

To my dear dad,

**THE EFFECTS OF SPEECH INTERFERENCE
IN ENCLOSED LEISURE SPACES:
A CASE STUDY IN BİLKENT
ROLL HOUSE, ANKARA**

**A THESIS
SUBMITTED TO THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
AND THE INSTITUTE OF ECONOMICS AND
SOCIAL SCIENCES OF
İHSAN DOĞRAMACI BİLKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF FINE ARTS**

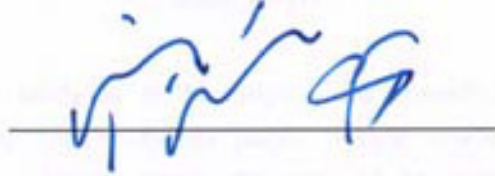
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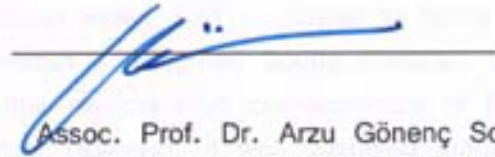
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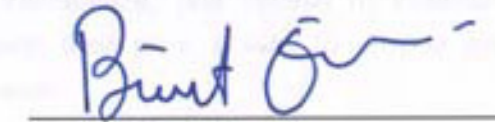
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Assoc. Prof. Dr. Arzu Gönenç Sorguç

Approved by the Institute of Fine Arts



Prof. Dr. Bülent Özgüç, Director of the Institute of Fine Arts

ABSTRACT

THE EFFECTS OF SPEECH INTERFERENCE IN ENCLOSED LEISURE SPACES: A CASE STUDY IN BİLKENT ROLL HOUSE, ANKARA

Pelin Meriç Gezginer

MFA in Interior Architecture and Environmental Design

Supervisor: Assoc. Prof. Dr. Semiha Yilmazer

June, 2011.

The aim of this study is to investigate the speech interference of users in an open-planned multi-activities public leisure space. Bilkent Roll House was chosen as a leisure space because of its variety of activities in an open-plan such as bowling, dart, billiards, play station and dining area. In this respect, to analyze acoustical parameters and users characteristics of this study, a pilot and case study was undertaken by using questionnaires/intelligibility tests, computer simulations and real-size measurements. Questionnaires /speech intelligibility tests and Leq measurements were done in order to analyze noise annoyance ratings of the users of selected space as pilot study. The speech interference parameters measured as a case study are; Reverberation Time (T30), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Equivalent Continuous A-weighted Sound Pressure Level (Leq A). The results showed that reverberation characteristics of Bilkent Roll House are at the required range. However, it was observed that, the speech parameters (STI & SNR) results are insufficient in terms of speech communication. In addition, the noise level (Leq A) of the activities in Bilkent Roll House increases slightly in time. However, the results of Leq A at the dining area of Bilkent Roll House indicate that, users are affected in an informal way by the speech interference, and instead of increasing their voice level, they prefer to deal with their main activity to provide speech intelligibility in multi-activity spaces.

Keywords: Speech Communication, Speech Interference, Speech Intelligibility, Multi-activity enclosed leisure space

ÖZET

BOŞ ZAMAN ETKİNLİKLERİ YAPILAN KAMUSAL MEKÂNDA KONUŞMA RAHATSIZLIĞININ ETKİLERİ: BİLKENT ROLL HOUSE ÖRNEĞİNDE

Pelin Meriç Gezginer

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Bu çalışmanın amacı, konuşma rahatsızlığının çoklu boş zaman etkinliği yapılan mekânda irdelenmesidir. Bu amaçla boş zaman etkinliklerini içeren bir mekâna sahip olduğu için kamusal mekân olarak Bilkent Roll House seçilmiştir. Bu etkinlikler; bowling, dart, yemek yeme alanı, bilardo ve bilgisayar oyunlarıdır. Bu amaçla, mekânın akustik parametrelerini ve kullanıcı davranışlarını belirlemek için bilgisayarda benzetim çalışmaları, yerinde ölçümler, anketler ve testler yapılmıştır. Anketler, anlaşılabilirlik testi ve Eşdeğer gürültü düzeyi (L_{eq}) ölçümleri kullanıcıların işitsel algıları ve gürültü rahatsızlık derecelerini ortaya koymak adına pilot bir çalışma olarak uygulanmıştır. Konuşma rahatsızlığını irdellemek için, Çınlama süresi (RT), Konuşma iletim indeksi (STI), Gürültü-Sinyal Oranı (SNR) ve Eşdeğer A ağırlıklı ses seviyesi ($L_{eq A}$) ölçülmüştür. Akustik ölçümler sonucunda, Çınlama Süresi'nin (RT) beklenen aralıkta olduğu, fakat Ses İletim İndeksi (STI) ve Gürültü-Sinyal Oranı'nın (SNR) yetersiz olduğu tespit edilmiştir. Bunlara ek olarak ölçümler sonucunda, eşdeğer A ağırlıklı gürültü düzeyinde tüm aktivitelerde zaman içinde artış gözlenirken, yemek alanında gürültü düzeyinin sabit kaldığı ve konuşma anlaşılabilirliğini arttırmak için kullanıcıların ana etkinliklerine döndükleri gözlemlenmiştir. Bunların sonucunda, Bilkent Roll House'da konuşma rahatsızlığı saptanmıştır.

Anahtar Kelimeler: Konuşma iletişimi, Konuşma Rahatsızlığı, Konuşma Anlaşılabilirliği, Çoklu boş zaman etkinliği içeren kamusal alan

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1. INTRODUCTION

Throughout history, humanity has been in need of high quality verbal communication, which is determined by speech intelligibility and speech effort level (Zaheeruddin & Jain, 2008). According to many researchers speech is considered the primary method of communication among humans. In built environments, noise has a major pollutant effect on speech communication. Speech interference has negative effects on humans during communication. Berglund & Lindvall claim that the interfering noise “renders speech incapable of being understood” (cited in Zaheeruddin & Jain, 2008, p.1979).

In the 1940's interest arose on the research of the effect of speech interference in speech communication on the formulation of Articulation Index (AI), as a subjective measurement of speech intelligibility. Articulation Index predicts the effects of speech interference for various conditions and has undergone modifications throughout the last century. Yet, in the 1950's and the 1960's, it was determined the relationship between Articulation Index and speech communication solely depended on the speech material. Articulation Index formulation which was recently renamed as Speech Intelligibility Index (SII) is insufficient to predict speech signal levels,

reverberation characteristics and time distortions in terms of speech communication and intelligibility. Therefore, Speech Transmission Index (STI) and Signal to Noise Ratio (SNR) were coined in order to check the quality of speech communication for the purpose of these conditions (Houtgast, T. & Steeneken, H. J. M. 1973).

During the same period, the ‘acoustics of cocktail parties’ was mentioned by Maclean (1959). In everyday environment, people are faced with complex sounds. Our auditory system has the ability to separate each individual source. In 1959, Maclean investigated the acoustics of cocktail parties and proposed a theoretical formula to evaluate a maximum number of occupants. Maclean’s studies were re-evaluated several times. For instance, Bronkhorst (2000) reviewed Maclean’s study and named the theory as the ‘cocktail party phenomenon’. This phenomenon simply tries to explain “how do we recognize what a person is saying when others are speaking at the same time?” (Bronkhorst, 2000, p.117). According to Bronkhorst (2000), “the cocktail party effect is the intelligibility of speech presented against a background of competing speech” that is the background noise (masker) of other talkers’ speech (p. 117). Today, this is described as a problem of ‘sound sources segregation’ (Hawley, Litovsky & Colburn, 1999).

