38,3	38,3	38,3	41,5	41,5	41,5	44,4	44,4	44,4	41,2	41,2	41,2	35,1	35,1	35,1
I	50,9	32,6	32,6	32,6	36,3	36,3	36,3	39,3	39,3	39,3	42,2	42,2	42,2	39,0	39,0	39,0	32,6	32,6	32,6

Table B.10 : Average traffic noise level difference between open space and urban (with no buildings and with buildings)

Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
-14,1	0,8	-18,0	-18,0	-18,0	-17,9	-17,9	-17,9	-15,7	-15,7	-15,7	-7,8	-7,8	-7,8	-12,8	-12,8	-12,8	-17,4	-17,4	-17,4

Sound propagation from main road to second row of buildings behind a narrow opening

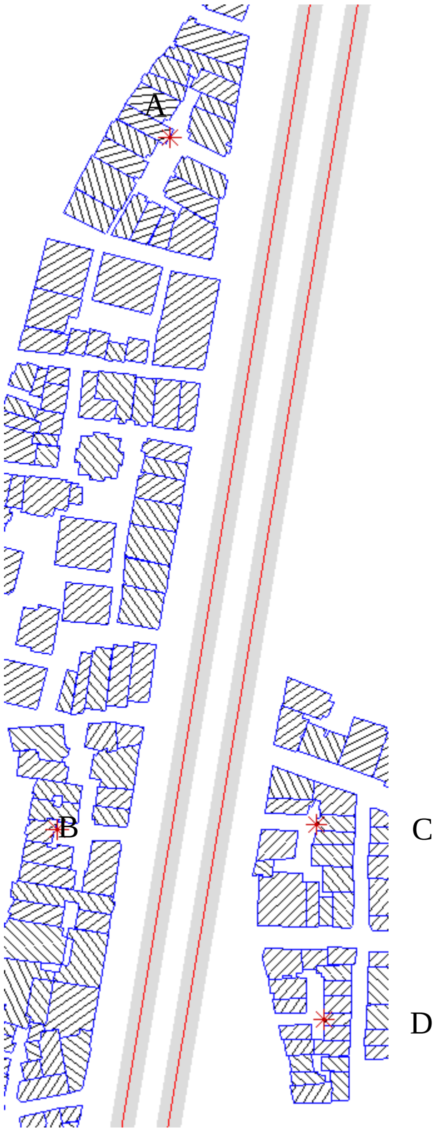

Figure B.4 : Map of area around Barbaros Avenue and receivers, for simulation of diffracted sound through narrow opening.

Table B.11 : Simulated A weighted equivalent traffic noise levels for receivers in area with no buildings (open space)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	65,7	50,7	50,7	50,7	54,7	54,7	54,7	56,1	56,1	56,1	50,9	50,9	50,9	52,4	52,4	52,4	50,6	50,6	50,6
B	66,0	51,0	51,0	51,0	54,9	54,9	54,9	56,4	56,4	56,4	51,5	51,5	51,5	52,7	52,7	52,7	50,8	50,8	50,8
C	67,6	52,0	52,0	52,0	56,0	56,0	56,0	58,0	58,0	58,0	54,5	54,5	54,5	54,5	54,5	54,5	52,1	52,1	52,1
D	64,1	49,7	49,7	49,7	53,6	53,6	53,6	54,2	54,2	54,2	48,3	48,3	48,3	50,6	50,6	50,6	49,3	49,3	49,3

Table B.12 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings (urban conditions)

R	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	61,2	43,8	43,8	43,8	48,3	48,3	48,3	51,7	51,7	51,7	48,6	48,6	48,6	49,3	49,3	49,3	46,6	46,6	46,6
B	60,7	44,0	44,0	44,0	48,0	48,0	48,0	50,7	50,7	50,7	48,4	48,4	48,4	48,7	48,7	48,7	46,1	46,1	46,1
C	64,4	46,5	46,5	46,5	51,1	51,1	51,1	54,7	54,7	54,7	53,1	53,1	53,1	52,3	52,3	52,3	49,1	49,1	49,1
D	60,2	43,7	43,7	43,7	47,9	47,9	47,9	50,5	50,5	50,5	46,8	46,8	46,8	48,0	48,0	48,0	46,1	46,1	46,1

Table B.13 : Average traffic noise level difference between open space and urban (with no buildings and with buildings)

Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
-4,2	0,8	-6,4	-6,4	-6,4	-6,0	-6,0	-6,0	-4,3	-4,3	-4,3	-2,1	-2,1	-2,1	-3,0	-3,0	-3,0	-3,7	-3,7	-3,7

