

A MODEL FOR ASSESSING ACOUSTIC COMFORT IN ENCLOSED PUBLIC SPACES

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DOCTOR OF PHILOSOPHY
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**by
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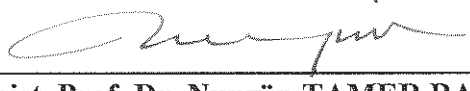
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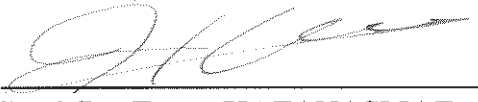
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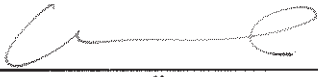
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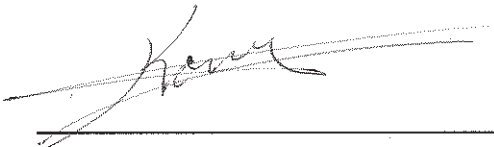

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ABSTRACT

A MODEL FOR ASSESSING ACOUSTIC COMFORT IN ENCLOSED PUBLIC SPACES

Acoustic comfort is one of the important topics in terms of user satisfaction. In order to determine and control acoustic comfort, measurable parameters are needed to be able to compare and improve soundscapes. Parameters for architectural acoustics, like reverberation time and sound pressure level are widely used for this purpose. Psychoacoustic parameters like loudness, sharpness, roughness and fluctuation strength are mostly used for determining the sound quality of mechanical sounds. They have also started to be used for evaluating soundscapes of open areas and enclosed spaces. This research aims to find out the relationship between the psychoacoustic parameters and acoustic comfort in non-acoustic enclosed public spaces, specifically in eating establishments. To reach this aim, both on-site measurements and in laboratory listening tests were conducted in five eating establishments. During on-site measurements, a simultaneous questionnaire study was also conducted. Subjective and objective data were comparatively evaluated. Listening tests were based on auralizations with calibrated simulation models. This provided a research model, that allows control over the acoustic environment without having to make real changes in the physical elements of the eating establishments. The auralization sound files were presented to listening test participants with headphones and they evaluated soundscapes with different psychoacoustic properties. The last chapter provides a summary of results and suggestions for future studies. Better acoustic comfort was found to be related with higher sharpness, lower reverberation time, lower loudness and lower roughness values for the examined parameter ranges.

ÖZET

KAPALI KAMUSAL MEKANLARDA AKUSTİK KONFOR DEĞERLENDİRMESİ İÇİN BİR MODEL

Mekanların değerlendirilmesinde kullanıcı memnuniyeti göz önünde bulundurulduğunda, akustik konfor önemli konu başlıklarından biridir. Akustik konforu değerlendirebilmek ve iyileştirmek adına değerlendirebilmek için, ölçülebilir parametrelere ihtiyaç vardır. Reverberasyon süresi ve ses basınç düzeyi gibi mimari akustik parametreler, bu amaç için sıklıkla kullanılmaktadır. Gürlük, keskinlik, kabalık ve dalgalanım kuvveti gibi psikoakustik parametreler ise genellikle mekanik cihazların ses kalitelerinin değerlendirilmelerinde kullanılmaktadır. Bu parametreler aynı zamanda kapalı ve açık mekanların akustik konfor değerlendirmelerinde de kullanılmaya başlamışlardır. Bu çalışmanın amacı, yemek mekanları özelinde, akustik amaçlı kullanılmayan kapalı kamusal alanlarda akustik konfor değerlendirmeleri ile psikoakustik parametrelerin ilişkisini araştırmaktır. Bu amaca ulaşmak için, beş yemek mekanında yerinde ölçümler ve laboratuvarında işitme testleri gerçekleştirilmiştir. Yemek mekanlarında ölçümlerle eş zamanlı olarak anketler yapılmıştır. Ortaya konan nesnel ve öznel veriler karşılaştırmalı olarak değerlendirilmiştir. Bunun yanında, bilgisayarda benzetim yoluyla mekanların modelleri oluşturulmuş ve gerçek mekan verileri ile kalibre edilmiştir. Mekanları temsil edecek işitselleştirmeler, bu modeller aracılığıyla hazırlanmıştır. Böylece mekanı akustik açıdan kontrol edebilmek için, gerçek mekanı fiziksel olarak değiştirmeye gerek bırakmayacak bir araştırma modeli ortaya konmuştur. Mekanlara ait işitselleştirme ses dosyaları, dinleme testi katılımcılarına kulaklıklarla dinletilmiş ve farklı psikoakustik değerlere sahip sesler hakkında değerlendirmeleri alınmıştır. Son kısımda ise sonuçlar özetlenerek, sonraki çalışmalar için önerilerde bulunulmuştur. Mekanlarda iyi akustik konfor, incelenmiş olan değer aralıklarında yüksek keskinlik, düşük reverberasyon süresi, düşük gürlük ve düşük kabalık değerleri ile ilişkili bulunmuştur.

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CHAPTER 1

INTRODUCTION

This first chapter includes the sections about argument, motivation, aim and scope. The reasons to choose to work on the selected subject are stated in argument section. In motivation section, a short summary concerning the lack of research about this topic in literature is given and research questions are stated. Lastly, the aim and scope of the thesis research is given.

1.1. Argument

User comfort in enclosed public spaces is one of the most important evaluation criteria for architecture. Research covering subjective user evaluations usually proceed with measurable parameters like sound pressure level or reverberation time. As these two parameters are not enough to represent the complex characters of all soundscapes, researchers are in search for supplementary evaluation methods. Recently, psychoacoustic parameters have started to be used while evaluating soundscapes in outdoors, urban settings as well as indoors. However, complex sounds such as street noise or ambient noise in a shopping mall are much different in character when compared to machinery noises that have distinguishable patterns. In the research field of mechanical engineering, the effect of engine noise on human perception is assessed through these parameters and various noise annoyance metrics have been formed by using them. However, in the research area of architectural acoustics, there are no commonly accepted ranges for psychoacoustic parameters. Their use is still recent. Desired range of reverberation times and acceptable noise levels have been developed and standardized, but even calculation methods of psychoacoustic parameters lack standards. More studies on understanding and defining psychoacoustic parameters' applicability for open and enclosed spaces are necessary.

1.2. Motivation

There is a research gap in acoustic comfort evaluation of enclosed public spaces. Reverberation time and sound pressure level are commonly used for defining the quality of spaces. Still, there are no generally accepted acoustic parameter ranges for *common* spaces, or *non-acoustic* spaces. Kang (2006) defines *non-acoustic* spaces as spaces without a special listening function, such as shopping malls or eating establishments. Room acoustics parameters alone are not enough to define the acoustic comfort in these complex soundscapes. This research aims to analyze the relationship between room acoustics parameters like reverberation time and equivalent continuous sound level; psychoacoustic parameters like sharpness, roughness and fluctuation strength, and the subjective comfort evaluations in enclosed public spaces.

Recommended ranges of values are defined for many acoustic parameters based on activities. For example, the desired reverberation time for a concert hall with a certain volume can be found in literature (Mehta, Johnson, and Rocafort 1999). Similarly, maximum sound pressure levels allowed for spaces accommodating certain functions are defined by regulations. Acoustics in a concert hall can be predicted by analyzing objective parameters (reverberation time RT, early decay time EDT, clarity C80, distinctness D50, center time TS, strength G, lateral energy fraction LEF, initial time delay gap ITDG, inter-aural cross correlation IACC) that are known to explain subjective evaluations (intimacy, liveness, warmth, loudness of direct and reverberant sound, definition, brilliance, diffusion, balance, blend, ensemble, immediacy of response, texture, freedom from echo and noise, dynamic range, tonal quality, uniformity) (Beranek 1962). On the other hand, studies on psychoacoustic parameters have not yet been able to define optimum ranges or recommended values for spaces. Yet, researchers especially in soundscape studies measure these parameters in both indoor and outdoor spaces (Kang et al. 2013). While these parameters are promising in characterizing noise and defining acoustic comfort in enclosed public spaces such as eating establishments and shopping centers, more research about what they express and their operating ranges is necessary.

Research questions of this study were:

- Can psychoacoustic parameters be tools for defining complex soundscapes of non-acoustic spaces like eating establishments?

- Is there regularity concerning the relationship between the number of occupants in an eating establishment and measured psychoacoustic parameters?
- How relevant is acoustic comfort evaluation of an enclosed space with psychoacoustic parameters, sound pressure level and reverberation time? Is there a certain preferred range for psychoacoustic parameters?
- How can we control sharpness, roughness and fluctuation strength of a space? On which elements of the eating establishments are these parameters dependent?

1.3. Aim & Scope

The aim of this study is to analyze and better understand psychoacoustic parameters in evaluating the complex soundscapes of enclosed spaces. The relationship between psychoacoustic parameters (loudness, sharpness, roughness and fluctuation strength), and subjective acoustic comfort is aimed to be discovered along with the relationship between psychoacoustic parameters and number of occupants. In eating establishments, the equivalent continuous sound levels can be predicted based on the number of occupants, taking into account the Lombard effect (Rindel 2012a). In this research, how psychoacoustic parameters change will be investigated as the ambient noise levels increase. Another goal is to find out if there is a characteristic range for psychoacoustic parameters in eating establishments.

In previous research, the psychoacoustic values were generally not linked with the number of occupants. The psychoacoustic parameter changes were given only in time domain, or the mean values for a certain time period were given. This research, investigates psychoacoustic parameters' relationship to both the sound sources and the physical attributes of spaces. Non-acoustic public spaces are where occupants freely move around, interact and communicate in groups. Very few of the activities are silent. There is a wide range of sounds created but often human speech dominates the ambient background noise which increases as the number of occupants increase. When characterizing these soundscapes, it is important to understand how psychoacoustic parameters change with the increasing number of sound sources. Similarly, it is important to know how acoustic properties of the enclosing building elements as well as the layout of the space affect psychoacoustic parameters.

Eating establishments are non-acoustic spaces shared by a number of people who sit and talk in groups and are mostly stationary. Acoustic investigations of these spaces are more manageable compared to spaces such as shopping malls, train stations, and courtyards. Sound sources are limited and activities follow a pattern. This is one major factor behind the fact that studies in eating establishments are common in the field of architectural acoustics. Eating establishments, especially ones serving in universities are a good choice for investigating the use of psychoacoustic parameters in evaluating acoustic comfort in enclosed non-acoustic spaces. In a university dining hall, the same group of people use the space regularly, creating very similar ambient noises every day. The acoustics of every hall is perceived differently and this is often a factor when choosing a place to go to. This thesis aims to provide insights into how psychoacoustic parameters can be utilized in comparing various ambient sounds dominated by noise due to occupants themselves. A questionnaire study about acoustic comfort accompanying on-site recordings have been conducted in each selected eating establishment in Izmir Institute of Technology campus. Additionally listening tests with headphones using on-site sound recordings and computer simulation auralizations were carried out in the laboratory.

The following chapters are background and definition of terms, literature review, methodology and conclusion. Background part introduces definition of terms which are related to this research. In literature review part, relevant remarkable studies about soundscape and psychoacoustics are mentioned, where methods, examples from questionnaires and their results are presented. Methodology part is where the research model is given; the equipment, software and properties of studied spaces are introduced; on-site measurements, recordings, questionnaires, simulations, auralizations and listening tests are explained; and results are given. As conclusion, the results of the study are discussed, contributions are stated, limitations and suggestions for further research are given.

CHAPTER 2

BACKGROUND AND DEFINITION OF TERMS

In this part, terminology for room acoustics and psychoacoustics will be introduced, which will frequently be used in the thesis later on. In order to understand the basis of psychoacoustic parameters, terms like auditory masking and critical bands should also be understood. Thus, besides the main psychoacoustic parameters, these supplementary explanations about hearing terminology are done in this chapter.

2.1. Room Acoustics

Room acoustics is the research area which includes architectural properties of spaces considering acoustics. It deals with evaluating acoustics of closed spaces with different uses, e.g. concert halls, lecture rooms, recording studios, conference rooms, eating establishments, or any room in a building.

2.1.1. Reverberation Time

Reverberation time [s] is the time it takes for sound to decrease by 60 dB in a room (Long 2014). The empirical formula established by Sabine is as follows:

$$T_{60} = 0.161 \frac{V}{A} \quad (2.1)$$

V: Volume of the room

A: Total area of absorption in the room

This value is commonly used by defining the quality of spaces. Suggested reverberation time values are defined especially for music and speech (Figure 2.1), but there are no generally accepted reverberation times for closed spaces with general purpose like lobbies and entrances where you just pass by, or cafes and restaurants for

dining. Still, in some countries there are regulations where we can find recommendations about reverberation times in spaces with certain functions.

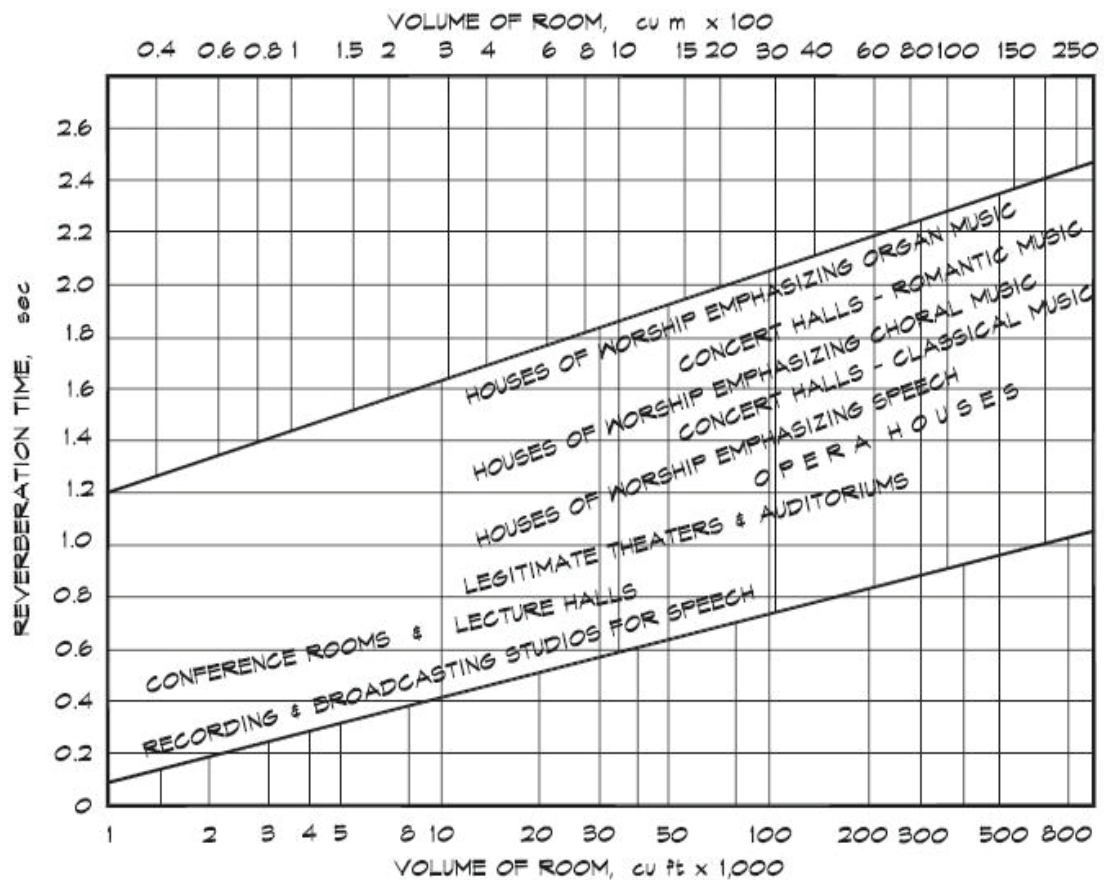


Figure 2.1. Suggested reverberation times for different volumes and functions (Source: Long 2014).

Australia government has standards (AS/NZS 2107 2000) about recommended design sound levels and reverberation times for building interiors. Surface materials of the volumes are determined according to the required reverberation time values given in these standards.

Also in Turkey, recently a regulation (T.C. Çevre ve Şehircilik Bakanlığı 2017) has been published where information about the maximum required reverberation time in certain spaces in a building is given (Table 2.1). According to this table, enclosed public spaces like eating establishments should have a reverberation time of one second or less.

Table 2.1. Allowable reverberation time values in buildings (Source: T.C. Çevre ve Şehircilik Bakanlığı 2017).

Function of the building	Space	Reverberation time [s]
Houses	Circulation areas	1.2
	Bedrooms	0.5
	Living areas. kitchen	0.8
Educational buildings	Classrooms. reading rooms	0.8
	Sports hall	1.8
	Circulation areas	1.2
	Kindergarten eating spaces	0.8
	Kindergarten sleeping rooms	0.5
Health facilities	Patient rooms	0.5
	Examination rooms. labs. surgery rooms	0.8
	Rooms with multiple beds	1.0
	Circulation areas	1.2
Administrative buildings	Open offices	1.0
	Meeting rooms. director's office	0.8
	Teleconference rooms	0.4
	Circulation areas	1.2
	Courtrooms	1.2
Accommodation facilities	Bedrooms	0.5
	Eating establishments	1.0
	Circulation areas	1.2
	Service support areas	1.0
Dormitories	Dormitory room	0.5
	Study rooms	0.8
	Circulation areas. dining halls	1.2
Cultural facilities	Museums	1.2
	Libraries	0.8
	Circulation areas	1.2
Commercial facilities	Shops	1.0
	Shopping malls	2.0
	Post offices. banks	1.2
	Circulation areas	1.2
Stations	Waiting areas	1.0
	Staff rooms	0.8
Entertainment facilities	Eating establishments	1.0
Industrial facilities	Staff rooms	0.8
	Circulation areas	1.2

2.1.2. Acoustical Capacity

In a study about eating facilities, Rindel proposes the concept of acoustic capacity (N_{max}) (Rindel 2012a). It is defined as the “maximum number of persons allowed in the room for sufficient quality of verbal communication.” The calculation method for acoustical capacity is presented in Equation 2.2.

$$N_{max} = \frac{V}{20 \times T} \quad (2.2)$$

V: Volume

T: Reverberation time in furnished but unoccupied state at mid frequencies (500 – 1000 Hz).

Figure 2.2 shows the quality of verbal communication, taking acoustical capacity in consideration.

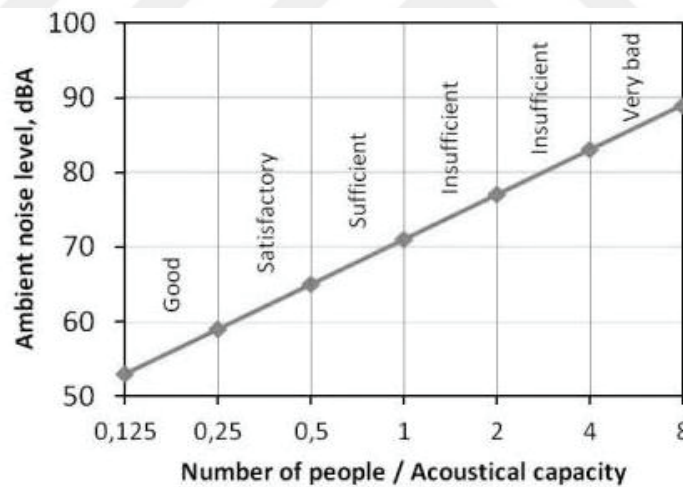


Figure 2.2. Quality of verbal communication (Source: Rindel 2012a).

2.1.3. Lombard Effect (Cocktail Party Effect)

When occupants are speaking inside a room, they raise their voice due to the ambient noise. This again leads to a higher ambient noise. Lombard effect is the name of this phenomenon (Rindel 2012a). In indoor environments, noise level is directly proportional with the number of occupants. As noise level increases, in order to

preserve speech intelligibility, people raise their voices, increasing the noise level. This rapid increase in the noise level is called the Lombard effect (or cocktail party effect), which can also be explained as “adaptations of speech to overcome the detrimental effects of noise in noisy places” as stated by Razavi (2006). Lazarus made various investigations and he identified the Lombard slope (c), the nonlinear distortion (increase in the speech level / noise level) (1986). Also, Lazarus pointed out that the effect starts at an ambient noise level L_{NA} of 45 dB and speech level L_{SA} of 55 dB in eating establishments.

Recently, Rindel proposed a model for predicting the average A-weighted noise level due to many people speaking in a room with an assumed diffuse sound field (2010). His aim was to present a prediction model that takes Lombard effect into account and he concluded that slope could vary between 0.5 - 0.7. Rindel’s study on background noise due to speech is presented in Equation 2.3.

$$L_{N,A} = \frac{1}{1-c} \cdot (69 - c \cdot 45 - 10 \log \left(g \cdot \left(\frac{0.16 \cdot V}{T_0 \cdot N} + A_p \right) \right)) \quad (2.3)$$

c : Lombard slope

V : Volume

g : Assumed group size

A_p : Absorption per person

N : Number of people

2.2. Psychoacoustics

Psychophysics is the research area where the relationship between sensory perception (psychology) and physical values (physics) is aimed to be found. Psychoacoustics is a branch of psychophysics, working on the human perception of sounds (Yost 2015). Yost mentions in his study that the history of psychoacoustics begins with Hermann von Helmholtz in 1800s and continues in Bell Laboratories between 1920 and 1960. He indicates that critical-band and equal-loudness contours are the most remarkable psychoacoustic contributions which Bell Laboratories made (Yost 2015).

The keystone book *Psychoacoustics* written by Fastl and Zwicker is a detailed explanation of the studies done by Institute of Telecommunications in Stuttgart from 1952 to 1967, and Institute of Electroacoustics in Munich since 1967, which are all translated from German language to English (Fastl and Zwicker 2007).

In order to create a basis for calculating psychoacoustic parameters, which gained importance in architectural acoustics, the basic terms critical band, bark scale, auditory masking (spectral masking), loudness and loudness level (sone and phon), and then their calculations according to standards should be understood in depth. Detailed information about these parameters are given in the following sub-sections with their corresponding formulas.

2.2.1. Critical Bands

Considering human ear, there are 24 discrete areas on the basilar membrane, which act like band-pass filters in order to distinguish between sounds according to their spectral contents. These cochlear filters have bandwidths which are called critical bands (z) when two tones are close enough to overlap and mask each other (Long 2014). These 24 bands between 20 Hz to 16000 Hz are approximately one-third octave wide above 500 Hz, where they are 100 Hz wide at lower frequencies. They are important for the phenomenon of masking and definition of consonance and dissonance regions (Long 2014).

Bark is the unit for the critical band frequency scale. 1 – 24 Bark covers the frequency range from 20 – 15500 Hz. This unit is named after the scientist Barkhausen, who introduced the ‘phon’ value for loudness level (Fastl and Zwicker 2007). Table 2.2 shows the critical bands’ center, lower and upper limit frequencies for all 24 critical bands.

In the same critical band, ten times the intensity is required to make the signal feel like twice as loud from the inner ear, due to the saturation effects in the organ of Corti. For two sounds from different critical bands which are widely enough separated and do not compete for the same nerve endings on the basilar membrane of the inner ear, this rule does not apply. Thus, adding a second sound of equal loudness causes a total sense about twice as loud.

Table 2.2. Critical bands' center, lower and upper limit frequencies (Source: Zwicker 1961).

Number	Center frequencies [Hz]	Cut-off frequencies [Hz]	Bandwidth [Hz]
		20	
1	50	100	80
2	150	200	100
3	250	300	100
4	350	400	100
5	450	510	110
6	570	630	120
7	700	770	140
8	840	920	150
9	1000	1080	160
10	1170	1270	190
11	1370	1480	210
12	1600	1720	240
13	1850	2000	280
14	2150	2320	320
15	2500	2700	380
16	2900	3150	450
17	3400	3700	550
18	4000	4400	700
19	4800	5300	900
20	5800	6400	1100
21	7000	7700	1300
22	8500	9500	1800
23	10500	12000	2500
24	13500	15500	3500

2.2.2. Auditory Excitation and Masking

Auditory excitation and masking are terms which are taken into account while calculating psychoacoustic parameters of complex sounds, e.g. loudness and sharpness. For this reason, definitions of these terms are given in this section.

Auditory masking takes place when the perception of one sound is affected by the presence of another sound. Auditory masking in the frequency domain is also called simultaneous masking, frequency masking or spectral masking. Spectral masking occurs

when a sound is made inaudible by another sound of the same duration as the original sound, due to critical band effects.

Auditory masking in the time domain is known as temporal masking. Masking which makes a sound inaudible immediately before the masker is called pre-masking and masking which makes a sound inaudible immediately following the masker is called post-masking.

Figure 2.3 shows excitation level versus critical-band rate pattern for a critical-band wide noise with a center frequency of 1 kHz and the critical-band levels.

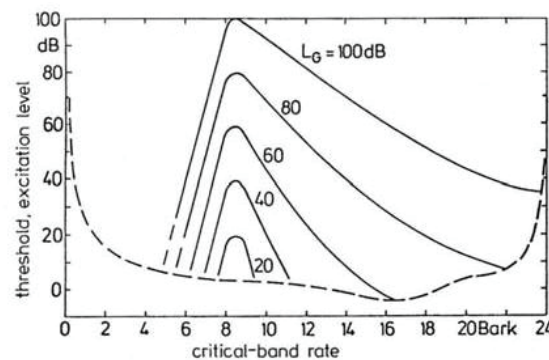


Figure 2.3. Excitation level versus critical-band rate (Source: Fastl and Zwicker 2007).

Masking pattern characteristics change by the frequency. Figure 2.4 shows frequency masking patterns of different frequencies.

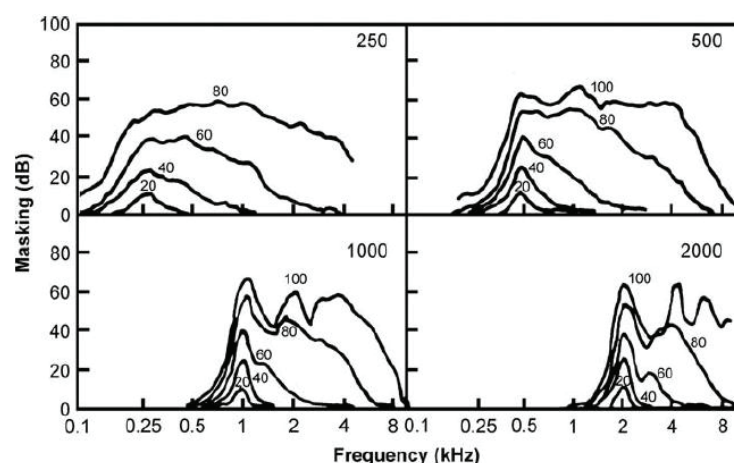


Figure 2.4. Different frequency masking patterns. (Source: Gelfand 2009, adapted from Ehmer 1959).

The masking which occurs in the same critical band is called on-frequency masking. This means that the listener cannot distinguish between these two sounds in the same critical band and they are perceived as one sound with the quieter sound masked by the louder one. The masking which occurs in widely separated frequencies is called off-frequency masking. The amount the masker raises the threshold of the signal is much less in off-frequency masking, but it does have some masking effect because some of the masker overlaps into the auditory filter of the signal. Figure 2.5 shows the excitation level versus critical-band rate pattern for narrow-band noises of given center frequency and a sound pressure level of 60 dB. The broken line indicates the threshold in quiet.

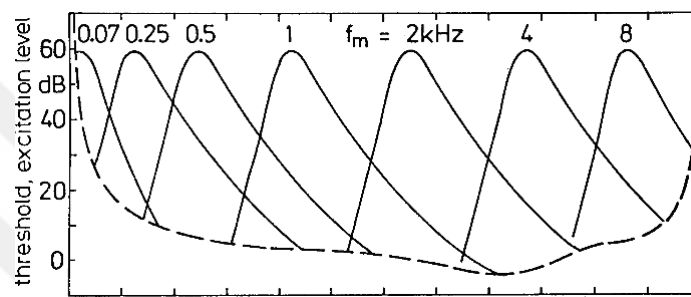


Figure 2.5. Excitation level versus critical-band rate (Source: Fastl and Zwicker 2007).

2.2.3. Psychoacoustic Parameters

Psychoacoustic parameters (loudness, sharpness, roughness and fluctuation strength) which are defined for understanding subjective evaluation of sound's physical effects, gained importance in the field of architectural acoustics. In particular, Loudness was introduced as a better parameter than A-weighted level, because it shows a much better correspondence with the subjective impression of volume.

Standardization of psychoacoustic parameters is important, especially in terms of comparing psychoacoustic results of different studies. Loudness parameter was standardized in the last years as DIN 45631 (DIN 1991), ISO 532 (ISO 2017) and ANSI S3.4 (ASA 2007). The calculation of sharpness is also standardized in DIN 45692 (DIN 2009). The standardization of roughness is recently under consideration by the German Institute for Standards DIN (Genuit 2010).

2.2.3.1. Loudness and Loudness Level

Loudness N [sone] is the “ratio of loudness of a sound to that of a 1 kHz tone 40 dB above the threshold of hearing. 1 sone is the loudness of a sound whose loudness level are 40 phons” (B&K 2016). **Loudness Level L_N** [phon] is “numerically equal to the sound pressure level of a 1 kHz free progressive wave which is judged by reliable listeners to be as loud as the unknown sound” (B&K 2016).

The human perception of the magnitude of a sound is called loudness (Long 2014). This subjective impression depends on sound pressure and frequency of the sound. There are frequency weighting schemes that can be considered as scales which enable to adapt objectively measureable acoustic values to human perception (e.g. the A-weighted sound level dBA). For determining loudness level, Normal Loudness Curves are used, which presume that people are less sensitive to low frequency sounds.

The relationship between the physical properties of sound (e.g. sound pressure) and the hearing threshold of human beings defines these curves. The first contours of these curves have been published by Fletcher and Munson (1933), as a result of acute hearing tests which were done on a group of people with a controlled set of sounds. Participants were played pure tone sounds at a particular frequency and amplitude with 10 dB intervals between 0 and 120 dB. These signals were played by headphones for one second duration with a 1.5 second pause between them. Then they were asked about the loudness of each tone they have perceived comparatively and the results of this subjective measurement procedure formed the loudness level contours. In 1956, Robinson and Dadson (1956) used loudspeakers in an anechoic chamber, repeated the measurements and created the equal loudness curves (Figure 2.6). These curves were standardized in 1987 by ISO as ISO 226 and a revision was made in 2003 (ISO 2003).

Human ear's response to increasing sound intensity is a logarithmic (power of ten) relationship. This is one of the motivations for using the decibel scale to measure sound intensity. A general rule for loudness is that the power must be increased by about a factor of ten to sound twice as loud. To more realistically assess sound loudness, the ear's sensitivity curves are factored in to produce a phon scale for loudness. The sone scale is based on the observation that a 10 phon increase in a sound level is most often perceived as a doubling of loudness.

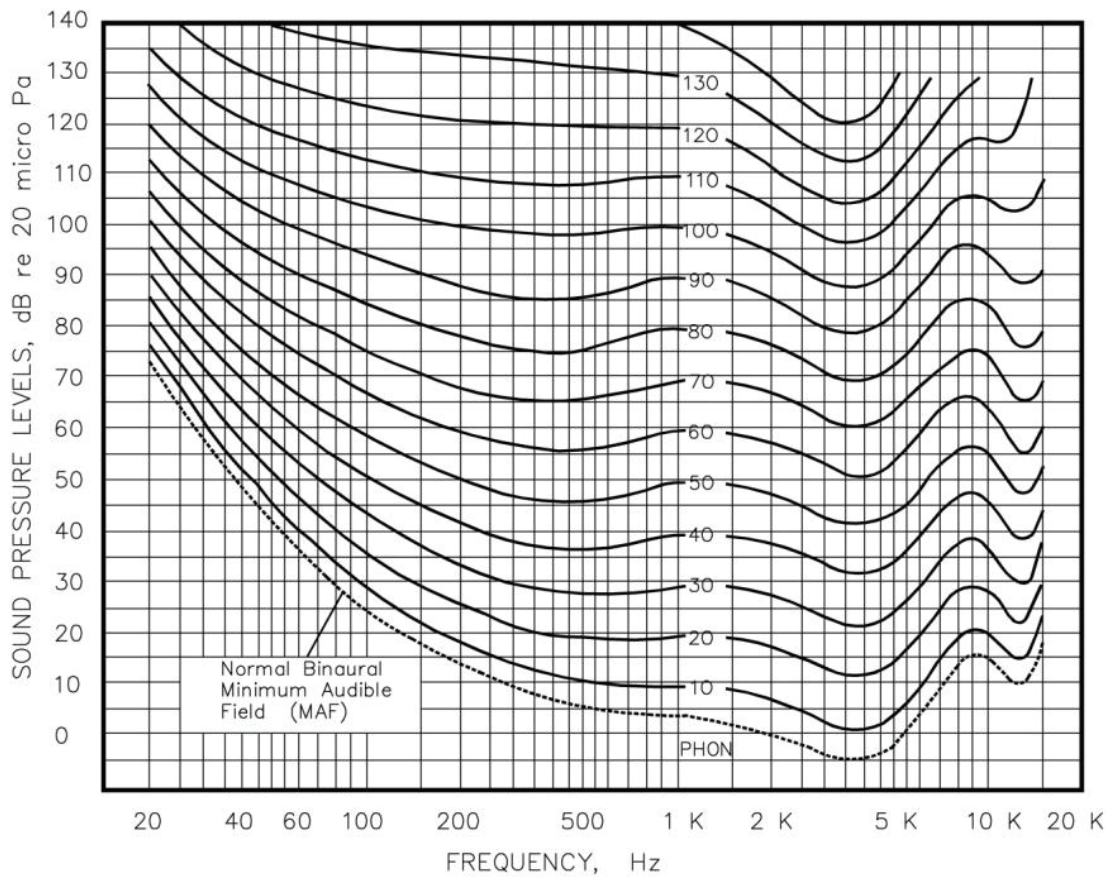


Figure 2.6. Normal Loudness Curves for Pure Tones (Source: Robinson and Dadson 1956, as cited in Long 2014).

The unit of phon is based on sound pressure measured on a logarithmic (dB) scale. Sone is a more linear scale of perception. For example, 4 sones is twice as loud as 2 sones (HyperPhysics 2016). Table 2.3 shows the sone values which correspond to phon values.