After these inventions were made, the studies on quality of speech communication and noise perception were undertaken for acoustical spaces since the middle of the past century. As acoustical spaces; concert halls, auditoriums, conference halls, meeting rooms etc. were studied in literature in terms of speech communication (Yang & Kang, 2005). For these spaces, the optimum reverberation time, signal to noise ratio and background noise levels were standardized to assure objective assessments while, the articulation index, speech transmission index and other real size measurements can be tested as subjective assessments.

Additionally, studies on soundscapes were made popular at the beginning of 21st century. In soundscape studies, the effects of environmental and physical factors such as, traffic, rain, children scrapping were examined (Yang & Kang, 2005).

Recently studies on ‘non-acoustical enclosed spaces’ (shopping malls, restaurants, lobbies etc.) have been undertaken in terms of speech communication. These studies reveal that both objective and subjective assessments relationship should be taken into consideration in order to obtain a better evaluation on intelligibility and annoyance scores of the non-acoustic enclosed spaces. The studies on non-acoustical spaces have

initiated in a number of studies in terms of intelligibility. It has been proven that by various interventions the level of intelligibility of the enclosed spaces can be increased (Kang, 2002). Upon examining these studies it is seen that most of the auditory perception and speech communication studies of enclosed spaces were applied to leisure spaces that consist of one activity, such as shopping malls, food court areas etc. (Chen & Kang, 2004, Navarro & Pimentel, 2007). However, studies on multi-activity leisure spaces are yet in need of examining in greater detail.

Our environment is fully filled with noise. Over the past decades, in terms of non-acoustic spaces, there has been an increasing attention on the non-occupational leisure space's noise levels. A public leisure space is an environment where people spend their time, in which they are free from obligations, and make their own decisions about how to spend their time. Due to high sound pressure levels in leisure spaces, there are various potential effects of noisy leisure activities. One of the most important affect of these noisy leisure activities is speech interference (Clark, 1991).

1.1. Aim and Scope

The objective of this thesis is to examine the determination of the speech interference level and vocal effort level in multi-activity enclosed leisure spaces (open-planned enclosures) when the ambient noise increases. In this respect, Bilkent Roll House was chosen as an enclosed leisure space, because of the variety of activities in an open-planned area: bowling, dart, billiards, play station and dining area.

Music sound, conversational sound, and sound from different activities like knocking down pins in bowling area, sounds from computers, dropping objects, chair scraping etc. are the main noise sources in Bilkent Roll House. Despite the fact that ambient noise consists of conversational and residual noises, fluctuating music sound is the dominant noise source.

The methods used for the assessment of occupied condition of Bilkent Roll House are questionnaires/intelligibility tests, computer simulations and real-size measurements. Questionnaires and speech intelligibility test were performed to analyze noise annoyance ratings and speech Intelligibility of the users in the selected space as a pilot study. Computer simulations and real-size measurements were implemented to analyze acoustical parameters

of the selected multi-activity leisure space in terms of speech interference in occupied condition as a case study.

In this study, it is assumed that there is speech interference in multi-activity enclosed leisure spaces. Users are affected from the ambient noise level in the Roll House because of high noise annoyance ratings proportions. The pain of noise causes the users to abandon comfort condition and they lose ability to understand each other.

1.2. Structure of the Thesis

This thesis consists of eight chapters. The introduction part that explains the leisure space concept and previous studies on leisure spaces in terms of speech interference. Aim, scope and structure of the study are the first chapter of this thesis.

The second chapter clarifies the Quality of Speech Communication. This chapter is divided into two parts. These are ‘Quality of Speech communication in living quarters’ and ‘Cocktail Party Phenomenon’ in speech communication. The third chapter, ‘Effects of Noise on Speech’ includes the basic definitions and acoustical properties used as a basis of the thesis. In this chapter the acoustical requirements of non-acoustic spaces are stated, which are Reverberation Time (RT), Sound Pressure Level (SPL) and Equivalent Continuous Sound Level (Leq A), Speech Intelligibility Index (SII), Speech Transmission Index (STI) and Signal to Noise Ratio (SNR).

The fourth chapter explains the case study of the selected multi-activity enclosed leisure space and consists of the spatial requirements of the selected space, design of the study and pilot study.

The fifth chapter consists of computer simulation of Bilkent Roll House.

Acoustical simulations were implemented to analyze acoustical parameters of the selected multi-activity leisure space in terms of speech interference for occupied condition by using computer simulations. The software used for the simulation is ODEON 9.2 Auditorium Acoustics.

Accordingly, the sixth chapter is the real-size measurements at Bilkent Roll House. The real-size measurements were applied on the most crowded day of the week on Friday and from 18:00 to 21:00 that is tournament time for occupied condition.

The seventh chapter consists of the ‘discussion’ part, the outcome product from the real-size measurements and computer simulations. In conclusion, in the eighth chapter, the study is summarized as a whole and the outcomes evaluated.

2. QUALITY OF SPEECH COMMUNICATION

Speech is a basic communication feature of human beings. It can greatly be affected from the noise sources. There are some studies on the quality of communication among people in noisy places (Navarro & Pimentel, 2007). The communication level should be high enough in order to understand the conversation among people. Therefore, there is a difference between noise and speech that speech carries meaning itself.

Additionally, noise pollution has a considerable effect on speech communication. In speech communication, interference has a masking process because noise “renders speech incapable of being understood” (Zaheeruddin & Jain, 2008, p.1979). In other words, it disturbs effective communication between speaker and listener and causes speech interference.

2.1. Quality of Speech Communication in Living Quarters

The prediction of speech communication is necessary for living quarters. In order to increase quality of communication, some methods are assessed to take into account; the speaker's vocal effort and speech intelligibility at listener's position. These methods are Speech Intelligibility Index (SII), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Speech Interference Level (SIL) (Lazarus, 1986).

Over the past decade, there has been a growing interest to predict speech intelligibility under different conditions (Pavlovic, 1987). Speech intelligibility is an indication of how well speech is recognized and defined as a part of spoken materials. It is the masking effect of noise on speech communication which includes words, messages and sentence intelligibility (Lazarus, 1987).

2.2. ‘Cocktail Party Phenomenon’ in speech communication

In addition to prediction methods and parameters of speech communication, ‘Cocktail Party Phenomenon’ was formulated which is an important term in speech communication. Maclean (1959) investigated ‘the acoustics of cocktail parties’ and proposed a theoretical formula to evaluate maximum number of occupants. In his study, the ambient noise was considered to be caused only by conversation and conversational groups. In the presence of increasing background noise that occurs by conversation, talkers will increase their vocal effort being consciously. Based on this evidence, Maclean (1959) suggested that conversation again becomes possible by reducing the talking distance.

In 2000, Bronkhorst reviewed the Maclean’s study and renamed the theory as the ‘cocktail party phenomenon’. This phenomenon simply explains “how do we recognize what a person is saying when others are speaking at the

same time?” (Bronkhorst, 2000, p.117). According to Bronkhorst (2000), “the cocktail party effect is the intelligibility of speech presented against a background of competing speeches” that is the background noise (masker) of other talkers’ speeches (p. 117). In addition, the talking distance is an important effect on cocktail party phenomenon. The speech level is defined by the orientation and the distance of the talker. According to Bronkhorst (2000), the speech levels are affected by Lombard effect that is the “tendency of talkers who increases their vocal effort in the background noise” of the other talkers (Bronkhorst, 2000, p. 118). During the conversation between two people, an increase of 2 dB, leads to an increase 10 dB in noise levels of one activity spaces. Therefore, there should be an increasing noise level graph in time.

3. EFFECTS OF NOISE ON SPEECH

The effects of noise on speech were investigated in a series of studies.