Sound propagation in street canyon

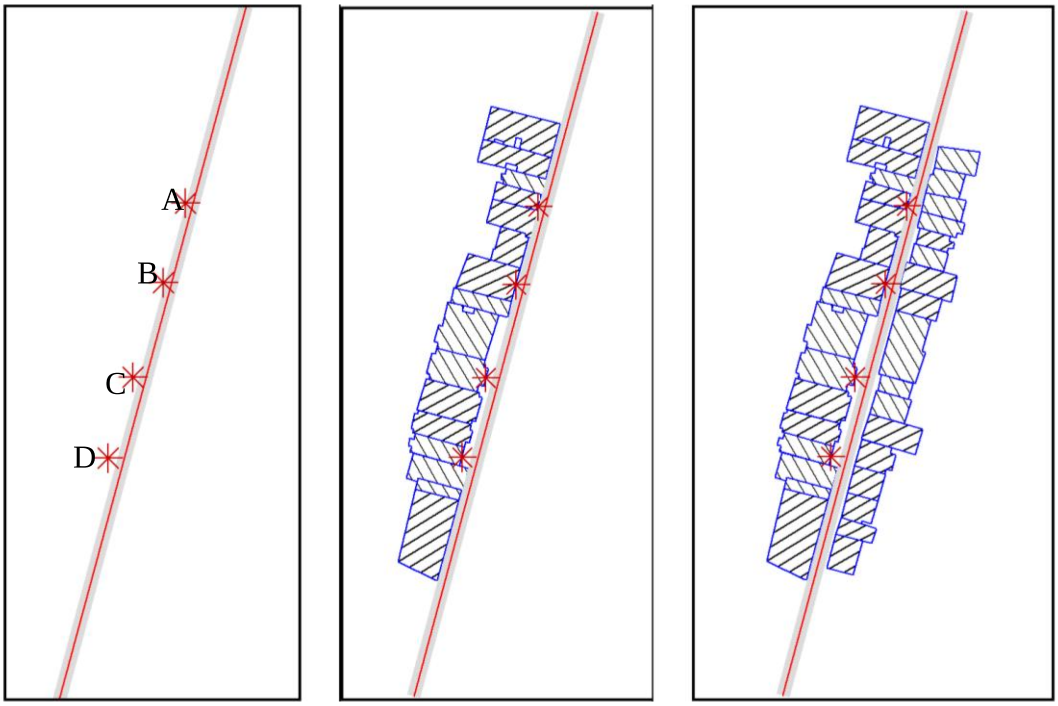

Figure B.5 : Map of area around Barbaros Avenue and receivers, for simulation of reflected sound in street canyon.

Table B.14 : Simulated A weighted equivalent traffic noise levels for receivers in area with no buildings (open space)

R	H, m	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	1,5	73,4	54,7	54,7	54,7	58,7	58,7	58,7	61,7	61,7	61,7	64,7	64,7	64,7	61,6	61,6	61,6	56,5	56,5	56,5
A	7,5	68,2	49,5	49,5	49,5	53,5	53,5	53,5	56,4	56,4	56,4	59,4	59,4	59,4	56,3	56,3	56,3	51,1	51,1	51,1
B	1,5	73,2	54,5	54,5	54,5	58,4	58,4	58,4	61,4	61,4	61,4	64,4	64,4	64,4	61,4	61,4	61,4	56,3	56,3	56,3
B	7,5	68,1	49,5	49,5	49,5	53,4	53,4	53,4	56,4	56,4	56,4	59,4	59,4	59,4	56,3	56,3	56,3	51,1	51,1	51,1
C	1,5	71,0	52,2	52,2	52,2	56,2	56,2	56,2	59,4	59,4	59,4	62,3	62,3	62,3	59,2	59,2	59,2	54,2	54,2	54,2
C	7,5	70,2	51,2	51,2	51,2	55,3	55,3	55,3	58,6	58,6	58,6	61,4	61,4	61,4	58,4	58,4	58,4	53,3	53,3	53,3
D	1,5	67,5	48,9	48,9	48,9	52,9	52,9	52,9	55,8	55,8	55,8	58,8	58,8	58,8	55,7	55,7	55,7	50,4	50,4	50,4
D	7,5	67,8	49,1	49,1	49,1	53,1	53,1	53,1	56,1	56,1	56,1	59,0	59,0	59,0	56,0	56,0	56,0	50,7	50,7	50,7