Table 2.3. Sone and corresponding phon values.

sone	1	2	4	8	16	32	64	128	256	512	1024
phon	40	50	60	70	80	90	100	110	120	130	140

The unit conversions between loudness and loudness level are given as Equation 2.4 (ISO 2017).

$$N = 2^{0.1\left(\frac{L_N}{phon} - 40\right)} sone \quad \text{for } L_N \geq 40 \text{ phon}$$

$$L_N = \left[40 + 33.22 \lg \left(\frac{N}{sone} \right) \right] phon \quad \text{for } N \geq 1 \text{ sone}$$

$$L_N = 40 \left(\frac{N}{sone} + 0.0005 \right)^{0.35} phon \quad \text{for } N < 1 \text{ sone} \quad (2.4)$$

For $N < 1$ sone, the graph changes its slope, as seen below, which shows that the sone-phon relationship is not linear between 0 and 1 sones.

There is also a relationship formula between loudness and A-weighted sound level. Figure 2.7 shows the relationship between sone scale and dBA level, with plus and minus 2 dBA accuracy (ASHRAE 1972).

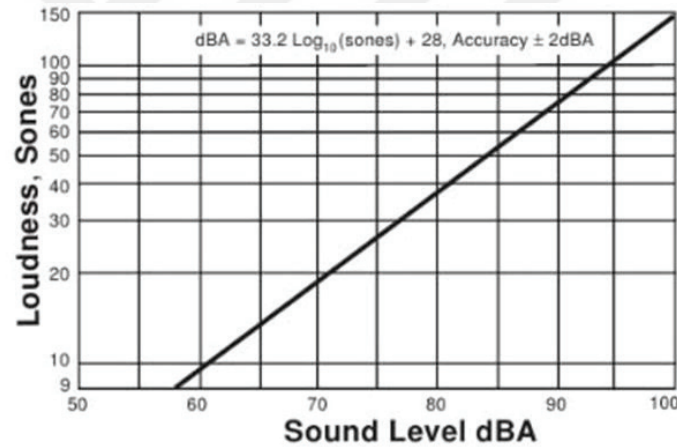


Figure 2.7. Relationship between dBA and sone levels (Source: ASHRAE 1972).

Considering the units, for identification a suffix GF or GD is added to the unit sones. G (from the German for Critical Band: Frequenzgruppe) identifies that Zwicker's method was used. F identifies the sound field as Frontal (SoneGF). D identifies the sound field as Diffuse (SoneGD).

Table 2.4 shows the minimum and maximum design criteria values for certain types of spaces considering sone scale. According to that, different kinds of eating establishments should have loudness values between 3 and 24 sones, in order to provide optimum acoustic requirements.

Table 2.4. Design criteria for loudness (Source: AMCA 1973).

Room Type	Sones	Room Type	Sones	Room Type	Sones	Room Type	Sones
Auditoriums		Indoor sports activities		Hotels		Public buildings	
Concert and opera halls	1.0 to 3	Gymnasiums	4 to 12	Lobbies	4.0 to 12	Museums	3 to 9
Stage theaters	1.5 to 5	Coliseums	3 to 9	Banquet rooms	8.0 to 24	Planetariums	2 to 6
Movie theaters	2.0 to 6	Swimming pools	7 to 21	Ball rooms	3.0 to 9	Post offices	4 to 12
Semi-outdoor amphitheaters	2.0 to 6	Bowling alleys	4 to 12	Individual rooms/suites	2.0 to 6	Courthouses	4 to 12
Lecture halls	2.0 to 6	Gambling casinos	4 to 12	Kitchens and laundries	7.0 to 12	Public libraries	2 to 6
Multi-purpose	1.5 to 5	Manufacturing areas		Halls and corridors	4.0 to 12	Banks	4 to 12
Courtrooms	3.0 to 9	Heavy machinery	25 to 60	Garages	6.0 to 18	Lobbies and corridors	4 to 12
Auditorium lobbies	4.0 to 12	Foundries	20 to 60	Residences		Retail stores	
TV audience studios	2.0 to 6	Light machinery	12 to 36	Two & three family units	3 to 9	Supermarkets	7 to 21
Churches and schools		Assembly lines	12 to 36	Apartment houses	3 to 9	Department stores (main floor)	6 to 18
Sanctuaries	1.7 to 5	Machine shops	15 to 50	Private homes (urban)	3 to 9	Department stores (upper floor)	4 to 12
Schools & classrooms	2.5 to 8	Plating shops	20 to 50	Private homes (rural & suburban)	1.3 to 4	Small retail stores	6 to 18
Recreation halls	4.0 to 12	Punch press shops	50 to 60	Restaurants		Clothing stores	4 to 12
Kitchens	6.0 to 18	Tool maintenance	7 to 21	Restaurants	4 to 12	Transportation (rail, bus, plane)	
Libraries	2.0 to 6	Foreman's office	5 to 15	Cafeterias	6 to 8	Waiting rooms	5 to 15
Laboratories	4.0 to 12	General storage	10 to 30	Cocktail lounges	5 to 15	Ticket sales office	4 to 12
Corridors and halls	5.0 to 15	Offices		Social clubs	3 to 9	Control rooms & towers	6 to 12
Hospitals and clinics		Executive	2 to 6	Night clubs	4 to 12	Lounges	5 to 15
Private rooms	1.7 to 5	Supervisor	3 to 9	Banquet room	8 to 24	Retail shops	6 to 18
Wards	2.5 to 8	General open offices	4 to 12	Miscellaneous			
Laboratories	4.0 to 12	Tabulation/computation	6 to 18	Reception rooms	3 to 9		
Operating rooms	2.5 to 8	Drafting	4 to 12	Washrooms and toilets	5 to 15		
Lobbies & waiting rooms	4.0 to 12	Professional offices	3 to 9	Studios for sound reproduction	1 to 3		
Halls and corridors	4.0 to 12	Conference rooms	1.7 to 5	Other studios	4 to 12		
		Board of Directors	1 to 3				
		Halls and corridors	5 to 15				

There are different loudness calculation methods developed by Fastl & Zwicker (2007), Stevens (1956) and Moore – Glassberg (1997).

“With increasing frequency separation of the two tones, loudness increases. This means that loudness is not produced from separate spectral components, but rather the two components influence each other, especially if their frequency separation is small” (Fastl and Zwicker 2007). Critical bandwidth plays an important role in loudness and the excitation level versus critical band rate pattern represents the influence of critical bandwidth and the part which continues under the slopes. Thus, the excitation level versus critical-band rate pattern is used as a basis, from where the loudness of complex sounds can be calculated.

Time-varying loudness is an algorithm defined by standards for calculating the loudness of non-steady-state noises, or signals that change with time. This algorithm measures the 1/3 octave spectrum using exponential averaging with a 2 ms time constant, combines the fractional-octave bands into critical bands, and applies temporal and spectral masking. This algorithm then returns the result as the specific loudness versus critical band rate, integrates the specific loudness, and applies temporal post-masking filters to measure the time-varying loudness. Time-varying loudness

calculation is defined by ISO 532-1 (ISO 2017) and DIN 45631/A (DIN 1991). Figure 2.8 shows the main principles applied in the algorithms of loudness calculation.

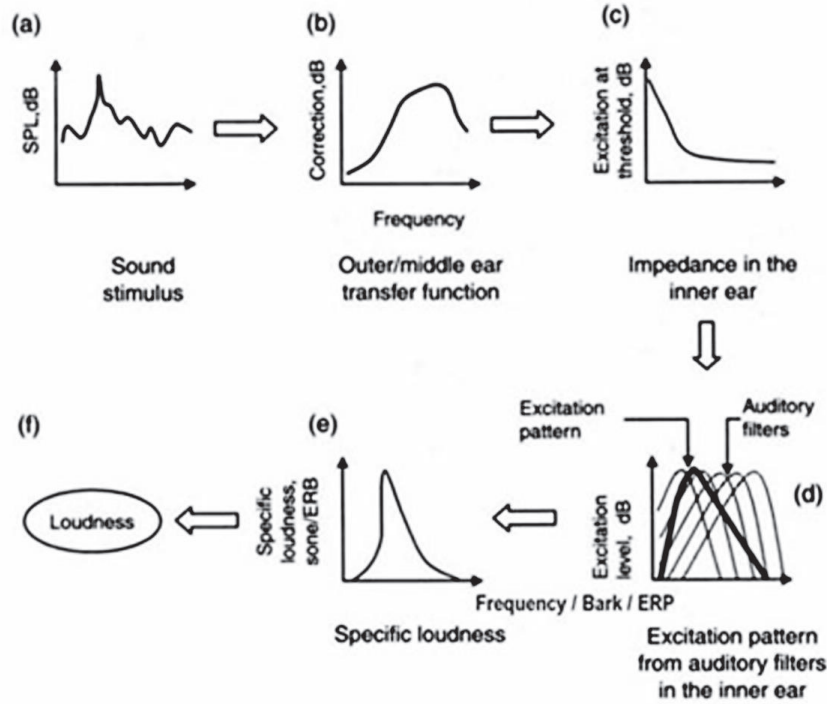


Figure 2.8. Explanation of loudness calculation algorithms (Source: Möser 2010).

Specific Loudness N' [sone/Bark] is the loudness evoked over a frequency band with a bandwidth of an auditory filter centred at the frequency of interest. It can be calculated from the dB level for each third octave band using the assumption that “a relative change in loudness is proportional to a relative change in intensity” (Fastl and Zwicker 2007).

So values of specific loudness can be calculated using a power law for each of the 24 critical bands. Masking curves can then be constructed around these levels representing the effect of critical bands. The equation is as follows:

$$N' = 0.08 \left(\frac{E_{TQ}}{E_0} \right)^{0.23} \left[\left(0.5 + 0.5 \frac{E}{E_{TQ}} \right)^{0.23} - 1 \right] \frac{\text{sone}_G}{\text{Bark}} \quad (2.5)$$

E_{TQ} : Excitation at threshold in quiet

E_0 : Excitation that corresponds to the reference intensity $I_0 = 10^{-12} \text{ W/m}^2$

The final value for loudness N is then calculated as the integral (i.e. the area) under the curve as defined by the standards and is presented in sones.

$$N = \int_0^{24Bark} N' dz \quad (2.6)$$

In ISO 532-1 (ISO 2017), there are correction tables. These corrections are mostly in lower frequencies and this shows that the psychoacoustic parameter loudness discards most of the low frequency noise due to ear's characteristics.

There are some differences between the results calculated by various loudness calculation method standards. Usually, ANSI method gives higher sone values for broadband signals, compared to DIN. On the other hand, for low frequency signals, DIN method delivers higher sone values (Head Acoustics 2016).

Just noticeable difference (JND) for loudness can be found in different areas of research. JND of loudness for construction machines is found to be 0,8 sone (Carletti and Pedrielli 2016). JND of loudness for refrigerator noise is found to be 0,5 sone (You and Jeon 2008).

2.2.3.2. Sharpness

“1 acum is the sharpness of a 60 dB narrow-band noise, one critical band wide with a centre frequency of 1 kHz (from 920 to 1080 Hz)” (B&K 2016).

Fastl and Zwicker (2007) pointed out that every acoustic sensation except loudness and pitch were used to be associated only with timbre which has a vague description. Sharpness is one of the sensations which can be extracted from timbre as a component which can be defined more concretely. Sharpness is connected with spectral envelope of the sound.

Sharpness is highly related with the amount of high frequency energy to the total sound energy. If high frequency components in the signal have a higher rate, the sound has more sharpness. An increase in sound level has a little effect on sharpness, as it doubles when the sound level is changed from 30 dB to 90 dB. Sharp sounds are unpleasant, aggressive and painful which are not preferred in terms of acoustic comfort.

Figure 2.9 shows two sounds with different frequency spectra, and thus different sharpness values.

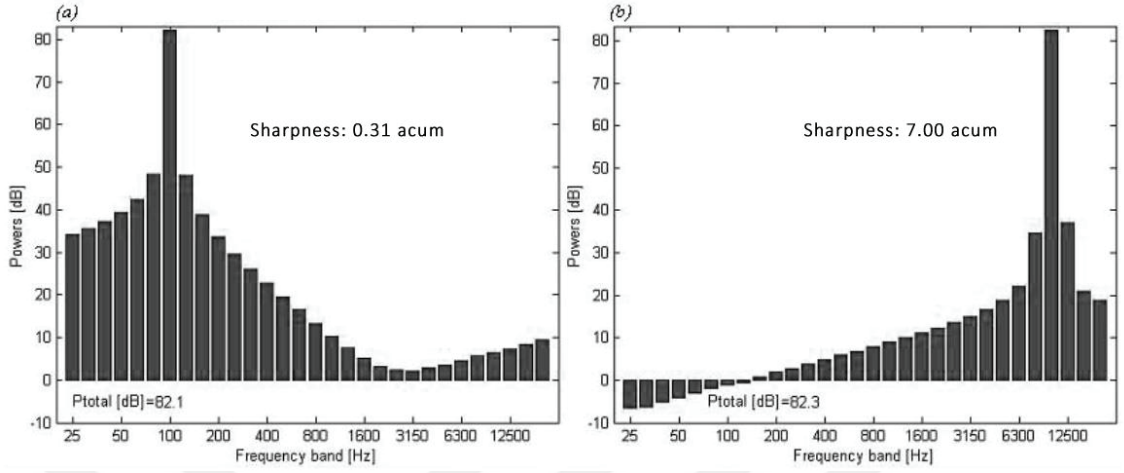


Figure 2.9. Sharpness value examples of two sounds (Source: SIRC 2019).

Figure 2.10 shows sharpness of narrow-band noise, high pass noise and low pass noise. It can be seen that high frequencies have more sharpness.

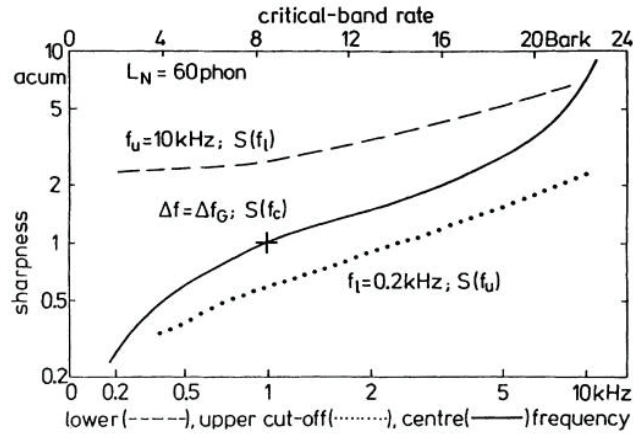


Figure 2.10. Sharpness of different noises (Source: Fastl and Zwicker 2007).

There are several methods to calculate sharpness including Bismarck (1974), Aures (1985) and Zwicker & Fastl's method (2007). The only standard about sharpness calculation method is DIN 45692 (DIN 2009) "Measurement technique for the simulation of the auditory sensation of sharpness" which explains the methods according to Aures and Von Bismarck.

The sharpness is calculated from the sound pressure signal waveform, the 1/3-octave band spectrum calculated over the frequency range 25 Hz to 12.5 kHz, or the specific loudness. The algorithm normalizes the specific loudness spectrum by the total loudness and weights the spectrum according to frequency. The algorithm returns the frequency-weighted result as the specific sharpness versus critical band rate and then integrates the specific sharpness to measure the sharpness (National Instruments 2016).

Sharpness can be calculated as the weighted first moment of the specific loudness. The calculation of a partial first moment at z is $N' \cdot z \cdot dz$ (Figure 2.11). This partial first moment is then weighted by the function $g(z)$ to give $g(z) \cdot N' \cdot z \cdot dz$. The sum of these weighted partial moments is calculated. This is then divided by the total loudness N .

$$S = c \cdot \frac{\int_0^{24Bark} N' g(z) \cdot z \cdot dz}{\int_0^{24Bark} N' dz} \quad (2.7)$$

where:

$$z \leq 15.8 \rightarrow g(z) = 1$$

$$z > 15.8 \rightarrow g(z) = 0.15 \cdot e^{0.42(z-15.8)} + 0.85$$

$$0.105 \leq c < 0.115$$

These $g(z)$ functions for corresponding z values are stated in DIN 45692 (2009). Values for other calculation methods are also given by the same standard.

For Aures method, following $g(z)$ functions are valid (DIN 2009):

$$g_A(z) = 0.078 \cdot \frac{e^{0.171 \cdot z}}{z} \cdot \frac{N}{\ln(0.05 \cdot N + 1)}$$

For Bismarck method, following $g(z)$ functions are valid (DIN 2009):

$$z \leq 15 \rightarrow g_B(z) = 1$$

$$z > 15 \rightarrow g_B(z) = 0.2 \cdot e^{0.308(z-15)} + 0.8$$

$$c = 0.11$$

Also, other $g(z)$ functions for corresponding z values are given (SIRC 2019):

$$z < 14 \rightarrow g(z) = 1$$

$$z > 14 \rightarrow g(z) = 0.00012 z^4 - 0.0056 z^3 + 0.1 z^2 - 0.81 z + 3.51$$

$$c = 0.11$$

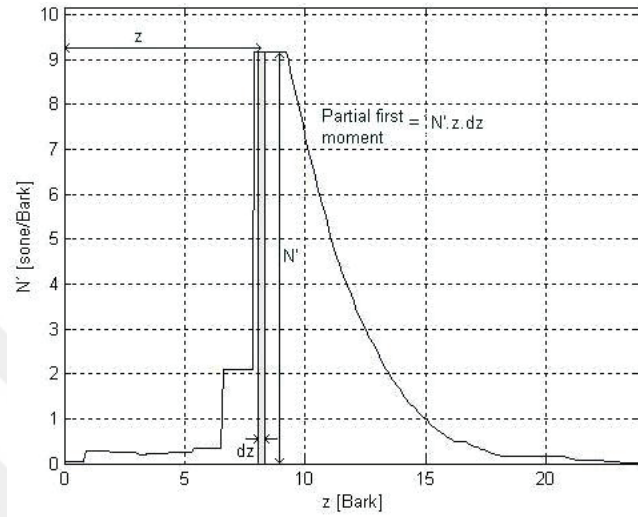


Figure 2.11. Graph of the partial first moment at a certain z value (Source: SIRC 2019).

$g(z)$ is a factor that places extra weight upon high frequencies (above 16 bark). This weighting function shown in Figure 2.12 is to express that sharpness increases with increasing frequency.

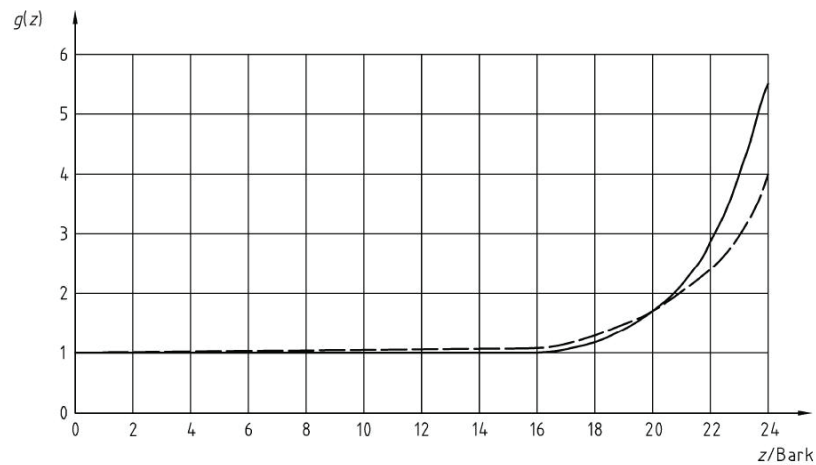


Figure 2.12. Weighting, $g(z)$, as a function of critical band rate (Source: DIN 2009).

The results from different calculation methods may vary (Head Acoustics 2016). DIN method is a good choice for determining sharpness of sound events with similar loudness. Aures method is recommended for situations with significant loudness differences.

Just noticeable difference (JND) for sharpness can be found in different areas of research. JND of sharpness for construction machines is found to be 0.04 acum (Carletti and Pedrielli 2016). JND of sharpness for refrigerator noise is found to be 0.08 acum (You and Jeon 2008).

Table 2.5 and Table 2.6 show sharpness set values for certain conditions (DIN 2009). Sharpness set values of narrow band noise with 4 sone loudness for critical bands and corresponding center frequencies are given in this table, which aims to standardize the values for sharpness.

Table 2.5. Sharpness set values of narrow band noise with 4 sone loudness for critical bands (Source: DIN 2009).

Center freq. Hz	Critical band Bark	Sharpness acum
250	2,5	0,38
350	3,5	0,49
450	4,5	0,60
570	5,5	0,71
700	6,5	0,82
840	7,5	0,93
1 000	8,5	1,00
1 170	9,5	1,13
1 370	10,5	1,26
1 600	11,5	1,35
1 850	12,5	1,49
2 150	13,5	1,64
2 500	14,5	1,78
2 900	15,5	2,06
3 400	16,5	2,40
4 000	17,5	2,82
4 800	18,5	3,48
5 800	19,5	4,43
7 000	20,5	5,52
8 500	21,5	6,81
10 500	22,5	8,55

Table 2.6. Sharpness set values of broad band noise with fixed upper limit of 10 kHz and varying lower frequency limit with 4 sone Loudness for critical bands (Source: DIN 2009).

Lower freq. limit Hz	Critical band Bark	Sharpness acum
250	2,5	2,70
350	3,5	2,74
450	4,5	2,78
570	5,5	2,85
700	6,5	2,91
840	7,5	2,96
1 000	8,5	3,05
1 170	9,5	3,12
1 370	10,5	3,20
1 600	11,5	3,30
1 850	12,5	3,42
2 150	13,5	3,53
2 500	14,5	3,69
2 900	15,5	3,89
3 400	16,5	4,12
4 000	17,5	4,49
4 800	18,5	5,04
5 800	19,5	5,69
7 000	20,5	6,47
8 500	21,5	7,46

2.2.3.3. Roughness

“1 asper is the roughness of a 60 dB, 1 kHz signal with 100% modulation at 70 Hz” (B&K 2016).

Roughness is the sensation for temporal sound variations. It is derived from amplitude and frequency modulation of the sound. The modulation range is between 15 and 300 Hz, where roughness reaches its maximum around 70 Hz (Fastl 2005). Around these frequencies, a sensation of stationary and rough sound occurs which is unpleasant (B&K 2016). As this frequency gets higher, the perception of modulation is reduced and roughness decreases. For both roughness and fluctuation strength, Figure 2.13 shows the modulation depth with the hatched area and the perceived masking depth ΔL on a sinusoidal waveform.

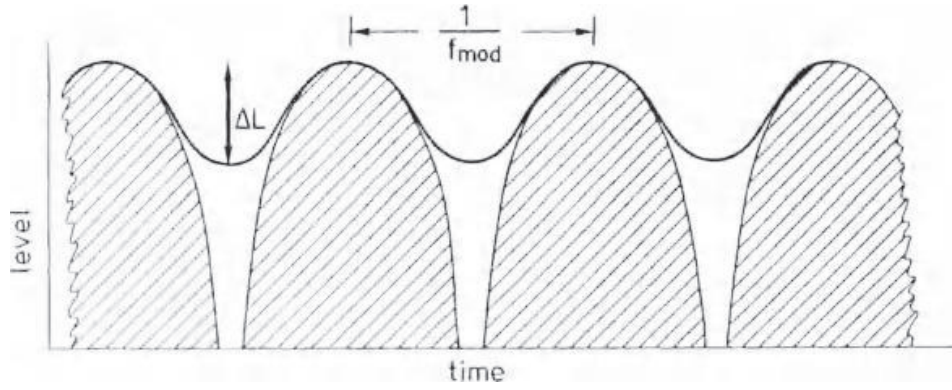


Figure 2.13. The effect of subjective duration on rapid amplitude modulated noise
(Source: Fastl and Zwicker 2007).

There is no standardization for roughness calculation yet. There are different methods developed by Fastl & Zwicker (2007), Sottek (1994) and Aures (1985). As stated by Genuit (2010), the standardization of roughness is recently under consideration by the German Institute for Standards DIN.

So, the roughness of a sound can be evaluated from the following equation (Fastl and Zwicker 2007).

$$R = 0.0003 \cdot f_{mod} \int_0^{24Bark} \Delta L_E(z) \cdot dz \quad (2.8)$$

f_{mod} : Frequency of modulation

ΔL_E : Perceived masking depth

The calculation process used by dB Sonic software (T&S Technologies 2015) is an improved model in account with Aures. The software calculates total roughness as the sum of all partial roughness values.

Just noticeable difference (JND) for roughness has been investigated by various research efforts. JND of roughness for refrigerator noise is found to be 0.04 asper (You and Jeon 2008). Daniel and Weber (1997) estimate JND level in roughness as 17%.

2.2.3.4. Fluctuation Strength

Fluctuation strength is a measure of low-frequency amplitude and frequency modulation below 20 Hz and its unit is vacil. It reaches its maximum around 4 Hz.

There are no strict boundaries between roughness and fluctuation strength. It can be stated that roughness is perceived at higher frequencies of modulation compared to fluctuation strength (Fastl 2006). Figure 2.13 can be used while explaining main principles of both fluctuation strength and roughness. Fluctuating signals are annoying and therefore undesired in terms of acoustic comfort. They are frequently used for creating warning signals (Fastl 2006). There is no standardization for fluctuation strength. The following formula by Fastl and Zwicker (2007) shows the calculation method for fluctuation strength (F).

$$F = \frac{0.008 \cdot \int_0^{24Bark} \Delta L \cdot dz}{\left(\frac{f_{mod}}{4Hz}\right) + \left(\frac{4Hz}{f_{mod}}\right)} \quad (2.9)$$

ΔL : Masking depth

f_{mod} : Modulation frequency

Just noticeable difference (JND) for fluctuation strength is given in the research area of mechanical engineering. JND of fluctuation strength for refrigerator noise is found to be 0.012 vacil (You and Jeon 2008).

2.2.4. Combined Metrics

In order to define subjective sound quality evaluations by the physical parameters of the sound, formulas with combinations of psychoacoustic parameters have been proposed. These combined metrics are mostly results of empirical studies. They include psychoacoustic parameters and some of them count also the effect of other variables like time of the day.

Combined metrics like sensory pleasantness, sensorial consonance, unbiased annoyance and psychoacoustic annoyance values are examples which have been formed in order to define acoustic comfort or discomfort. According to a study (Guski, Felscher-Suhr, and Schuemer 1999), annoyance is rated to be the main effect of environmental noise (Figure 2.14), followed by disturbance, anger, restrictions of welfare and stress, when asked to international experts.

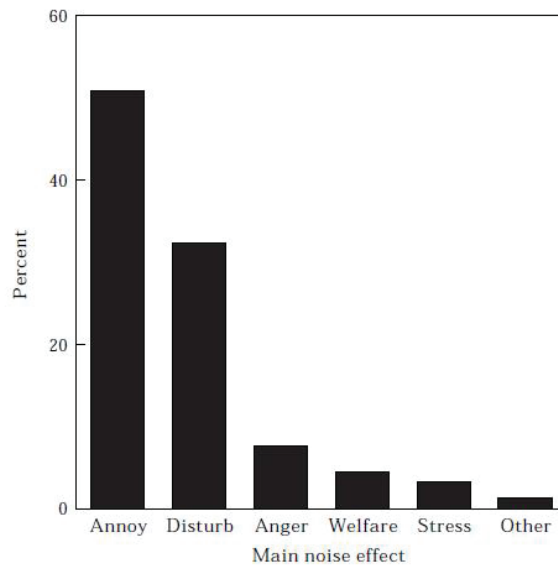


Figure 2.14. Effects of noise (Source: Guski, Felscher-Suhr, and Schuemer 1999).

In literature, there are several multicomponent annoyance calculation methods considering different noise sources. In Table 2.7, annoyance index formulas for vacuum cleaner, washing machine motors and hairdryers are given depending on loudness, sharpness, roughness, fluctuation strength and other related parameters.

Table 2.7. Different annoyance calculation methods (Source: SIRC 2019).

Index	Descriptions
Annoyance index for vacuum cleaner	Using a combination of loudness L, sharpness S, roughness R, fluctuation strength F, tone to noise ratio T and prominence ratio P in varying quantities. Annoyance = $0.655L - 2.618S + 0.047R + 2.708F - 0.04T - 0.106P$
Washing machine motors	Used a combination of stationary loudness L, statistical instantaneous mean loudness $L_{instmean}$ and statistical sharpness standard deviation S_{σ} . Annoyance = $87.817 + 126.66L + 0.047L_{instmean} + 644.94S_{\sigma}$
Hairdryers	Used a combination of tone to noise ratio T and statistical instantaneous minimum loudness $L_{instmean}$. Annoyance = $491.28 + 5.89T + 11.46 L_{instmean}$

2.2.4.1. Sensory Pleasantness

Sensory pleasantness is based on relative values of sharpness, roughness, tonality, and loudness. As stated by Fastl and Zwicker (2007); loudness, sharpness and roughness parameters can be calculated, but the tonality values used by sensory pleasantness calculations are judged subjectively.

The relationships between sensory pleasantness and other sensations are given as curves in Figure 2.15. Because the data are measured using magnitude estimation method with an anchor, which is a subjective method, only relative values can be given. It depends mostly on sharpness. Sensory pleasantness decreases with increasing sharpness. Pure tones show the largest sensory pleasantness, while noise has low sensory pleasantness. The influences of roughness and tonality are smaller. Loudness influences sensory pleasantness only for values that are larger than the normal loudness of communication between two people in quiet.

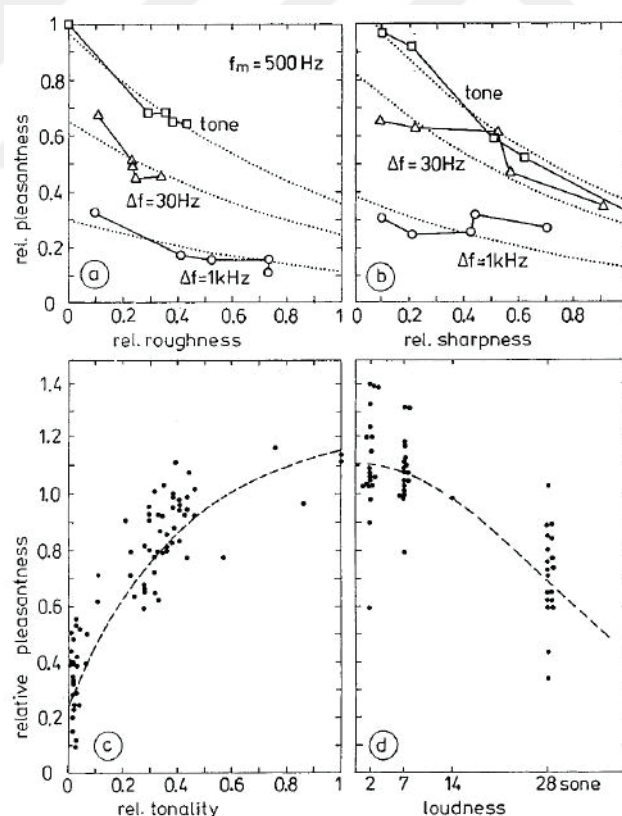


Figure 2.15. Relationship between sensory pleasantness and other sensations (Source: Fastl and Zwicker 2007).

Fastl (2005) states that this model by Terhardt (1984), (1985) has proven successful to rate sensory pleasantness of sounds – in particular, the pleasantness of speech and music. However, in this model, clearly audible tonal components receive a bonus, while, when dealing with noise-emission problems, tonal components are rather undesired and thus usually are assigned a penalty instead. Consequently, this model of sensory pleasantness is not recommended to estimate pleasantness related to noise emissions.

2.2.4.2. Unbiased Annoyance

Unbiased Annoyance was proposed for the first time by Zwicker and Fastl. It means that “noise annoyance does not depend on the relationship of the listener to the sources of the noise” (Park et al. 2012). In the model, the value of UBA is calculated from N_{10} loudness, which is the loudness value reached or exceeded in ten percent of the measurement time, averaged sharpness, and fluctuation strength, together with a day-night correction. This formula defines noise annoyance as a multicomponent concept depending on more than one acoustical variable.

$$UBA = d(N_{10})^{1.3} \left\{ 1 + 0.25(S - 1) \log(N_{10} + 10) + 0.3F \left(\frac{1+N_{10}}{N_{10}+0.3} \right) \right\} \quad (2.10)$$

$$d = 1 \quad \text{from 6 am to 10 pm}$$

$$d = 1 + \left(\frac{N_{10}}{5} \right)^{0.5} \quad \text{from 10 pm to 6 am}$$

2.2.4.3. Psychoacoustic Annoyance

Fastl and Zwicker (2007) corrected the formula for the unbiased annoyance with the work of their colleague Widmann (1995), and they published a formula for Psychoacoustic Annoyance (PA). In the new formula, N_{10} values are changed to N_5 and as a component of psychoacoustic annoyance, roughness is added (Park et al. 2012).

From the formula it becomes clear that loudness is a dominant feature of annoyance. Also, sharpness as well as roughness and fluctuation strength play important roles. To give an example; by a dentist’s drill, not only the loudness but also the sharpness is responsible for the annoyance.

It is stated by Fastl (2005), that Widmann's model of psychoacoustic annoyance can account for various practical situations, but it is certainly not designed to solve all questions of sound quality. He says that the appropriate recipe for a mixture of psychoacoustic quantities may vary for different families of product sounds and different applicational context.

Psychoacoustic annoyance can be described in line with data from psychoacoustic experiments not only for synthetic sounds but also for technical sounds like car noise, air conditioner noise, or noise from tools like circular saws, drills etc.

$$PA = N_5(1 + \sqrt{\omega_s^2 + \omega_{FR}^2}) \quad (2.11)$$

ω_s : Effect of sharpness with N_5 percentile loudness in sone.

$\omega_s = (S - 1.75)0.25\log(N_5 + 10)$ for $S > 1.75$ acum.

ω_{FR} : Influence of fluctuation strength and roughness.

$$\omega_{FR} = \frac{2.18}{(N_5)^{0.4}} (0.4F + 0.6R)$$

2.2.4.4. Sensorial Consonance

Sensorial Consonance is another method which is proposed by Terhardt and Stoll (1981). The formula is given below.

$$W^- = \sqrt{S^2 + 0.25R^2 + 0.1(T^-)^2} \quad (2.12)$$

Loudness is not an input parameter of this model, while it is of major importance in the other models. Sensorial consonance takes into account roughness, sharpness and tonality. It is defined by its opposite, the disagreement W^- . R is the roughness, S the sharpness, T^- the non-tonality, which means the complementary value of the tonality T . Table 2.8 shows sounds with their sharpness, roughness and tonality values with their sensorial consonance values accordingly. Also psychoacoustic parameter values for sounds like a woman's voice, a man's voice, and a coffee grinder, which can be found in an eating establishment sound environment, are given in this table.

Table 2.8. Psychoacoustic and sensorial consonance values of certain sounds (Source: Terhardt and Stoll 1981).