The first studies were undertaken in the 1960's by the investigations on the hearing loss associating with noise exposure. These studies were dealt with the occupational noises and hearing loss on industrial workers in both field and laboratory studies (Taylor, Pearson, Mair, & Burns, 1965).

In the 1970's, it was emphasized that there are noise sources that cause noise exposure that are inside non occupational places, have potential risk of damaging the ability of hearing (Clark, 1991). Accordingly, the attention on non occupational spaces focused into soundscapes.

Recently, the attention on noise exposure shifted into living quarters. In this manner, effects of noise in non acoustical enclosures were studied. The studies were started to focus on the effects of ambient noise level and the human voice level on speech. Hence, some important acoustical topics on the effects of noise on speech that should be mentioned in enclosed leisure spaces in terms of speech interference. These topics are acoustical requirements of non acoustic spaces.

3.1. Acoustical Requirements of Non-acoustic spaces

Acoustical requirements show variances in 'acoustic' and 'non-acoustic spaces'. This segregation comes from the usage function of spaces. The acoustical spaces, such as auditoriums, concert halls, opera houses, churches, require serious acoustical design. On the other hand, the non-acoustic spaces, such as shopping malls, educational, commercial buildings do not need that much acoustical design, they still need good acoustical comfort conditions (Rettinger, 1988).

In enclosed leisure spaces, the acoustical requirements for effects of noise on speech are Reverberation Time (RT), Sound Pressure level (SPL) and Equivalent Continuous A-weighted Sound Level (Leq A), Background Noise Level, Speech Intelligibility Index (SII), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Speech Interference Level (SIL). These assessments describe the acoustical parameters and formations within that space. In enclosed leisure spaces, these assessments are quite important in order to evaluate the characteristics of spaces.

3.1.1. Reverberation Time (RT)

Reverberation Time (RT) is the time required for the mean square sound pressure, takes for the sound decay by 60 dB after its termination

(Rettinger, 1988). Intelligibility of sound in indoors is typically rated by reverberation time (T60 or RT60). The process of decaying is evaluated by units of seconds. It was first defined by W. C. Sabine nearly a hundred years ago. There are three types of formulas for calculating reverberation time (RT). Those are Sabine's formula, Eyring formula and Millington-Sette formula. In Sabine's formula that is mostly used in live fields, it is wanted to deal with persistence of reflected sound energy. Hence, it is required to know the size of the room in m³ and the total sound absorption coefficient (Egan, 1988). Eyring formula is mostly used in spaces where the sound absorption coefficient of all surfaces are equal and lastly, the Millington-Sette formula can be used in spaces where the sound absorption coefficient of surfaces show variations (Çalışkan, 2006).

-Sabine's Formula:

$$T_{60} = 0,161 \times V / \Sigma A$$

where,

- V= volume of the room,
- ΣA = total sound absorption coefficients of all surfaces

-Eyring formula:

$$T_{60} = (0.163 V) / (\alpha_i S_i + nA_p + 4mV)$$

where,

- V= volume of the room,
- S_i = surface area,
- n= number of people in volume of the room,
- A_p = sound absorption of each person in the room,
- m= energy reduction coefficient

-Millington-Sette formula:

$$T_{60} = (0.163 V) / (-S_i \ln(1 - \alpha_i) + nA_p + 4mV)$$

where,

- V= volume of the room,
- S_i = surface area,
- $-\ln(1 - \alpha_i)$ =sound absorption coefficient of the material i
- n= number of people in volume of the room,
- A_p = sound absorption of each person in the room,
- m= energy reduction coefficient

If the reverberation time is longer than a room requires, the negative effects of reverberation time can be seen in terms of intelligibility. Long

reverberation time on speech, annoys speakers and people who communicate with others in enclosed leisure spaces (Rettinger, 1988). Therefore, the reverberation time should be calculated carefully by using appropriate absorbers and reflectors. T60 depends on the volume of the rooms (m^3) and the absorption coefficients of the materials of the room (Cowan, 1994). T60 varies within different frequencies, because absorption coefficients of materials changes within frequencies.

Besides, there is an optimum reverberation time chart that indicates the optimum reverberations according to room and activity type of the space (Mehta, Johnson & Rocafort, 1999). There is a standardization of optimum reverberation time at different spaces, due to the fact that some spaces and activities require long reverberation time as acoustic spaces such as concert halls, religious buildings while others require low reverberation time as non-acoustical spaces like leisure activity spaces.

3.1.2. Sound Pressure level (SPL) and Equivalent Continuous A-weighted Sound Level (Leq A)

Sound Pressure Level (SPL) is a force that is air-borne vibrations causing variations in pressure. These variations and fluctuations in pressure are capable of being detected by ear. Sound Pressure is a parameter of

the resulting variations at normal atmospheric pressure. It can be expressed on the logarithmic scale of decibel (dB) as a level (Moore, 1988).

Equivalent Continuous A-weighted Sound Level ($L_{eq} dB_A$) is the “time integrated squared sound pressure of an acoustical disturbance over a given period of time, generally an hour but sometimes twenty-four hours” (Rettinger, 1988, p.25). It is the most common ‘weighting network’ filtering the sound level meters and varies frequency sensitivity, because human ear cannot detect all frequencies in the same manner. Human ear are most sensitive to frequencies between 200 Hz to 10 kHz (Cowan, 1994). Thereby, Equivalent Continuous A-weighted Sound Levels ignores low frequencies and chooses the frequencies that human ear are sensitive. Thus, $L_{eq} dB_A$ correlates with human reaction and annoyance.

A-weighted sound levels ($L_{eq} A$) are not only used for the correlations with noise annoyance, but also in used to determine the residual noise level (L_{NAq}) and conversational (speech) noise (L_{SAq}). The equivalent A-weighted conversational noise level (L_{SAq}) can be obtained from each measuring point. In order to obtain A-weighted conversational noise (L_{SAq}), the A-weighted residual noise level (L_{NAq}) should subtract (logarithmic calculation) from the A-weighted equivalent sound level of the room

($L_{eq A}$) (Beranek, 1992). Otherwise, it would be difficult to separate conversational and residual A-weighted noises.

$$L_N = 10 \log (10^{L_N + S/10} - 10^{L_N/10})$$

The measurements of Equivalent A-weighted Sound Levels ($L_{eq A}$) can be undertaken in any enclosure in which sound stationary and number of occupants varies over a period of time (Tang, Chan & Chan, 1997).

Tang et al. (1997) pointed out that people tend to raise their voices to achieve an effective communication in high noise levels where number of occupants varies in time. Especially, in environments that are inadequately surrounded by sound absorption materials. Due to high noise levels, people suffer from the low speech intelligibility level, therefore, their annoyance ratings increase. A talker may not be heard because of high noise levels in background noise of a conversation, continuous ambient background noise of the public space and the residual noises due to sources such as dropping objects, chair scraping or similar sources (which are instant noises).

3.1.3. Background Noise Level

Knudsen (1978) analyzed the background noise as continuous (non-stop) masking noise. According to him, this noise should be taken into consideration in three ways. The first is the background noise level in

ambient noise. The second one is the expected background noise level that is at least 5 dB lower than the ambient noise. Final one is the frequency spectrum of the background noise that can directly affect the degree of speech interference.

Background noise sound level represents the masking availability of the noise. Moore (1988) stated that background noise is important at both enclosed and open-planned public spaces. In public spaces, the background noise level should be designed to mask the adequate sound pressure level. However, a designer should be aware of that the level of background noise should not be high (more than 80 dB) since it can cause both annoyance and restrict communication in open-planned public spaces (Egan, 1988). Many researchers investigated the effects of background noise in open-planned areas and found that the speech intelligibility is an unavoidable index at speech communication. Therefore, the background noise level should be at a preferred level (less than 80 dB).