Table B.15 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings on one side

R	H, m	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	1,5	75,2	75,5	72,5	69,8	71,3	69,0	67,0	68,2	66,6	65,3	67,2	66,4	65,8	62,4	62,2	62,1	57,1	57,3	57,8
A	7,5	68,4	68,5	65,5	62,8	64,4	62,1	60,1	61,5	59,9	58,6	60,5	59,7	59,1	55,7	55,5	55,4	50,3	50,5	51,0
B	1,5	75,4	75,7	72,7	70,0	71,5	69,2	67,2	68,5	66,9	65,6	67,5	66,7	66,1	62,7	62,5	62,4	57,4	57,6	58,1
B	7,5	70,3	70,3	67,3	64,6	66,2	63,9	61,9	63,3	61,7	60,4	62,4	61,6	61,0	57,6	57,4	57,3	52,1	52,3	52,8
C	1,5	73,5	73,6	70,6	67,9	69,4	67,1	65,1	66,5	64,9	63,6	65,6	64,8	64,2	60,7	60,5	60,4	55,4	55,6	56,1
C	7,5	71,9	71,4	68,4	65,7	67,7	65,4	63,4	65,0	63,4	62,1	64,0	63,2	62,6	59,1	58,9	58,8	53,8	54,0	54,5
D	1,5	68,6	68,1	65,1	62,4	64,7	62,4	60,4	61,7	60,1	58,8	60,7	59,9	59,3	55,9	55,7	55,6	50,4	50,6	51,1
D	7,5	70,1	70,2	67,2	64,5	66,1	63,8	61,8	63,1	61,5	60,2	62,1	61,3	60,7	57,4	57,2	57,1	51,9	52,1	52,6

Table B.16 : Simulated A weighted equivalent traffic noise levels for receivers in area with buildings on both sides (street canyon)

R	H, m	Leq (dBA)	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
A	1,5	75,6	56,6	56,6	56,6	60,8	60,8	60,8	63,9	63,9	63,9	66,9	66,9	66,9	63,9	63,9	63,9	58,9	58,9	58,9
A	7,5	69,6	50,4	50,4	50,4	54,5	54,5	54,5	57,8	57,8	57,8	60,9	60,9	60,9	58,0	58,0	58,0	52,9	52,9	52,9
B	1,5	76,0	57,1	57,1	57,1	61,1	61,1	61,1	64,2	64,2	64,2	67,3	67,3	67,3	64,3	64,3	64,3	59,2	59,2	59,2
B	7,5	71,4	52,3	52,3	52,3	56,4	56,4	56,4	59,6	59,6	59,6	62,7	62,7	62,7	59,7	59,7	59,7	54,5	54,5	54,5
C	1,5	74,0	54,9	54,9	54,9	59,0	59,0	59,0	62,3	62,3	62,3	65,3	65,3	65,3	62,3	62,3	62,3	57,2	57,2	57,2
C	7,5	72,5	52,8	52,8	52,8	57,3	57,3	57,3	60,8	60,8	60,8	63,8	63,8	63,8	60,8	60,8	60,8	55,7	55,7	55,7
D	1,5	69,7	50,0	50,0	50,0	54,7	54,7	54,7	58,0	58,0	58,0	61,0	61,0	61,0	57,9	57,9	57,9	52,7	52,7	52,7
D	7,5	71,0	52,0	52,0	52,0	56,1	56,1	56,1	59,2	59,2	59,2	62,3	62,3	62,3	59,3	59,3	59,3	54,1	54,1	54,1

Table B.17 : Average traffic noise level difference between open space and urban (with no buildings and with buildings)

		Leq (dBA)	Std. dev.	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Single-Open	1,5	1,9	0,5	20,7	17,7	15,0	12,7	10,4	8,4	6,7	5,1	3,8	2,7	1,9	1,3	0,9	0,8	0,6	0,7	0,9	1,4
Single-Open	7,5	1,6	0,8	20,3	17,3	14,6	12,3	10,0	8,0	6,4	4,8	3,5	2,5	1,7	1,1	0,7	0,5	0,4	0,5	0,7	1,2
Single-Open		1,8	0,7	20,5	17,5	14,8	12,5	10,2	8,2	6,5	4,9	3,6	2,6	1,8	1,2	0,8	0,6	0,5	0,6	0,8	1,3
Double-Open	1,5	2,6	0,4	2,1	2,1	2,1	2,4	2,4	2,4	2,5	2,5	2,5	2,6	2,6	2,6	2,6	2,6	2,6	2,7	2,7	2,7
Double-Open	7,5	2,6	0,8	2,1	2,1	2,1	2,3	2,3	2,3	2,5	2,5	2,5	2,6	2,6	2,6	2,7	2,7	2,7	2,8	2,8	2,8
Double-Open		2,6	0,6	2,1	2,1	2,1	2,3	2,3	2,3	2,5	2,5	2,5	2,6	2,6	2,6	2,7	2,7	2,7	2,7	2,7	2,7