Name	Sharpness [acum]	Roughness [asper]	Tonality	Sensorial consonance
Musical chord	0.056	0.1	1	0.91
Woman's voice	0.124	0	1	0.77
Bell	0.137	0.07	1	0.77
Man's voice	0.101	0.4	1	0.65
Pure tone	0.128	0	1	0.63
Water fountain	0.193	0.22	0	0.44
Airplane	0.104	0.18	0	0.39
Vacuum cleaner	0.183	0.08	0	0.35
Motorcycle	0.164	0.45	0	0.33
A.M. tone	0.126	0.46	1	0.33
Car	0.135	0.56	0	0.32
Typewriter	0.285	0.22	0	0.3
White noise	0.253	0	0	0.29
Telephone ring	0.392	0.33	1	0.27
Coffee grinder	0.204	0.11	0	0.26
Impact drill machine	0.22	0.23	0	0.24
Circular saw	0.314	0.04	0	0.14

CHAPTER 3

LITERATURE REVIEW

In this section, remarkable studies which are relevant to this research will be presented. The main sub-sections are soundscape studies about open and enclosed spaces, acoustic and psychoacoustic properties of eating establishments, methods used by hearing studies and questionnaire examples from the literature. Previous studies about similar topics provided us comparable psychoacoustic data and introduced us beneficial research methods that can be used in terms of building up a method for this thesis research.

3.1. Soundscape Studies

The term ‘Soundscape’ was first used by Schafer (1969). He defines soundscape in his book *The Soundscape: Our Sonic Environment and the Tuning of the World* as ‘any acoustic field of study’ (Schafer 1994). He categorizes the main themes of a soundscape by mentioning the difference between keynote sounds, signals and soundmarks. According to his definitions, keynote sounds help to outline the character of people which live in them. These sounds do not have to be listened intentionally but they cannot be overlooked. In contrast, signals are listened to consciously and that’s why they are foreground sounds. Soundmarks are like landmarks. They are unique community sounds.

In soundscape research, identified sounds are aimed to be categorized in order to establish a common terminology. The definition of soundscape is “acoustic environment as perceived or experienced and/or understood by a person or people, in context”, as stated in ISO 12913-1 (ISO 2014). The general aim is to find out what sound characters are described to be undesired and to eliminate them in sound environments. Also recording and documenting important unique soundscapes is another main goal of these studies. Soundscape studies in architecture and landscape topics mainly focus on acoustic comfort of users and inhabitants. The definitions of desired and undesired

sounds gain importance while determining acoustic comfort as comfort is dependent on these variables. Soundscape is mainly studied under two main topics in terms of space and sound, which are indoor and outdoor soundscape.

3.1.1. Urban Sound Environments

Previous research has shown that only reducing the sound pressure level in urban areas does not necessarily improve acoustic comfort (De Ruiter 2000), (De Ruiter 2004), (Schulte-Fortkamp 2001). Acoustic environments of spaces have a great influence on the overall comfort (Raimbault, Bérangier, and Dubois 2003), (Kang 2004). Thus, a method to improve soundscapes needs to be established.

Kang's book 'Urban sound environment' introduces methods and analyses about outdoor soundscapes in a detailed way (2007). Soundscape evaluation is explained considering its relationships with sound, user, space and other physical conditions. The research is mostly carried out over case studies in urban open public spaces with questionnaires and measurements. By the questionnaires, participants were asked to evaluate the acoustic environment of the site over a five point scale, from very quiet to very noisy. They were also asked to classify at least three sounds selected from 15 typical sound sources in that environment as favorite, neither favorite nor annoying or annoying. A ranking is aimed to be established in order to find out desired and undesired sounds. In order to collect objective data, equivalent continuous sound pressure level LA_{eq} , sound pressure level and reverberation times are measured. Sounds were recorded and psychoacoustic indices like loudness, sharpness and roughness were analyzed using software.

Acoustic comfort is evaluated by analyzing identified sounds (being grouped as 'first, second and third noticed sounds'), effects of individual sounds and other factors, sound level and subjective comfort evaluations through surveys. Soundscapes are studied through semantic processing in order to identify the emotional meaning of words. Semantic differential technique originally developed by Osgood et. al (1957) as is used in recent research (Kang and Zhang 2010), (Hall et al. 2013). Adjectives for semantic differential analysis which have been used in different studies are listed in Table 3.1 and Table 3.2.

Table 3.1. Soundscape evaluation form used in a soundscape walk (Source: Kang 2007).

	Very	Fairly	Little	Neutral	Little	Fairly	Very	
Agitating	3	2	1	0	-1	-2	-3	Calming
Comfortable	3	2	1	0	-1	-2	-3	Uncomfortable
Directional	3	2	1	0	-1	-2	-3	Everywhere
Echoed	3	2	1	0	-1	-2	-3	Deadly
Far	3	2	1	0	-1	-2	-3	Close
Fast	3	2	1	0	-1	-2	-3	Slow
Gentle	3	2	1	0	-1	-2	-3	Harsh
Hard	3	2	1	0	-1	-2	-3	Soft
Interesting	3	2	1	0	-1	-2	-3	Boring
Like	3	2	1	0	-1	-2	-3	Dislike
Meaningful	3	2	1	0	-1	-2	-3	Meaningless
Natural	3	2	1	0	-1	-2	-3	Artificial
Pleasant	3	2	1	0	-1	-2	-3	Unpleasant
Quiet	3	2	1	0	-1	-2	-3	Noisy
Rough	3	2	1	0	-1	-2	-3	Smooth
Sharp	3	2	1	0	-1	-2	-3	Flat
Social	3	2	1	0	-1	-2	-3	Unsocial
Varied	3	2	1	0	-1	-2	-3	Simple
Beautiful	3	2	1	0	-1	-2	-3	Ugly
Bright	3	2	1	0	-1	-2	-3	Dark
Friendly	3	2	1	0	-1	-2	-3	Unfriendly
Happy	3	2	1	0	-1	-2	-3	Sad
High	3	2	1	0	-1	-2	-3	Low
Impure	3	2	1	0	-1	-2	-3	Pure
Light	3	2	1	0	-1	-2	-3	Heavy
Safe	3	2	1	0	-1	-2	-3	Unsafe
Steady	3	2	1	0	-1	-2	-3	Unsteady
Strong	3	2	1	0	-1	-2	-3	Weak

Table 3.2. Adjective scales for semantic differential used in an international study on warning signals (Source: Kuwano et al. 2000; as cited in Fastl 2005).

adjective scales	
loud	soft
deep	shrill
frightening	not frightening
pleasant	unpleasant
dangerous	safe
hard	soft
calm	exciting
bright	dark
weak	powerful
busy	tranquil
conspicuous	inconspicuous
slow	fast
distinct	vague
weak	strong
tense	relaxed
pleasing	unpleasing

Soundscapes of open public spaces like parks and streets have been studied considering user preferences and sound properties of these spaces (Yang and Kang 2005), (Raimbault and Dubois 2005), (Botteldooren, De Coensel, and De Muer 2006), (Szeremeta and Zannin 2009), (Yu and Kang 2010), (Torija et al. 2010), (Hall et al.

2013), (Jennings and Cain 2013), (Marry and Defrance 2013). Categorization of sounds and standardization of terminology is an important topic in this field of study (Brown, Kang, and Gjestland 2011), (Rychtáriková and Vermeir 2013). Table 3.3 shows a categorization of sounds under natural sounds, human sounds and sounds of tools and technology (Schafer 1969). This table shows that our sonic environment has changed in terms of its contents.

Table 3.3. Change in percentages of sound categories in our sonic environment (Source: Schafer 1969).

	Natural sounds	Human sounds	The sounds of tools and technology
Primitive cultures	69%	26%	5%
Medieval, Renaissance and Pre-industrial cultures	34%	52%	14%
Post-industrial cultures	9%	25%	66%
Today	6%	26%	68%

Recognized soundscape categories and related sounds in city parks are analyzed in order to find their out acoustic qualities (Table 3.4).

Table 3.4. Soundscape categories and related sounds in city parks (Source: Liu et al. 2014).

Soundscape category	Sound
Human sound	Surrounding speech, Children shouting, Footsteps, Exercising
Traffic sound	Traffic sound
Mechanical sound	Bicycle riding, Entertainment facilities, Airplanes, Lawn mowing, Road cleaning, Music, Indistinguishable sound
Biological sound	Birds, Dogs, Insects
Geophysical sound	Water sound, Leaves rustling, Wind

A more generalized classification is shown in Figure 3.1, where especially sounds in urban acoustic environments are sorted (ISO 2018). The main title of acoustic environment is divided into two sub-headings, which are indoor and outdoor acoustic environments. A taxonomy of the acoustic environment for soundscape studies is given below.

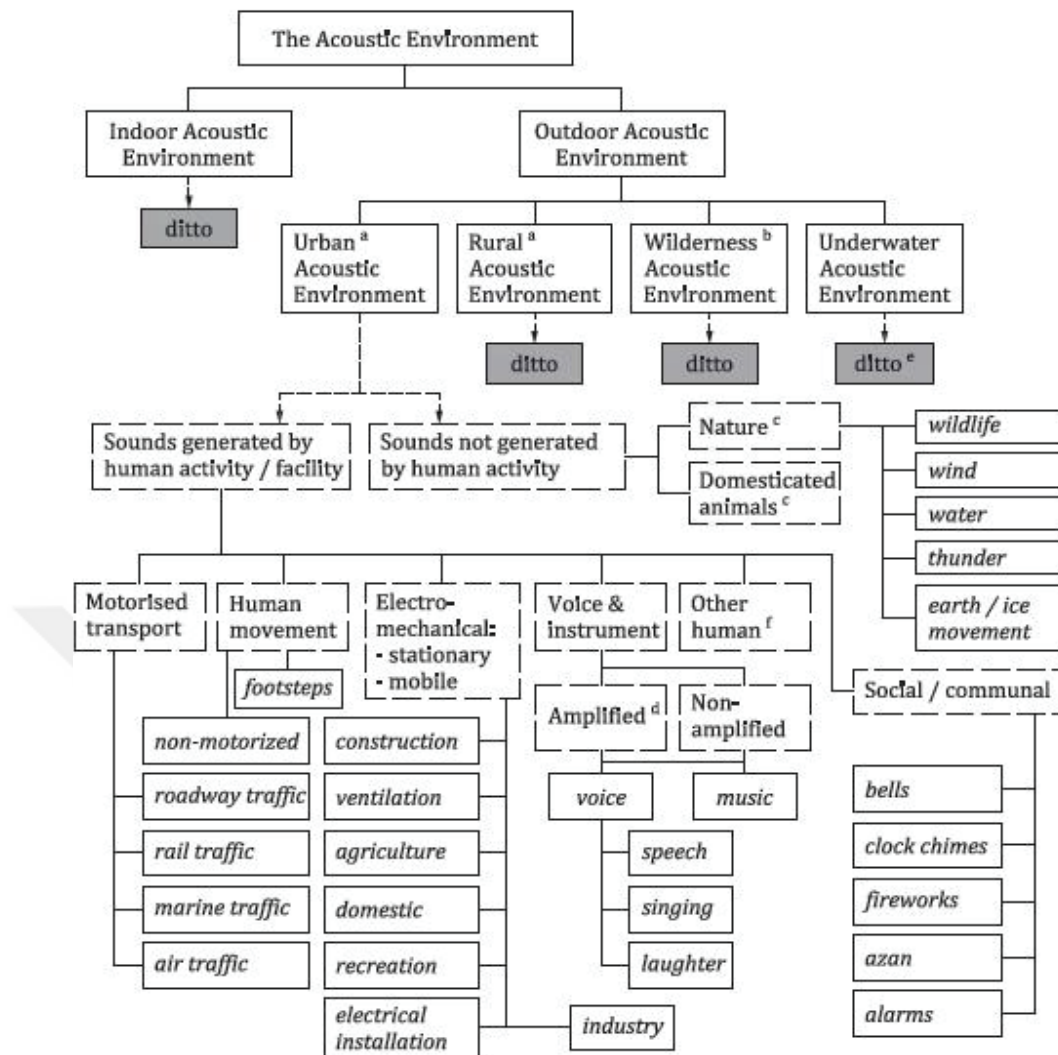


Figure 3.1. A taxonomy of the acoustic environment for soundscape studies (Source: Brown, Kang, and Gjestland 2011; as stated in ISO 12913-2 2018).

3.1.2. Sound Environments of Enclosed Spaces

Enclosed spaces have different functional and acoustic characteristics compared to outdoor areas. Surrounded by walls, floors, and ceilings, in these spaces indoor acoustic parameters, especially reverberation time needs to be considered. Also due to the change in function, users' requirements and expectations become different when compared to outdoor soundscapes. Indoor acoustic comfort issues have been researched utilizing parameters like equivalent sound pressure level, roughness, sharpness, loudness and results of socio-acoustic surveys (Özçevik and Yüksel Can 2008), (Dökmeci 2009), (Dökmeci and Kang 2010), (Dökmeci and Kang 2011), (Dökmeci and

Kang 2012), (Kang, Meng, and Jin 2012). In these studies, cases like libraries and atriums of shopping malls have been analyzed. More recently, underground spaces like underground shopping streets and railway stations (especially long rooms and spaces) have been analyzed (Meng, Kang, and Jin 2012), (Meng, Kang, and Jin 2013).

In Dökmeci and Kang's study, enclosed public areas specialized for eating, shopping, talking, studying, leisure and walking have been analyzed by comparing spaces in the University of Sheffield student union building and Sheffield winter gardens (2011). Food-courts, café areas, university union and museum shops, computer study spaces, green zones and central foyers are among the studied range of spaces. Same function areas in these two buildings have been compared in terms of psychoacoustic parameters. It is stated that "function and architectural characteristics of spaces have a great impact on the overall sound environment and the noise compositions" (Dökmeci and Kang 2011).

The book, *Soundscape of European Cities and Landscapes*, edited by Kang et al. is a collection of soundscape themed papers. It is divided into the following five sections, with corresponding working groups: Understanding and Exchanging, Collecting and Documenting, Harmonising, Creating and Designing, Outreach and Training (Kang et al. 2013). These headings expose the important issues in soundscape research today. Studies falling under Understanding and Exchanging heading focus on understanding problems through international and interdisciplinary cross-breeding, modelling and exchanging technical know-how. Collecting and Documenting working group is focused on creating common databases for soundscape data and case studies. Harmonising section gives information about studies which are done in order to have a common vocabulary, methodology and indicators. Creating and Designing part deals with developing guidelines considering sonic environment and heritages, and laying foundation for standards. Outreach and Training working group is for raising awareness, dissemination and training of early-stage researchers, and papers explaining the activities which were done to reach this aim are presented on this section.

3.1.2.1. Acoustics of Eating Establishments

The often problematic acoustic environments in restaurants, cafes and dining halls are examined by many researchers who tried to define acceptable and preferred

ranges for various performance criteria. Soyer and Houdet (1986) investigated 18 school dining halls. 12 were acoustically treated and 6 were non-treated. Their results show that acoustically treated halls have an L_{Aeq} value between 77-82 dBA and the non-treated ones between 81-85 dBA. It is also mentioned that acoustically treated dining halls have an average reverberation time of 0.8 seconds and that this value is acceptable for this function. Astolfi and Filippi (2004) investigated four pizzeria-restaurants with reverberation times between 0.4 and 0.8 seconds in terms of speech communication by measurements and questionnaires. They used SII as an index for evaluating speech intelligibility and speech privacy. In their questionnaires, they asked questions to evaluate noise annoyance, room pleasantness, acoustic comfort, speech intelligibility at the table and speech privacy for each room.

Kang's paper (2006) aims to analyze case study results of 8 non-acoustic public building types through measurements and questionnaires, in terms of creating comfortable acoustic environments. In his research, it is stated that the sound pressure level in the studied restaurant was measured to be 61 dB without background music and 80 dB with background music. While defining specific sounds in restaurant soundscapes, sound pressure level of each component is measured and given (refrigerator: 63-68 dBA, cutlery: 68-75 dBA, talking from counter: 63-75 dBA, arranging chairs: 75-82 dBA, talking and walking of the staff members: 70-88 dBA). Reverberation time is measured as 0.4 seconds and evaluated as a low value for a restaurant (Kang 2006). In the study of Hodgson et al. (2009), 10 eating establishments with volumes between 176 - 1176 m³ and reverberation times between 0.5 – 1.5 seconds have been evaluated through measurements and questionnaires in terms of acoustics. The employee and customer questionnaires have been evaluated in terms of L_{Aeq} , dimensions of the space, number of chairs and reverberation time values. In Battaglia's study (2015), 11 restaurants with reverberation times between 0.4 – 1.5 seconds have been evaluated. No relationship has been found between the background noise (70-84 dBC) and acoustic comfort evaluations, which was stated to be surprising considering the number of studies that assume increased sound level in restaurants causes discomfort. A narrow range between 0.5 – 0.7 seconds of reverberation time has been found to provide acoustic comfort for customers. Svensson et al. (2014) aimed to find a model for acoustic comfort in eating establishments in their research. They analyzed 5 spaces with a volume larger than 1700 m³. As results, acoustic comfort is found to be

negatively correlated with number of chairs. The reverberation times in four spaces are between 1.05 and 1.08 seconds and in the last space it is 0.6 seconds. In the study of Zelem et al. (2015), a student dining hall with a volume of 1775 m³ is analyzed in terms of number of persons, overall sound level, dimensions of the space, sound absorption, reverberation time and acoustic comfort. It is mentioned that a reverberation time over 2 seconds can make users uncomfortable. Watson and Downey (2008) state that a common quiet restaurant has an overall sound level of 67 dBA and a busy restaurant 80 dBA.

Research papers in this section aimed to establish a connection between measurable parameters like reverberation time, sound pressure level, space dimensions, number of chairs, speech intelligibility index, and subjective evaluations obtained through questionnaires, such as acoustic comfort, noise annoyance and communication. Besides these measurable acoustic values, psychoacoustic parameters are promising tools for further examination of these subjective evaluations and studies covering these parameters will be presented in the following section.

3.1.2.2. Psychoacoustic parameters

Over the last two decades, use of psychoacoustic parameters for characterizing soundscapes has been increasing. Loudness has long been used in defining criteria. Air Moving and Conditioning Association's AMCA (1973) published a table where the minimum and maximum loudness design criteria values for certain types of spaces are given in sone scale. In that table, recommendations for eating establishments like restaurants (4-12 sones), cafeterias (6-8 sones), cocktail lounges (5-15 sones), social clubs (3-9 sones), night clubs (4-12 sones) and banquet rooms (8-24 sones) can be found.

Yet, the use of other parameters such as sharpness and roughness does not have a long history in indoor soundscape studies. An extensive study by Lindborg (2015) introduces psychoacoustic, physical and perceptual evaluation of 112 restaurants. Average loudness of all spaces is 20.8 sones, mean sharpness is 1.27 acum and mean roughness is 0.05 asper. It is stated that the roughness values get higher and the sound levels differ in a wider range, as restaurants get louder. Restaurants with higher sound levels are more crowded, include less natural sounds compared to man-made sounds

and these spaces are evaluated to have uncomfortable soundscapes. It is also stated that expensive restaurants tend to have more silent and visually more preferred built environments. Restaurants with pleasant acoustic environments include fewer types of sound sources perceived by users. In Ortiz and Schulte-Fortkamp's study in open spaces (2013), psychoacoustic analyses of binaural recordings in two public parks are presented. Schlosspark has loudness values of 4 and 4.6 sone for the left and right ears, where Treptower Park has 5.2 and 6 sone. Roughness values are 0.2 and 0.4 asper and sharpness 1.8 and 1.9 acum in Schlosspark, where roughness is 0.8 and 1.1 asper and sharpness is 1.6 and 1.7 acum in Treptower Park. These values were obtained through soundwalks. Dökmeci et. al (2013) used the soundwalk method to measure urban soundscapes in a city center, on a route with eight measurement points. At these points, SPL values varied between 37.7 and 76.3 dBA, loudness values between 5.6 and 27.5 sones, sharpness values between 1.25 and 2.8 acum, fluctuation strength values between 0.00485 and 0.01720 vacil and roughness values between 0.019 and 0.0573 asper.

In a study which aims to record and analyze soundscapes, binaural recordings and measurements of overall sound levels are simultaneously obtained. The soundwalks lasted 15 minutes. These recordings were divided into 5 minutes long parts, edited and evaluated in terms of psychoacoustic parameters (Özçevik and Yüksel Can 2012). In another study about evaluating indoor soundscapes of libraries, measurements were taken in the 3 foyers. Each measurement sample was 15 minutes long. Physical factors (sound event variation, duration, time, intensity level, fluctuation, spectral distribution), sound pressure level (A-weighted, un-weighted), and psychoacoustic parameters (loudness, roughness, sharpness) were considered and their relation with subjective evaluation of the sound environment was assessed (Dökmeci and Kang 2013). In the study of Svensson et. al (2014), the aim was to compare the sound level, number of persons and acoustic comfort. LA_{eq} was calculated in 5-minute intervals every 15 minutes of the two-hour measurements and averaged over the four positions for each of the seven measurements. During the measurements, the number of people present in the eating establishments was counted every 15th minute in order to be able to compare the occupancy with the sound level.

Studies above provide information about measured psychoacoustic values of various soundscapes. Different methods and measuring durations are introduced in this section. In terms of psychoacoustics, it can be understood from the studies above, that

roughness rises when eating establishments get louder. It can be seen, that the psychoacoustic parameters loudness and sharpness are defined by standards and can easily be compared between different studies. However, some roughness and fluctuation strength values obtained from different studies vary in a wide spectrum, which may be caused by different calculation methods, as there is no standardization for these parameters yet.

3.2. Methods Used By Hearing Studies

In this part, data collection methods in hearing study topics with subjective evaluations will be introduced. While explaining the methods, essential data like the number of participants for studies including questionnaires, or the equipment information which had been used, were given.

3.2.1. Methods Used For Forming Equal Loudness Curves

Fletcher and Munson's equal-loudness contours were first measured using headphones (1933). In their study, participants listened to pure tones at various frequencies and over 10 dB increments in stimulus intensity. The listener was also presented with a reference tone at 1000 Hz, for each frequency and intensity. The reference tone was adjusted until it was perceived to be of the same loudness as the test tone. Fletcher and Munson averaged their results over many test subjects to derive reasonable results. Following that, an experimental study was made by Robinson and Dadson (1956), which was believed to be more accurate, and this became the basis for a standard ISO 226 (ISO 2003).

The International Organization for Standardization decided to revise its standard curves as defined in ISO 226, referring to the results of several studies. This has resulted in the recent acceptance of new curves standardized as ISO 226. The committee responsible for this revision has commented on the fact that the original Fletcher-Munson contours are in better agreement with recent results than the Robinson-Dadson, which appear to differ by as much as 10 to 15 dB especially in the low-frequency region.

Figure 3.2 shows laboratory conditions and techniques used by the experiments (Fletcher and Munson 1933).

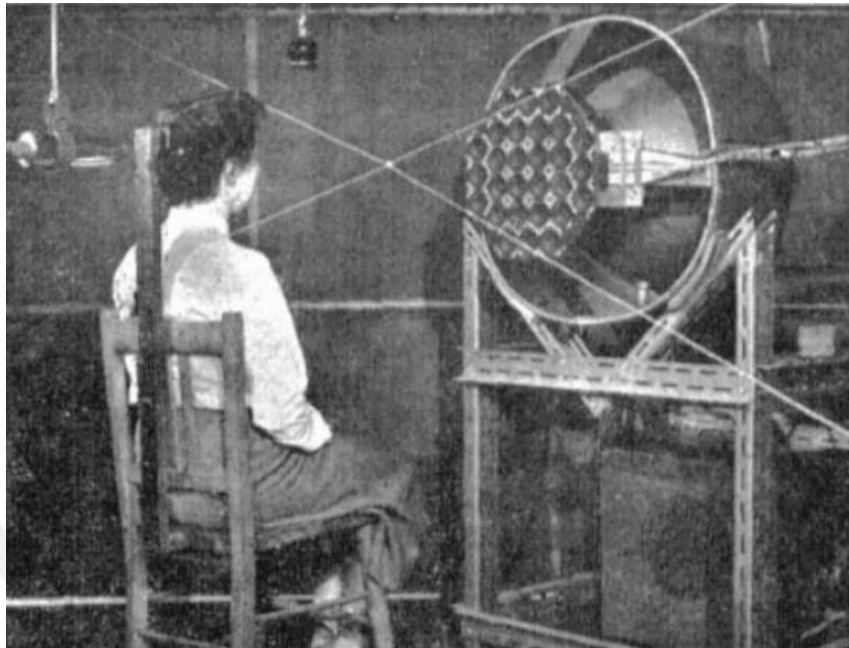


Figure 3.2. Laboratory conditions (Source: Fletcher and Munson 1933).

3.2.2. Psychoacoustic Annoyance Method

Psychoacoustic annoyance method of Widmann (1998) is a method to evaluate sounds with longer durations. The main task of the subject along the experiment is to scale the instantaneous perceived loudness on the length of a bar at the computer screen. At the end of the session the subject has to answer a questionnaire about the sounds and to scale the overall loudness for the whole session by different methods, for example magnitude estimation and line length.

Suzuki and Takeshima's work (2004) is about studies on the equal-loudness-level contours and their experimental conditions. They collected all studies about this topic and compared them considering their different measurement conditions and survey settings. In Table 3.5, we can see the frequency ranges of the test tone, the reference tones, the number and age of the subjects, listening conditions and the methods.

Table 3.5. Summary of all studies about equal loudness curves (Source: Suzuki and Takeshima 2004).

Year	Researchers	Listening condition	No. of subjects (age)	Method	Reference tone frequency (level)	Test tone frequency (Hz)
1927	Kingsbury	Earphone	22 (unspecified)	MA	700 Hz (fix)	60–4000
1933	Fletcher–Munson	Earphone with FF correction	11 (unspecified)	CS	1 kHz (variable)	62–16 000
1937	Churcher–King	FF	10 (unspecified)	CS	1 kHz (fix)	54–9000
1955	Zwicker–Feldtkeller	Earphone with FF equalizer	8 (unspecified)	Modified Békésy	1 kHz (fix)	50–16 000
1956	Robinson–Dadson	FF	90 (16–63)/ 30 (ave. 30)	CS	1 kHz (variable)	25–15 000
1972	Whittle <i>et al.</i>	PF	20 (ave. 20)	CS	higher freq. (fix)	3.15–50
1983	Kirk	PF	14 (18–25)	RMLSP	63 Hz (fix)	2–63
1984	Møller–Andresen	PF	20 (18–25)	RMLSP	63 Hz (fix)	2–63
1989	Betke–Mellert	FF	13–49 (17–25)	CS	1 kHz (fix)	50–12 500
1989	Suzuki <i>et al.</i>	FF	9–32 (19–25)	CS	1 kHz (fix)	31.5–16 000
1990	Fastl <i>et al.</i>	FF	12 (21–25)	CS	1 kHz (fix)	100–1000
1990	Watanabe–Møller	FF	10–12 (18–30)	Bracketing	1 kHz (fix)	25–1000
1994	Müller–Fichtl	Open headphones	8 (21–25)	CP	—	62.5–10 000
1994	Poulsen–Thøgersen	FF	29 (18–25)	Bracketing	1 kHz (fix)	1000–16 000
1997	Lydolf–Møller	FF	27 (19–25)	RMLSP	1 kHz (fix)	50–1000
		PF	27 (19–25)	RMLSP	100 Hz (fix)	20–100
1997	Takeshima <i>et al.</i>	FF	9–30 (19–25)	CS	1 kHz (fix)	31.5–12 500
1999	Bellmann <i>et al.</i>	FF	12 (unspecified)	Adaptive 1up–1down	1 kHz (fix)	100–1000
		PF	12 (unspecified)	Adaptive 1up–1down	100 Hz (fix)	16–160
2001	Takeshima <i>et al.</i>	FF	7–32 (18–25)	RMLSP	1 kHz (fix)	50–16 000
2002	Takeshima <i>et al.</i>	FF	21 (20–25)	RMLSP	1 kHz (fix)	1000–12 500

3.2.3. Continuous Assessment Method of the Unpleasantness of a Sound

This method example is from Geissner and Parizet's work (2005). In their research, three typical sounds were synthesized. Two of these were amplitude modulated pure tones, with a rough character: the first one a 1 kHz tone modulated at 70 Hz and the second one a 4 kHz tone modulated at 50 Hz. In both cases, the modulation factor was 1. The third sound was an 8 kHz pure tone, which means that it is a very sharp sound. Each of these sounds was mixed with a low frequency random noise (white noise band-pass filtered between 20 and 200 Hz), of the same loudness level as the signal itself.

The loudness was evaluated according to ISO 532 standard using the MTS Sound Quality software from the recordings realized with a dummy head (Bruel & Kjaer type 4100), the headphones used for sound presentation (Sennheiser HD600) being placed on it. A total of 37 people, 30 men and 7 women, aged from 18 to 57 (average: 26) participated in the experiment. The participants who took part on listening tests did not report any hearing problem.

Paired comparison test is the first method. Before building the series, the order of sounds was randomly rearranged, in order to eliminate any order effect in the pair series. After listening to each pair, the subject had to answer the question ‘Which is the most unpleasant sound?’ using an analog categorical scale with five labels (‘A is much more unpleasant than B’, ‘A is more unpleasant than B’, ‘A and B are equally unpleasant’).

Continuous assessment is the second method. The listener held a box with a cursor sliding along a scale divided into five categories, ‘Not at all unpleasant’, ‘Slightly unpleasant’, ‘Moderately unpleasant’, ‘Very unpleasant’, ‘Extremely unpleasant’. The cursor controlled a potentiometer which made it possible to modify the amplitude of a 1 kHz sinusoidal signal produced by an external generator. The listener’s task was to adjust the position of the cursor so that his/her sensation could be represented by the semantic scale. The signal thus controlled was sampled and recorded by the audio sound card of a PC (at the sampling rate of 8 kHz). At the same time, the audio sequence was played over the headphones in the listening room. At the end of the assessment, the envelope of the signal amplitude was calculated.

Some predictive models were used, as sensory pleasantness, unbiased annoyance (UBA) or psychoacoustic annoyance (PA), but only sensorial consonance model proposed by Terhardt and Stoll could predict the subjective evaluation. This was expected by the researchers, as loudness is not an input parameter of that model, while it is of major importance in the other models.

3.2.4. Psycho-physical Evaluation Methods

Fastl’s work presents four important psycho-physical methods for sound quality evaluation in psychoacoustics, which are random access ranking, semantic differential, category scaling and magnitude estimation (2005).

By **random access ranking**, which is graphically explained by the scheme given as Figure 3.3 below, subjects are asked to rank sounds from best to worst, where they can click on sound icons and listen to these sounds several times until they give their last choice.

best Sound Quality			worst Sound Quality		
1	2	3	4	5	6
 A	 B	 C	 D	 E	 F

Figure 3.3. Random access sound quality ranking scheme (Source: Fastl 2005).

Semantic differential methods are used in order to categorize the sounds in soundscapes. Subjects are asked to rank the scale of adjectives for certain sounds.

By **category scaling** (Figure 3.4), the loudness of sounds is assessed by subjects in different scales.

	too loud	
50	very loud	very loud
	loud	loud
		slightly loud
25	neither soft nor loud	neither soft nor loud
		slightly soft
	soft	soft
0	very soft	very soft
	inaudible	

Figure 3.4. Category scaling schemes (Source: Fastl 2005).

By **magnitude estimation** method (Figure 3.5), pairs of sounds are presented to subjects and they are asked to estimate the loudness of the test sound compared to the anchor sound.



Figure 3.5. Illustration of sounds for magnitude estimation (Source: Fastl 2005).

3.3. Questionnaire Examples From Previous Studies

Svensson et al. (2014) conducted questionnaires in eating establishments about acoustic comfort during lunch. The questions were about general acoustic comfort, speech intelligibility, privacy, noise annoyance from other talkers and background noise and annoyance from the reverberation. In order to evaluate these parameters in questions, participants had to rate the following statements with positive (1) or negative (0) answers:

- Q1- This eating establishment is acoustically comfortable.
- Q2- I can hear (and understand) the people at my table.
- Q3- I feel that my conversation is overheard by people at other tables.
- Q4- I am annoyed by noise from people speaking at other tables.
- Q5- I am annoyed by general background noise in the eating establishment.
- Q6- The reverberation in this eating establishment is annoying.

In another study, Battaglia (2015) had four questions in his questionnaire for restaurants considering acoustics, where participants had to give answers in a scale from 1 to 4. By answering these questions, participants have rated the main topics Quietude, Communication, Privacy, and Comfort.

- Q1- How noisy does this restaurant sound to you?
- Q2- How difficult is it to converse with other diners at your table?
- Q3- How disturbing are sounds of conversations from other tables?
- Q4- What is your comfort level with the way this restaurant sounds?

Hodgson et al. (2009) had a longer questionnaire compared to other studies. Their questions related to acoustics were designed to find answers to the following: Which sounds cause discomfort, what kind of effects has noise on customers, to which distance are conversations audible, etc. The questionnaire paper is given below as Figure 3.6.

Customer questionnaire

- 1a. What were your reason(s) for visiting this eating establishment today: *eating/drinking; talking; business meeting; studying/working; celebration; relaxing.*
- 1b. With respect to those reasons you have checked, indicate how well the sound environment in this eating establishment met your expectations for an ideal environment? [very well; well; average; poorly; very poorly]
2. How frequently do you come to this eating establishment? [for the first time; less than once a month; more than once a month; almost every day]
- 3a. Do you prefer any specific seating location in this eating establishment? [yes; no]
- 3b. If yes, is this because of noise concerns in this eating establishment? [yes; no]
- 4a. How many people (including you) were having this meal together? Please specify the number of people in each of the following groups: children; adults; seniors.
- 4b. How many customers were in the restaurant during your visit?
5. Please indicate how much each of the following sources of noise in this eating establishment bothers you during this visit: *people speaking; people moving; adjacent-table conversation; cell phones; heating/ventilation/air-conditioning (HVAC); kitchen activities; kitchen equipment; clinking sounds; outside noise; music; reverberation* [not at all; a little; some; a lot; very much].
6. Please indicate to what extent noise in this eating establishment contributes to your experiencing the following problems during this visit: *reduced enjoyment; difficulty hearing at the table; difficulty talking with waiter; broken concentration; tired voice; headache; fatigue* [not at all; a little; some; a lot; very much].
- 7a. Please indicate to what extent you can easily hear conversations from: adjacent tables; cashier counter; kitchen [not at all; a little; some; a lot; very much]
- 7b. Please indicate to what extent you feel others can overhear conversations at your table [not at all; a little; some; a lot; very much]
- 8a. Sex [female; male]
- 8b. Age
- 9a. Is English your first language? [yes; no]
- 9b. Is English the main language spoken in this eating establishment? [yes; no]
- 10a. During this visit, would you prefer to have your meal in a noisy or quiet setting? [noisy; quiet; doesn't matter]
- 10b. During this visit, would you prefer to have music with your meal? [yes; no; doesn't matter]
- 10c. If yes, what level of music would you prefer? [very high; high; moderate; low; very low]
- 11a. Are you aware of having a hearing impairment? [yes; no]
- 11b. If yes, how severe? [mild; moderate; moderately severe; severe; profound]

Figure 3.6. A questionnaire example (Source: Hodgson, Razavi, and Steininger 2009).