In daily life, speech is not always completely intelligible due to the effects of background noises. "Noise decreases the intelligibility of speech by raising the listener's threshold of hearing, at the same time, masking the

information. This loss of information may be partially compensated for by moving closer, talking louder or using electronic amplification” (Knisler, Frey, Coppens & Sander, 2000, p.362).

Kang (2002) examined the effects of speech interference in terms of background noise from other talkers in dining spaces and found that the speech communication between diners is generally poor. He stated “diners complained that they must raise voices because of noise disturbance from other talkers but the intelligibility was still poor” (p. 1315).

According to Zaheeruddin & Jain (2008), background noise level should be between 55– 65 dB at 1000 frequency for good speech communication in ambient public environment. In public spaces, it is evaluated at 1000 frequency since human ear are most sensitive around 1000 Hz.

3.1.4. Speech Intelligibility Index (SII)

As a subjective measurement, studies related to the articulation index are still active almost 70 years in predicting the speech communication ability of listeners in various noise levels. Articulation index (AI) is a subjective measure of speech intelligibility. It can be evaluated by a group of listeners who write the words and sentences from the selected list. In this manner,

a rating table was created which indicates the intelligibility conditions (Egan, 1988). Mehta, Johnson & Rocafort (1999) stated that articulation index (AI) is a signal to noise ratio assessment. Its rating table lies between 0.00 and 1.00. In this table 0.00 represents zero intelligibility and 1.00 represents complete intelligibility (See at Table 3.1.)

Table 3.1. AI rating table (Mehta, Johnson & Rocafort, 1999).

AI	Intelligibility Rating
0.0 – 0.2	Insufficient
0.2 – 0.4	Unsatisfactory
0.4 – 0.6	Sufficient
0.6 – 0.8	Good
0.8 – 1.0	Excellent

Articulation index (AI) has been renamed as Speech Intelligibility Index (SII), where the basic assumptions of the method have not change. The only difference is, SII's rating table (intelligibility score) lies between 0 % to 100 % correctly heard words (Bronkhorst, 2000). These tables are also highly correlated with Speech Transmission Index (STI) and Signal to Noise Ratio (SNR). By these correlations, some diagrams and tables were evolved, based the intelligibility of the monosyllable words. In this case, the relationship between speech intelligibility and the prediction parameters (AI,

STI, SNR and SIL) will be regarded as a known factor (See at Figure 3.1).

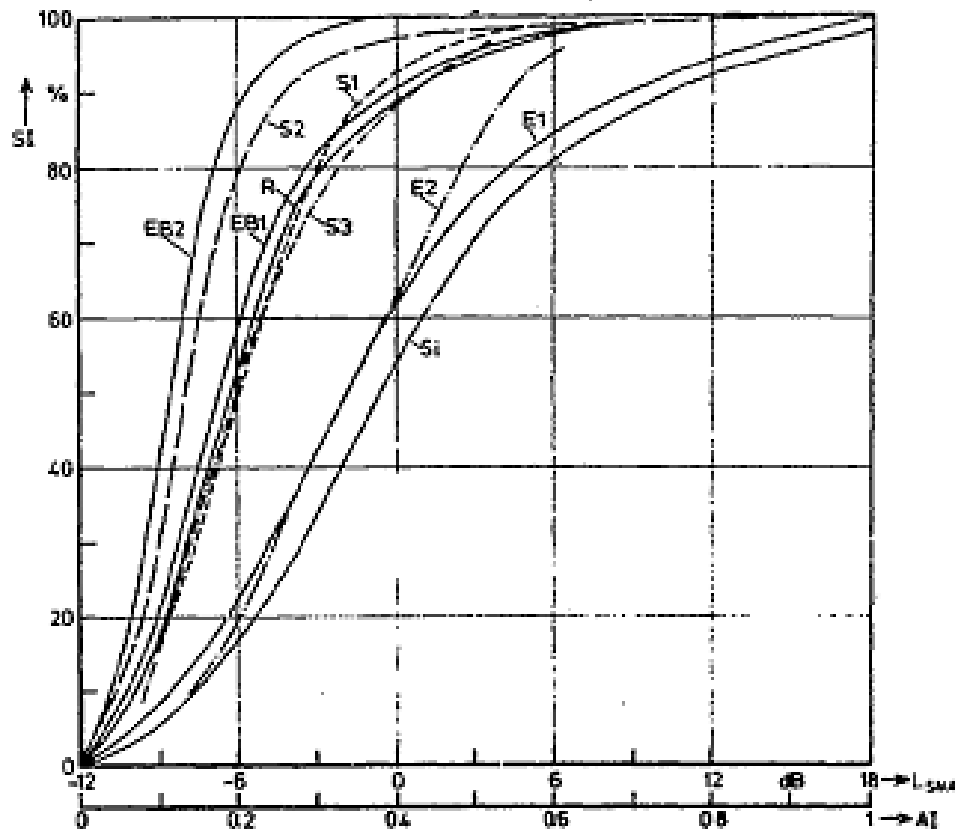


Figure 3.1. The relation between AI and Speech Intelligibility score for meaningless syllables (Si), monosyllables (E), sentences (S) and limited monosyllables (EB) (Lazarus, 1986, 440).

In literature, many researchers prefer to use monosyllable words instead of the sentences to determine speech intelligibility score. Because the speech intelligibility evaluations of verbal communication have a range from unsatisfactory to excellent for the intelligibility values of monosyllables, AI, STI and SNR (Table 3.2).

Table 3.2. The quality of speech intelligibility, for the values to predict speech intelligibility (Articulation Index(AI), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and The intelligibility of monosyllabic words (SIM)) by Authors (Lazarus, 1987, 246).

SIM in % $\approx$	0	10	20	40	65	75	85	90	95	98	100
AI	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
STI	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1
L_{SNA} in dB	-12	-9	-6	-3	0	3	6	9	12	15	18
Beranek 1947 ³	Unsatisfactory			Acceptable dependent on the spectrum			Satisfactory to very good				
Beranek 1949 according to Kryter 1972 ⁴	Impossible to difficult			Slightly aggravated to satisfactory			Satisfactory to very good				
Görlich 1978 ⁵	Very bad	Unsatisfactory		Sufficient		Good		Very good			
Houtgast and Steeneken 1978 ⁶	Unsatisfactory			Satisfactory		Good		Excellent			
Kryter 1970 ⁷ (p. 90)	Normally not acceptable	Acceptable for some purposes		Good		Very good to excellent		Excellent			
ISO 4870 1975 ⁸	Bad		Satisfactory			Good	Very good	Excellent			
May 1978 ⁹	Unsatisfactory			Scanty, but acceptable		Good		Very good			
Summary	Insufficient	Insufficient but acceptable for some purposes		Sufficient to satisfactory		Good		Very good, Excellent			

Additionally, "Speech intelligibility extent characterizes the difficulty of perceiving speech, i.e. the hearer's impairment and effort to understand speech. Speech level intensity characterizes the speaker's effort to produce

speech” (Lazarus, 1987, p.250). Table 3.3. shows the speaker’s effort and the hearer’s impairment.

Table 3.3. Quality of verbal communication, dependent on the speaker’s effort (Lazarus, 1987, 250).

<i>Speaking</i>		<i>Hearing</i>		<i>Verbal communication</i>	
$L_{SA,1m}$ (in dB)	<i>Effort</i>	L_{SNA} (in dB)	<i>Impediment</i>	<i>Effort</i>	<i>Quality</i>
>78	High	< -3	High	High	Insufficient
72	↑	-3...0	↑	↑	Sufficient
66		0...3			Satisfactory
60		3...9			Good
54		9...18			Very good
<48	No	>18	No	No	Excellent

Recently, Andersson & Chigot (2004) mentioned that American National Standards Institute named the articulation index rating table as S3.5

(Methods for the calculation of articulation index, 1969). It is standardized due to assess intelligibility in the activity of conversation. As an objective measurement, articulation index can be measured with the rapid sound transmission index (RASTI). For this index, computer simulations and acoustical evaluation equipments can be used.