APPENDIX C

Table C.1 : Grouping of on-site surveys

Survey No	District	Street	Building No	Floor No	Dead-end road	Service road	Ccollective road	Small main road	Surface	Slope	L_{den}Annoyance	Urban propagation	Main Road
14	YILDIZ	ŞAİR NAHİFİ	12	2	X						1		
13	YILDIZ	ŞAİR NAHİFİ	6	1	X						5		
113	DİKİLİTAŞ	MANOLYA	15	2	X					UP	6		
114	DİKİLİTAŞ	MANOLYA	13	2	X					UP	0		
116	DİKİLİTAŞ	MANOLYA	2	0	X					UP	6		
117	DİKİLİTAŞ	MANOLYA	5	1	X					UP	4		
115	DİKİLİTAŞ	MANOLYA	9	1	X					UP	4		
119	DİKİLİTAŞ	DİKİLİTAŞ	23	0	X					UP	0		
118	DİKİLİTAŞ	DİKİLİTAŞ	13	1	X					UP	8		
120	DİKİLİTAŞ	DİKİLİTAŞ	22	2	X					UP	5		
122	DİKİLİTAŞ	DİKİLİTAŞ	13	1	X					UP	5		
169	DİKİLİTAŞ	CAMİ MEYDANI	18	2	X				Pav.	DOWN	10		
170	DİKİLİTAŞ	CAMİ MEYDANI	25	2	X				Pav.	DOWN	0		
33	TÜRKALİ	LOŞBAHÇE	.	1	X				Pav.	DOWN	0		
36	SİNANPAŞA	SELAMLIK	8	1	X				Pav.	DOWN	2		
35	SİNANPAŞA	SELAMLIK	1	1	X				Pav.	DOWN	3		
37	SİNANPAŞA	SELAMLIK	7	1	X				Pav.	DOWN	0		
34	SİNANPAŞA	SELAMLIK	3	1	X				Pav.	DOWN	3		
67	ABBASAĞA	SALNAMECİ	35	1	X				Pav.	DOWN	5		
68	ABBASAĞA	SALNAMECİ	31	0	X				Pav.	DOWN	2		
123	DİKİLİTAŞ	SETÜSTÜ	2	4	X				Pav.	UP	4		
124	DİKİLİTAŞ	SETÜSTÜ	6	5	X				Pav.	UP	6		
125	DİKİLİTAŞ	SETÜSTÜ	8	1	X				Pav.	UP	8		
110	DİKİLİTAŞ	LEYLAK	6	1	X				Pav.	UP	2		
111	DİKİLİTAŞ	LEYLAK	6	1	X				Pav.	UP	5		
112	DİKİLİTAŞ	LEYLAK	4	1	X				Pav.	UP	3		
27	SİNANPAŞA	MAŞUKLAR	19	3	X				Pav.	UP	10		
29	SİNANPAŞA	MAŞUKLAR	32	2	X				Pav.	UP	9		
28	SİNANPAŞA	MAŞUKLAR	29	1	X				Pav.	UP	10		
30	SİNANPAŞA	MAŞUKLAR	37	1	X				Pav.	UP	1		
86	ABBASAĞA	KALAS	7	1	X				Pav.	UP	7		
87	ABBASAĞA	KALAS	3	1	X				Pav.	UP	8		
88	TÜRKALİ	TÜRKÇEŞME	11	1	X				Pav.	UP	5		
84	ABBASAĞA	AB. KUYU	2	4	X				Pav.	DOWN	5	Maşuklar Yokuşu NARROW	Maşuklar: Daed-end, Pav., UP
85	ABBASAĞA	AB. KUYU	6	3	X				Pav.	DOWN	5		
168	ABBASAĞA	AB. KUYU	17	2	X				Pav.	DOWN	7		
164	GAYRETTEPE	NECATİ ALBRUZ	15	1		X				UP	0		
46	BALMUMCU	MORBASAN	4	1		X				UP	4		
81	GAYRETTEPE	HATTAT HALİM	9	3		X				UP	3		
82	GAYRETTEPE	HATTAT HALİM	20	1		X				UP	5		
165	GAYRETTEPE	NECATİ ALBRUZ	7	1		X				UP	7		
166	GAYRETTEPE	NECATİ ALBRUZ	5	1		X				UP	5		
167	BALMUMCU	KARA HASAN	2	2		X				UP	7		
242	ABBASAĞA	YILDIZ CADDESİ	38	4		X				UP	9		
134	ABBASAĞA	NURTANESİ	28	1		X				UP	0		
135	ABBASAĞA	NURTANESİ	59	1		X				UP	10		
206	CİHANNÜMA	AKDOĞAN	30	1		X			Pav.	DOWN	8		
42	CİHANNUMA	AKDOĞAN	5	1		X			Pav.	DOWN	6		
44	CİHANNUMA	AKDOĞAN	38	1		X			Pav.	DOWN	5		
45	CİHANNUMA	AKDOĞAN	40	1		X			Pav.	DOWN	7		
159	VİŞNEZADE	REFİK OSMAN	14	1		X			Pav.	UP	10		
160	VİŞNEZADE	REFİK OSMAN	10	1		X			Pav.	UP	8		
109	DİKİLİTAŞ	HORA	12	1		X			Pav.	UP	3		
108	DİKİLİTAŞ	HORA	8	1		X			Pav.	UP	9		
107	DİKİLİTAŞ	HORA	10	1		X			Pav.	UP	2		
70	CİHANNUMA	YENİM. FIRIN	21	0	X						4		
72	CİHANNUMA	YENİM. FIRIN	13	3	X						3	Çömezler NARROW 40m	Çömezler: Service, Pav., DOWN
69	CİHANNUMA	YENİM. FIRIN	6	2	X						3		
71	CİHANNUMA	YENİM. FIRIN	15	0	X						5		
76	CİHANNUMA	HÜSNÜ SAVMAN	1	1	X						0		
75	CİHANNUMA	HÜSNÜ SAVMAN	19	1	X						5		
210	CİHANNUMA	HÜSNÜ SAVMAN	20	2	X						4		
233	CİHANNUMA	HÜSNÜ SAVMAN	41	2	X						3		
73	CİHANNUMA	HÜSNÜ SAVMAN	3	1	X						2		
74	CİHANNUMA	HÜSNÜ SAVMAN	16	1	X						5		
209	CİHANNUMA	HÜSNÜ SAVMAN	22	1	X						0		
232	CİHANNUMA	HÜSNÜ SAVMAN	41	1	X						9		
234	CİHANNUMA	HÜSNÜ SAVMAN	36	0	X						8		
211	CİHANNUMA	HÜSNÜ SAVMAN	28	5	X						3		
212	CİHANNUMA	HÜSNÜ SAVMAN	28	4	X						3		
213	CİHANNUMA	HÜSNÜ SAVMAN	28	3	X						4		