CHAPTER 4

METHODOLOGY

This chapter describes how the use of psychoacoustic parameters in eating establishments has been investigated. The methods employed are presented, equipment and software are introduced, selected eating establishments described and their reverberation times are reported. The details of on-site sound recordings and questionnaires are given. The properties of simulation models for auralizations on listening tests and the prepared sound files are presented.

4.1. Overview

This research was carried out in order to examine the relationship between psychoacoustic parameters and subjective evaluations about acoustic comfort in enclosed spaces, particularly in eating establishments. Study was formed of four phases. *Preparation* phase included literature review, selection of eating establishments, and measurements of selected eating establishments. *On-site data collection*, which is the second phase, is divided into three parts: On-site measurements, on-site questionnaires and on-site sound recordings. In this phase, all the necessary objective and subjective data was collected in selected eating establishments. As the third phase, *listening tests* were conducted. Listening tests with headphones were done in this part. During these tests, on-site sound recordings and simulation auralizations were used. Auralizations were done with computer models, which were calibrated according to measured reverberation time values of eating establishments. Except these auralizations which represent spaces in real life, also auralizations to examine the effect of one particular psychoacoustic variable, e.g. sharpness or roughness, were created. *Evaluation* was the last phase of this study. Objective data from measurements and subjective data from questionnaires and listening tests were evaluated comparatively. The flow chart of the applied model is given below as Figure 4.1.

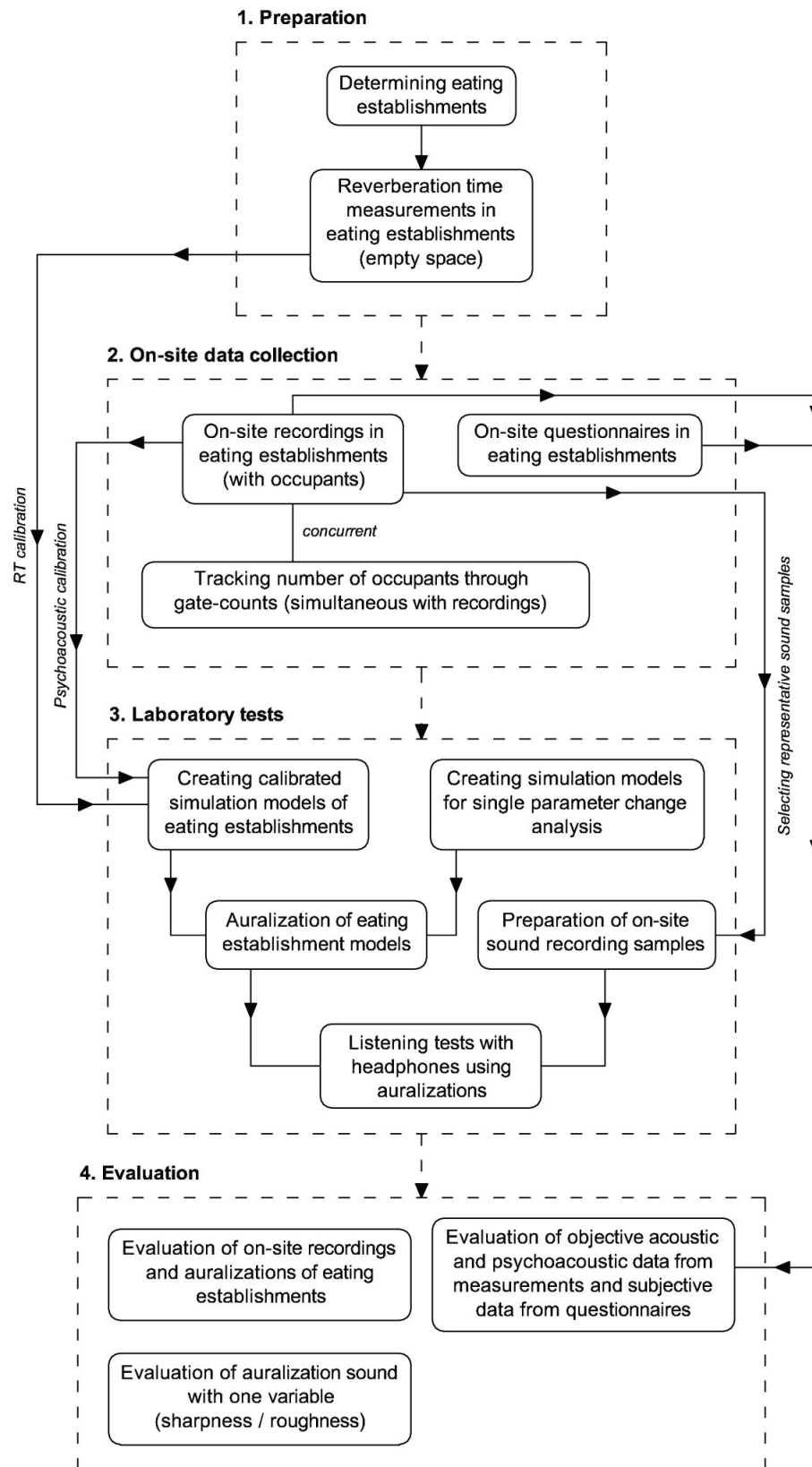


Figure 4.1. Flow chart of applied research model.

In order to study the effect of psychoacoustics on acoustic comfort evaluations of enclosed spaces, it was decided to examine the relationship between the number of occupants and measured psychoacoustic values. Thus, eating establishments were chosen to be worked on, because they are common non-acoustic spaces where the number of occupants inside can really increase, so that a wide range of occupant number can be observed, compared to other types of spaces where it is not possible to track a large number of users inside.

Four eating establishments in IYTE were selected regarding following decisions. All of them were serving without background music. This character was eliminating the risk of getting affected by desired or undesired types of background music for questionnaire participants during acoustic comfort evaluations. Another reason to choose these spaces was their different volumes and reverberation times varying in a wide range, which allowed us to make comparisons between them and their related acoustic / psychoacoustic values.

The main goal is the comparison between eating establishments in the university. However, acoustics in all four spaces is problematic drawing criticism from the campus community. Therefore, a restaurant that performs well acoustically was also included in the study to serve as a reference point in comparisons. In order to compare the soundscape and acoustic comfort in university eating establishments and an acoustically preferred restaurant, field recordings and questionnaires in a hotel's restaurant were conducted. The soundscape of this restaurant was expected to be evaluated as being more comfortable.

4.1.1. Equipment and Software

Reverberation time measurements in selected eating establishments were done with an omni-directional source (Brüel & Kjaer – Omni Power 4292), a microphone, a power amplifier (Brüel & Kjaer – 2716) and a sound level meter (Brüel & Kjaer – 2260 Investigator) as shown in Figure 4.2. The microphone is calibrated with a calibrator and necessary corrections are done. Reverberation time measurements were done in eating establishments without occupants.



Figure 4.2. Omni directional loudspeaker and sound level meter.

For sound recordings; a laptop, a G.R.A.S. 40AE 1/2" microphone, a G.R.A.S. 26CA 1/2" preamp and 01dB dB4 four channel sound recorder (Figure 4.3) were used.



Figure 4.3. Microphone, preamp and sound card.

The recordings were saved in a portable computer through dBFA recorder software and evaluated using dBsonic v.4.6.4.155 software's psychoacoustic module. Auralizations for listening tests were created in ODEON software (vers. 14.05 combined). For the listening tests, Audio-Technica ATH-M50 headphones (Figure 4.4) were used.



Figure 4.4. Headphones used during listening tests.

4.2. Preparation Phase

In the first phase of this study, literature survey indicated that eating establishments provide a favorable setting to conduct the required measurements for investigating the use of psychoacoustic parameters in characterizing acoustic performance in enclosed spaces. The four large eating establishments in İzmir Institute of Technology (IYTE) were selected to conduct the study in.

Since these four eating spaces on campus are acoustically problematic, to serve as a counter reference point, an eating establishment that is known to have good acoustics was also included in the study. It should be noted that the restaurant holds a totally different character. The materials used on surfaces as well as the occupants' activities and communication patterns are vastly different than what is observed in the university spaces. Therefore, the restaurant measurements should not be directly compared to the university spaces.

Also in this first phase, the selected spaces were surveyed and their reverberation times were measured.

4.2.1. Selected Eating Establishments

Four selected dining spaces in IYTE are Canteen of Faculty of Architecture (CA), Main Dining Hall of IYTE (MD), Teknopark Restaurant (TE) and Yaşam Merkezi Restaurant (YM). Figure 4.5 shows the locations of eating establishments on the campus map.

All of the spaces are considered by the campus community to be problematic in terms of acoustics. The restaurant selected as a preferred acoustic environment is the restaurant of Key Hotel located in downtown İzmir (KEY). The volumes are given in Table 4.1.

Table 4.1. Volumes of analyzed eating establishments.

Name	CA	MD	TE	YM	KEY
Volume	777 m ³	1724 m ³	650 m ³	1372 m ³	264 m ³



Figure 4.5. Locations of four eating establishments on IYTE campus map.

CA (Canteen of Faculty of Architecture)

CA is the canteen space of Faculty of Architecture, where students and faculty members can dine during the regular breaks and lunchtime. Its volume is 777 m³ and there is no background music or TV in this space. There are usually no noises coming from metal or porcelain dishes, as the general type of the food which is served are sandwiches or rolls. Also tea and coffee are served in paper cups. A photo of the space CA is given as Figure 4.6.



Figure 4.6. Photograph of the eating establishment CA.

MD (Main Dining Hall)

MD is the main dining hall of the university and is only open during lunchtime. There are several spaces in the main dining hall building and this selected space in which the research is conducted, is mainly used by students. Its volume is 1724 m^3 and there is no background music or TV in this space. The fixed menu is served in metal plates and there is no tea service. A photo of the space MD is given as Figure 4.7.



Figure 4.7. Photograph of the eating establishment MD.

TE (Teknopark restaurant)

TE is a restaurant in the techno park area of the university, which is open all day. It is mainly used by the techno park personnel, students, academic and administrative staff. Its volume is 650 m^3 and there is no background music in this space. There is a TV inside, but it was turned off during the study. The lunch is served on porcelain plates and tea in glasses. A photo of the space TE is given as Figure 4.8.

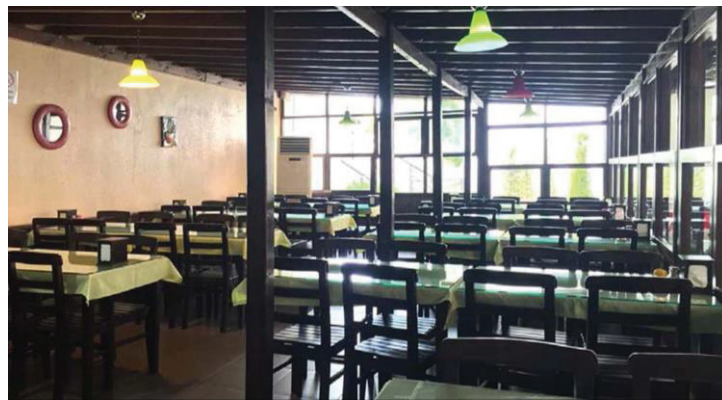


Figure 4.8. Photograph of the eating establishment TE.

YM (Yaşam Merkezi Restaurant)

YM is a restaurant in the social center of the university. It is mainly used by students, academic and administrative staff. Its volume is 1372 m³ and there was no background music or TV sounds during the study in this space. The lunch is served on porcelain plates and tea in glasses. A photo of the space YM is given as Figure 4.9.



Figure 4.9. Photograph of the eating establishment YM.

KEY (Restaurant of Key Hotel)

KEY is a restaurant of a hotel in İzmir. It is mainly used by hotel customers and conference or meeting participants. Its volume is 264 m³ and during measurements, background music was played in the restaurant. The dinner is served on porcelain plates. A photo of the space KEY is given as Figure 4.10.

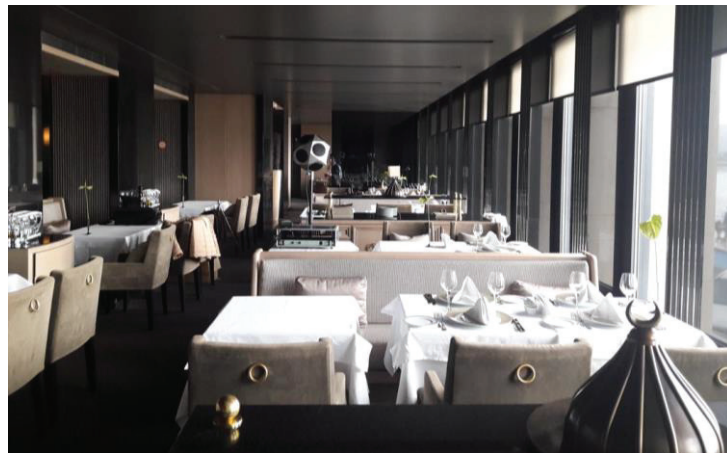


Figure 4.10. Photograph of the hotel eating establishment KEY.

4.2.2. Reverberation Times

Reverberation time measurements in all spaces were measured using the interrupted method as described by ISO 3382-2 (ISO 2008). The measurements in all spaces were carried out during times where no occupants were present. Overall average reverberation time values of four measured dining spaces in IYTE varied between 0.9 and 1.9 s. The hotel restaurant case KEY had a lower reverberation time compared to the other eating establishments; 0.5 seconds. Reverberation times according to octave band frequencies can be seen on Table 4.2. Considering average RT values, YM has the highest RT_{avg} with 1.9 seconds.

Table 4.2. Reverberation times of studied eating establishments.

Name	RT_{avg} [s]	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
CA	1.6	2.3	1.9	1.8	1.4	1.2	1.1
MD	1.6	2.3	1.8	1.4	1.5	1.4	1.2
TE	0.9	1.1	1.1	0.9	0.8	0.7	0.6
YM	1.9	2.7	2.1	1.7	1.8	1.7	1.4
KEY	0.5	0.3	0.3	0.6	0.6	0.6	0.6

4.3. On-site Data Collection Phase

In the second phase of the study, all necessary objective and subjective data was collected in selected eating establishments. The objective data which was obtained on-site in eating establishments through measurements and sound recordings will be presented.

4.3.1. On-site Sound Recordings for Psychoacoustic Analysis

Dining halls were serving without background music during the recordings, except KEY. Each measurement day, recordings were carried out using a Type 1 microphone, 01dB dB4 four channel sound recorder connected to a laptop. The same microphone position was used each day. The microphone was placed at a central

location at least 1 m away from any sound sources, at 1.2 m height - the ear level of a seated person.

Sound recordings in four eating establishments at the university were taken three days in each space during lunch times. The number of occupants was tracked during the recordings manually through gate-counts. For each recording, the number of occupants started from zero, reached a maximum number and then decreased until the dining hall was empty again.

Each recording of the whole lunch time was divided into two-minute periods. The data was evaluated in terms of psychoacoustics for each two-minute period and reported for octave band frequencies between 125 and 4000 Hz as given in Appendix E. The recordings in KEY were done not during lunch, but during dinner time, and for one day.

The psychoacoustic values for each two-minute long period were grouped based on number of persons and averaged. Groups ranged from 10 to 150, in intervals of ten persons. The averages and standard deviations are calculated for each group. Sound pressure levels are also averaged and compared against expected values based on the Lombard effect equation (Eq 2.3) for predicting noise levels in eating establishments.

4.3.2. On-site Questionnaires

Questionnaires were conducted during lunch time in CA, MD, TE, YM and during dinner time in KEY eating establishments. The survey consisted of three parts; demographical questions (age, gender, educational status, visiting frequency), acoustic quality questions where participants could give answers in a five-point Likert scale, and open-ended questions where participants should give short answers with 2-3 words.

4.3.2.1. Questions

Question 1 “Please rate the noise level of this dining space from ‘very silent’ (1) to ‘very noisy’ (5)” was asked to find answers for the subjective evaluation of **noisiness**.

Question 2 “Please rate the level of your conversation’s intelligibility with people at your table from ‘we totally don’t understand what we talk’ (1) to ‘we

completely understand what we talk' (5))" was asked to find out the **communication** quality and subjective speech intelligibility.

Question 3 "Please rate how you feel about your conversation being heard from other tables from 'I'm totally not afraid of that' (1) to 'I absolutely worry about that' (5)" was asked to understand how customers feel about **privacy concerns** in that dining space.

Question 4 "Please rate the overall acoustic comfort in this dining space from 'very poor' (1) to 'very good' (5) was asked to find out customers' ideas about **acoustic comfort**.

Question 5 "Please rate the reverberation in this dining space from 'not disturbing at all' (1) to 'totally disturbing' (5) was asked in order to understand how customers feel about the **reverberation** subjectively.

In Question 6, participants were asked to write the "most distracting" sounds in that space.

In Question 7 participants were asked to write the "most dominant" sounds in that space.

These questions were open-ended, in order not to limit the participants and to have the chance of catching some hint about sound sources which might not be mentioned in previous studies. A survey sample in Turkish language is given as Appendix A.

4.4. Listening Tests

In the third phase of this study *listening tests* were conducted in the laboratory. Listening tests using headphones were carried out where participants were asked to evaluate on-site sound recordings as well as simulation based auralizations. Auralizations were prepared using simulation models which were calibrated using measured reverberation time values of eating establishments. Participants were also asked to evaluate synthetically modified versions of the auralizations that vary only in a single parameter to isolate and better understand the effects of the psychoacoustic parameters.

This part of the study focuses on the four eating establishments in IYTE. KEY is not considered due to two reasons:

1) It has a very different character and would introduce bias in listening tests that aims to compare similar sounds that differ only in one psychoacoustic parameter.

2) The maximum number of occupants recorded in the space is below the selected range for comparisons.

Listening tests in following parts of this research were conducted with students or employees in IYTE. The aim was to make participants listen to on-site recordings and simulation auralizations and let them evaluate these sounds. For listening tests, four-second long sounds were presented to participants.

4.4.1. Simulation Models

Simulation models of the eating establishments were prepared in ODEON software (v.14.05 combined). The models were calibrated with the measurements. Simulations were done in order to create a comparable and modifiable acoustic environment. The simulation environment allows exploring how changes in the character of sound sources and material properties of the space enclosure affect psychoacoustic parameters.

During on-site measurements in these eating establishments, the maximum reached occupant numbers are as such: MD (150), YM (150), TE (80) and CA (70). Seventy was the maximum occupant number which could be found in all these spaces. Odeon model screenshots can be seen in Table 4.3.

In order to create sound auralizations in Odeon, computer models were created and calibrated according to the measured reverberation times of these four eating establishments. The room model included the absorption and the rough geometry of tables.

Simulation models were calibrated by adjusting surface materials and thus sound absorption coefficients. As it was stated in Odeon's application note for restaurants (Rindel 2012b) that the absorption represented by the dining people is often of minor importance and can be neglected, the model was created without occupants. Table 4.4 shows the results of simulation models' calibrated reverberation times. During the calibrations, sound absorption coefficients of surface materials were changed and RT values were controlled. Same process continued until the correct values were reached.

Table 4.3. Simulation model screenshots of four eating establishments.

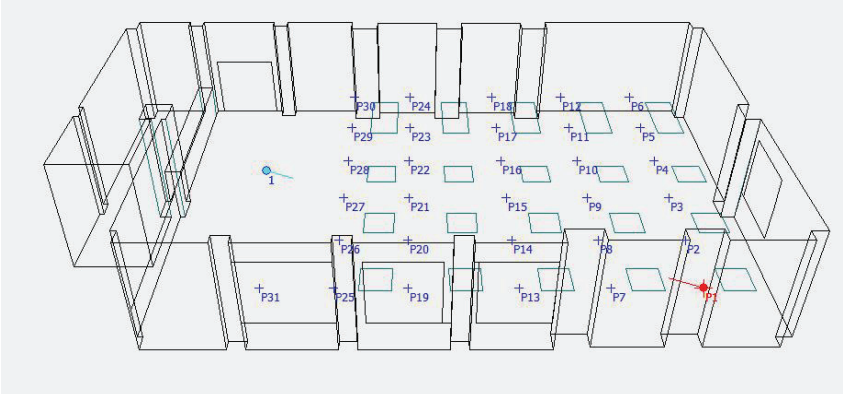
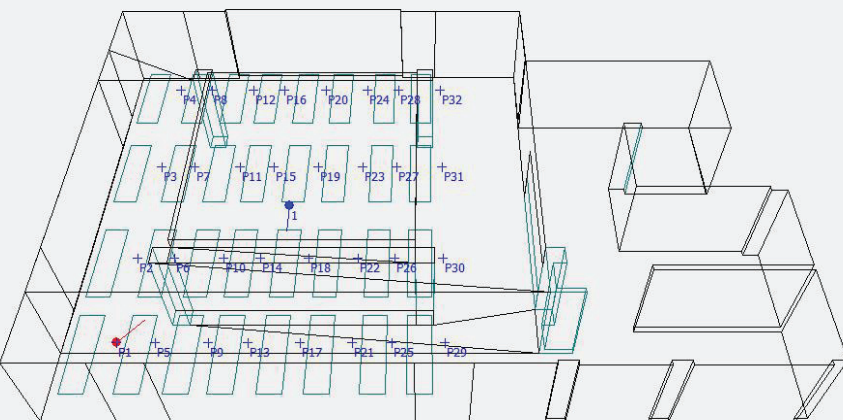
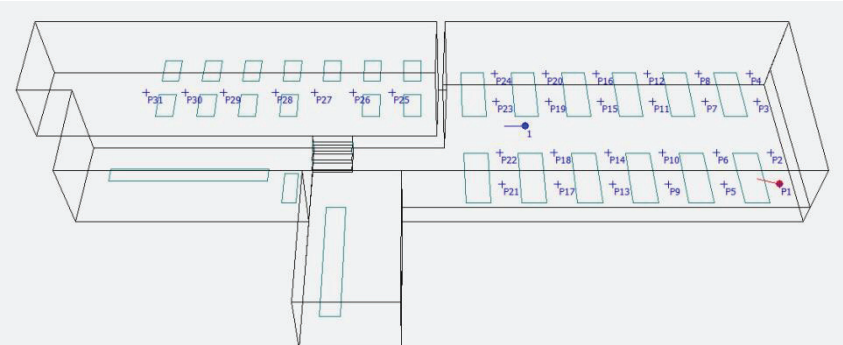
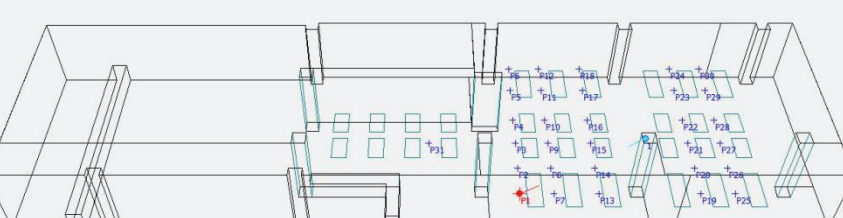
Name of the space	Perspective of simulation models
CA	 Perspective view of simulation model CA. The space is a rectangular room with a grid of tables and chairs. A blue dot labeled '1' is positioned in the center of the room. A red dot is located near the bottom right corner. The tables are labeled with IDs such as P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, and P31.
MD	 Perspective view of simulation model MD. The space is a rectangular room with a grid of tables and chairs. A blue dot labeled '1' is positioned in the center of the room. A red dot is located near the bottom left corner. The tables are labeled with IDs such as P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, P31, and P32.
TE	 Perspective view of simulation model TE. The space is a rectangular room with a grid of tables and chairs. A blue dot labeled '1' is positioned in the center of the room. A red dot is located near the bottom right corner. The tables are labeled with IDs such as P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, and P31.
YM	 Perspective view of simulation model YM. The space is a rectangular room with a grid of tables and chairs. A blue dot labeled '1' is positioned in the center of the room. A red dot is located near the bottom left corner. The tables are labeled with IDs such as P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, P31, and P32.

Table 4.4. RT values of on-site measurements and Odeon simulations.

	Reverberation time [s]	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
CA	Measurements Average: 1.6	2.3	1.9	1.8	1.4	1.2	1.1
	Odeon Average: 1.61	2.27	1.86	1.78	1.39	1.24	1.15
MD	Measurements Average: 1.6	2.3	1.8	1.4	1.5	1.4	1.2
	Odeon Average: 1.6	2.31	1.80	1.38	1.48	1.42	1.23
TE	Measurements Average: 0.9	1.1	1.1	0.9	0.8	0.7	0.6
	Odeon Average: 0.88	1.09	1.07	0.91	0.81	0.76	0.68
YM	Measurements Average: 1.9	2.7	2.1	1.7	1.8	1.7	1.4
	Odeon Average: 1.91	2.59	2.13	1.82	1.83	1.75	1.35

4.4.2. Auralizations

Auralization sound files for listening tests were created in Odeon. On the first and second parts of the listening test, the aim was to create a soundscape in computer models similar to on-site recordings. As 70 was the maximum occupant number in all these spaces, the on-site measurement values for this number (Table 4.5) were taken and auralizations in Odeon were adjusted according to these psychoacoustic values. Sharpness and SPL values for 60-69 occupants in each eating establishment were equalized with measurements during auralizations.

Table 4.5. Measured mean on-site psychoacoustic values for 70 occupants.

	Level	Loudness	Sharpness	Fluct. Str.	Roughness
	[dBA]	[sone]	[acum]	[vacil]	[asper]
CA	71.75	26.88	1.18	0.27	0.32
MD	69.27	23.18	1.20	0.32	0.33
TE	69.48	22.98	1.28	0.52	0.33
YM	72.52	27.59	1.19	0.29	0.33

In order to be able to control the effect of reverberation times in eating establishment models properly, anechoic sound files were used for auralizations. Thirty female and thirty male anechoic sound files were used in this research (Acoustical Design Collaborative 2011). These files were sorted according to their sharpness values and they were inserted in the model according to the need of a sharp or unsharp sound during auralization calibrations. Also tableware sounds were included in the model. The group size (g) was taken as 4 and all auralizations were made according to that number. Table 4.6 shows the psychoacoustic values of on-site recordings and calibrated auralizations, which were used on the first and the second part of the listening tests. Auralization files, chosen from a variety of alternatives, were the optimized final results with the nearest psychoacoustic values to on-site recordings. These psychoacoustic values were derived from dB Sonic software.

Table 4.6. Comparisons of psychoacoustic values of on-site recordings and simulation auralizations.

	Number of occupants	Level	Loudness	Sharpness	Fluct Str.	Roughness
		[dBA]	[sone]	[acum]	[vacil]	[asper]
CA On-site recording	64	71.17	26.43	1.18	0.20	0.31
CA Odeon auralization	64	71.17	26.18	1.18	0.21	0.35
MD On-site recording	64	67.81	22.55	1.20	0.18	0.33
MD Odeon auralization	64	67.81	22.23	1.20	0.16	0.30
TE On-site recording	65	67.09	20.89	1.28	0.53	0.33
TE Odeon auralization	64	67.09	20.96	1.28	0.29	0.35
YM On-site recording	65	72.18	27.08	1.19	0.36	0.35
YM Odeon auralization	64	72.18	28.53	1.19	0.21	0.32

For the third part of the listening test, where the effect of sharpness was evaluated, three auralizations in MD model for 64 occupants with sharpness values 1.00 – 1.10 and 1.20 acum were created, where sound pressure level and roughness values

were kept constant. A difference of 0.1 acum, which is above the just-noticeable difference of sharpness, was chosen between the sounds in order to have a distinguishable increase or decrease. Increasing value of sharpness for three sound files can be seen on the Table 4.7.

Table 4.7. Three auralization sound files with different sharpness values.

	Level [dBA]	Loudness [sone]	Sharpness [acum]	Fluct Str. [vacil]	Roughness [asper]
Sound 1	67.8	21.2	1.00	0.16	0.30
Sound 2	67.8	21.8	1.10	0.19	0.30
Sound 3	67.8	22.2	1.20	0.16	0.30

For the fourth part of the listening test, where both the effect of roughness and fluctuation strength were evaluated, three auralizations for each of the A and B parts were created. A minimum difference of 0.1 asper, which is above the just-noticeable difference of roughness, was chosen between the sounds in order to have a distinguishable increase or decrease. Roughness increases rapidly with increasing sound pressure level. Yet, SPL was aimed to be kept constant. Two other methods for changing roughness was discovered. The first was to change the reverberation time of the room while keeping the total sound level constant. The second was to change the number of occupants while keeping the total sound level unchanged.

For the 4-A part of the listening test, three sound files were created using the first method of altering reverberation times. In these sound files, roughness and fluctuation strength values vary while sound levels, sharpness values and the number of occupants (32) were kept constant. Table 4.8 shows the values for three auralization sound samples for part 4-A.

Table 4.8. Three auralizations for part 4-A with increasing roughness & fluctuation strength values obtained by RT change.

	Average surface abs.	RT [s]	Level [dBA]	Loudness [sone]	Sharpness [acum]	Fluct Str. [vacil]	Roughness [asper]
Sound 1	20%	0.96	67.81	21.08	1.24	0.44	0.31
Sound 2	50%	0.46	67.81	19.39	1.24	0.72	0.42
Sound 3	80%	0.27	67.81	19.05	1.24	0.96	0.53

For the 4-B part of the listening test, three more sound files were created where roughness and fluctuation strength values were changed, this time using the second method of changing the number of occupants in the model. The sound levels, sharpness values and the reverberation times (0.27 s.) were kept constant. Table 4.9 shows the values for three auralization sound samples for part 4-B.

Table 4.9. Three auralizations for part 4-B with increasing roughness & fluctuation strength values obtained by occupant number change.

	Number of occ.	Average surface abs.	Level [dBA]	Loudness [sone]	Sharpness [acum]	Fluct Str. [vacil]	Roughness [asper]
Sound 1	128	80%	67.81	19.48	1.24	0.43	0.29
Sound 2	64	80%	67.81	20.99	1.24	0.60	0.41
Sound 3	32	80%	67.81	19.05	1.24	0.96	0.53

4.4.3. Listening Tests

Listening tests in the laboratory comprises four main parts, which have been mentioned in the previous section. Participants listened to on-site recordings and Odeon auralization sound files. All sound files were 4 seconds long. Each participant listened to a total of 52 sound files. During these tests, both *continuous assessment* and *paired comparison* methods were applied. Listening tests took about 15-20 minutes for each participant. A sample of the listening test in Turkish language is given in Appendix B.

On the first part, participants listened to on-site sound recordings in four eating establishments -made during a time period representing 70 occupants inside- with headphones and they were shown a photograph taken from that particular eating establishment. This listening test part consisted of two sub-sections 1-A and 1-B. For part 1-A, they evaluated four eating establishment sound files separately in a 5 point Likert scale. For part 1-B, they were asked to compare these sounds in pairs.

On the second part, they listened to the auralization files of the same spaces' computer models, with the same occupant number, SPL and sharpness values. This listening test part consisted of two sub-sections 2-A and 2-B. Similar to the first part, they first evaluated four eating establishment auralization files separately, and then they

were asked to compare these auralizations in pairs. There were two control questions on the 1-A and 2-A parts, where participants were asked about one eating establishment's acoustic comfort twice.

The third part of the listening test was to control the effect of sharpness. On this part of the listening test, participants were asked to evaluate auralization sounds which are created for just one eating establishment model (MD). The number of occupants (64), reverberation time and roughness parameters were kept constant, only sharpness was changed. Auralizations with sharpness values 1.00 – 1.10 and 1.20 acum were compared by the participants. It was observed from on-site questionnaires, that high sharpness values relate to good acoustic comfort evaluations. This was also checked by these auralization evaluations.

The fourth part was to control the effect of roughness and fluctuation strength parameters. These two parameters were investigated together, as they define a similar effect in sound. This listening test part consisted of two sub-sections 4-A and 4-B. On part 4-A, participants were asked to evaluate three sounds with different roughness (R0.31, R0.42 and R0.53) and fluctuation strength (F0.44, F0.72 and F0.96) values, obtained by changing the reverberation times of the Odeon models. On part 4-B, participants evaluated again three sounds with different roughness (R0.29, R0.41 and R0.53) and fluctuation strength (F0.43, F0.60 and F0.96) values, this time obtained through changes in number of occupants.

A total of 45 participants, who are undergraduate and graduate students in IYTE, have taken part on listening tests. The average of participants' age was 26 (min. 18; max. 36). All participants had a medical audiometry report from a hospital showing that they had no hearing problems. This assured that there would be no inaccurate evaluations due to hearing loss. An example of these reports is given in Appendix C. Listening tests were conducted using an Audio-Technica ATH-M50 headphone and a computer.

Research ethics committee approval documents are given in Appendix D.

4.5. Limitations

Participants had to evaluate and compare a total of 52 sound files. It was decided to keep the sound samples short in the listening test, not to cause much disturbance for

participants, as it would be very uncomfortable to listen to noise for longer than 15 minutes. This precaution caused a limitation. On-site questionnaires were done during lunch time in the actual space of the eating establishment. The architectural space was also present for the participants. They occupied the space for a certain period of time, during the lunch hour. Thus, their evaluations would be accurate to evaluate the spaces' soundscape. 4 second long sound samples used by listening tests were aimed to represent these eating establishments' soundscapes. But as these sounds were shorter than occupants' exposure time to noise in real life, participants of the listening tests could not evaluate the acoustic comfort accurate enough.



CHAPTER 5

RESULTS

In this chapter, results of on-site measurements are given in terms of psychoacoustic parameters. Then, the results of on-site questionnaires are presented. The objective data from measurements and subjective data from questionnaires are compared. Lastly, the results of listening tests are presented in terms of acoustic comfort.

5.1. Results of On-site Measurements

The frequency histogram for each corresponding group is given as Figure 5.1.