Andersson & Chigot (2004) took into consideration the parameters of articulation index in five topics. First one is the 'voice effort' of the individual talking. Second one is the 'orientation' of the talker compared to listener. Next one is the attenuation of the speech over 'distance'. The other one is the attenuation of speech due to the presence of 'screen and barriers'. The final one is the 'reinforcements of speech due to the reflectors'.

3.1.5. Speech Transmission Index (STI)

Speech Transmission Index (STI) is a parameter of speech intelligibility that checks the speech signal levels, reverberation characteristics and the time distortion. It was formulated to check the quality of speech communication (Houtgast, T. & Steeneken, H. J. M. 1973).

Egan (1988), Kuttruff (1991) and others imply that the unit of speech transmission performance may also be explained with percentage. If the speech transmission performance is more than 50%, speech transmission is satisfactory to hear the words and sentences separately.

Speech transmission index (STI) has a range from 0.00 to 1.00, where 0.00 represents none and 1.00 represents complete intelligibility level (Egan, 1988) (Table 3.4.).

Table 3.4. Quality of STI values (Lazarus, 1987)

STI	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	Insufficient		Insufficient but acceptable for some purposes		Sufficient to Satisfactory		Good		Excellent	

STI was developed with in the same line with Articulation index. Many researchers investigated the STI while researching the AI results. These two are related to each other and direct measures of speech intelligibility.

Morimoto et al. (2004) mentioned that speech transmission performance is not only evaluated by objectively but also by subjective tests like “listeners indicate the percentage of words and sentences that they recognize” (p. 1607). However, even if the intelligibility of speech is perfect, the speech transmission performance may not be satisfactory in all cases.

3.1.6. Signal to Noise Ratio (SNR)

Signal to noise ratio is a parameter which provides the intelligibility between the speaker and the receiver (listener) and highly correlates with speech transmission index (Lazarus, 1986). In terms of speech intelligibility, face to face communication at short distances in public spaces requires sufficient sound pressure level and signal to noise ratio.

To get sufficient SNR, the transmitted noise level (signal) should be over the ambient background noise level. If the signal sound level lower than the required, it means ambient background noise level is very high. Because of this, the signal speaker has to increase his/her signal sound level to transmit the signal to receiver (listener). However, if signals increase their speech level, the ambient noise level of the space increases too (Bronkhorst, 2000).

In non-acoustic enclosed leisure spaces, the sufficient SNR value for face to face communication at short distances is more than +3 for good communication that can be obtained by using quality of verbal communication table that depend on the speaker's effort (See at Table 3.5.).

Table 3.5. Assessment and intelligibility rating at the listener position, given in three standards. (Volberg et al, 2006, p.408).

	ISO 9921-1 [1]		ISO 9921 [2]			ANSI [11]	
	Intelligibility rating	SNR _{Aeff} in dB	Intelligibility rating	STI	SNR _{Aeff} in dB	SII	SNR _{Aeff} in dB
0	excellent	> 18	–	–	–	–	–
1	very good	12...18	excellent	> 0.75	> 7.5	–	–
2	Good	6...12	good	0.60...0.75	3.0...7.5	> 0.75	> 7.5
3	satisfactory	0...6	fair	0.45...0.60	–1.5...3.0	–	–
4	sufficient	–3...0	poor	0.30...0.45	–6.0...–1.5	< 0.45	< –1.5
5	unsatisfactory	–6...–3	bad	< 0.30	< –6.0	–	–
6	insufficient	< –6	–	–	–	–	–

3.1.7. Speech Interference

Speech interference is one of the major effects of noise pollution effecting human beings. “Noise decreases the intelligibility of speech by raising the listener’s threshold of hearing while, at the same time, masking the information. This loss of information may be partially compensated for by moving closer, talking louder or using electronic amplification” (Kinsler, Frey, Coppens, & Sanders, 2000, p. 362). Speech interference disturbs effective communication between speaker and listener. The masking effect of noise on speech communication is evaluated in terms of speech intelligibility (Rhebergen & Versfeld, 2005).

Speech Interference Level (SIL):

In terms of SIL procedure, the Speech Interference Level (L_{SIL}) can be calculated from the noise of sound level on the basis of four octaves; $f_i = 0.5, 1, 2$ and 4 kHz.

$$L_{SIL} = 10 \log_{10} \sum L_{Ni}$$

where, L_{SIL} = Speech Interference Level,

L_{Ni} = noise of sound level.

Additionally, speech interference level can also be obtained by determining signal to noise ratio at the hearer's position. For the satisfactory

intelligibility, $L_{SA}(r) - L_{SIL} = 10 \text{ dB}$

where,

L_{SA} = Speech sound level (vocal effort),

r = distance,

L_{SIL} = Speech Interference Level (Lazarus, 1986).

Speech intelligibility level procedure (SIL) is one of the methods of predicting speech intelligibility that determines the speech interference level by taking into consideration both speakers' sound level and the intelligibility scores at hearer's position. To date, SIL procedure has been proposed in the literature and it has also been involved in various standards like ISO, ANSI, DIN and AFNOR (Lazarus, 1986). SIL procedures (SIL curves) help us to elaborate the criteria for the quality of verbal communication and the limit values for noise level.

The basic requirements for SIL curves are SII (percentage of correctly understood monosyllabic words), AI, SNR, STI and the speech level (vocal effort) of the speaker (Lazarus, 1986). In the light of this information, SIL curves can be calculated as follows:

$$L_{SA, 1m} - L_{NA}(r) - 20\log/1m = L_{SNA}$$

$$\text{or, } L_{NA}(r) = L_{NA, 1m} - L_{SNA} - 20\log/1m$$

$$\&, L_{SNA} = L_{SA} - L_{NA}$$

where,

- $L_{NA, 1m}$ = Noise level at the hearer's position,
- r = distance,
- $L_{SA, 1m}$ = Vocal effort (speech level) of speaker,
- L_{SNA} = Signal to Noise Ratio.

According to these equations, Figure 3.2. shows the relationship between noise level (L_{NA}) the maximum speaker-hearer distance(r) for a given difference between speech level ($L_{SA, 1m}$) and SNR at the hearer's position that equal to noise level at 1m. distance. On the other hand, if the speech level (vocal effort) ($L_{SA, 1m}$) and SNR (L_{SNA}) are known SIL curves can be formed too (Figure 3.3).