Table C.1 (continued):

Survey No	District	Street	Building No	Floor No	Dead-end road	Service road	Ccollective road	Small main road	Surface	Slope	L_{den}Annoyance	Urban propagation	Main Road
48	SİNANPAŞA	ŞEHİT DURSUN	17	2	X				Pav.	DOWN	4	Ihlamurdere NARROW - 40m	Ihlamurdere: Service, Pav., FLAT
47	SİNANPAŞA	ŞEHİT DURSUN	23	1	X				Pav.	DOWN	5		
54	SİNANPAŞA	ÇELEBİOĞLU	13	1	X				Pav.		8		
55	SİNANPAŞA	ÇELEBİOĞLU	17	1	X				Pav.		3		
58	SİNANPAŞA	ÇELEBİOĞLU	33	3	X				Pav.		0		
56	SİNANPAŞA	ÇELEBİOĞLU	18	1	X				Pav.		2		
57	SİNANPAŞA	ÇELEBİOĞLU	31	1	X				Pav.		10		
59	SİNANPAŞA	ALAYBEYİ	13	2							8		
32	SİNANPAŞA	KÖYİÇİ	14	2							10		
127	DİKİLİTAŞ	EMİRHAN	95	2			X				8		
126	DİKİLİTAŞ	EMİRHAN	70	1			X				9		
77	GAYRETTEPE	VEFA BAYIRI	7	2			X			UP	10		
78	GAYRETTEPE	HOŞSOHBET	5	1			X			UP	8		
214	GAYRETTEPE	HOŞSOHBET	9	1			X			UP	2		
215	GAYRETTEPE	NERGİS	2	1			X			UP	5		
79	GAYRETTEPE	HOŞSOHBET	23	1			X			UP	3		
80	GAYRETTEPE	HOŞSOHBET	20	4			X			UP	7		
39	CİHANNUMA	ŞEHİT KAZIM	4	1			X		Pav.		0		
38	CİHANNUMA	ŞEHİT KAZIM	2	1			X		Pav.		5		
40	CİHANNUMA	ŞEHİT KAZIM	8	1			X		Pav.		2		
41	CİHANNUMA	ŞEHİT KAZIM	10	2			X		Pav.		8		
154	TÜRKALİ	ŞAİR NEDİM	22	1			X		Pav.	UP	5		
153	TÜRKALİ	ŞAİR NEDİM	24	2			X		Pav.	UP	3		
1	VİŞNEZADE	AFACAN	25	1			X		Pav.	UP	5		
2	VİŞNEZADE	AFACAN	25	2			X		Pav.	UP	6		
133	DİKİLİTAŞ	IHLAMUR Y.	38	1			X		Pav.	UP	4		
131	DİKİLİTAŞ	IHLAMUR Y.	34	2			X		Pav.	UP	10		
132	DİKİLİTAŞ	IHLAMUR Y.	43	1			X		Pav.	UP	7		
130	DİKİLİTAŞ	ÜZENGİ	2	1			X		Pav.	UP	9		
129	DİKİLİTAŞ	ÜZENGİ	1	1			X		Pav.	UP	3		
128	DİKİLİTAŞ	ÜZENGİ	3	1			X		Pav.	UP	9		
237	ABBASAĞA	ÜZENGİ	4	0			X		Pav.	UP	7		
238	ABBASAĞA	ÜZENGİ	4	1			X		Pav.	UP	8		
240	ABBASAĞA	ÜZENGİ	4	3			X		Pav.	UP	8		