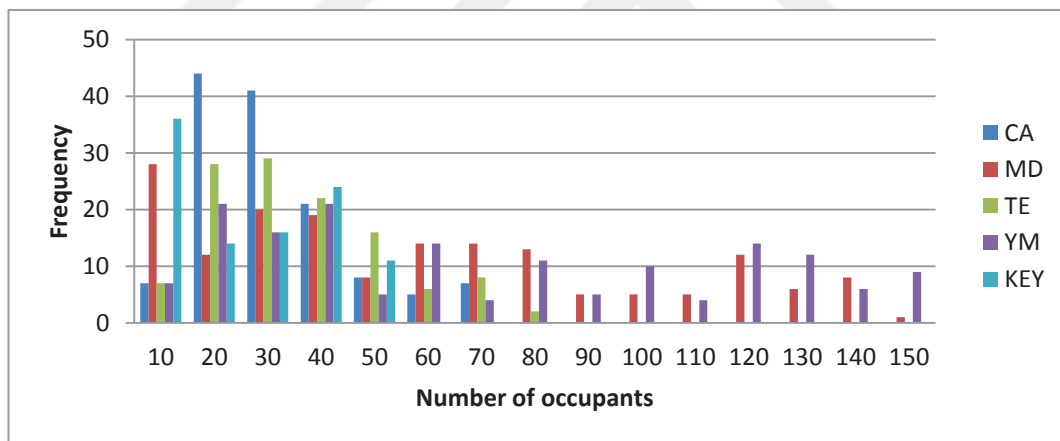


Figure 5.1. Frequency histogram of two-minute measurements for corresponding number of occupants during measurements.

MD and YM have the largest volumes and reverberation times. These two spaces had a maximum of 150 occupants inside during the full condition. TE had a maximum of 80, CA a maximum of 70 and KEY a maximum of 50 occupants inside during all recordings. As most of the regularities are achieved after 40 occupants, the results of KEY were not necessarily interpreted in some sections. The average results are given in Table 5.1.

Table 5.1. Psychoacoustic values of analyzed spaces depending on number of occupants.

Persons	SPL					Loudness				
	[dBA]					[sone]				
	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY
10	57.65	60.13	60.99	64.80	53.66	10.40	12.14	11.75	15.25	6.93
20	59.89	61.91	63.40	63.67	59.28	12.45	14.57	14.03	14.82	10.28
30	63.80	63.01	64.38	67.01	61.29	16.07	15.75	15.33	19.22	12.64
40	66.78	63.80	67.00	67.92	62.04	19.19	15.58	18.74	20.99	13.72
50	67.96	66.83	68.52	68.95	63.71	20.89	19.43	20.72	22.13	14.51
60	69.67	68.48	69.63	71.16		23.67	22.27	22.51	25.89	
70	71.75	69.27	69.48	72.52		26.88	23.18	22.98	27.59	
80		70.29	71.18	73.63			24.69	25.76	29.90	
90		69.88		74.02			24.35		30.75	
100		71.77		77.03			26.75		36.89	
110		70.89		76.14			25.50		35.29	
120		71.34		76.32			26.54		35.97	
130		72.21		75.95			28.13		35.34	
140		72.26		77.36			28.20		38.04	
150		72.37		78.31			28.33		39.95	

Persons	Sharpness					Fluct Str.					Roughness				
	[acum]					[vacil]					[asper]				
	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY
10	1.27	1.26	1.33	1.22	1.42	0.26	0.32	0.49	0.40	0.31	0.26	0.30	0.28	0.32	0.23
20	1.22	1.26	1.27	1.21	1.44	0.26	0.32	0.51	0.34	0.52	0.26	0.30	0.30	0.30	0.29
30	1.19	1.21	1.28	1.20	1.34	0.26	0.31	0.52	0.36	0.49	0.27	0.30	0.30	0.31	0.26
40	1.19	1.26	1.27	1.23	1.30	0.26	0.39	0.52	0.34	0.54	0.29	0.30	0.31	0.31	0.27
50	1.17	1.20	1.27	1.19	1.35	0.23	0.31	0.54	0.34	0.63	0.29	0.31	0.32	0.31	0.29
60	1.17	1.20	1.26	1.18		0.27	0.31	0.52	0.30		0.31	0.32	0.32	0.32	
70	1.18	1.20	1.28	1.19		0.27	0.32	0.52	0.29		0.32	0.33	0.33	0.33	
80		1.20	1.26	1.17			0.31	0.47	0.29			0.33	0.33	0.34	
90		1.21		1.17			0.29		0.30			0.32		0.35	
100		1.20		1.17			0.33		0.27			0.33		0.37	
110		1.21		1.18			0.32		0.28			0.33		0.37	
120		1.20		1.17			0.30		0.28			0.33		0.37	
130		1.21		1.18			0.32		0.27			0.34		0.37	
140		1.20		1.17			0.30		0.26			0.34		0.38	
150		1.22		1.15			0.31		0.27			0.34		0.38	

Standard deviations of the psychoacoustic values in 10-person intervals decrease while the number of occupants increase, as shown in Table 5.2, which could be taken as a sign that these parameters are in a certain trend.

Table 5.2. Standard deviations for psychoacoustic data.

Persons	Level					Loudness				
	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY
10	1.10	7.69	1.65	2.12	4.82	1.03	5.10	1.20	2.30	0.86
20	2.64	5.69	1.84	2.46	3.48	1.98	5.34	1.56	2.19	1.33
30	2.98	2.86	2.50	2.33	2.96	2.82	3.12	1.97	2.93	1.74
40	2.80	3.16	2.08	1.92	2.10	2.85	3.24	2.55	2.50	1.65
50	2.44	0.79	2.11	4.06	2.00	2.73	1.07	2.49	4.98	0.92
60	1.08	1.95	1.09	2.82		1.89	2.08	1.54	3.79	
70	0.80	1.89	1.64	4.11		1.36	2.27	2.06	7.08	
80		1.44	0.37	1.47			1.79	0.30	2.65	
90		1.02		2.59			1.70		4.07	
100		1.01		1.97			1.70		4.20	
110		0.44		2.40			0.86		4.72	
120		1.04		1.71			1.72		3.33	
130		1.37		1.28			2.22		2.54	
140		1.05		0.97			1.35		1.90	
150		0.00		0.79			0.00		1.64	

Persons	Sharpness					Fluct Str.					Roughness				
	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY	CA	MD	TE	YM	KEY
10	0.08	0.14	0.11	0.04	0.04	0.03	0.26	0.06	0.07	0.11	0.01	0.04	0.02	0.02	0.03
20	0.06	0.11	0.05	0.03	0.07	0.04	0.08	0.08	0.07	0.16	0.01	0.02	0.02	0.02	0.04
30	0.03	0.07	0.04	0.06	0.05	0.03	0.09	0.12	0.05	0.06	0.01	0.01	0.02	0.02	0.01
40	0.03	0.05	0.03	0.05	0.05	0.03	0.06	0.04	0.03	0.06	0.01	0.01	0.01	0.02	0.01
50	0.01	0.03	0.03	0.05	0.05	0.02	0.04	0.08	0.06	0.08	0.01	0.01	0.02	0.02	0.02
60	0.01	0.02	0.02	0.05		0.04	0.06	0.04	0.03		0.01	0.02	0.00	0.01	
70	0.01	0.02	0.01	0.02		0.03	0.05	0.05	0.01		0.01	0.01	0.01	0.03	
80		0.02	0.00	0.03			0.03	0.03	0.02			0.01	0.00	0.01	
90		0.02		0.04			0.01		0.02			0.01		0.02	
100		0.02		0.03			0.03		0.02			0.02		0.02	
110		0.02		0.02			0.04		0.01			0.00		0.02	
120		0.02		0.02			0.02		0.02			0.01		0.01	
130		0.01		0.02			0.04		0.03			0.01		0.01	
140		0.01		0.02			0.04		0.02			0.01		0.01	
150		0.00		0.01			0.00		0.01			0.00		0.01	

Sound pressure levels rise with rising number of occupants, as expected (Figure 5.2). As the highest level, 78.31 dB was reached in YM by 150 occupants. YM is the space with the largest volume and the longest reverberation time.

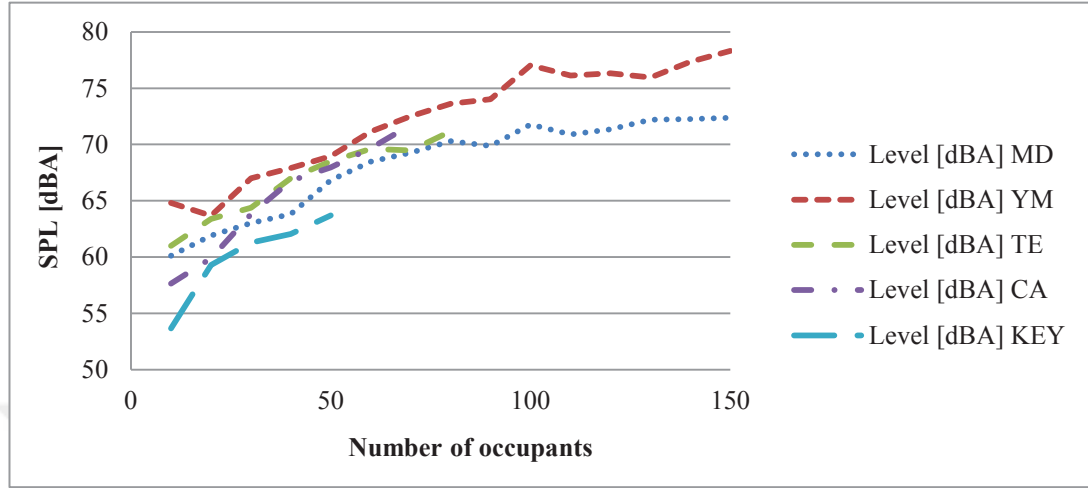


Figure 5.2. SPL values depending on number of occupants.

Overall sound levels are also calculated for each corresponding number of occupants, using Lombard effect equation (Eq. 2.3) proposed by Rindel (2010) for eating establishments in IYTE, in order to compare calculations and measurements. Lombard slope value c is taken as 0.4 and group size was 4. Outcomes of calculations are in a very close range to on-site measurements. Results are given as Figure 5.3, where solid lines represent on-site measurements and dashed lines the calculations.

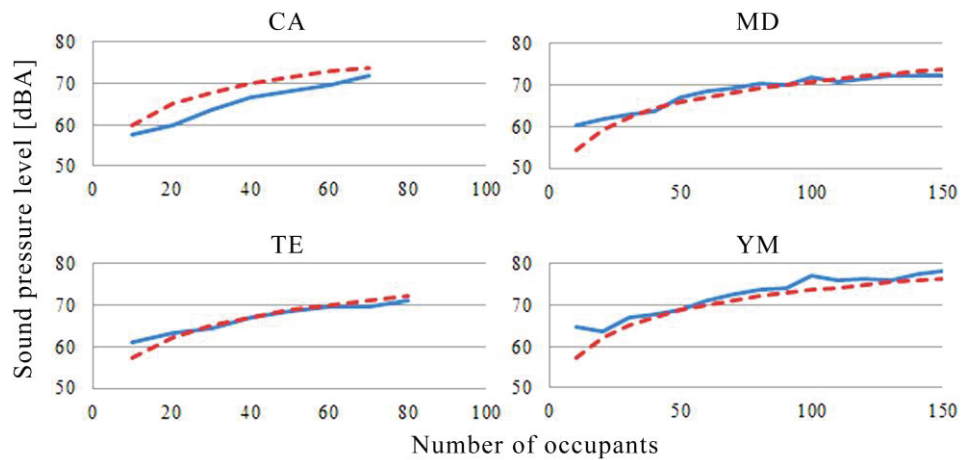


Figure 5.3. Comparison of measured and calculated values for overall sound levels.

Also loudness parameter rises with increasing number of occupants, as expected (Figure 5.4). As the highest level, 39.95 sone was reached in YM by 150 occupants. KEY has noticeably the lowest SPL and loudness values for each number of occupants partition, compared to other studied four eating establishments.

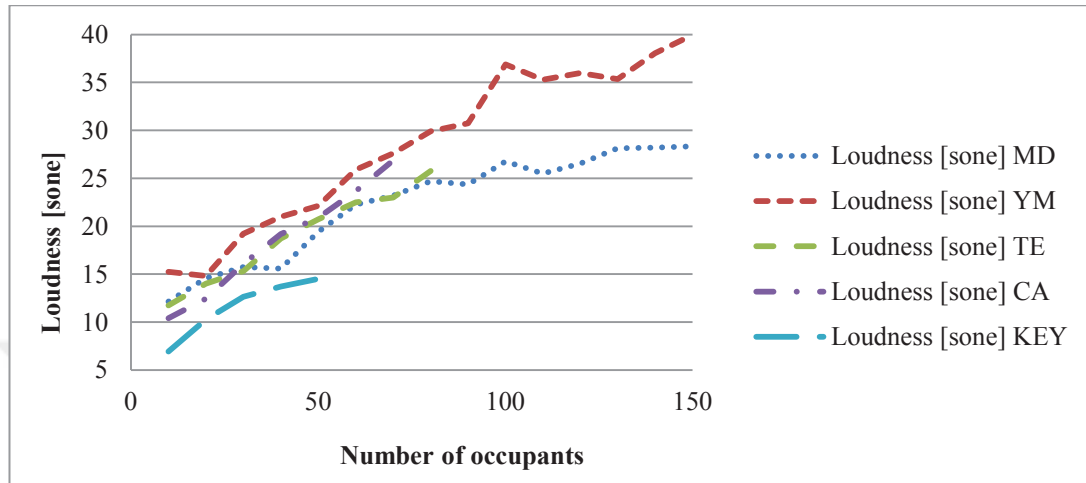


Figure 5.4. Loudness values depending on number of occupants.

Between 0 and 40 occupants, sharpness tends to fall and after 40 people it has the tendency to stay stable. Between 40-140 occupants, sharpness changes in a very narrow range in each eating establishment: 0.20-0.21 acum in MD, 1.17-1.19 acum in YM, 1.26-1.28 acum in TE and 1.17-1.18 acum in CA (Figure 5.5).

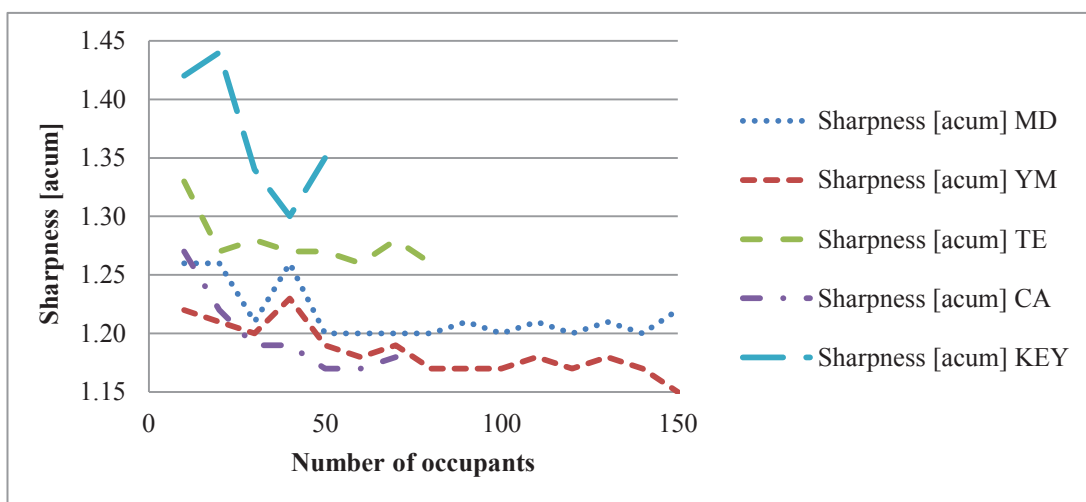


Figure 5.5. Sharpness values depending on number of occupants.

Average sharpness values of all three measurement days are 1.27 acum in TE, 1.22 acum in MD, 1.20 acum in CA and 1.19 acum in YM. Also the average value obtained from the sharpnesses depending on the number of occupants has the same ranking; 1.28 acum in TE, 1.22 acum in MD, 1.20 acum in CA and 1.18 acum in YM. KEY has a noticeably higher sharpness, an average of 1.37 acum, which can be related to the music which was playing on the background.

Roughness rises when the number of occupants rises (Figure 5.6). It rises from 0.30 to 0.34 asper in MD; 0.30 to 0.38 asper in YM; 0.28 to 0.33 asper in TE; 0.26 to 0.32 asper in CA; and 0.23 to 0.29 asper in KEY. It is clear that roughness is in a rising trend in all five spaces. This is mostly due to the the increase in sound pressure level with increasing number of occupants.

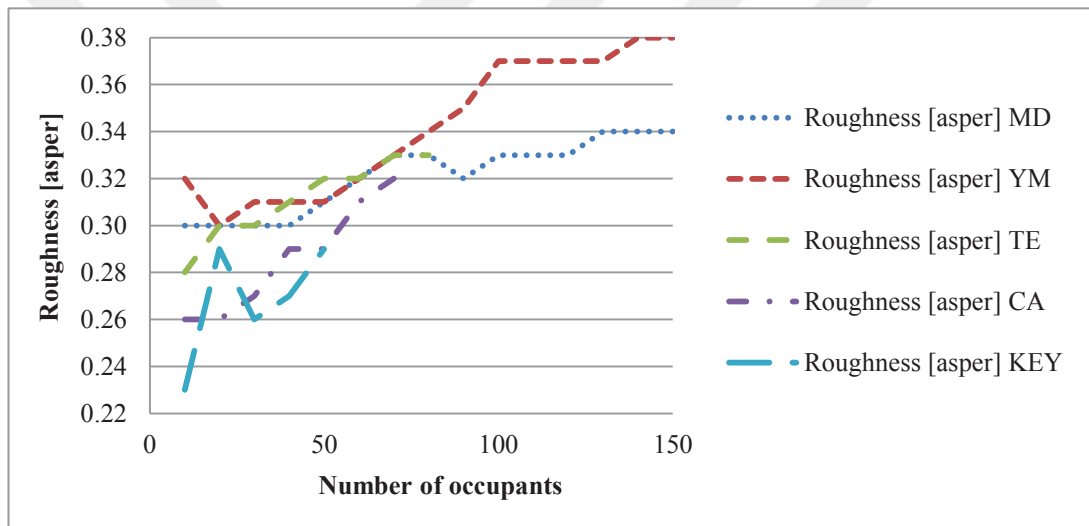


Figure 5.6. Roughness values depending on number of occupants.

Fluctuation strength graph is given as Figure 5.7. There is no trend that is common to all spaces. It is not possible to identify if the values of this parameter fall or stay stable depending on the number of occupants. Every space has a certain fluctuation strength range in itself with the exception of KEY that displays a sharp increase. The eating establishment TE has a noticeably high range, compared to the other three spaces in IYTE campus.

It should be noted that fluctuation strength is still not a standardized parameter according to literature.

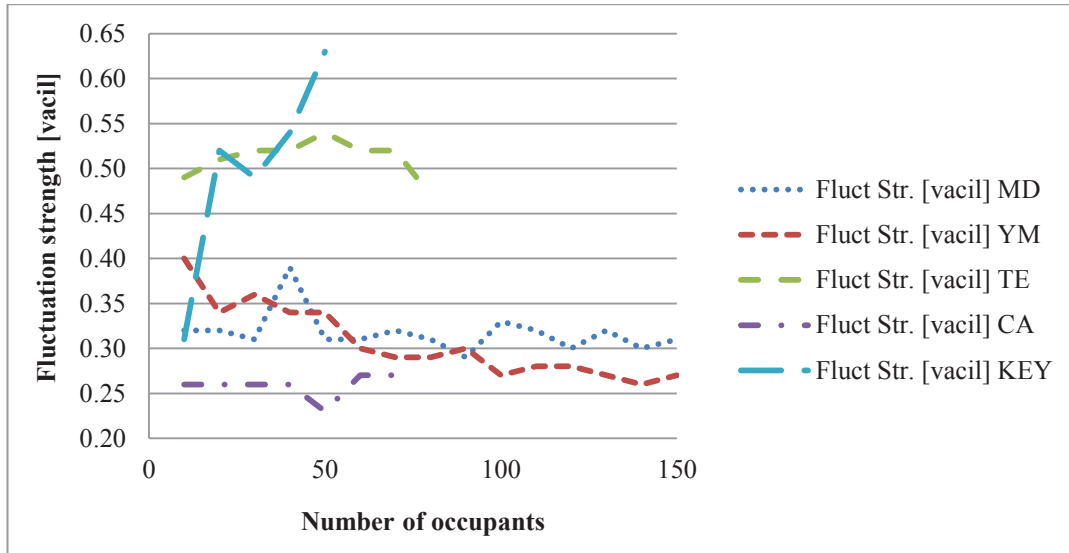


Figure 5.7. Fluctuation Strength values depending on number of occupants.

5.2. Results of On-site Questionnaires

A total number of 177 questionnaires were evaluated in dining spaces CA (38), MD (48), TE (36), YM (36) and KEY (19). 60% of the participants were male and 40% were female. The average of participants' age was 28 (min. 18; max. 58). The answers are summarized in Table 5.3.

Table 5.3. Subjective evaluations of questionnaire participants in eating establishments.

	Noisiness	Communication	Privacy concerns	Acoustic comfort	Subjective reverberation
CA	3.68	2.89	2.79	2.29	3.34
MD	3.46	3.67	2.21	2.44	2.98
TE	3.25	3.58	2.25	2.94	2.64
YM	4.08	2.64	2.00	2.03	3.78
KEY	1.63	4.63	2.05	4.32	1.53

According to the results of questionnaires, KEY was found to have the highest acoustic comfort with 4.32 points among all the other four eating establishments. Also in Battaglia's study (2015), it was stated that restaurants with a reverberation time between 0.5 and 0.7 seconds provide optimum acoustic comfort. Customers marked KEY as the most silent space. It was also evaluated as the most comfortable space for communication and participants had a feeling of low reverberation time inside.

The relationship between these subjective answers was analyzed. The analyses of questionnaire results show that the feelings of subjective reverberation and noisiness have a direct relationship. When the noisiness rises, the feeling of subjective reverberation observed by the occupants also rises. Figure 5.8 shows the relationship between these two subjective evaluations.

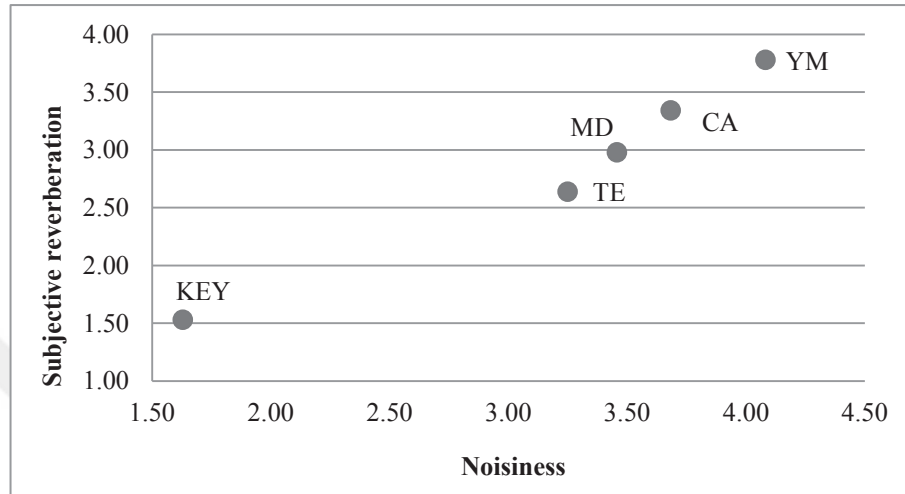


Figure 5.8. Relationship between noisiness and subjective reverberation.

Also the subjective reverberation and acoustic comfort are found to be inversely proportional to each other. When the feeling of subjective reverberation decreases, acoustic comfort rises. Figure 5.9 shows the relationship of these subjective evaluations.

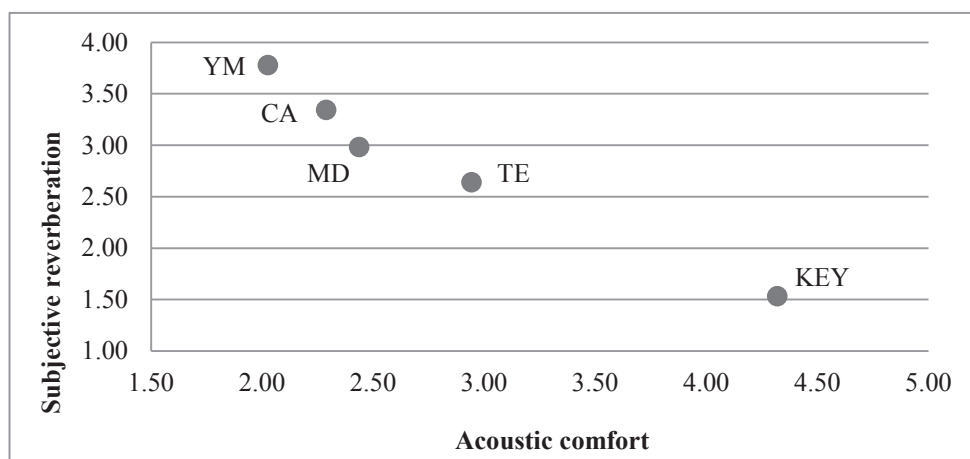


Figure 5.9. Relationship between acoustic comfort and subjective reverberation.

Two open-ended questions were asked about the most annoying and most dominant sound in the dining space. Answers to open-ended questions had similarities but their frequency percentage changed according to the dining space. Common answers were cutlery noise, human speech, humming and chair pulling noise in all these spaces.

In MD, cutlery (46%), human speech (25%) and chair pulling (13%) were most annoying sounds, where human speech (46%), cutlery (29%) and humming (13%) were the most dominant ones.

In YM, human speech (47%), humming (28%) and cutlery (28%) were most annoying sounds, where human speech (53%), humming (36%) and cutlery (14%) were the most dominant ones.

In CA, human speech (53%) and humming (16%) were most annoying sounds, where human speech (74%) was the most dominant one.

In TE, cutlery (64%) and human speech (19%) were the most annoying sounds, where cutlery (44%), human speech (33%) and humming (11%) were the most dominant ones.

In KEY, 84% of the participants stated that they heard no annoying sounds at all. Only 11% of the participants mentioned that background music was annoying. Also, 58% of the participants did not categorize any dominant sound inside KEY eating establishment, where 21% reported that background music and 15% reported that cutlery was the dominant sound in that soundscape.

5.3. Comparison of On-site Objective and Subjective Data

Measurements were compared with questionnaire results and their relationship was analyzed. It can be inferred that acoustic comfort in these eating establishments decreases with increasing loudness, as seen in Figure 5.10. Except the average values of CA, the values of four eating establishments are in a notable agreement. YM has the highest mean loudness and the worst acoustic comfort, where KEY has the lowest mean loudness and best acoustic comfort according to on-site measurements and questionnaires.

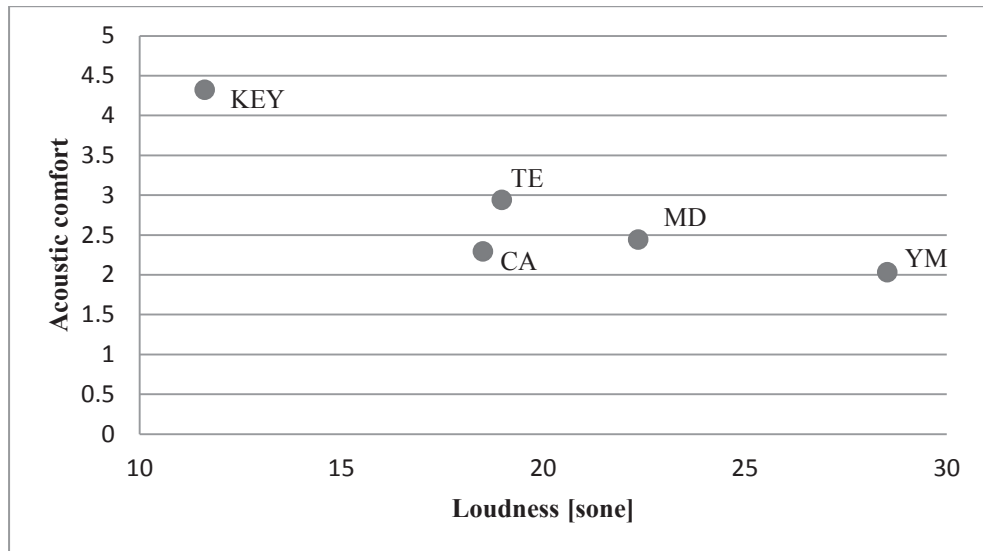


Figure 5.10. Relationship between acoustic comfort and mean loudness.

The subjective answers given to acoustic comfort questions in questionnaires were found to be related with reverberation time. Acoustic comfort rises when the reverberation time falls. This inversely proportional relationship was expected. Reverberation time has been investigated by many studies in literature. For example, in Battaglia's study, it was stated in the results, that there was a strong relationship between reverberation time and acoustic comfort (2015). Figure 5.11 shows the relation between reverberation time and acoustic comfort in five eating establishments.

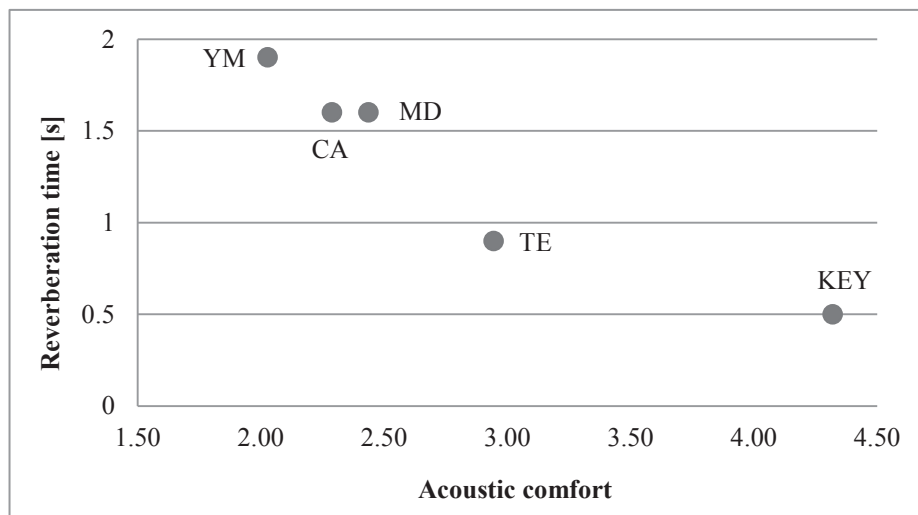


Figure 5.11. Relationship between mean RT and acoustic comfort.

When all subjective evaluations were compared with psychoacoustic values, sharpness was found to be related with acoustic comfort, in a directly proportional way. This means that acoustic comfort increases when sharpness rises. Figure 5.12 shows the relationship between average sharpness values, their corresponding maximum and minimum values and acoustic comfort.

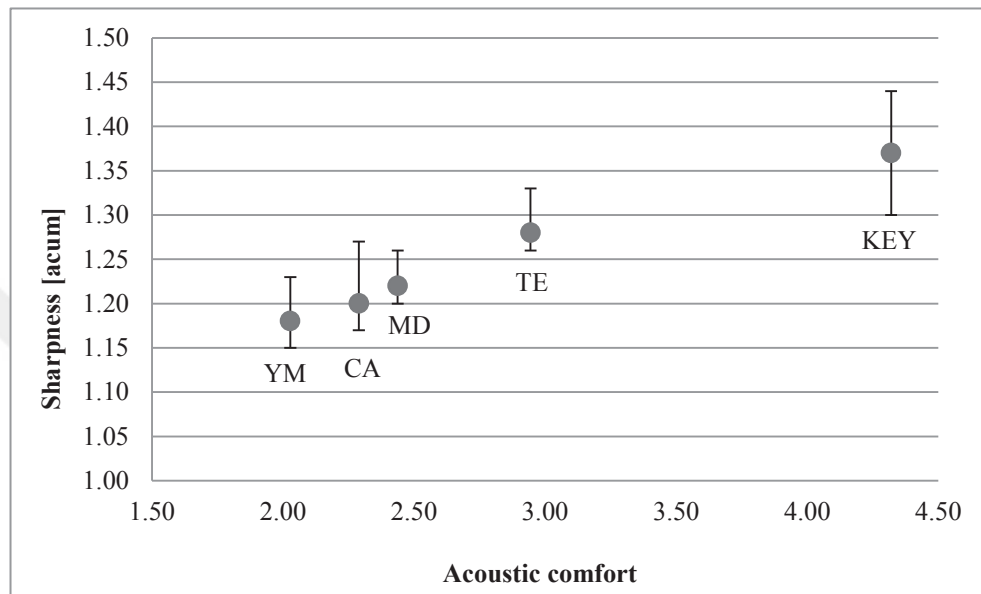


Figure 5.12. Relationship between acoustic comfort and mean sharpness.

According to literature, we know that alarms and warning sirens have a very high sharpness value and that they are disturbing sounds. But this research shows that eating establishments have a certain sharpness range which is dependent on the occupant noise. It does never rise as high as an alarm sound. With the precondition that sharpness stays within that range of eating establishments, we can say that acoustic comfort gets better when sharpness rises. This can also be interpreted this way: Occupants are mostly annoyed by the mid and low frequency noise in eating establishments, according to on-site measurements and questionnaires. This result can also be related with the time occupants spend inside the eating establishments. They spend nearly about an hour during lunch time in those spaces and low frequency sounds might be more distractive when exposed to them for a long time.

Privacy concerns decrease, when roughness rises. It can be interpreted that occupants are not worried about their conversations being heard from other tables when

roughness rises, due to the rough character of the background noise in that eating establishment. Figure 5.13 shows the relationship between average roughness values, their corresponding maximum and minimum values and privacy concerns.