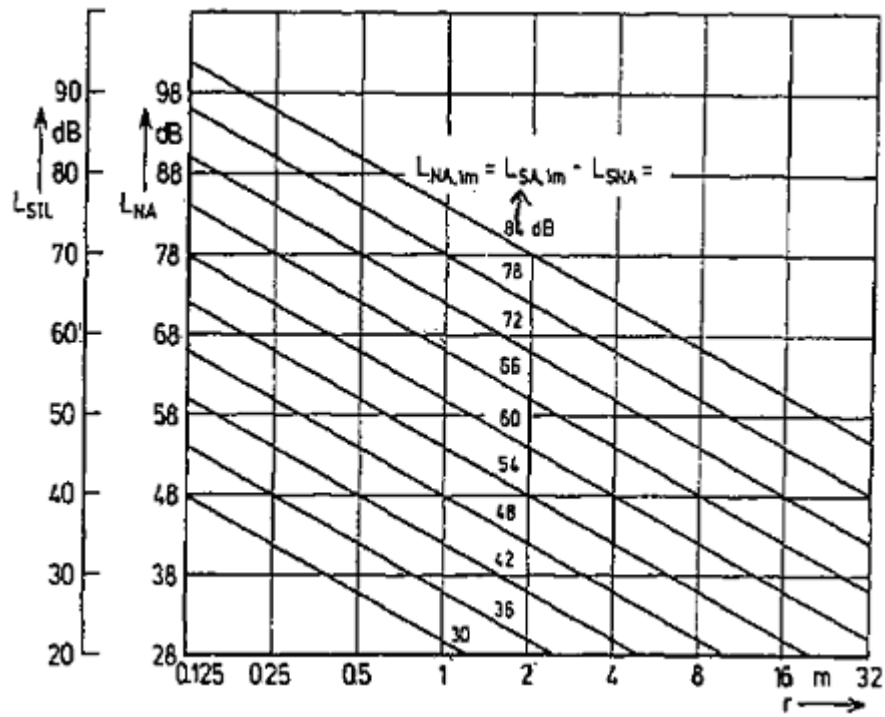


Figure 3.2. The generalized SIL curves (Lazarus, 1987, 248).

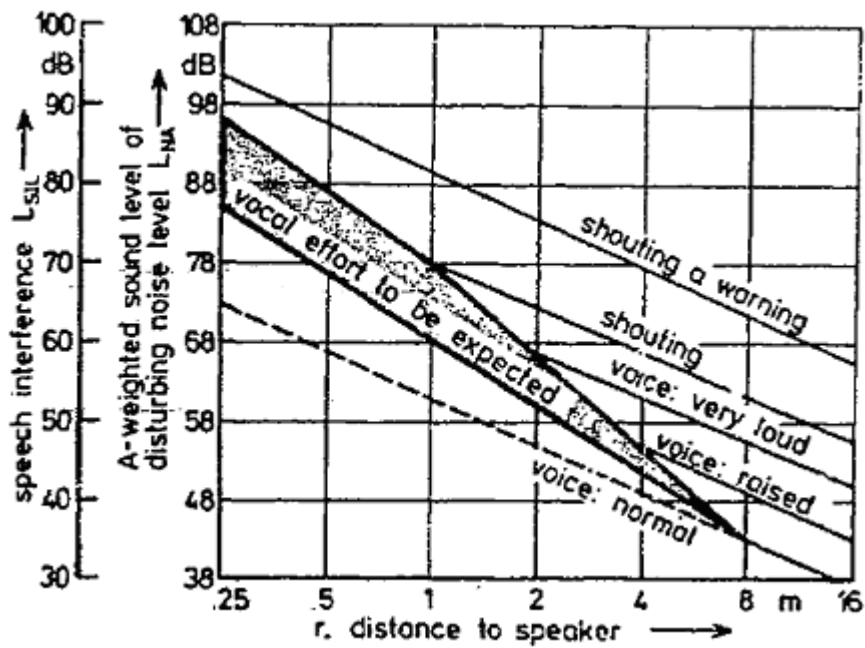


Figure 3.3. SIL- Distance Diagram (Lazarus, 1986, 447).

In addition to speech interference level, there is also a preferred version that is the Preferred Speech Interference Level (PSIL). In the case of face to face communication at short distance (1 meter), PSIL would be at adequate rating to indicate necessary vocal effort at a given noise level. The PSIL can be calculated by using A-weighted sound pressure level (L_A). $PSIL \approx L_A - 7 \text{ (dB)}$ (Beranek, 1992).

Many factors contribute to the effect of noise on communication interference. The most important ones are the number of people and ambient noise levels.

Number of People:

Many researchers argue that (Plomp, 1977, Hawley, Litovsky & Colburn, 1999, Bronkhorst, 2000, Drullman & Bronkhorst, 2004) speech intelligibility is determined by three factors. These are number of people, spatial distribution and the temporal envelope of the interfering sounds. There is a close relation between number of people (signals) and temporal envelope. When the fluctuating sounds are mixed, it can be easily seen that the fluctuations from interfering signal decrease. On the other hand, there is also relation between number of people and spatial distribution. According to this, when the number of people (signals) is increased, the signals need to be separated (Bronkhorst, 2000).

Ambient Noise:

In 1965, Zadeh considered ambient noise level as a function of speech intelligibility to measure speech interference. He points that “the degree of interference of noise with speech depends on the ambient noise level. The higher the level of the masking noise, the greater will be the percentage of speech sounds will be that became incomprehensible to the listener”

(cited in Zaheeruddin & Jain, 2008, p. 1979). Additionally, the effects of ambient noise on speech interference have different influencing factors such as age and distance between speaker and listener. According to Zadeh (1965), the ambient noise level should not exceed 65 dB (A) for young and middle ages, and 55dB (A) for old people, for good communication at normal distance (short and medium). Also the older the people, the shorter the communication distance must be to provide intelligibility (cited in Zaheeruddin & Jain, 2008).

4. BİLKENT ROLL HOUSE

4.1. Space Description (Layout/shape/size)

As a multi-activity leisure space, the Bilkent Rollhouse has been chosen. It is placed at the Bilkent neighborhood of Ankara, Turkey and is located in Ankuva shopping mall (See Figure 4.1.). It offers several kinds of activities like bowling, dart, billiards, computer games, PS, and dining area. The customers of this space include students of Bilkent University, inhabitants of the neighborhood and tournament players.



Figure 4.1. Site view of Ankuva Shopping Mall

(<http://www.uzaydanbak.com/points/details/100347>)

As plan layout, the activity areas in Bilkent Rollhouse are placed as open-planned organization (See Figure 4.2.). All the activity areas have close

relation with each other. Totally, all activity areas in Bilkent Rollhouse spread to 3800 square meters. The height of the ceiling is 4.00 meters.

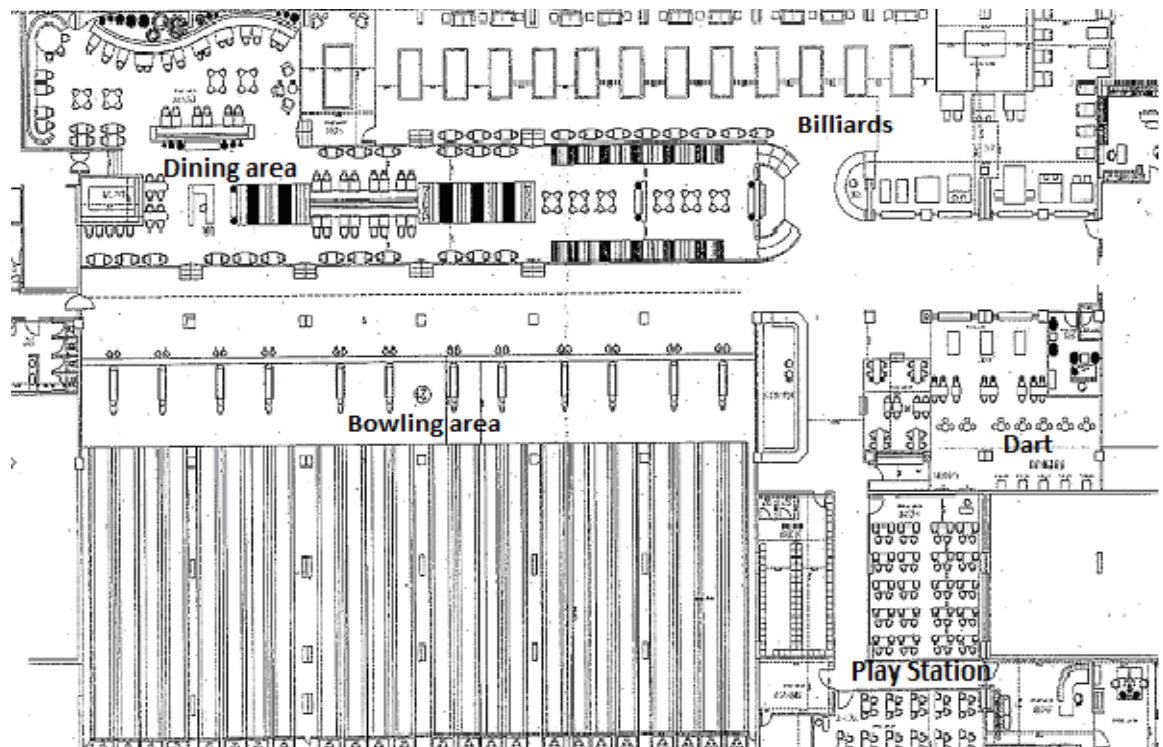


Figure 4.2. The Plan of Bilkent Roll House

The general floor finishing material of the area is carpet. Other than this, parquet in dining area and marble at the entrance of the area are used.