155	VİŞNEZADE	HACI HALİT A.	19	3	X						3	Şair Nedim NARROW - 40m	Şair Nedim: Collective, Pav., UP
50	SİNANPAŞA	ŞAİR VEYSİ	2	2	X				Pav.		6		
49	SİNANPAŞA	ŞAİR VEYSİ	7	4	X				Pav.		3		
51	SİNANPAŞA	ŞAİR VEYSİ	21	1	X				Pav.		4		
52	SİNANPAŞA	ŞAİR VEYSİ	6	1	X				Pav.		9		
239	ABBASAĞA	ÜZENGİ	4	2				X		UP	5		
241	ABBASAĞA	ÜZENGİ	19	0				X		UP	10		
236	ABBASAĞA	CEDİDİYE	5	0				X		UP	0		
235	ABBASAĞA	CEDİDİYE	3	1				X		UP	4		
243	ABBASAĞA	CEDİDİYE	13	3				X		UP	5		
244	ABBASAĞA	CEDİDİYE	13	4				X		UP	6		
245	ABBASAĞA	CEDİDİYE	13	1				X		UP	8		
99	DİKİLİTAŞ	YENİDOĞAN	51	1	X				Pav.		8		
102	DİKİLİTAŞ	YENİDOĞAN	41	1	X				Pav.		5		
103	DİKİLİTAŞ	YENİDOĞAN	31	1	X				Pav.		6		
104	DİKİLİTAŞ	YENİDOĞAN	10	1	X				Pav.		8		
226	DİKİLİTAŞ	YENİDOĞAN	6	2	X				Pav.		7		
227	DİKİLİTAŞ	YENİDOĞAN	45	0	X				Pav.		9		
101	DİKİLİTAŞ	YENİDOĞAN	33	3	X				Pav.		5		
224	DİKİLİTAŞ	YENİDOĞAN	2	6	X				Pav.		2		
223	DİKİLİTAŞ	YENİDOĞAN	2	5	X				Pav.		5		
225	DİKİLİTAŞ	YENİDOĞAN	6	4	X				Pav.		0		
100	DİKİLİTAŞ	YENİDOĞAN	47	4	X				Pav.		5		
222	DİKİLİTAŞ	YENİDOĞAN	2	4	X				Pav.		8		
279	BALMUMCU	GAZİ UMUR P.	5	2	X						0	Barbaros DETACHED	Barbaros
95	BALMUMCU	GAZİ UMUR P.	20	1	X						6		
96	BALMUMCU	GAZİ UMUR P.	11	1	X						1		
98	BALMUMCU	GAZİ UMUR P.	4	1	X						5		
273	BALMUMCU	GAZİ UMUR P.	13	3	X						0		
275	BALMUMCU	GAZİ UMUR P.	9	1	X						5		
277	BALMUMCU	GAZİ UMUR P.	5	0	X						3		
283	BALMUMCU	GAZİ UMUR P.	19	2	X						5		
97	BALMUMCU	GAZİ UMUR P.	3	1	X						7		
150	BALMUMCU	GAZİ UMUR P.	19	0	X						5		
274	BALMUMCU	GAZİ UMUR P.	9	1	X						9		
276	BALMUMCU	GAZİ UMUR P.	7	3	X						6		
278	BALMUMCU	GAZİ UMUR P.	5	1	X						10		
280	BALMUMCU	GAZİ UMUR P.	15	2	X						0		
281	BALMUMCU	GAZİ UMUR P.	15	3	X						2		
282	BALMUMCU	GAZİ UMUR P.	17	2	X						2		