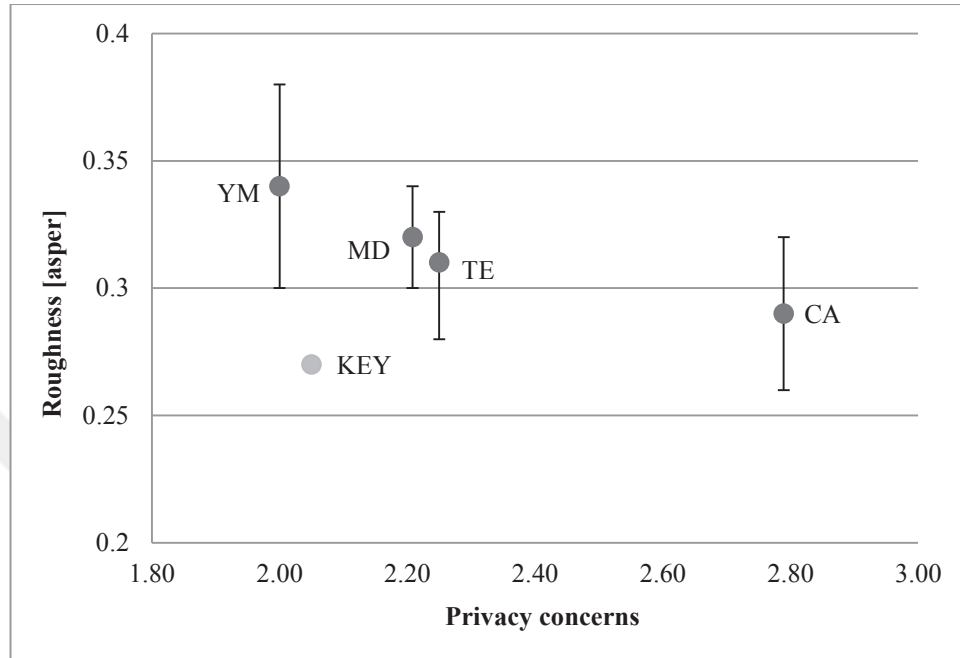


Figure 5.13. Relationship between mean roughness and privacy concerns.

5.4. Results of Listening Tests

The ranking orders below are always given from the best evaluated eating establishment soundscape to the worst one. All evaluations of 45 participants are given as tables in Appendix F.

On part 1-A of the listening test, where participants evaluated four eating establishments' on-site sound recording files separately in a 5 point Likert scale (1: worst acoustic comfort, 5: best acoustic comfort), the average ranking of the eating establishments were as such: MD (3), TE (2.33), CA (2.29) and YM (2). On part 1-B, where the participants made a pairwise comparison, the averages of eating establishments' weightings on the matrix are as such: MD (0.37), TE (0.21), CA (0.21) and YM (0.21). The highest weighting represents the best evaluation by the participants. This shows that on-site sound recording of MD was rated to provide the best acoustic comfort, and all the other three spaces were equally comfortable among themselves.

On part 2-A of the listening test, where participants evaluated four eating establishments' simulation auralization sound files separately in a 5 point Likert scale (1: worst acoustic comfort, 5: best acoustic comfort), the average ranking of the eating establishments were as such: CA (2.58), MD (2.33), TE (2.13) and YM (2). On part 2-B, where the participants made a pairwise comparison, the averages of eating establishments' weightings on the matrix are as such: CA (0.28), TE (0.26), MD (0.24) and YM (0.22). The highest weighting represents the best evaluation by the participants. This shows that simulation auralization sound file of CA was rated to provide the best acoustic comfort, and the auralization sound file of YM was rated to be the worst.

There is a general consensus taking both the first and the second parts of the listening test, that YM has the worst acoustic quality. Not only by the listening tests, also by the on-site questionnaires as mentioned on previous sections, YM was rated to provide the worst acoustic comfort among others due to its acoustic and psychoacoustic values.

MD was rated remarkably better than the other three eating establishments in part 1 in terms of acoustic comfort. This might have been caused by the previous experiences and positive prejudices of the participants about the eating establishments in IYTE, as they were shown photographs of the eating establishments during this part of the listening test. As all the participants of the listening tests were students of IYTE, they might have remembered how it feels to be in these eating establishments in terms of acoustic comfort and this might have led them to evaluate MD better than the other spaces. Nevertheless, on-site recording sound files and simulation auralizations were not rated exactly same by the participants, in terms of acoustic comfort.

On part 3 of the listening test, participants evaluated simulation auralization sound files with different sharpness values. Where the participants made a pairwise comparison, the averages of sound files' weightings on the matrix are as such: S1.00 (0.35), S1.20 (0.33) and S1.10 (0.32). These three mean values are very close to each other, as some of the participants thought that the density of high frequencies are disturbing in a soundscape, while some others find low frequency dense noise in a soundscape worse. There is no consensus about the effect of sharpness on acoustic comfort in eating establishments according to the listening tests. Still, the best case is rated to be the one with the lowest sharpness value.

On part 4-A of the listening test, participants evaluated simulation auralization sound files with different roughness and fluctuation strength values, obtained by changing the reverberation times of the Odeon models. Where the participants made a pairwise comparison, the averages of sound files' weightings on the matrix are as such: R0.31 (0.36), R0.42 (0.34) and R0.53 (0.30). Even though these mean values are close to each other, there is a linear tendency of participants to rate low roughness and fluctuation strength values better and high values worse in terms of acoustic comfort (Figure 5.14).

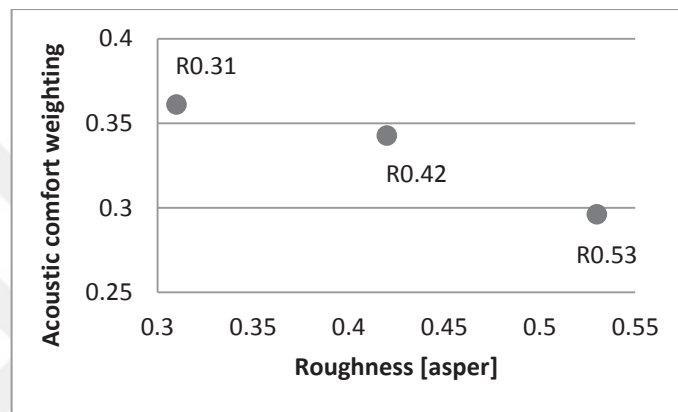


Figure 5.14. Tendency of participants to rate low roughness values better in terms of acoustic comfort.

On part 4-B of the listening test, participants evaluated simulation auralization sound files with different roughness and fluctuation strength values, obtained through changes in number of occupants in simulation models. Where the participants made a pairwise comparison, the averages of sound files' weightings on the matrix are as such: R0.29 (0.44), R0.53 (0.31) and R0.41 (0.25). It can be inferred that the lowest roughness and fluctuation strength values provided the best acoustic comfort, but still there is no direct relationship between these psychoacoustic values and acoustic comfort, taking listening tests in consideration.

In part 1-A and 2-A, there were two control questions. Participants were asked for their evaluation for the sound file representing the eating establishment TE twice. 7 tests had a difference of 2 or more points for the control questions. In addition to that, the consistency ratio CR values for the answers were calculated and 9 participants' tests were found to show inconsistencies due to their CR values which were higher than 0.2.

When a total of 15 participants' answers with a difference of 2 or more points for the control questions and with a higher CR higher than 0.2 were taken out from the results, following results from 30 participants were obtained.

On part 1-A, the ranking order didn't change: MD (2.83), TE (2.43), CA (2.27) and YM (2.07). On part 1-B, where the participants made a pairwise comparison, the averages of eating establishments' weightings on the matrix didn't change and are as such: MD (0.34), TE (0.22), CA (0.22) and YM (0.22). On part 2-A, the ranking order didn't change: CA (2.53), MD (2.23), TE (2.17) and YM (1.83). On part 2-B, where the participants made a pairwise comparison, the ranking order again didn't change. The averages of eating establishments' weightings on the matrix are as such: CA (0.29), TE (0.27), MD (0.24) and YM (0.21).

On part 3 for sharpness evaluation, where the participants made a pairwise comparison, the ranking order was corrected, as shown in Figure 5.15. The averages of sound files' weightings on the matrix are as such: S1.20 (0.35), S1.10 (0.33) and S1.00 (0.32).

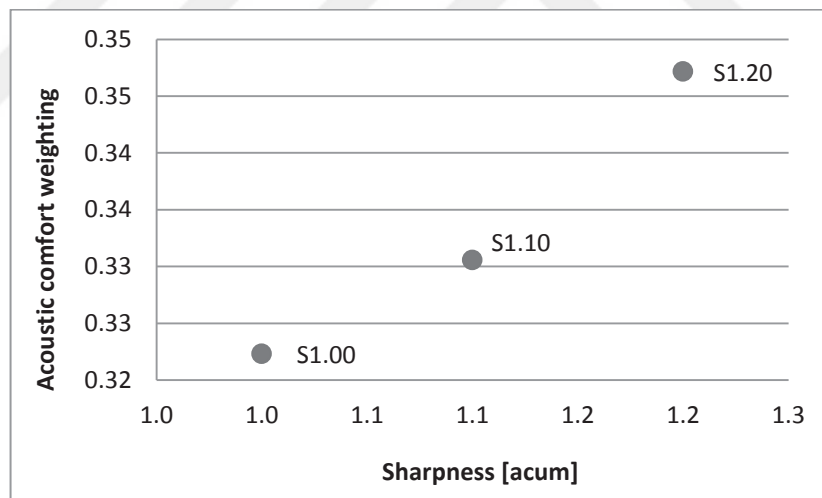


Figure 5.15. Tendency of participants to rate high sharpness values better in terms of acoustic comfort.

On part 4-A for roughness and fluctuation strength evaluation by constant number of occupants, where the participants made a pairwise comparison, the ranking order didn't change. The averages of sound files' weightings on the matrix are as such: R0.31 (0.38), R0.42 (0.34) and R0.53 (0.28). On part 4-B for roughness and fluctuation

strength evaluation by constant reverberation time, where the participants made a pairwise comparison, the ranking order didn't change again. The averages of sound files' weightings on the matrix are as such: R0.29 (0.45), R0.53 (0.31) and R0.41 (0.24).

Taking out and canceling 15 listening test results with potential inconsistencies, made a noticeable correction on the results. On part 3, where sharpness parameter was evaluated by the participants, the results were found to be parallel to on-site questionnaires. Higher sharpness values were evaluated to provide better acoustic comfort, both on listening tests and on-site questionnaires.



CHAPTER 6

CONCLUSION

6.1. Findings and Discussion

This dissertation reports on a research investigating the effectiveness of using psychoacoustics parameters of loudness, sharpness, roughness, and fluctuation strength for characterizing ambient noise in eating establishments. These parameters were investigated because parameters of room acoustics alone were not sufficient enough to describe soundscapes of spaces, and thus acoustic comfort. According to literature, psychoacoustic parameters are used in mechanical engineering to define sound characteristics of machines efficiently, and are promising tools for defining soundscapes of indoor and outdoor spaces.

Loudness parameter is directly related to sound pressure levels and is already standardized and being utilized. It simply describes the perceived level of sound. Sharpness describes the high-frequency content of a sound. There are alternative calculation methods for this parameter but a DIN standard has been established. Roughness parameter tries to describe the strength of the modulation (fluttering) in the sound. Its calculation involves tracking of amplitude modulations over time. There are alternative methods under consideration of a DIN standards committee but no standards have been established yet. Fluctuation strength is calculated by the same methods as roughness but for modulation frequencies below 20 Hz (slower repetitions). The human ear is able follow these slow modulations and perceives them as pulses or beats. As the modulation increases in speed, between 20 Hz and 300 Hz the sound is perceived as being “rough”. Modulations above 300 Hz are not perceived. These parameters have proved useful particularly for characterizing machinery noises that are continuous and follow regular regimes. However, with ambient noise in eating establishments that is a broadband signal without any patterns, the findings of this research suggest their usefulness is limited.

Loudness parameter has been widely used in studies about subjective evaluation of sound and noise in architecture. It has an established and known position in sound perception research, compared to other psychoacoustic parameters. As an expected outcome; in this study, the results show that high loudness values are not preferred in terms of acoustic comfort, when on-site measurements and questionnaires are evaluated. Considering measured loudness ranges, values below 15 sone were classified as ‘low (L)’; values between 15 - 25 sone ‘medium (M)’ and values above 25 sone as ‘high (H)’.

Sharpness values in eating establishments show a slightly decreasing trend as the number of occupants increase. However, over all four spaces, sharpness values stay within a narrow range of 1.15 – 1.30 acum. Even in the smaller restaurant with low reverberation time, the maximum sharpness was 1.45 acum. Considering the soundscape literature that reports values as high as 2.8 acum for urban sounds (Dökmeci et al. 2013), these values are low and show little variance. The questionnaire results appear to show a slight preference towards higher sharpness values. This can be attributed to both the desire to avoid low frequency noises, and the slight increase in speech intelligibility when low frequency noise is reduced. Also listening tests confirmed these results. In listening tests, participants evaluated soundscapes with higher sharpness values to provide better acoustic comfort. Sharpness ranges in measured cases were sorted among themselves. Values below 1.25 acum were classified as L; values between 1.25 – 1.30 acum as M, and values above 1.30 acum as H.

Roughness values, over all spaces, vary in the range of 0.25 – 0.40 asper. As in the case of sharpness, this is a narrow range. Literature reports roughness values as high as 1.1 asper for recordings in urban settings (Ortiz and Schulte-Fortkamp 2013). The questionnaire results show a slight trend towards reduction in the values of privacy concerns as roughness increases. This may be explained by the fact that roughness increases when sound pressure level increases. Higher noise levels limit speech intelligibility but enhance the feeling of privacy. The questionnaire results do not indicate any relationship between acoustic comfort and roughness but the listening tests suggest a very slight preference towards lower roughness values. Considering measured roughness ranges, values below 0.30 asper were classified as L; values between 0.30 – 0.33 asper as M, and values above 0.33 asper as H among themselves.

Fluctuation strength values, over all spaces, vary in the range of 0.23 – 0.54 vacil. However, there is no trend or pattern to the values when grouped by number occupants. As the space gets crowded, fluctuation strength values change unpredictably. As the number of occupants increase, in CA, MD, and TE fluctuation strength can be seen as stable varying slightly, in YE fluctuation strength is reduced, and in KEY it increases. Furthermore, controlling fluctuation strength values for auralizations was also not possible. No relationship with another parameter was discovered. Still, listening tests suggest a very slight preference towards lower fluctuation strength values, in terms of acoustic comfort. Fluctuation strength values below 0.30 vacil were classified as L; values between 0.30 – 0.40 vacil as M, and values above 0.40 vacil as H, taking measured cases into consideration.

Apart from psychoacoustic parameters, reverberation time was shown to be related to acoustic comfort. When reverberation time of an eating establishment was lower, that space was rated to have a better acoustic comfort. This finding is valid for the examined range of reverberation time values; 0.5 – 1.9 seconds. Considering measured reverberation time ranges, values below 0.8 seconds were classified as L; values between 0.8 – 1.4 seconds as M, and values above 1.4 seconds as H.

Ranges of variables were sorted among themselves as stated on the previous paragraphs and categorized in Table 6.1. These ranges were classified as L (low), M (medium) and H (high) and were used for defining acoustic comfort.

Table 6.1. Summary table for variable ranges.

	L	M	H	
RT	< 0.8	$0.8 \leq x \leq 1.4$	> 1.4	[s]
Loudness	< 15	$15 \leq x \leq 25$	> 25	[sone]
Sharpness	< 1.25	$1.25 \leq x \leq 1.30$	> 1.30	[acum]
Roughness	< 0.30	$0.30 \leq x \leq 0.33$	> 0.33	[asper]
Fluctuation Strength	< 0.30	$0.30 \leq x \leq 0.40$	> 0.40	[vacil]
Acoustic Comfort	< 2.20	$2.20 \leq x \leq 3.20$	> 3.20	-

Ranges for parameters classified as L, M and H were analyzed for studied eating establishment cases and a layout for configurations is given. Table 6.2 is the summary table showing parameter configurations concerning five cases.

Table 6.2. Summary table showing parameter configurations.

	RT	Loudness	Sharpness	Roughness	Fluctuation Strength	<i>Acoustic Comfort</i>
CA	H	M	L	L	L	M
MD	H	M	L	M	M	M
TE	M	M	M	M	H	M
YM	H	H	L	H	M	L
KEY	L	L	H	L	H	H

This table shows that acoustic comfort is rated by the participants as ‘high’, when the average values of reverberation time, loudness and roughness are ‘high’ and the values of sharpness are ‘low’. This configuration can be observed by the case KEY. When the average values of reverberation time, sound pressure level, loudness and roughness are ‘high’ and the values of sharpness are ‘low’, acoustic comfort is rated by the participants as ‘low’. This opposite configuration which is supporting the same argument, is found by the case of YM. Also, when RT, loudness, sharpness and roughness values are ‘medium’, acoustic comfort is rated to be ‘medium’, which again supports the same argument and is seen in the case of TE.

How psychoacoustic parameters can be controlled through architectural elements is of importance as well. Sharpness is mainly dependent on the source characteristics (e.g. being high or low pitched) and the sound absorptance properties of surface materials can also be effective in determining the ratio of high frequency sounds in a space. As sound sources; tables, chairs, tableware and tablecloths are the elements which can be controlled. For instance, choosing plastic tableware would decrease sharpness value of the source, while metal knives and forks would increase it because of

the high frequency noise they create. Also surface materials of walls and other architectural elements can be effective on absorbing high or low frequencies. Designers can select the materials of these elements according to the desired sharpness value, while planning eating establishments.

Roughness can be controlled in two ways: First, by changing the number of occupants. Even if the SPL is constant, roughness increases with decreasing number of occupants. Second, by changing reverberation times. Roughness increases as reverberation time decreases, even when the total SPL is constant. The listening test results suggest a relationship, however weak, between low roughness and high acoustic comfort. If reverberation time is to be increased in order to lower roughness, a trade-off is involved since lower reverberation times are known to be preferred in eating establishments. A balance should be provided, between these two conflicting parameters that are both inversely related to acoustic comfort, and, at the same time, inversely related to each other.

Considering five studied eating establishment cases, KEY has a high acoustic comfort rate with a configuration of low reverberation time, low loudness, high sharpness and low roughness. YM has the opposite configuration, and thus, a low acoustic comfort rate. Based on this model, improvements need to be done in YM in order to change the acoustic comfort level from L, to M or H. In YM, the change that will make the most impact would be decreasing the reverberation time using more sound absorbing materials. RT can be lowered from 1.9 seconds to below 1.4 seconds into M range. Installing an acoustic ceiling would achieve this performance level. Alternatively, baffles can hung, upholstered seats can replace plastic chairs, or additional absorptive panels can be placed on walls.

These improvements on reverberation time will also positively affect the sound pressure level inside the eating establishment reducing loudness. The average loudness in YM needs to be decreased from 28.53 sones to 25 sones or less, into the M range. If the reduction in RT is not adequate, in order to decrease loudness further, the number of persons inside the eating establishment could be reduced by limiting the number of chairs and tables. Yet, this will of course have an adverse effect on the revenue of the establishment. Furthermore, it should be noted that reverberation time and roughness parameters have a trade-off and decreasing RT will increase roughness that is already rated as H.

Sharpness is low in YM and in order to take it to a degree of M or H, sound sources can be controlled. The average sharpness value in YM is 1.18 acum and in order to take it to the M range, a value of 1.25 acum or higher is needed. Apart from human conversation, in YM, common sound sources are tableware, air conditioning system, and chairs being pushed. In YM, the most effective increase in sharpness can be achieved through decreasing the low frequency noise of air conditioning systems. Also, to increase sharpness, during RT adjustments, more absorption should be provided for low frequencies compared to high frequencies.

Roughness in YM is high and should be lowered to a degree of M or L. It has a value of 0.34 asper and it needs to be reduced to 0.30 asper or lower. In order to control roughness and decrease it, reverberation time can be increased as the first method. However, since reducing RT in YM is simple and has positive effects on other parameters, increasing it should not be preferred. The second method for reducing roughness involves increasing the number of occupants. This improvement can be done by increasing the number of tables and chairs in an eating establishment. However, this would increase loudness – another trade-off.

To sum up, in YM, increasing sound absorbing materials especially for low frequencies, will improve reverberation time, loudness, and sharpness. Roughness will increase but is already too high. In order to lower roughness, more seating can be added, but this will start offsetting the improvement in loudness. This trade-off needs to be investigated for YM.

The total effect of the above mentioned improvements could take the overall acoustic comfort from L to M or H, depending on the degree of the changes. Improvements can be planned similarly, for other eating establishment case studies CA, MD and TE. As more cases are investigated using the psychoacoustic parameter based analysis model presented, the model may allow effective evaluation of options for improving acoustic comfort in eating establishments.

A summary of research findings about studied acoustic and psychoacoustic parameters and their relationships with subjective evaluations based on questionnaires and listening tests are given as Table 6.3. This table includes also design implications about psychoacoustic parameters sharpness and roughness.

Table 6.3. Summary of findings about parameters.

Parameters	Research findings and design implications	
Reverberation Time	Acoustic comfort rises when RT falls. (Valid for examined range: 0.5 – 1.9 s.)	
SPL and Loudness	SPL and Loudness rise with increasing number of occupants. Acoustic comfort decreases with increasing loudness.	
Sharpness	Findings	Better acoustic comfort is related with higher sharpness values. (Valid for examined range: 1.15 – 1.45 acum.)
	Design Implications	Sharpness can be controlled through changing source characteristics (high or low pitched) and surface materials (sound absorption coefficients).
Roughness	Findings	Privacy concerns decrease as roughness increases. Lower roughness is slightly preferred in terms of acoustic comfort, independent of sound level.
	Design Implications	Roughness can be controlled through changes in RT (inverse relationship) or number of occupants (inverse relationship).
Fluctuation Strength		No relationship to other parameters and no control methods are discovered. Lower fluctuation strength is slightly preferred in terms of acoustic comfort, independent of sound level.

6.2. Contributions

This dissertation on the effectiveness of utilizing psychoacoustic parameters loudness, sharpness, roughness and fluctuation strength for defining acoustic comfort in eating establishments, makes the following four contributions:

- Better acoustic comfort is shown to be related with higher sharpness and lower roughness values within the examined parameter ranges, for the five investigated cases.
- A characterization of the ambient noise in university dining halls using psychoacoustic parameters for analysis has been done.
- How psychoacoustic parameters are affected by the changing number of occupants in eating establishments is determined.
- The relationship of common design parameters and psychoacoustic values is explored for enclosed spaces.

6.3. Future work

Listening tests have advantages. For example, they provide the ability to listen to samples from multiple environments in quick succession and compare them. In the field, the participants are not be able to completely remember their impressions from the previous space visited. Yet, listening tests have some disadvantages as well. For example, participants are not exposed to the space and the durations of the sounds need to be limited. Therefore the comparison is between two sounds listened through headphones, rather than two acoustic environments. A follow up study that involves retrofitting in one or two eating establishments will complement the findings of this study when questionnaires are conducted before and after retrofitting. The retrofitting can be planned in multiple phases where a new element that affects the acoustic performance is introduced to the space in each phase, creating environments with varying values for psychoacoustic parameters. Furthermore, the study could repeat the listening tests in a listening room rather than using headphones and allow a longer exposure to the sound in an immersive setting.

The configurations of parameters and the resulting acoustic comfort rates can be controlled through improvements in an increased number of eating establishment cases as further research. The improvements can be done as on-site treatments and corresponding on-site objective and subjective data can be collected in order to be evaluated comparatively, in terms of psychoacoustic parameters and acoustic comfort.

The proposed model is applicable for spaces like cafes, restaurants, dining halls, shopping malls, foyers, lobbies and all types of enclosed spaces with various functions, where the number of occupants increase or decrease in a certain time period and where users are able to have a conversation. Further research in the mentioned spaces could take this research a step further.

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APPENDIX A

A SAMPLE OF ON-SITE QUESTIONNAIRES

Akustik Konfor Anketi (Anket yaklaşık 2 dakika sürer)

İçinde bulunduğunuz mekanın adı:

•Cinsiyetiniz: ☐ Kadın ☐ Erkek

•Yaşınız:

•Eğitim durumunuz: ☐ İlkokul ☐ Ortaokul ☐ Lise ☐ Lisans ☐ Yüksek Lisans ☐ Doktora

•Bu mekana/restorana geliş sıklığınız nedir?

☐ Ayda 1-2 kez ☐ Haftada 1-2 kez ☐ Haftada 2'den fazla

•Soru 1: İçinde bulunduğunuz mekanın gürültü seviyesini değerlendiriniz.

Çok sakin ☐1 – ☐2 – ☐3 – ☐4 – ☐5 Çok gürültülü

•Soru 2: Karşınızdaki kişi ile rahatça konuşabiliyor musunuz?

Konuştuklarımızı hiç anlamıyoruz ☐1 – ☐2 – ☐3 – ☐4 – ☐5 Konuştuklarımızı çok iyi duyuyoruz

•Soru 3: Konuşmalarınızın diğer masalardan duyulduğunu hissedip çekiniyor musunuz?

Hiç çekinmiyorum ☐1 – ☐2 – ☐3 – ☐4 – ☐5 Çok çekiniyorum

•Soru 4: İçinde bulunduğunuz mekanın akustik konforunu genel olarak değerlendiriniz.

Çok kötü ☐1 – ☐2 – ☐3 – ☐4 – ☐5 Çok iyi

•Soru 5: Mekandaki yansıma / çınlamayı değerlendiriniz.

Hiç rahatsız edici değil ☐1 – ☐2 – ☐3 – ☐4 – ☐5 Çok rahatsız edici

•Soru 6: Bu anketi yaparken en rahatsız olduğunuz ses nedir?

•Soru 7: Bu anketi yaparken algıladığınız en baskın ses nedir?

Figure A. 1. An on-site questionnaire sample in Turkish language.

APPENDIX B

A SAMPLE OF LISTENING TESTS



İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
SOSYAL ve BEŞERİ BİLİMLERİ
BİLİMSEL ARAŞTIRMA VE YAYIN ETİK KURULU

BİLGİLENDİRİLMİŞ ONAM FORMU

LÜTFEN BU DÖKÜMANI DİKKATLİCE OKUMAK İÇİN ZAMAN AYIRINIZ

Sizi Doç. Dr. Mustafa Emre İLAL tarafından yürütülen “Kapalı kamusal mekanlarda akustik konfor değerlendirmesi için bir model” başlıklı **araştırmaya** davet ediyoruz. Bu araştırmaya katılıp katılmama kararını vermeden önce, araştırmanın neden ve nasıl yapılacağını bilmeniz gerekmektedir. Bu nedenle bu formun okunup anlaşılması büyük önem taşımaktadır. Eğer anlayamadığınız ve sizin için açık olmayan şeyler varsa, ya da daha fazla bilgi isterseniz bize sorunuz.

Bu çalışmaya katılmak tamamen **gönüllülük** esasına dayanmaktadır. Çalışmaya **katılmama** veya katıldıktan sonra herhangi bir anda çalışmadan **çıkma** hakkında sahipsiniz. **Çalışmayı yanıtlamanız, araştırmaya katılım için onam verdiğiniz** biçiminde yorumlanacaktır. Size verilen **formlardaki** soruları yanıtlarken kimsenin baskısı veya telkini altında olmayın. Bu formlardan elde edilecek kişisel bilgiler tamamen gizli tutulacak ve yalnızca araştırma amacı ile kullanılacaktır.

1. Araştırmayla İlgili Bilgiler:

- Araştırmanın Amacı: Psikoakustik parametrelerin yemek mekanlarında akustik konfor üzerinde etkisinin incelenmesi.
- Araştırmanın İçeriği: Yemek mekanlarına ait ses kayıtlarının ve bilgisayar modellerinden elde edilen seslerin katılımcılara dinletilerek değerlendirilmesine dayanan anket çalışması.
- Araştırmanın Nedeni: ☐ Özgün araştırma ☒ Tez çalışması
- Araştırmanın Öngörülen Süresi (*Araştırma takviminde öngörülen süredir*): 6 hafta
- Araştırmaya Katılması Beklenen Katılımcı/Gönüllü Sayısı: 50
- Araştırmanın Yapılacağı Yer(ler): İYTE Mimarlık Fakültesi

2. Çalışmaya Katılım Onayı:

Yukarıda yer alan ve araştırmadan önce katılımcıya/gönüllüye verilmesi gereken bilgileri okudum ve katılmam istenen çalışmanın kapsamını ve amacını, gönüllü olarak üzerime düşen sorumlulukları tamamen anladım. **Çalışma hakkında yazılı ve sözlü açıklama aşağıda adı belirtilen araştırmacı tarafından yapıldı, soru sorma ve tartışma imkanı buldum ve tatmin edici yanıtlar aldım. Bana, çalışmanın muhtemel riskleri ve faydaları sözlü olarak da anlatıldı.** Bu çalışmayı istediğim zaman ve herhangi bir neden belirtmek zorunda kalmadan bırakabileceğimi ve bıraktığım takdirde herhangi bir olumsuzluk ile karşılaşmayacağımı anladım.

Bu koşullarda söz konusu araştırmaya kendi isteğimle, hiçbir baskı ve zorlama olmaksızın katılmayı kabul ediyorum.

Katılımcının (Kendi el yazısı ile)

Adı-Soyadı:.....
İmzası:

(Varsa) Velayet veya Vesayet Altında Bulunanlar İçin:

Veli veya Vasisinin (kendi el yazısı ile)

Adı-Soyadı:.....
İmzası:

Not: Bu form, iki nüsha halinde düzenlenir. Bu nüshalardan biri imza karşılığında gönüllü kişiye verilir, diğeri araştırmacı tarafından saklanır.

Yürütücünün;

Adı Soyadı ve İmzası

(Varsa) Danışmanın;

Adı Soyadı ve İmzası

(Varsa) Diğer araştırmacıların;

Adı Soyadı ve İmzası

* Bilgilendirilmiş onam formu, bütün araştırmacılar tarafından imzalanmalıdır.

Figure B. 1. First page of the listening test sample in Turkish language.

Yemekhane ses ortamı değerlendirme anketi

•Cinsiyetiniz: ☐ Kadın ☐ Erkek

•Yaşınız:

Bu anket, yemek mekanlarında akustik konforun araştırıldığı bir doktora tez çalışmasının bir parçasıdır. Lütfen tüm anket boyunca dinleyeceğiniz ses ortamların değerlendirirken, cevaplarınızı bu yemek mekanlarında uzun süre bulunduğunuzu hayal ederek veriniz.

1. Bölüm:

(4 farklı mekan için 70 kişilik durumların yerinde yapılmış kayıtlar dinletilerek değerlendirilmesi)

A) Mekanlara ait fotoğraflara bakarak dinleyeceğiniz 5 ses ortamını akustik konfor açısından 1 (Çok kötü) – 5 (Çok iyi) arasında puan vererek değerlendiriniz.

	CA	MD	TE	YM	X
Değerlendirme					

B) Arka arkaya dinleyeceğiniz ikili ses dosyalarını karşılaştırmalı olarak değerlendiriniz.

Puanlamayı hangi ses ortamında bulunmayı tercih ettiğinizi ve tercih ettiğiniz ortamın diğerine kıyasla akustik konfor açısından ne kadar daha iyi olduğunu değerlendirerek yapınız.

Birinci ses	5 (Son derece iyi)	4 (Çok idaha yi)	3 (Oldukça iyi)	2 (Biraz daha iyi)	1 (Eşit seviyede)	2 (Biraz daha iyi)	3 (Oldukça iyi)	4 (Çok daha iyi)	5 (Son derece iyi)	İkinci ses
CA										MD
CA										TE
CA										YM
MD										TE
MD										YM
TE										YM

Figure B. 2. Second page of the listening test sample in Turkish language.

2. Bölüm:

(4 farklı mekan için 70 kişilik durumların *Odeon ses dosyaları* dinletilerek değerlendirilmesi)

A) Dinleyeceğiniz 5 ses ortamını akustik konfor açısından 1 (Çok kötü) – 5 (Çok iyi) arasında puan vererek değerlendiriniz.

	S1	S2	S3	S4	S5
Değerlendirme					

B) Arka arkaya dinleyeceğiniz ikili ses dosyalarını karşılaştırmalı olarak değerlendiriniz.

Puanlamayı hangi ses ortamında bulunmayı tercih ettiğinizi ve tercih ettiğiniz ortamın diğerine kıyasla akustik konfor açısından ne kadar daha iyi olduğunu değerlendirerek yapınız.

Birinci ses	5 (Son derece iyi)	4 (Çok daha iyi)	3 (Oldukça iyi)	2 (Biraz daha iyi)	1 (Eşit seviyede)	2 (Biraz daha iyi)	3 (Oldukça iyi)	4 (Çok daha iyi)	5 (Son derece iyi)	İkinci ses
S1										S2
S1										S2
S1										S2
S1										S2
S1										S2
S1										S2

3. Bölüm:

(3 farklı *keskinlik* değerine sahip yemekhane seslerinin değerlendirilmesi)

Arka arkaya dinleyeceğiniz ikili ses dosyalarını karşılaştırmalı olarak değerlendiriniz.

Puanlamayı hangi ses ortamında bulunmayı tercih ettiğinizi ve tercih ettiğiniz ortamın diğerine kıyasla akustik konfor açısından ne kadar daha iyi olduğunu değerlendirerek yapınız.

Birinci ses	5 (Son derece iyi)	4 (Çok daha iyi)	3 (Oldukça iyi)	2 (Biraz daha iyi)	1 (Eşit seviyede)	2 (Biraz daha iyi)	3 (Oldukça iyi)	4 (Çok daha iyi)	5 (Son derece iyi)	İkinci ses
S1										S2
S1										S2
S1										S2

Figure B. 3. Third page of the listening test sample in Turkish language.

4. Bölüm:

(3 farklı *kabalık* değerine sahip yemekhane seslerinin değerlendirilmesi)

- A) **Arka arkaya dinleyeceğiniz ve kişi sayılarının sabit olduğu ikili ses dosyalarını karşılaştırmalı olarak değerlendiriniz.** Puanlamayı hangi ses ortamında bulunmayı tercih ettiğinizi ve tercih ettiğiniz ortamın diğerine kıyasla akustik konfor açısından ne kadar daha iyi olduğunu değerlendirerek yapınız.

Birinci ses	5 (Son derece iyi)	4 (Çok daha iyi)	3 (Oldukça iyi)	2 (Biraz daha iyi)	1 (Eşit seviyede)	2 (Biraz daha iyi)	3 (Oldukça iyi)	4 (Çok daha iyi)	5 (Son derece iyi)	İkinci ses
S1										S2
S1										S2
S1										S2

- B) **Arka arkaya dinleyeceğiniz ve çınlama sürelerinin sabit olduğu ikili ses dosyalarını karşılaştırmalı olarak değerlendiriniz.** Puanlamayı hangi ses ortamında bulunmayı tercih ettiğinizi ve tercih ettiğiniz ortamın diğerine kıyasla akustik konfor açısından ne kadar daha iyi olduğunu değerlendirerek yapınız.

Birinci ses	5 (Son derece iyi)	4 (Çok daha iyi)	3 (Oldukça iyi)	2 (Biraz daha iyi)	1 (Eşit seviyede)	2 (Biraz daha iyi)	3 (Oldukça iyi)	4 (Çok daha iyi)	5 (Son derece iyi)	İkinci ses
S1										S2
S1										S2
S1										S2

Figure B. 4. Fourth page of the listening test sample in Turkish language.