As suspended ceiling material, it is seen that acoustical panel finishing are applied. Walls are generally covered by wallpapers and plaster with paint (See at Figure 4.3 and Fiigure 4.4. and Appendix A).



Figure 4.3. General view from billiards area



Figure 4.4. General view from dining area

4.2. Design of Study

In order to analyze acoustical parameters and users characteristics of this study, a pilot study and case study were performed. These studies consist three different methods; computer simulations, real-size measurements and questionnaires/intelligibility tests. The assessment tools of these methods are: ODEON 9.2 Auditorium Acoustics Software for computer simulations, DIRAC 3.0 Room Acoustics Software Type 7841, B&K Omnipower Sound Source Type 4296, B&K Power Amplifier Type 2716, B&K Sound Level Meter Type 2230 for real-size measurements (Briel & Kjaer, BB1078-14, 2003), Noise Annoyance Survey and Speech Intelligibility Test for questionnaires and intelligibility tests.

At the first step, a pilot study has been done. In this study, questionnaires and speech intelligibility test were performed to analyze noise annoyance ratings and speech Intelligibility of the selected space's users. Upon this application the equivalent continuous sound pressure level (L_{eq}) was measured at the tournament condition that is Friday evenings between 18:00 to 21:00, to check the noise level of the selected space with its annoyance ratings. L_{eq} values were measured by using B&K Sound Level Meter Type 2230 at ear height (1.2 meters) and all the measurements were taken in each 15 minutes.

As a case study, computer simulations and real-size measurements were implemented to analyze acoustical parameters of the selected multi-activity leisure space in terms of speech interference in occupied condition. The parameters that were measured are Reverberation Time (T30) and Speech Transmission Index (STI) by using computer simulation tool and Equivalent Continuous A-weighted Sound Level (Leq A), Speech Transmission Index (STI) and Signal to Noise Ratio (SNR) by using real-size measurement tools.

4.3. Pilot study on speech interference in Bilkent Roll House

The aim of this pilot study is to investigate the speech interference of users' in an open-planed public leisure space (Yilmazer & Gezginer, 2010^{1,2}). In this respect, Equivalent Continuous Sound Level was measured by using B&K Sound Level Meter Type 2230 upon the questionnaire application in order to check the noise annoyance rating of Bilkent Roll House users. Noise annoyance rating is a subjective assessment that is generally used at SPL and Leq A measurements to evaluate the annoyance rating and speech interference level of users at the selected space. Noise annoyance rating is an important evaluation factor of subjective measurement that is in relation with noise perception. According to Morimoto et al. (2004), “ it is necessary to compare the subjective measures with the

objective measures of realistic situations that could be a reference for judging whether or not the objective measure (physical measure) is useful for evaluating” (p. 1607).

Hence, questionnaires were applied at the most crowded day of the week which is Friday and in between 18:00 to 21:00 that is tournament time for occupied condition to check noise annoyance. For this study, a survey was prepared which has 12 questions and supports each other (See at Appendix B). Questionnaires were applied to 60 users at 90% full occupied condition to determine annoyance ratings.

The participants were asked to evaluate the noise annoyance of the space selecting from 1 to 5 scales from the questionnaires. These are very quiet, quiet, neutral, noisy, and very noisy. In order to determine assessment of the noise annoyance, Leq values were measured at five different points, P1, P2, P3, P4, P5, at the each activity (See Figure 4.5.). The sound level meter set to fast response and linear weighting curve was applied. For each identified point, the measurements were taken at ear height that is 1.2 meter and repeated 3 times on every Friday. Each acquisition at each point lasted 1 min and time interval between two subsequent samples is 15 minutes. Although measurements were not taken simultaneously due

to presence of only one sound level meter, conditions in the space like number of users and placing of users during the measurements were stable. Figure 4.6. shows the Equivalent Continuous Sound Level (L_{eq}) values and annoyance ratings of five different measuring points.