Table C.1 (continued):

Survey No	District	Street	Building No	Floor No	Dead-end road	Service road	Ccollective road	Small main road	Surface	Slope	L_{den}Annoyance	Urban propagation	Main Road
11	YILDIZ	ÇİTLENBİK	2	1		X					5	Barbaros NARROW 120m	Barbaros
12	YILDIZ	ÇİTLENBİK	1	1		X					7		
15	CİHANNUMA	MEHMET ALİ B.	3	1		X					4		
16	CİHANNUMA	MEHMET ALİ B.	12	1		X					4		
290	CİHANNÜMA	MEHMET ALİ B.	1	1		X					8		
300	CİHANNÜMA	MEHMET ALİ B.	1	1		X					7		
24	CİHANNUMA	MAZHARPAŞA	14	1		X					2		
25	CİHANNUMA	MAZHARPAŞA	21	1		X					4		
23	CİHANNUMA	MAZHARPAŞA	16	2		X					3		
257	CİHANNÜMA	MAZHARPAŞA	17	2							5		
246	CİHANNÜMA	YENİM. FIRIN	57	4	X						6	Barbaros NARROW - 80m	Barbaros
248	CİHANNÜMA	YENİM. FIRIN	57	2	X						8		
208	CİHANNÜMA	YENİM. FIRIN	28	5	X						8		
247	CİHANNÜMA	YENİM. FIRIN	57	1	X						2		
18	CİHANNUMA	CİHANNUMA	9	1	X						7		
19	CİHANNUMA	CİHANNUMA	7	2	X						0		
262	CİHANNÜMA	CİHANNÜMA	32	1	X						7		
263	CİHANNÜMA	CİHANNÜMA	32	2	X						10		
17	CİHANNUMA	CİHANNUMA	15	1	X						3		
264	CİHANNÜMA	CİHANNÜMA	32	4	X						3		
94	GAYRETTEPE	BAYINDIR	3	4		X					7		
93	GAYRETTEPE	BAYINDIR	1	1		X					4		
249	CİHANNÜMA	FARUK CANITEZ	4	2							0		
250	CİHANNÜMA	FARUK CANITEZ	2	3							4		
293	CİHANNÜMA	DALBUDAK	9	4							5	Barbaros NARROW - 60m	Barbaros
136	CİHANNUMA	DÖRTYÜZÇEŞM.	3	1							3		
137	CİHANNUMA	İSMAİLİYE	1	1							7		
207	CİHANNÜMA	DÖRTYÜZÇEŞM.	10	1							4		
292	CİHANNÜMA	DALBUDAK	9	0							10		
8	CİHANNÜMA	SERENCEBEY Y.	14	1	X					DOWN	8		
266	CİHANNÜMA	SERENCEBEY Y.	3	1	X					DOWN	8		
9	CİHANNÜMA	SERENCEBEY Y.	14	1	X					DOWN	10		
267	CİHANNÜMA	SERENCEBEY Y.	3	1	X					DOWN	10		
268	CİHANNÜMA	SERENCEBEY Y.	3	3	X					DOWN	3		
203	CİHANNÜMA	ABBASAĞA A.	1	2							4		
202	CİHANNÜMA	ABBASAĞA A.	1	0							2		
301	CİHANNÜMA	AKMAZÇEŞME	42	2							2		
228	CİHANNÜMA	AKMAZÇEŞME	50	4							5		
92	CİHANNUMA	ABBASAĞA	7	0		X				DOWN	5	Barbaros NARROW - 50m	Barbaros
285	CİHANNÜMA	SERENCEBEY Y.	10	1	X					DOWN	5		
286	CİHANNÜMA	SERENCEBEY Y.	10	2	X					DOWN	3		
287	CİHANNÜMA	SERENCEBEY Y.	10	3	X					DOWN	4		
43	CİHANNUMA	BOSTANCI VELİ	6	1							7		
229	CİHANNÜMA	RESSAM HAMDİ	3	4							5		
230	CİHANNÜMA	RESSAM HAMDİ	3	1							10		
231	CİHANNÜMA	BOSTANCI VELİ	6	1							5		
258	CİHANNÜMA	MAZHARPAŞA	3	2							0	Barbaros NARROW - 40m	Barbaros
259	CİHANNÜMA	MAZHARPAŞA	3	2							6		
261	CİHANNÜMA	MAZHARPAŞA	5	2							2		
260	CİHANNÜMA	MAZHARPAŞA	5	1							10		
284	CİHANNÜMA	SERENCEBEY Y.	8	1	X					DOWN	5		
22	CİHANNUMA	BOSTANCIBAŞI	13	1							4		
265	CİHANNÜMA	BOSTANCIBAŞI	18	1							0		
291	CİHANNÜMA	BOSTANCIBAŞI	9	0							5		
20	CİHANNUMA	BOSTANCIBAŞI	15	2							6		
21	CİHANNUMA	BOSTANCIBAŞI	16	2							8		
7	CİHANNÜMA	SERENCEBEY Y.	6	1	X					DOWN	10		
10	CİHANNÜMA	SERENCEBEY Y.	30	1	X					DOWN	3	180m from Barbaros	Barbaros
270	CİHANNÜMA	SERENCEBEY Y.	29	1	X					DOWN	5		
271	CİHANNÜMA	SERENCEBEY Y.	29	1	X					DOWN	2		
272	CİHANNÜMA	SERENCEBEY Y.	43	0	X					DOWN	7		
288	CİHANNÜMA	SERENCEBEY Y.	33	2	X					DOWN	5		
201	CİHANNÜMA	SERENCEBEY Y.	53	3	X					DOWN	9		
269	CİHANNÜMA	SERENCEBEY Y.	27	2	X					DOWN	8		
289	CİHANNÜMA	SERENCEBEY Y.	39	1	X					DOWN	10		
299	CİHANNÜMA	SERENCEBEY Y.	29	0	X					DOWN	8		
60	ESENTEPE	M.ABDULLAH	39	2							2	100m from Barbaros	Barbaros
216	GAYRETTEPE	FUAT SARP	4	7							5		
83	GAYRETTEPE	FUAT SARP	7	1							8		
162	GAYRETTEPE	HAMİDİYE	3	1							2		
163	GAYRETTEPE	HAMİDİYE	9	3							5		
63	ESENTEPE	FAZIL BİLGE	1	1							4	80m from Barbaros	Barbaros
62	ESENTEPE	FAZIL BİLGE	1	1							7		
295	YILDIZ	MUHTARI EV.	10	2							10	60m from Barbaros	Barbaros
296	YILDIZ	MUHTARI EV.	10	1							9		
298	YILDIZ	MUHTARI EV.	4	2							5		
294	YILDIZ	MUHTARI EV.	3	2							6		
297	YILDIZ	MUHTARI EV.	4	1							1		