APPENDIX C

A SAMPLE OF MEDICAL AUDIOMETRY REPORT

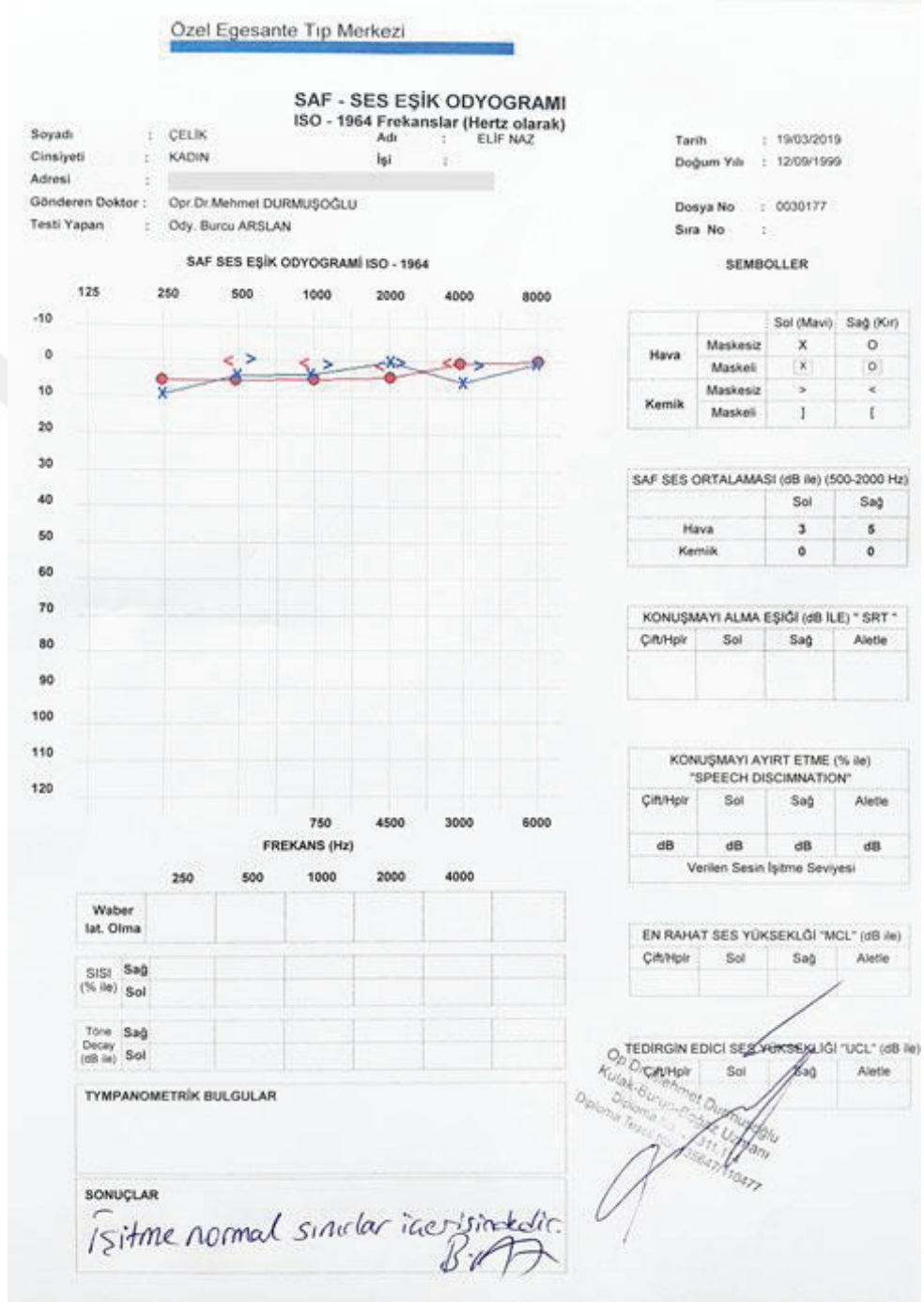


Figure C. 1. A sample of medical hearing test report.

APPENDIX D

RESEARCH ETHICS COMMITTEE APPROVAL



İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
BİLİMSEL ARAŞTIRMA VE YAYIN ETİĞİ KURULU

TARİH : 21.03.2019
YER : İYTE
KATILIMCILAR : Etik Kurul Başkanı; Prof. Dr. Şeniz ÇIKIŞ
Etik Kurul Başkan Yardımcısı; Prof. Dr. Tahsin BAŞARAN
Etik Kurul Üyesi; Prof. Dr. Başak İPEKOĞLU
Etik Kurul Üyesi; Prof. Dr. A.Nuri BAŞOĞLU
Etik Kurul Üyesi; Prof. Dr. Koray KORKMAZ
Etik Kurul Üyesi; Prof. Dr. Serdar KALE
Etik Kurul Üyesi; Prof. Dr. Z. Tuğçe KAZANASMAZ

BİLİMSEL ARAŞTIRMA VE YAYIN ETİĞİ KURULU PROJE ONAY FORMU	
Projenin Adı	Kapalı kamusal mekanlarda akustik konfor değerlendirmesi için bir model
Projenin Yürütücüsü	Doç. Dr. Mustafa Emre İLAL
Projenin Süresi	6 hafta
Projenin Niteliği	Doktora tezi / Anket çalışması
Proje Yürütücüsünün Haberleşme Bilgileri	Email: emreilal@iyte.edu.tr Telefon: 05336419925
Projenin Amacı	Kapalı kamusal alanlarda bir değerlendirme kriteri olarak sıklıkla kullanılan reverberasyon süresi, konforu tanımlamada tek başına yeterli olmamaktadır. Bu parametreye ek olarak, psikoakustik değerlerin kullanıcıların akustik açıdan mekanı değerlendirmelerine etkisi araştırılarak, mekanlarda bu parametrelerin hangi aralıklarda olduğu durumların konfor açısından optimum şartları sağladığını bulmak, çalışmanın temel hedeflerinden biridir. Dinleme anketi ile, kullanıcıların farklı değerlere sahip bu parametreleri nasıl değerlendirdikleri incelenecektir. Anket sonucunda çıkacak veriler nesnel veriler ile karşılaştırılarak, yemek mekanları için psikoakustik parametrelerdeki değişimin kullanıcı memnuniyeti üzerindeki etkisi hakkında sonuçlara varılması beklenmektedir.
Uygulanacak Yöntem	Veri toplama aracı olarak, katılımcılara dinleme anketleri uygulanacaktır. Katılımcılara yemek mekanlarına ait oluşturulan ses dosyaları kulaklıkla dinletilecek; ikili karşılaştırma ve sürekli değerlendirme yöntemleri üzerinden bu sesleri değerlendirmeleri istenecektir. Dinleme anketleri, İYTE Mimarlık Fakültesi'nde gerçekleştirilecektir. Anketler sırasında katılımcılar, kulaklıkla dinleyecekleri sesleri akustik konfor açısından değerlendirecektir. Anket sonuçları, ses dosyalarının psikoakustik parametreleri ile karşılaştırılacaktır. Ses dosyalarına ait nesnel psikoakustik değerler, dBsonic yazılımı ile hesaplanmıştır. Anket sonucunda çıkacak olan

Figure D. 1. First page of the research ethics committee approval.



**İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
BİLİMSEL ARAŞTIRMA VE YAYIN ETİĞİ KURULU**

	öznel değerlendirmeler, nesnel değerler ile Excel ve SPSS yazılımları aracılığıyla karşılaştırılarak değerlendirilecektir.
Kullanılacak biyolojik, psikolojik, teknik vb. tüm yöntemleri açıklayan etik ile ilgili özet	Katılımcılar, gönüllülük esasıyla ankete katılacaklardır. Uygulanacak anket, toplamda yaklaşık 15 dakika sürecektir. Katılımcılara hem yerinde yapılmış ses kayıtları, hem de bilgisayar ortamında benzetim yöntemi ile oluşturulmuş ve psikoakustik parametreler açısından aynı yemek mekanlarını temsil eden ses dosyaları dinletilerek, bunları akustik konfor açısından değerlendirmeleri istenecektir. Kulaklıkla dinletilecek olan yemek mekanı sesleri, kullanıcıların günlük hayatta karşılaştıkları seslere benzerdir ve bu sesler katılımcıların sağlıklarında fiziksel ve ruhsal açıdan bir sorun oluşturmayacak seviyededir.

İzmir Yüksek Teknoloji Enstitüsü Mimarlık Fakültesi Mimarlık Bölümü Öğretim Üyesi Doç. Dr. Mustafa Emre İLAL'ın yürütücüsü olduğu "Kapalı Kamusal Mekanlarda Akustik Konfor Değerlendirmesi İçin Bir Model" adlı proje değerlendirilmiştir.

Proje etik açısından uygun bulunmuştur. ☒

Proje etik açısından geliştirilmesi gerekmektedir. ☐

Proje etik açısından uygun bulunmamıştır. ☐

BAŞKAN

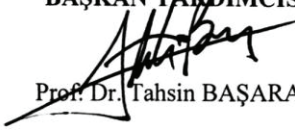
Prof. Dr. Şeniz ÇIKIŞ

Figure D. 2. Second page of the research ethics committee approval.

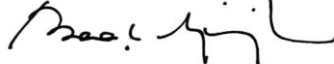


**İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
BİLİMSEL ARAŞTIRMA VE YAYIN ETİĞİ KURULU**

BAŞKAN YARDIMCISI


Prof. Dr. Tahsin BAŞARAN

ÜYE


Prof. Dr. Başak İPEKOĞLU

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(KATILMADI)

Prof. Dr. A.Nuri BAŞOĞLU

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Prof. Dr. Koray KORKMAZ

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Prof. Dr. Serdar KALE

ÜYE


Prof. Dr. Z.Tuğçe KAZANASMAZ

Figure D. 3. Third page of the research ethics committee approval.



İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
SOSYAL VE BEŞERİ BİLİMLER BİLİMSEL ARAŞTIRMA VE YAYIN
ETİĞİ KURULU

KARAR BELGESİ

ARAŞTIRMACININ / PROJE YÜRÜTÜCÜSÜNÜN ADI SOYADI / UNVANI	Doç.Dr. Mustafa Emra İLAL
BÖLÜMÜ	Mimarlık Fakültesi Mimarlık Bölümü
ARAŞTIRMANIN / PROJENİN TÜRÜ	☐ Yüksek Lisans Tezi ☐ Araştırma Projesi ☒ Doktora Tezi ☐ Diğer _____
ARAŞTIRMANIN / PROJENİN BAŞLIĞI	Kapalı Kamusal Mekanlarda Akustik Konfor değerlendirme için Bir Model
KARARIN ALINDIĞI TOPLANTI TARİHİ	21.03.2019
TOPLANTI KARAR SAYISI	1 1
KARAR	Proje toplantıya katılan üyelerin oy birliği ile etik açıdan uygun bulunmuştur.

BAŞKAN

Prof. Dr. Şeniz ÇIKIŞ

BAŞKAN YARDIMCISI

Prof. Dr. Fahsin BAŞARAN

ÜYE

Prof. Dr. Başak İPEKOĞLU

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Prof. Dr. Koray KORKMAZ

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Prof. Dr. Serdar KALE

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ÜYE

Prof. Dr. Z. Tuğçe KAZANASMAZ

Figure D. 4. Fourth page of the research ethics committee approval.

APPENDIX E

PSYCHOACOUSTIC PARAMETERS IN EATING ESTABLISHMENT SOUNDSCAPES BASED ON TIME

Table E. 1. Measurement values in CA on 23.11.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	9	56.79	9.57	1.26	0.26	0.25
2	4	9	57.41	10.33	1.45	0.29	0.27
4	6	8	57.99	10.54	1.30	0.27	0.26
6	8	10	58.86	11.22	1.36	0.32	0.27
8	10	10	60.54	14.20	1.43	0.19	0.28
10	12	11	58.78	12.42	1.19	0.26	0.27
12	14	10	56.13	10.44	1.16	0.17	0.25
14	16	14	56.72	10.75	1.24	0.19	0.26
16	18	12	54.21	9.40	1.30	0.22	0.26
18	20	12	57.74	11.28	1.30	0.22	0.26
20	22	13	57.12	11.19	1.20	0.25	0.26
22	24	13	59.77	13.06	1.21	0.23	0.27
24	26	11	58.03	11.97	1.16	0.18	0.25
26	28	12	58.01	10.85	1.23	0.23	0.25
28	30	12	55.61	9.50	1.27	0.28	0.25
30	32	10	56.02	9.55	1.23	0.27	0.24
32	34	14	57.28	10.69	1.27	0.26	0.26
34	36	14	61.33	13.20	1.19	0.27	0.27
36	38	17	62.00	14.31	1.19	0.33	0.28
38	40	20	62.97	15.05	1.20	0.30	0.28
40	42	28	61.65	14.74	1.27	0.28	0.28
42	44	29	63.74	15.90	1.23	0.32	0.28
44	46	30	66.22	18.46	1.24	0.32	0.29
46	48	25	63.77	16.61	1.23	0.28	0.28
48	50	23	63.26	15.55	1.18	0.31	0.28
50	52	19	61.76	14.15	1.32	0.28	0.27
52	54	18	63.69	15.95	1.19	0.29	0.29
54	56	27	61.55	14.36	1.21	0.24	0.26

(cont. on next page)

Table E. 1 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
56	58	21	60.28	13.08	1.24	0.24	0.27
58	60	29	62.41	14.93	1.24	0.28	0.28
60	62	24	63.51	15.58	1.19	0.29	0.27
62	64	29	64.59	16.95	1.19	0.27	0.27
64	66	25	65.96	17.70	1.20	0.27	0.28
66	68	28	66.67	18.48	1.19	0.27	0.27
68	70	33	68.16	20.24	1.18	0.27	0.29
70	72	27	68.16	20.30	1.16	0.26	0.29
72	74	26	68.86	21.41	1.15	0.25	0.30
74	76	25	68.50	21.23	1.14	0.25	0.30
76	78	22	65.90	18.55	1.13	0.21	0.27
78	80	20	66.06	17.87	1.10	0.23	0.28
80	82	17	66.65	18.91	1.17	0.29	0.28
82	84	9	59.12	12.48	1.23	0.21	0.27
84	86	9	57.51	10.66	1.24	0.23	0.25
86	88	9	55.95	9.66	1.23	0.24	0.23
88	90	6	58.77	9.56	1.20	0.27	0.26

Table E. 2. Measurement values in CA on 30.11.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	12	62.22	14.35	1.21	0.29	0.29
2	4	15	61.26	13.69	1.21	0.28	0.28
4	6	14	59.54	12.01	1.20	0.29	0.28
6	8	14	60.19	11.57	1.17	0.22	0.26
8	10	12	60.68	12.30	1.21	0.32	0.26
10	12	12	56.64	9.51	1.22	0.28	0.24
12	14	13	60.81	12.90	1.23	0.35	0.26
14	16	13	61.41	13.06	1.17	0.35	0.27
16	18	15	58.23	11.11	1.17	0.29	0.26
18	20	16	61.90	13.51	1.22	0.29	0.27
20	22	15	59.22	11.46	1.15	0.26	0.25
22	24	14	56.72	10.00	1.20	0.23	0.25
24	26	11	56.64	9.66	1.23	0.26	0.24

(cont. on next page)

Table E. 2 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
26	28	20	58.79	11.09	1.25	0.25	0.25
28	30	19	60.27	12.83	1.22	0.26	0.26
30	32	18	60.34	12.05	1.22	0.30	0.26
32	34	22	62.94	14.86	1.18	0.29	0.27
34	36	23	59.72	12.81	1.18	0.28	0.27
36	38	23	57.38	10.86	1.16	0.24	0.25
38	40	20	61.51	13.17	1.19	0.29	0.27
40	42	21	58.37	11.10	1.22	0.25	0.26
42	44	29	59.79	12.28	1.21	0.23	0.26
44	46	29	62.91	14.90	1.25	0.30	0.28
46	48	30	59.11	12.09	1.30	0.28	0.26
48	50	30	61.82	13.70	1.25	0.25	0.27
50	52	28	62.01	14.67	1.19	0.24	0.26
52	54	34	63.92	16.32	1.18	0.27	0.27
54	56	37	62.95	15.66	1.19	0.26	0.27
56	58	46	62.66	15.37	1.18	0.24	0.27
58	60	51	68.86	22.05	1.18	0.28	0.30
60	62	58	70.33	24.48	1.18	0.25	0.31
62	64	64	72.13	27.57	1.19	0.24	0.32
64	66	63	72.85	28.95	1.19	0.26	0.33
66	68	62	71.07	25.72	1.20	0.24	0.32
68	70	66	72.41	27.53	1.18	0.28	0.32
70	72	62	72.00	27.44	1.18	0.25	0.32
72	74	63	70.85	25.73	1.17	0.29	0.31
74	76	62	70.93	25.19	1.17	0.34	0.32
76	78	57	69.73	24.10	1.17	0.30	0.31
78	80	52	71.06	26.19	1.18	0.31	0.32
80	82	37	68.32	21.55	1.19	0.25	0.30
82	84	42	68.20	21.33	1.16	0.23	0.30
84	86	35	67.85	20.48	1.21	0.28	0.30
86	88	30	67.22	19.69	1.18	0.25	0.29
88	90	26	64.98	17.53	1.17	0.22	0.28
90	92	20	65.21	17.71	1.20	0.26	0.29
92	94	16	64.75	16.29	1.18	0.26	0.29
94	96	11	61.40	12.72	1.16	0.29	0.26
96	98	12	61.03	12.30	1.15	0.28	0.25
98	100	10	62.50	13.50	1.17	0.26	0.26

Table E. 3. Measurement values in CA on 04.12.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	19	61.37	13.26	1.21	0.24	0.26
2	4	19	61.70	13.88	1.18	0.21	0.25
4	6	20	62.92	14.72	1.16	0.23	0.27
6	8	23	62.23	14.32	1.15	0.24	0.25
8	10	26	63.31	15.43	1.18	0.27	0.27
10	12	25	63.01	15.42	1.18	0.23	0.26
12	14	26	63.82	15.78	1.20	0.27	0.27
14	16	28	64.42	16.36	1.20	0.27	0.27
16	18	32	66.07	18.22	1.18	0.26	0.28
18	20	35	68.73	20.94	1.18	0.23	0.29
20	22	37	67.85	20.24	1.18	0.23	0.29
22	24	37	66.45	18.94	1.16	0.24	0.29
24	26	39	66.94	19.05	1.17	0.23	0.28
26	28	34	69.23	22.11	1.18	0.24	0.30
28	30	43	67.52	20.10	1.17	0.23	0.29
30	32	42	67.90	20.58	1.19	0.25	0.30
32	34	49	67.69	20.04	1.17	0.20	0.29
34	36	50	68.39	21.54	1.16	0.22	0.30
36	38	43	69.01	22.24	1.16	0.23	0.30
38	40	39	67.60	20.37	1.18	0.22	0.30
40	42	46	71.00	24.71	1.17	0.23	0.31
42	44	47	69.66	22.77	1.18	0.22	0.30
44	46	38	70.78	23.52	1.17	0.25	0.31
46	48	30	69.03	20.01	1.16	0.27	0.29
48	50	29	69.40	21.75	1.18	0.28	0.30
50	52	31	69.67	22.60	1.20	0.29	0.30
52	54	31	68.44	21.02	1.19	0.26	0.29
54	56	27	67.67	19.81	1.21	0.25	0.29
56	58	26	69.56	21.41	1.21	0.30	0.30
58	60	28	66.83	17.68	1.17	0.28	0.28
60	62	29	64.04	15.50	1.18	0.25	0.27
62	64	33	66.11	17.73	1.18	0.21	0.28
64	66	29	65.26	17.45	1.17	0.22	0.28
66	68	24	62.07	14.03	1.18	0.22	0.26
68	70	18	60.03	12.24	1.21	0.22	0.25
70	72	15	60.69	12.63	1.22	0.29	0.27
72	74	14	64.31	15.30	1.20	0.24	0.27
74	76	12	61.02	12.59	1.20	0.21	0.25

Table E. 4. Measurement values in MD on 17.03.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
0	2	4	49.61	4.39	1.48	0.16	0.32
2	4	4	50.85	5.07	1.41	0.24	0.28
4	6	5	47.29	3.99	1.55	0.16	0.34
6	8	5	45.48	4.62	1.48	0.17	0.29
8	10	13	52.25	6.73	1.42	0.27	0.28
10	12	21	59.63	10.98	1.36	0.41	0.32
12	14	30	64.47	15.75	1.34	0.41	0.33
14	16	33	66.88	16.92	1.29	0.52	0.32
16	18	33	61.50	12.40	1.29	0.43	0.29
18	20	36	59.65	11.60	1.31	0.37	0.28
20	22	45	67.22	18.79	1.23	0.31	0.32
22	24	45	66.67	19.58	1.21	0.30	0.32
24	26	52	65.15	19.20	1.19	0.28	0.31
26	28	59	66.31	20.41	1.21	0.27	0.31
28	30	59	68.15	22.60	1.19	0.25	0.32
30	32	61	68.14	22.03	1.22	0.31	0.33
32	34	58	68.31	22.04	1.19	0.33	0.32
34	36	60	66.61	20.62	1.18	0.29	0.31
36	38	61	67.48	21.08	1.19	0.32	0.32
38	40	59	66.62	20.33	1.18	0.27	0.32
40	42	61	69.12	22.90	1.17	0.28	0.32
42	44	61	68.71	22.90	1.19	0.29	0.32
44	46	59	67.47	21.84	1.20	0.28	0.32
46	48	58	69.20	23.41	1.18	0.27	0.32
48	50	60	67.88	22.15	1.19	0.27	0.32
50	52	64	70.26	24.73	1.19	0.31	0.33
52	54	72	71.01	25.45	1.19	0.34	0.34
54	56	71	69.45	24.42	1.20	0.26	0.33
56	58	63	70.35	23.32	1.21	0.32	0.33
58	60	76	68.03	21.86	1.21	0.30	0.34
60	62	83	70.63	25.48	1.19	0.30	0.32
62	64	99	71.45	26.90	1.17	0.29	0.33
64	66	114	71.69	26.92	1.19	0.28	0.32
66	68	119	71.59	27.37	1.21	0.30	0.34
68	70	120	72.44	29.01	1.20	0.29	0.34
70	72	127	72.33	27.92	1.22	0.37	0.35
72	74	137	73.93	29.19	1.22	0.40	0.38

(cont. on next page)

Table E. 4 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
74	76	143	72.37	28.33	1.22	0.31	0.34
76	78	137	72.92	29.30	1.20	0.32	0.33
78	80	139	72.60	29.16	1.20	0.31	0.34
80	82	130	72.92	29.67	1.19	0.31	0.33
82	84	127	74.68	32.10	1.22	0.35	0.35
84	86	116	72.15	28.05	1.19	0.30	0.33
86	88	114	73.43	30.24	1.21	0.34	0.35
88	90	97	73.15	29.49	1.20	0.34	0.34
90	92	76	72.17	27.84	1.18	0.33	0.33
92	94	66	74.01	28.93	1.21	0.43	0.34
94	96	52	73.12	27.68	1.22	0.43	0.33
96	98	33	69.63	22.65	1.17	0.33	0.32
98	100	20	66.03	18.85	1.18	0.26	0.30
100	102	16	66.94	19.76	1.18	0.28	0.32
102	104	10	65.26	17.96	1.15	0.22	0.30
104	106	10	67.84	19.42	1.16	0.34	0.33
106	108	8	66.59	18.20	1.16	0.33	0.32
108	110	7	69.14	19.70	1.15	0.42	0.33
110	112	4	70.84	20.18	1.19	0.54	0.37
112	114	4	73.61	19.73	1.20	0.77	0.35
114	116	3	73.60	16.87	1.27	1.16	0.47
116	118	3	68.00	11.33	1.29	0.65	0.34
118	120	3	67.09	10.88	1.31	0.67	0.30

Table E. 5. Measurement values in MD on 31.03.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min		dBA	sone	acum	vacil	asper
0	2	25	63.10	16.73	1.19	0.28	0.32
2	4	25	63.00	16.34	1.16	0.26	0.30
4	6	27	62.30	16.22	1.19	0.25	0.30
6	8	27	63.10	16.71	1.17	0.27	0.30
8	10	27	62.59	16.57	1.16	0.22	0.30
10	12	29	63.51	17.14	1.17	0.25	0.30
12	14	21	63.20	16.64	1.16	0.20	0.30

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Table E. 5 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min		dBA	sone	acum	vacil	asper
14	16	18	61.85	15.76	1.15	0.21	0.29
16	18	22	62.47	16.14	1.15	0.19	0.29
18	20	21	62.63	16.35	1.14	0.19	0.30
20	22	19	63.82	17.46	1.16	0.19	0.29
22	24	23	64.20	17.77	1.20	0.26	0.30
24	26	28	65.21	18.34	1.18	0.25	0.30
26	28	36	66.55	20.06	1.19	0.27	0.31
28	30	46	66.48	20.32	1.20	0.29	0.31
30	32	46	68.43	21.11	1.19	0.33	0.31
32	34	53	68.18	21.22	1.20	0.35	0.32
34	36	59	69.12	22.88	1.21	0.29	0.31
36	38	65	68.51	22.66	1.20	0.27	0.32
38	40	67	69.23	23.55	1.18	0.28	0.31
40	42	70	69.37	23.63	1.20	0.29	0.31
42	44	74	71.49	25.74	1.19	0.33	0.31
44	46	73	72.73	26.99	1.19	0.37	0.32
46	48	77	68.93	23.21	1.23	0.32	0.31
48	50	74	69.67	24.13	1.18	0.28	0.32
50	52	90	70.91	25.71	1.19	0.30	0.32
52	54	103	71.15	26.30	1.18	0.29	0.33
54	56	113	72.71	27.49	1.16	0.28	0.33
56	58	116	71.28	26.65	1.20	0.31	0.33
58	60	124	71.64	26.93	1.19	0.29	0.34
60	62	135	71.77	27.10	1.21	0.29	0.34
62	64	125	71.52	27.00	1.19	0.28	0.33
64	66	130	70.78	26.03	1.20	0.28	0.33
66	68	126	70.65	25.80	1.21	0.32	0.34
68	70	132	72.13	28.20	1.20	0.26	0.34
70	72	132	71.06	26.93	1.20	0.26	0.34
72	74	119	71.20	26.91	1.20	0.26	0.33
74	76	112	70.92	26.32	1.21	0.27	0.33
76	78	100	70.67	25.78	1.19	0.26	0.33
78	80	83	69.23	23.55	1.19	0.26	0.32
80	82	83	70.78	26.09	1.21	0.30	0.33
82	84	76	71.35	26.26	1.19	0.27	0.32
84	86	67	71.90	26.63	1.18	0.31	0.32
86	88	54	70.71	24.68	1.16	0.28	0.32

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Table E. 5 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min		dBA	sone	acum	vacil	asper
88	90	41	66.93	20.24	1.15	0.25	0.30
90	92	35	66.52	19.98	1.16	0.26	0.29
92	94	28	68.91	21.64	1.19	0.36	0.31
94	96	20	67.53	19.27	1.23	0.38	0.33
96	98	18	68.29	20.25	1.21	0.38	0.33
98	100	14	67.47	19.70	1.20	0.35	0.33
100	102	9	64.85	17.61	1.16	0.21	0.30
102	104	9	66.38	17.93	1.14	0.28	0.30
104	106	6	61.11	14.67	1.15	0.16	0.29
106	108	2	59.69	14.14	1.15	0.09	0.28
108	110	0	59.23	13.70	1.13	0.06	0.27
110	112	0	59.78	13.83	1.13	0.07	0.28
112	114	0	58.87	13.44	1.13	0.04	0.28
114	116	0	58.86	13.49	1.12	0.02	0.27
116	118	0	58.95	13.46	1.12	0.07	0.28
118	120	0	58.67	13.38	1.12	0.04	0.28

Table E. 6. Measurement values in MD on 07.04.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min		dBA	sone	acum	vacil	asper
0	2	6	52.32	6.36	1.40	0.31	0.31
2	4	6	51.50	5.69	1.46	0.33	0.25
4	6	6	53.89	6.77	1.43	0.37	0.27
6	8	9	53.97	7.32	1.38	0.32	0.28
8	10	13	56.47	8.12	1.36	0.39	0.29
10	12	15	54.70	8.20	1.41	0.38	0.30
12	14	18	56.08	8.41	1.38	0.39	0.29
14	16	24	57.30	10.25	1.33	0.37	0.30
16	18	23	62.03	11.71	1.30	0.43	0.31
18	20	26	56.96	10.05	1.33	0.40	0.29
20	22	30	57.57	10.54	1.33	0.40	0.29
22	24	33	60.44	12.38	1.33	0.44	0.31
24	26	30	60.35	12.46	1.28	0.40	0.29
26	28	32	61.34	13.66	1.24	0.34	0.28

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Table E. 6 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min		dBA	sone	acum	vacil	asper
28	30	33	62.85	14.42	1.30	0.40	0.31
30	32	31	64.46	15.30	1.28	0.47	0.31
32	34	36	64.83	16.39	1.28	0.37	0.32
34	36	34	64.06	15.11	1.26	0.44	0.33
36	38	36	62.63	14.19	1.25	0.38	0.30
38	40	35	64.08	15.92	1.24	0.38	0.31
40	42	39	65.93	16.63	1.23	0.42	0.30
42	44	45	65.66	17.89	1.23	0.33	0.30
44	46	57	68.03	21.11	1.20	0.30	0.30
46	48	67	68.52	21.67	1.20	0.33	0.31
48	50	75	68.50	22.10	1.21	0.32	0.31
50	52	87	70.36	24.80	1.24	0.30	0.33
52	54	91	72.47	26.63	1.22	0.34	0.34
54	56	95	70.85	25.04	1.23	0.35	0.36
56	58	106	71.13	25.94	1.22	0.33	0.33
58	60	117	70.14	24.31	1.23	0.31	0.33
60	62	116	70.24	24.92	1.23	0.29	0.32
62	64	108	70.23	24.07	1.22	0.36	0.33
64	66	110	70.18	24.50	1.19	0.28	0.32
66	68	114	70.49	24.81	1.21	0.32	0.33
68	70	101	71.29	25.42	1.23	0.34	0.34
70	72	83	68.42	21.82	1.22	0.29	0.32
72	74	77	70.16	24.12	1.21	0.32	0.34
74	76	74	70.87	25.19	1.23	0.35	0.35
76	78	63	69.11	21.39	1.23	0.42	0.36
78	80	59	69.04	22.22	1.23	0.35	0.36
80	82	55	69.36	22.10	1.23	0.42	0.36
82	84	42	66.78	18.75	1.20	0.38	0.31
84	86	41	66.50	18.76	1.20	0.30	0.30
86	88	33	68.50	19.70	1.22	0.39	0.31
88	90	25	64.20	13.90	1.24	0.47	0.30
90	92	20	62.28	13.44	1.23	0.46	0.30
92	94	17	61.91	13.09	1.28	0.43	0.30
94	96	8	62.37	12.12	1.28	0.47	0.28
96	98	6	63.68	12.62	1.27	0.47	0.32
98	100	6	57.39	8.30	1.28	0.41	0.28

Table E. 7. Measurement values in TE on 08.11.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	9	61.19	10.85	1.29	0.50	0.27
2	4	11	60.29	11.12	1.28	0.54	0.29
4	6	13	60.98	11.39	1.28	0.57	0.31
6	8	14	62.33	12.09	1.29	0.54	0.30
8	10	17	65.95	15.98	1.25	0.64	0.30
10	12	21	66.17	15.09	1.29	0.60	0.30
12	14	28	66.21	16.72	1.26	0.60	0.30
14	16	32	67.22	18.36	1.29	0.53	0.29
16	18	36	67.55	19.13	1.29	0.55	0.30
18	20	44	68.06	20.64	1.29	0.59	0.31
20	22	56	68.40	21.31	1.29	0.55	0.32
22	24	61	66.50	19.82	1.30	0.52	0.32
24	26	60	68.03	20.50	1.29	0.56	0.32
26	28	60	69.28	22.28	1.30	0.57	0.33
28	30	65	69.74	23.79	1.28	0.45	0.33
30	32	65	71.01	25.15	1.27	0.47	0.33
32	34	65	71.79	25.69	1.28	0.57	0.34
34	36	68	69.71	23.19	1.28	0.52	0.32
36	38	70	70.91	25.54	1.26	0.48	0.33
38	40	70	71.44	25.97	1.26	0.45	0.32
40	42	63	69.75	23.43	1.27	0.51	0.33
42	44	55	69.17	21.78	1.24	0.46	0.32
44	46	49	71.29	25.18	1.24	0.51	0.32
46	48	50	71.26	25.54	1.26	0.47	0.32
48	50	49	69.22	22.98	1.27	0.45	0.31
50	52	44	68.90	21.55	1.25	0.52	0.31
52	54	42	67.82	20.65	1.22	0.44	0.31
54	56	43	69.10	21.08	1.28	0.58	0.33
56	58	41	64.89	17.46	1.29	0.50	0.30
58	60	43	70.11	19.34	1.33	0.74	0.36
60	62	42	64.95	16.72	1.25	0.48	0.31
62	64	47	66.40	18.35	1.25	0.49	0.31
64	66	39	69.65	22.01	1.22	0.42	0.32
66	68	33	69.50	18.35	1.24	0.47	0.30
68	70	25	69.39	18.62	1.28	0.61	0.32
70	72	20	63.96	15.04	1.26	0.42	0.30
72	74	19	66.04	17.10	1.31	0.56	0.31

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Table E. 7 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
74	76	16	64.50	15.69	1.29	0.51	0.29
76	78	15	65.08	13.75	1.32	0.62	0.31
78	80	15	64.09	14.73	1.23	0.51	0.29
80	82	15	63.07	13.40	1.25	0.51	0.31
82	84	17	65.86	15.91	1.25	0.53	0.31
84	86	17	63.41	14.77	1.22	0.41	0.28
86	88	17	63.29	14.11	1.27	0.55	0.29
88	90	15	62.66	14.02	1.25	0.50	0.28
90	92	13	64.30	14.67	1.23	0.59	0.29
92	94	10	61.06	12.26	1.23	0.45	0.28
94	96	8	60.78	12.26	1.26	0.42	0.28
96	98	8	61.51	12.00	1.25	0.47	0.26
98	100	5	63.85	13.21	1.39	0.46	0.28