Table C.1 (continued):

Survey No	District	Street	Building No	Floor No	Dead-end road	Service road	Ccollective road	Small main road	Surface	Slope	L_{den}Annoyance	Urban propagation	Main Road
61	ESENTEPE	CEMİL CAHİT TOPDEMİR	7	2							6	40m from Barbaros	Barbaros
221	DİKİLİTAŞ	BARBAROS BULVARI	12 9	4							5	35m	
217	DİKİLİTAŞ	BARBAROS BULVARI	13 1	4							8	35m	
218	DİKİLİTAŞ	BARBAROS BULVARI	12 9	6							8	35m	
219	DİKİLİTAŞ	BARBAROS BULVARI	12 9	5							6	35m	
220	DİKİLİTAŞ	BARBAROS BULVARI	12 9	5							7	35m	
64	ESENTEPE	İZZETTİN ÇALIŞLAR	5	3							10	30m from Barbaros	Barbaros
255	GAYRETTEPE	BARBAROS BULVARI	14 3	0							0	25m	
251	GAYRETTEPE	BARBAROS BULVARI	14 7	9							7	25m	
252	GAYRETTEPE	BARBAROS BULVARI	14 7	7							8	25m	
253	GAYRETTEPE	BARBAROS BULVARI	14 7	6							5	25m	
204	GAYRETTEPE	BARBAROS BULVARI	14 7	2							2	25m	
205	GAYRETTEPE	BARBAROS BULVARI	14 7	- 1							0	25m	
254	GAYRETTEPE	BARBAROS BULVARI	14 7	5							6	25m	

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- 2006-2015: Research Assistant at Istanbul Technical University, Faculty of Architecture, Department of Architecture.
- 2006- 2013: Expertise in application projects through ITU Circulating Capital about building acoustics and room acoustics.
- 2006- 2013: Measurement experience in laboratory and field through ITU Circulating Capital about building acoustics, room acoustics and environmental acoustics.
- 2008: Honorable mention award for acoustic consultancy in Istanbul Metropolitan Municipality City Theater Beyoglu Hall Architectural Competition.

List of Publications and Patents:

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