Table E. 8. Measurement values in TE on 15.11.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
0	2	9	60.51	11.51	1.41	0.55	0.31
2	4	9	58.23	9.68	1.51	0.58	0.30
4	6	12	60.53	12.31	1.47	0.65	0.32
6	8	18	64.70	14.66	1.33	0.65	0.31
8	10	25	62.69	13.75	1.37	0.65	0.31
10	12	26	66.38	17.76	1.29	0.57	0.30
12	14	30	65.72	17.00	1.26	0.53	0.30
14	16	31	65.85	17.59	1.31	0.56	0.31
16	18	34	65.38	16.48	1.32	0.59	0.34
18	20	38	66.37	18.52	1.29	0.51	0.30
20	22	40	69.28	22.11	1.27	0.48	0.30
22	24	42	71.07	25.05	1.22	0.49	0.31
24	26	36	70.50	24.59	1.23	0.54	0.31
26	28	38	68.93	21.64	1.28	0.53	0.31
28	30	37	67.23	19.22	1.24	0.55	0.31
30	32	37	67.66	20.00	1.23	0.53	0.30
32	34	37	64.58	15.46	1.26	0.46	0.30

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Table E. 8 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
34	36	31	62.12	13.90	1.28	0.50	0.30
36	38	29	61.82	13.23	1.17	0.30	0.29
38	40	31	63.75	15.20	1.26	0.51	0.30
40	42	30	65.00	17.04	1.29	0.53	0.31
42	44	32	65.97	16.57	1.27	0.49	0.31
44	46	26	65.83	16.01	1.36	0.71	0.33
46	48	24	64.31	15.21	1.37	0.69	0.34
48	50	19	60.67	12.50	1.31	0.51	0.31
50	52	20	59.55	12.12	1.27	0.41	0.28
52	54	22	62.74	12.91	1.26	0.41	0.29
54	56	23	64.50	16.42	1.29	0.55	0.30
56	58	25	62.89	14.35	1.26	0.51	0.30
58	60	25	61.67	12.68	1.25	0.39	0.27
60	62	27	61.74	13.26	1.26	0.42	0.28
62	64	25	65.36	15.62	1.32	0.53	0.32
64	66	22	62.70	14.30	1.25	0.31	0.28
66	68	22	61.72	13.54	1.23	0.32	0.28
68	70	22	62.93	14.52	1.23	0.38	0.29
70	72	23	61.37	12.54	1.24	0.42	0.29
72	74	21	60.78	12.54	1.23	0.41	0.27
74	76	19	64.36	15.14	1.22	0.43	0.29
76	78	16	62.45	13.82	1.26	0.43	0.30
78	80	12	62.97	13.74	1.22	0.38	0.27
80	82	11	60.22	11.92	1.21	0.38	0.27
82	84	8	60.88	12.77	1.20	0.43	0.26

Table E. 9. Measurement values in TE on 17.11.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
0	2	14	64.07	15.19	1.29	0.47	0.29
2	4	21	64.91	16.18	1.33	0.55	0.30
4	6	28	66.74	18.10	1.33	0.59	0.32
6	8	34	67.28	18.62	1.30	0.59	0.31
8	10	34	67.30	19.06	1.28	0.54	0.32

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Table E. 9 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
10	12	39	68.77	21.30	1.27	0.49	0.31
12	14	48	67.87	20.59	1.26	0.51	0.31
14	16	54	70.66	22.50	1.25	0.57	0.32
16	18	54	69.07	22.12	1.26	0.52	0.33
18	20	51	69.21	21.78	1.28	0.54	0.32
20	22	44	67.68	18.07	1.34	0.64	0.33
22	24	46	67.28	19.26	1.31	0.55	0.32
24	26	43	72.36	22.51	1.28	0.66	0.33
26	28	39	68.55	21.25	1.24	0.47	0.31
28	30	34	69.04	20.89	1.22	0.60	0.32
30	32	29	68.40	19.37	1.30	0.70	0.33
32	34	26	69.35	16.89	1.30	0.73	0.34
34	36	27	64.77	15.72	1.26	0.46	0.31
36	38	25	67.40	18.17	1.23	0.54	0.32
38	40	22	64.54	16.34	1.29	0.53	0.31
40	42	22	63.63	15.28	1.25	0.47	0.31
42	44	22	64.28	15.47	1.25	0.54	0.31
44	46	19	65.71	15.48	1.32	0.60	0.33
46	48	17	64.68	12.99	1.21	0.45	0.29
48	50	16	62.60	13.23	1.23	0.43	0.30
50	52	14	65.90	16.18	1.25	0.50	0.30
52	54	11	63.33	14.56	1.24	0.46	0.30

Table E. 10. Measurement values in YM on 19.04.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	25	66.27	18.37	1.28	0.42	0.36
2	4	26	64.97	17.70	1.37	0.45	0.32
4	6	36	64.83	17.04	1.34	0.39	0.30
6	8	35	66.06	18.52	1.30	0.35	0.31
8	10	34	65.29	18.15	1.26	0.33	0.31
10	12	34	68.68	21.64	1.27	0.40	0.37
12	14	44	66.55	19.52	1.23	0.32	0.31
14	16	53	66.37	19.27	1.25	0.34	0.31

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Table E. 10 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
16	18	58	70.84	24.49	1.20	0.34	0.33
18	20	78	71.67	26.51	1.19	0.30	0.33
20	22	98	72.83	28.79	1.16	0.25	0.33
22	24	110	73.46	30.30	1.16	0.27	0.34
24	26	118	75.18	33.03	1.15	0.25	0.35
26	28	112	76.63	36.00	1.14	0.26	0.36
28	30	120	75.98	34.92	1.15	0.26	0.36
30	32	124	74.62	32.63	1.17	0.30	0.35
32	34	129	75.32	33.74	1.16	0.27	0.36
34	36	141	76.62	36.50	1.16	0.30	0.37
36	38	141	78.04	39.87	1.17	0.27	0.38
38	40	146	78.16	39.65	1.15	0.26	0.37
40	42	134	77.78	39.14	1.16	0.24	0.38
42	44	146	78.73	41.05	1.15	0.26	0.39
44	46	148	79.37	41.78	1.15	0.26	0.39
46	48	138	77.43	37.78	1.15	0.28	0.37
48	50	137	78.03	39.04	1.15	0.24	0.38
50	52	142	77.83	38.57	1.13	0.26	0.37
52	54	141	78.69	40.47	1.14	0.25	0.39
54	56	141	78.87	41.65	1.15	0.25	0.39
56	58	144	78.47	40.02	1.16	0.27	0.38
58	60	137	78.45	40.37	1.15	0.25	0.38
60	62	129	77.42	37.99	1.15	0.25	0.38
62	64	118	77.40	38.15	1.15	0.22	0.38
64	66	119	79.30	41.21	1.13	0.26	0.39
66	68	107	76.71	35.82	1.14	0.28	0.37
68	70	97	78.70	40.61	1.16	0.25	0.39
70	72	98	79.16	41.56	1.16	0.26	0.39
72	74	92	78.22	39.21	1.14	0.23	0.38
74	76	91	78.35	39.76	1.14	0.25	0.38
76	78	90	76.99	36.39	1.16	0.29	0.36
78	80	73	74.93	32.23	1.16	0.29	0.35
80	82	58	73.29	28.47	1.13	0.30	0.33
82	84	53	72.94	28.35	1.12	0.26	0.33
84	86	55	73.30	28.47	1.12	0.27	0.32
86	88	49	73.68	28.12	1.14	0.33	0.33
88	90	30	70.50	23.82	1.19	0.38	0.31

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Table E. 10 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
90	92	26	69.80	23.26	1.19	0.35	0.32
92	94	24	70.21	24.20	1.14	0.33	0.31
94	96	22	68.59	22.33	1.16	0.35	0.31
96	98	18	69.18	20.37	1.19	0.37	0.31
98	100	16	66.07	17.55	1.14	0.43	0.30

Table E. 11. Measurement values in YM on 28.04.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
0	2	2	63.89	12.15	1.17	0.37	0.34
2	4	7	62.93	14.26	1.23	0.37	0.30
4	6	10	65.52	13.15	1.25	0.32	0.33
6	8	11	59.84	11.70	1.21	0.27	0.26
8	10	10	61.87	12.33	1.20	0.27	0.28
10	12	11	60.70	12.08	1.18	0.25	0.27
12	14	12	64.32	15.45	1.22	0.28	0.29
14	16	16	63.73	15.94	1.23	0.28	0.29
16	18	23	65.25	16.80	1.18	0.30	0.29
18	20	25	65.89	16.81	1.17	0.28	0.28
20	22	44	64.48	16.97	1.20	0.26	0.29
22	24	54	66.28	19.47	1.21	0.25	0.30
24	26	61	68.05	20.30	1.21	0.28	0.30
26	28	65	70.72	24.32	1.20	0.30	0.32
28	30	70	72.15	27.30	1.19	0.30	0.33
30	32	74	74.13	30.44	1.18	0.30	0.34
32	34	85	72.99	28.92	1.17	0.29	0.34
34	36	92	75.28	32.59	1.16	0.28	0.35
36	38	90	75.56	32.77	1.16	0.30	0.35
38	40	87	74.98	32.18	1.13	0.30	0.35
40	42	82	74.35	30.92	1.14	0.32	0.35
42	44	71	75.09	32.39	1.14	0.33	0.35
44	46	73	75.25	33.15	1.14	0.28	0.34
46	48	76	74.13	30.77	1.15	0.28	0.34
48	50	81	74.08	30.91	1.14	0.26	0.34

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Table E. 11 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
50	52	77	74.49	31.72	1.14	0.28	0.34
52	54	74	73.41	29.63	1.16	0.28	0.33
54	56	71	73.86	29.84	1.16	0.26	0.34
56	58	61	73.69	28.94	1.17	0.29	0.33
58	60	56	72.57	27.62	1.16	0.32	0.32
60	62	54	71.66	26.76	1.18	0.29	0.32
62	64	57	72.91	28.62	1.15	0.30	0.33
64	66	55	72.47	27.22	1.16	0.28	0.32
66	68	58	71.01	25.78	1.17	0.30	0.32
68	70	56	71.76	26.94	1.16	0.31	0.33
70	72	49	72.81	26.78	1.15	0.35	0.32
72	74	35	69.35	22.75	1.19	0.34	0.31
74	76	39	67.51	20.73	1.19	0.35	0.31
76	78	32	66.56	19.04	1.18	0.31	0.29
78	80	32	68.11	20.72	1.17	0.31	0.29
80	82	32	68.58	21.24	1.18	0.34	0.29
82	84	30	67.72	20.83	1.18	0.30	0.29
84	86	32	69.30	22.24	1.15	0.31	0.29
86	88	33	71.37	25.46	1.18	0.33	0.32
88	90	23	70.13	21.81	1.15	0.30	0.29
90	92	20	68.42	20.12	1.17	0.38	0.31
92	94	21	68.64	20.02	1.17	0.37	0.31
94	96	15	64.45	16.45	1.21	0.37	0.29
96	98	14	61.99	13.82	1.22	0.36	0.28
98	100	24	61.90	14.27	1.20	0.32	0.28
100	102	20	65.26	16.27	1.19	0.37	0.29
102	104	19	64.12	15.70	1.20	0.35	0.28
104	106	19	61.97	13.57	1.18	0.30	0.27
106	108	19	60.75	11.39	1.24	0.34	0.29
108	110	19	64.87	13.53	1.18	0.39	0.29

Table E. 12. Measurement values in YM on 09.05.2017.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
0	2	10	64.34	16.27	1.21	0.34	0.31
2	4	10	68.92	16.27	1.23	0.55	0.35
4	6	11	62.24	14.44	1.27	0.32	0.30
6	8	13	62.20	13.96	1.23	0.35	0.31
8	10	14	64.01	15.52	1.18	0.39	0.33
10	12	14	61.48	14.73	1.22	0.31	0.31
12	14	17	64.41	17.02	1.15	0.38	0.32
14	16	21	66.18	17.06	1.17	0.37	0.31
16	18	21	65.16	16.69	1.18	0.35	0.30
18	20	31	64.62	15.93	1.19	0.35	0.31
20	22	29	66.49	19.21	1.27	0.40	0.33
22	24	40	67.24	19.27	1.24	0.42	0.32
24	26	58	66.17	19.75	1.30	0.30	0.32
26	28	79	70.82	24.88	1.24	0.33	0.33
28	30	85	70.39	25.35	1.21	0.27	0.33
30	32	103	72.59	28.49	1.18	0.29	0.34
32	34	114	73.93	31.16	1.18	0.28	0.36
34	36	124	74.62	32.64	1.19	0.28	0.36
36	38	127	74.51	32.52	1.19	0.24	0.36
38	40	123	74.20	32.12	1.20	0.27	0.35
40	42	116	74.33	32.30	1.17	0.27	0.36
42	44	131	75.82	35.04	1.19	0.28	0.37
44	46	127	76.04	35.89	1.19	0.29	0.37
46	48	116	75.91	35.66	1.20	0.27	0.37
48	50	127	78.01	39.07	1.19	0.33	0.37
50	52	126	76.86	37.20	1.18	0.24	0.38
52	54	129	76.96	37.87	1.18	0.22	0.38
54	56	124	76.82	37.45	1.20	0.28	0.37
56	58	130	76.65	36.85	1.19	0.25	0.37
58	60	119	76.83	36.84	1.18	0.29	0.37
60	62	111	76.02	36.18	1.19	0.30	0.37
62	64	113	75.74	35.13	1.22	0.32	0.36
64	66	115	78.13	39.56	1.19	0.29	0.39
66	68	113	78.08	39.81	1.19	0.29	0.38
68	70	111	77.51	38.23	1.17	0.28	0.38
70	72	106	77.63	39.00	1.19	0.27	0.38
72	74	100	77.62	37.85	1.19	0.29	0.38

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Table E. 12 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
74	76	96	78.27	39.66	1.21	0.31	0.38
76	78	94	76.98	37.52	1.22	0.29	0.38
78	80	86	77.41	36.37	1.20	0.32	0.38
80	82	69	77.63	36.80	1.18	0.30	0.37
82	84	54	74.61	31.25	1.25	0.36	0.36
84	86	38	68.46	22.37	1.23	0.32	0.33
86	88	33	65.68	18.68	1.27	0.34	0.31
88	90	35	66.40	19.11	1.23	0.34	0.31
90	92	34	69.16	22.54	1.25	0.36	0.32
92	94	36	70.27	24.66	1.29	0.35	0.34
94	96	36	68.43	22.02	1.24	0.34	0.33
96	98	35	69.45	23.21	1.26	0.33	0.33
98	100	20	69.01	22.54	1.26	0.41	0.33

Table E. 13. Measurement values in KEY on 15.02.2018.

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
0	2	1	51.48	6.80	1.43	0.31	0.23
2	4	2	50.15	6.09	1.48	0.32	0.23
4	6	2	48.46	5.93	1.45	0.18	0.20
6	8	2	51.45	6.71	1.39	0.32	0.26
8	10	2	48.52	6.01	1.48	0.22	0.21
10	12	2	48.66	6.01	1.49	0.26	0.22
12	14	2	49.76	6.44	1.41	0.29	0.21
14	16	2	58.05	6.68	1.40	0.29	0.24
16	18	2	56.49	7.04	1.41	0.43	0.22
18	20	2	62.00	7.59	1.41	0.58	0.25
20	22	2	56.10	7.89	1.51	0.50	0.28
22	24	2	59.04	9.11	1.48	0.44	0.27
24	26	2	55.82	8.77	1.38	0.37	0.24
26	28	2	58.02	9.63	1.50	0.33	0.26
28	30	2	50.18	6.46	1.38	0.23	0.19
30	32	2	48.24	5.69	1.44	0.16	0.18
32	34	2	48.64	5.93	1.43	0.21	0.19

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Table E. 13 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
34	36	2	54.27	7.19	1.43	0.33	0.24
36	38	2	54.35	6.67	1.38	0.39	0.26
38	40	2	57.98	6.84	1.48	0.47	0.25
40	42	2	51.52	7.10	1.40	0.27	0.22
42	44	2	63.21	7.63	1.43	0.41	0.27
44	46	2	56.64	6.93	1.35	0.51	0.28
46	48	2	55.08	7.27	1.42	0.45	0.24
48	50	2	51.89	6.73	1.37	0.28	0.22
50	52	2	50.07	6.56	1.40	0.27	0.21
52	54	2	70.22	6.91	1.34	0.24	0.20
54	56	2	50.36	6.76	1.44	0.24	0.22
56	58	2	52.79	6.96	1.39	0.35	0.23
58	60	2	55.76	7.24	1.40	0.34	0.26
60	62	2	51.65	7.34	1.41	0.18	0.22
62	64	2	51.66	6.77	1.38	0.23	0.20
64	66	2	51.53	6.75	1.46	0.22	0.21
66	68	2	49.25	6.12	1.45	0.19	0.19
68	70	2	50.84	6.24	1.46	0.19	0.19
70	72	2	51.70	6.81	1.41	0.29	0.23
72	74	19	63.57	10.89	1.36	0.42	0.31
74	76	24	57.72	10.72	1.37	0.37	0.26
76	78	27	56.21	9.78	1.38	0.48	0.28
78	80	31	56.88	10.18	1.36	0.49	0.29
80	82	38	58.76	11.57	1.33	0.53	0.29
82	84	39	58.43	10.93	1.29	0.51	0.27
84	86	39	59.71	11.41	1.31	0.58	0.28
86	88	39	62.10	13.73	1.28	0.52	0.28
88	90	40	61.37	13.27	1.29	0.54	0.27
90	92	40	61.83	13.91	1.29	0.52	0.28
92	94	40	62.80	14.19	1.32	0.64	0.29
94	96	40	62.63	14.90	1.34	0.60	0.28
96	98	40	61.85	14.20	1.34	0.58	0.28
98	100	40	67.21	15.51	1.36	0.74	0.31
100	102	40	63.26	14.36	1.38	0.67	0.32
102	104	40	63.03	14.27	1.35	0.60	0.28
104	106	40	65.39	13.49	1.34	0.63	0.30
106	108	40	66.62	16.45	1.47	0.77	0.31

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Table E. 13 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBa	sone	acum	vacil	asper
108	110	40	64.84	15.07	1.39	0.60	0.29
110	112	38	63.74	14.99	1.29	0.59	0.29
112	114	35	60.78	13.04	1.34	0.56	0.27
114	116	35	59.20	11.29	1.39	0.62	0.27
116	118	35	62.70	13.03	1.32	0.69	0.29
118	120	31	60.94	12.82	1.43	0.61	0.29
120	122	31	62.83	13.51	1.35	0.60	0.28
122	124	31	62.26	14.00	1.32	0.53	0.29
124	126	31	64.93	15.80	1.29	0.56	0.28
126	128	31	63.46	15.06	1.32	0.60	0.28
128	130	31	62.87	14.78	1.26	0.49	0.26
130	132	31	63.94	15.66	1.25	0.49	0.26
132	134	31	62.79	14.61	1.24	0.51	0.25
134	136	31	63.52	14.77	1.28	0.54	0.27
136	138	31	64.13	14.94	1.24	0.50	0.25
138	140	32	64.13	16.11	1.25	0.51	0.26
140	142	32	63.12	14.96	1.24	0.41	0.25
142	144	32	62.10	14.04	1.27	0.47	0.26
144	146	32	63.86	14.88	1.27	0.47	0.25
146	148	32	61.77	13.28	1.32	0.58	0.29
148	150	25	61.90	13.09	1.31	0.48	0.25
150	152	25	63.11	13.53	1.35	0.58	0.28
152	154	25	61.81	12.81	1.30	0.49	0.28
154	156	25	61.14	12.52	1.36	0.47	0.27
156	158	25	63.20	13.17	1.38	0.52	0.26
158	160	25	62.20	13.96	1.35	0.51	0.27
160	162	25	61.31	12.56	1.31	0.50	0.25
162	164	25	63.54	14.74	1.31	0.46	0.25
164	166	25	64.24	13.62	1.34	0.62	0.26
166	168	25	65.75	15.18	1.24	0.53	0.24
168	170	29	63.02	13.70	1.30	0.44	0.25
170	172	29	62.50	13.39	1.31	0.46	0.25
172	174	29	56.47	9.63	1.41	0.47	0.27
174	176	23	56.51	9.79	1.43	0.41	0.27
176	178	16	56.43	8.84	1.41	0.44	0.26
178	180	14	58.04	9.78	1.41	0.51	0.28
180	182	14	60.66	10.41	1.48	0.66	0.33

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Table E. 13 (cont.).

Start time	End time	Number of persons	Level	Loudness	Sharpness	Fluct Str.	Roughness
min	min	-	dBA	sone	acum	vacil	asper
182	184	14	55.57	9.04	1.33	0.37	0.24
184	186	14	56.22	9.37	1.38	0.35	0.24
186	188	14	54.52	8.40	1.38	0.39	0.22
188	190	14	56.66	9.66	1.38	0.42	0.26
190	192	14	56.74	9.78	1.39	0.36	0.30

APPENDIX F

RESULT TABLES OF LABORATORY LISTENING TESTS

Table F. 1. Listening test evaluation results for on-site recordings on part 1-A (Likert scale).

	CA	MD	TE	YM	Control (TE)
p1	2	3	2	2	2
p2	2	3	2	1	2
p3	3	1	4	2	4
p4	1	3	2	2	2
p5	2	2	1	2	1
p6	3	2	2	2	2
p7	3	4	3	1	4
p8	2	3	2	3	2
p9	3	4	2	2	2
p10	2	4	3	1	5
p11	2	1	2	2	3
p12	2	3	3	2	2
p13	3	2	5	1	5
p14	3	5	4	2	3
p15	3	3	2	2	2
p16	3	2	3	3	3
p17	2	4	3	2	2
p18	2	1	3	2	3
p19	2	3	2	1	4
p20	2	4	1	1	2
p21	3	4	2	3	2
p22	3	2	3	2	3
p23	2	2	2	2	2
p24	2	3	2	1	1
p25	3	3	2	1	2
p26	3	1	1	1	1
p27	2	3	1	2	2
p28	2	1	2	1	2
p29	2	4	2	3	2
p30	4	4	2	1	2
p31	2	3	2	1	2
p32	1	3	2	2	1

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Table F. 1 (cont.).

	CA	MD	TE	YM	Control (TE)
p33	1	3	2	3	3
p34	3	4	2	3	3
p35	2	2	1	1	1
p36	2	3	4	3	4
p37	2	4	2	4	4
p38	2	3	2	2	3
p39	3	3	2	2	3
p40	1	4	2	2	3
p41	1	3	1	2	1
p42	3	5	4	4	4
p43	3	5	4	4	4
p44	2	3	3	2	3
p45	2	3	2	2	2
Avg.	2.29	3.00	2.33	2.00	2.56
Ranking	3	1	2	4	-

Table F. 2. Listening test evaluation results for on-site recordings on part 1-B (Pairwise comparison).

	CA	MD	TE	YM
p1	0.126	0.308	0.332	0.235
p2	0.211	0.400	0.237	0.152
p3	0.442	0.238	0.213	0.107
p4	0.120	0.457	0.202	0.221
p5	0.105	0.501	0.159	0.236
p6	0.416	0.297	0.140	0.147
p7	0.439	0.121	0.246	0.194
p8	0.168	0.484	0.117	0.231
p9	0.092	0.492	0.184	0.232
p10	0.091	0.566	0.130	0.213
p11	0.329	0.142	0.329	0.200
p12	0.231	0.425	0.149	0.195
p13	0.280	0.120	0.363	0.238
p14	0.226	0.459	0.171	0.144
p15	0.344	0.247	0.211	0.197
p16	0.392	0.279	0.165	0.165
p17	0.142	0.450	0.211	0.197
p18	0.280	0.338	0.283	0.099
p19	0.163	0.418	0.214	0.205

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Table F. 2 (cont.).

	CA	MD	TE	YM
p20	0.195	0.472	0.137	0.196
p21	0.288	0.165	0.206	0.342
p22	0.340	0.191	0.305	0.164
p23	0.287	0.329	0.206	0.177
p24	0.147	0.459	0.189	0.205
p25	0.285	0.280	0.188	0.246
p26	0.197	0.507	0.167	0.129
p27	0.151	0.467	0.106	0.275
p28	0.165	0.107	0.445	0.283
p29	0.389	0.264	0.164	0.184
p30	0.120	0.457	0.221	0.202
p31	0.115	0.506	0.214	0.165
p32	0.108	0.479	0.217	0.197
p33	0.148	0.362	0.246	0.243
p34	0.119	0.520	0.187	0.174
p35	0.167	0.333	0.167	0.333
p36	0.129	0.290	0.290	0.290
p37	0.114	0.530	0.151	0.205
p38	0.258	0.470	0.117	0.155
p39	0.387	0.275	0.198	0.140
p40	0.095	0.494	0.177	0.234
p41	0.169	0.394	0.197	0.239
p42	0.094	0.454	0.260	0.192
p43	0.160	0.378	0.105	0.358
p44	0.236	0.280	0.282	0.202
p45	0.159	0.316	0.245	0.280
Avg.	0.214	0.367	0.210	0.209
Ranking	2	1	3	4

Table F. 3. Listening test evaluation results for simulation auralizations on part 2-A (Likert scale).

	CA	MD	TE	YM	Control (TE)
p1	3	2	1	3	2
p2	2	2	2	1	2
p3	3	2	2	2	3
p4	3	2	2	4	2
p5	3	3	2	2	3
p6	3	3	3	2	2

(cont. on next page)

Table F. 3 (cont.).

	CA	MD	TE	YM	Control (TE)
p7	3	3	4	1	3
p8	2	2	1	1	2
p9	3	2	1	2	3
p10	4	3	3	2	5
p11	2	2	1	3	1
p12	3	2	2	1	2
p13	3	2	3	1	2
p14	2	3	2	2	4
p15	4	4	3	3	3
p16	4	3	2	3	2
p17	1	2	2	1	2
p18	2	2	3	2	2
p19	2	1	2	2	2
p20	2	2	2	3	3
p21	4	3	2	2	1
p22	3	3	2	1	2
p23	3	3	2	2	2
p24	2	1	1	1	1
p25	2	2	2	3	1
p26	2	3	1	3	3
p27	3	2	2	1	2
p28	2	1	1	1	2
p29	3	3	3	3	2
p30	4	2	2	1	3
p31	2	3	3	1	4
p32	2	2	2	2	1
p33	1	1	1	2	1
p34	3	3	2	3	3
p35	2	2	2	1	1
p36	3	3	4	3	4
p37	3	4	2	2	1
p38	1	1	1	1	2
p39	2	2	3	3	4
p40	3	2	1	2	3
p41	2	1	1	1	2
p42	2	2	4	3	4
p43	3	4	3	2	2
p44	2	2	3	2	3
p45	3	3	3	3	3
Avg.	2.58	2.33	2.13	2.00	2.38
Ranking	1	2	3	4	-

Table F. 4. Listening test evaluation results for simulation auralizations on part 2-B
(Pairwise comparison).

	CA	MD	TE	YM
p1	0.203	0.232	0.168	0.398
p2	0.242	0.369	0.234	0.155
p3	0.168	0.481	0.131	0.220
p4	0.423	0.162	0.144	0.271
p5	0.353	0.284	0.117	0.246
p6	0.385	0.238	0.207	0.170
p7	0.145	0.213	0.424	0.218
p8	0.412	0.334	0.170	0.085
p9	0.370	0.293	0.172	0.165
p10	0.160	0.243	0.456	0.141
p11	0.290	0.129	0.290	0.290
p12	0.211	0.344	0.247	0.197
p13	0.222	0.111	0.417	0.250
p14	0.117	0.231	0.484	0.168
p15	0.338	0.288	0.169	0.205
p16	0.525	0.273	0.080	0.122
p17	0.366	0.313	0.213	0.108
p18	0.197	0.239	0.394	0.169
p19	0.264	0.177	0.229	0.330
p20	0.240	0.294	0.110	0.356
p21	0.426	0.208	0.226	0.140
p22	0.227	0.123	0.423	0.227
p23	0.286	0.286	0.143	0.286
p24	0.282	0.177	0.296	0.246
p25	0.313	0.204	0.248	0.235
p26	0.418	0.214	0.205	0.163
p27	0.271	0.423	0.162	0.144
p28	0.269	0.193	0.417	0.121
p29	0.337	0.240	0.282	0.141
p30	0.283	0.338	0.239	0.141
p31	0.147	0.189	0.459	0.205
p32	0.239	0.169	0.394	0.197
p33	0.288	0.165	0.206	0.342
p34	0.437	0.237	0.181	0.144
p35	0.247	0.211	0.344	0.197
p36	0.342	0.165	0.288	0.206
p37	0.329	0.329	0.142	0.200
p38	0.262	0.240	0.133	0.365

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Table F. 4 (cont.).

	CA	MD	TE	YM
p39	0.242	0.136	0.287	0.335
p40	0.306	0.160	0.149	0.385
p41	0.344	0.247	0.197	0.211
p42	0.154	0.127	0.469	0.250
p43	0.220	0.243	0.350	0.187
p44	0.165	0.279	0.392	0.165
p45	0.288	0.169	0.338	0.205
Avg.	0.283	0.238	0.263	0.216
Ranking	1	3	2	4

Table F. 5. Listening test evaluation results for simulation auralizations with different sharpness values on part 3 (Pairwise comparison).

	S1.00	S1.10	S1.20
p1	0.557	0.320	0.123
p2	0.574	0.286	0.140
p3	0.172	0.350	0.478
p4	0.539	0.297	0.164
p5	0.574	0.286	0.140
p6	0.525	0.334	0.142
p7	0.143	0.286	0.571
p8	0.332	0.368	0.300
p9	0.594	0.297	0.109
p10	0.241	0.211	0.548
p11	0.159	0.252	0.589
p12	0.170	0.443	0.387
p13	0.133	0.211	0.655
p14	0.263	0.448	0.288
p15	0.411	0.328	0.261
p16	0.198	0.312	0.490
p17	0.490	0.312	0.198
p18	0.198	0.312	0.490
p19	0.512	0.330	0.158
p20	0.566	0.242	0.192
p21	0.198	0.312	0.490
p22	0.157	0.467	0.376
p23	0.198	0.312	0.490
p24	0.159	0.252	0.589
p25	0.548	0.241	0.211

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Table F. 5 (cont.).

	S1.00	S1.10	S1.20
p26	0.170	0.443	0.387
p27	0.539	0.297	0.164
p28	0.312	0.198	0.490
p29	0.589	0.252	0.159
p30	0.159	0.252	0.589
p31	0.320	0.557	0.123
p32	0.387	0.443	0.170
p33	0.648	0.230	0.122
p34	0.574	0.286	0.140
p35	0.312	0.198	0.490
p36	0.490	0.312	0.198
p37	0.490	0.312	0.198
p38	0.195	0.537	0.268
p39	0.164	0.297	0.539
p40	0.142	0.334	0.525
p41	0.490	0.312	0.198
p42	0.200	0.400	0.400
p43	0.443	0.387	0.170
p44	0.261	0.328	0.411
p45	0.333	0.333	0.333
Avg.	0.352	0.323	0.326
Ranking	1	3	2

Table F. 6. Listening test evaluation results for simulation auralizations with different roughness values on part 4-A (Pairwise comparison).

	R0.31	R0.42	R0.53
p1	0.655	0.211	0.133
p2	0.151	0.472	0.377
p3	0.539	0.297	0.164
p4	0.429	0.429	0.143
p5	0.444	0.444	0.111
p6	0.123	0.320	0.557
p7	0.118	0.501	0.380
p8	0.334	0.525	0.142
p9	0.252	0.589	0.159
p10	0.126	0.416	0.458
p11	0.490	0.312	0.198
p12	0.164	0.297	0.539

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Table F. 6 (cont.).

	R0.31	R0.42	R0.53
p13	0.126	0.416	0.458
p14	0.102	0.211	0.686
p15	0.608	0.272	0.120
p16	0.639	0.243	0.118
p17	0.123	0.320	0.557
p18	0.140	0.286	0.574
p19	0.170	0.443	0.387
p20	0.594	0.297	0.109
p21	0.537	0.268	0.195
p22	0.170	0.387	0.443
p23	0.624	0.267	0.108
p24	0.589	0.252	0.159
p25	0.571	0.286	0.143
p26	0.200	0.400	0.400
p27	0.623	0.239	0.137
p28	0.120	0.608	0.272
p29	0.172	0.478	0.350
p30	0.333	0.333	0.333
p31	0.268	0.537	0.195
p32	0.548	0.241	0.211
p33	0.478	0.350	0.172
p34	0.639	0.118	0.243
p35	0.500	0.250	0.250
p36	0.329	0.264	0.407
p37	0.500	0.250	0.250
p38	0.170	0.387	0.443
p39	0.548	0.211	0.241
p40	0.098	0.334	0.568
p41	0.170	0.387	0.443
p42	0.579	0.234	0.187
p43	0.512	0.360	0.128
p44	0.143	0.429	0.429
p45	0.500	0.250	0.250
Avg.	0.361	0.343	0.296
Ranking	1	2	3

Table F. 7. Listening test evaluation results for simulation auralizations with different roughness values on part 4-B (Pairwise comparison).

	R0.29	R0.41	R0.53
p1	0.655	0.211	0.133
p2	0.250	0.250	0.500
p3	0.539	0.164	0.297
p4	0.639	0.243	0.118
p5	0.560	0.312	0.128
p6	0.548	0.211	0.241
p7	0.304	0.172	0.524
p8	0.448	0.288	0.263
p9	0.525	0.142	0.334
p10	0.537	0.195	0.268
p11	0.537	0.195	0.268
p12	0.500	0.250	0.250
p13	0.601	0.170	0.229
p14	0.332	0.300	0.368
p15	0.539	0.297	0.164
p16	0.490	0.198	0.312
p17	0.297	0.164	0.539
p18	0.263	0.288	0.448
p19	0.387	0.170	0.443
p20	0.400	0.367	0.233
p21	0.537	0.268	0.195
p22	0.325	0.235	0.440
p23	0.490	0.312	0.198
p24	0.500	0.250	0.250
p25	0.264	0.407	0.329
p26	0.250	0.250	0.500
p27	0.500	0.250	0.250
p28	0.589	0.159	0.252
p29	0.539	0.297	0.164
p30	0.312	0.198	0.490
p31	0.288	0.448	0.263
p32	0.500	0.250	0.250
p33	0.200	0.400	0.400
p34	0.667	0.167	0.167
p35	0.490	0.312	0.198
p36	0.312	0.198	0.490
p37	0.400	0.400	0.200
p38	0.192	0.131	0.677

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Table F. 7 (cont.).

	R0.29	R0.41	R0.53
p39	0.198	0.312	0.490
p40	0.164	0.297	0.539
p41	0.411	0.261	0.328
p42	0.655	0.133	0.211
p43	0.589	0.252	0.159
p44	0.329	0.264	0.407
p45	0.600	0.200	0.200
Avg.	0.437	0.250	0.313
Ranking	1	3	2

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