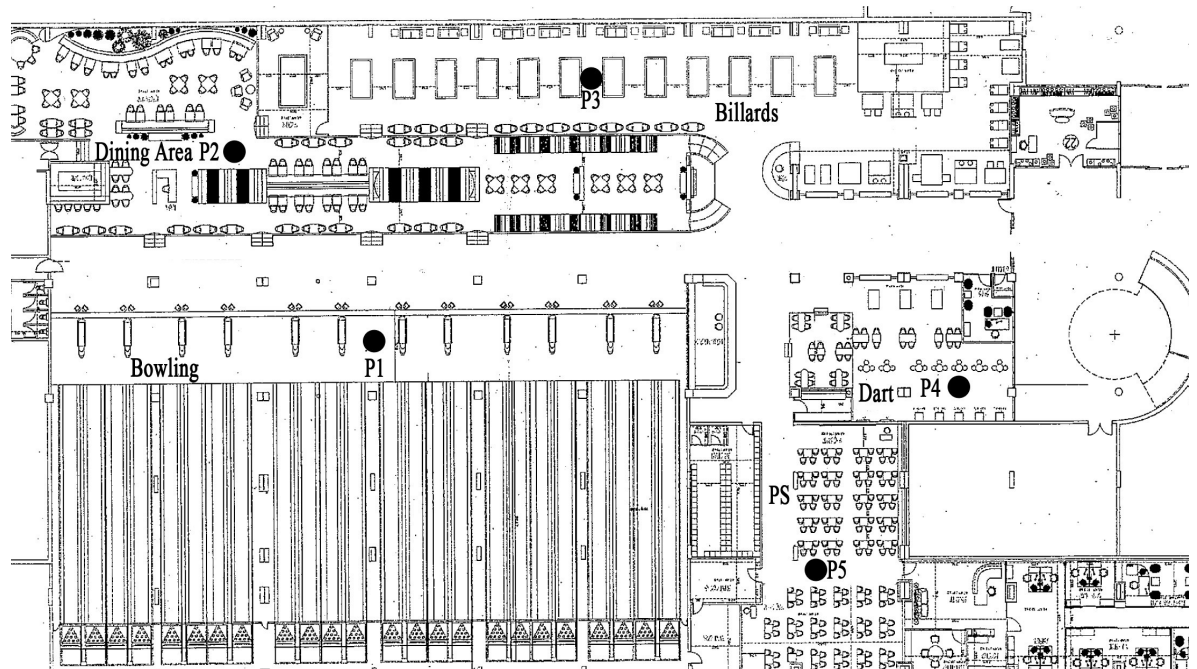


Figure 4.5. L_{eq} Measurement points on the plan of the Bilkent Roll House

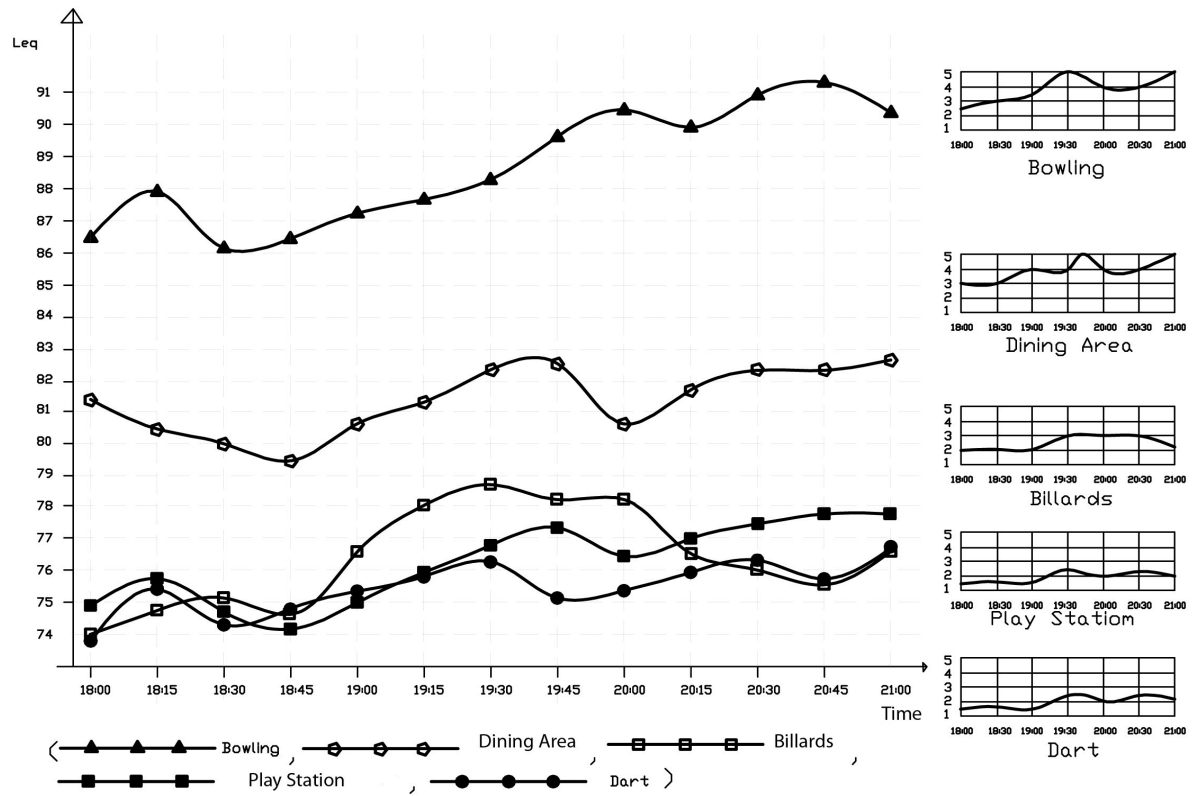


Figure 4.6. Equivalent Continuous Sound Level (Leq) values and annoyance rating of five different measuring points.

According to diagram above, the ambient noise can be explained as the noise in bowling area, because this noise is dominant in the Bilkent Roll House. It means that all activities will be affected by this noise and must be taken into account as base. Moreover, there is the ambient noise level of the space and additionally the overlapping human voice levels. These human voice levels (overlapping noise) make the noise level of selected space to increase that is called 'cocktail party phenomenon'.

Additionally, Figure 4.6 shows that noise level in the dining area is stable, hence; there is no overlapping human noise. When the other areas' noise levels increase slightly in time, dining area's noise levels are stable.

However, the annoyance ratings in dining area increase slightly on time.

This findings opposes in literature, users of Roll House get in a common behavior psychologically. In this manner, users give up speaking loudly, they accept repeating or prefer silence and focus on their main activity.

The noise level in the dining area is stabilized by users unconsciously because of the low noise annoyance ratings. The pain of noise causes the users to abandon comfort condition and as they lose ability of understanding each other, they leave their vocal effort, change behaviors and lose communication quality.

Speech intelligibility is an indication of how well speech is recognized and defined as a part of spoken materials in terms of speech communication (Lazarus, 1986, p. 1987). In this manner, speech intelligibility was measured via articulation index (AI) in the dining area of the Bilkent Roll House in occupied condition subjectively. After application of the word list to the users, the AI contours were prepared. The word lists were again applied on the most crowded day of the week which is Friday and from 18:00 to 21:00 at 85 dB ambient noise with 60 dB vocal effort between

1 meter distance. After application of the word list to the users, the AI contours were prepared (See Figure 4.7).

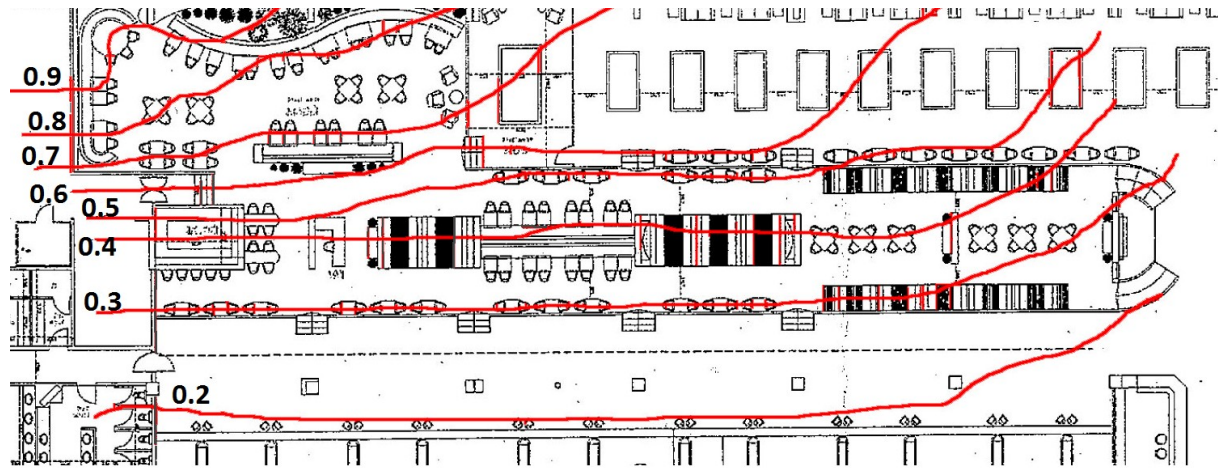


Figure 4.7 Articulation Index (AI) Contours of Bilkent Roll House

Figure 4.7. indicates that Articulation index in Bilkent Roll House at occupied condition is ranging between 0.2 to 0.9. At the front seats of bowling and dining area AI range is between 0.2 to 0.3. This range is defined as an unsatisfactory rating (See at Table 3.1.). At the front seats of dining area and billiards, the AI value shows 0.3 to 0.7 which is better than the front seats of the bowling area and corresponds to a good intelligibility rating. This value increased towards the rear rank of the dining area to 0.9 intelligibility, is in excellent rate.

5. COMPUTER SIMULATIONS

In this chapter, acoustical measurements were implemented to analyze acoustical parameters of the selected multi-activity leisure space in terms of speech interference for occupied condition by using computer simulations.

The computer simulations were fulfilled at the office environment. These parameters are Reverberation Time (T30) and Speech Transmission Index (STI).

5.1. Equipments and Method

To date, computer simulations have wide use opportunities because of its flexible modeling and simple modification techniques (Rindel, 2000).

In this study, Reverberation time (RT) and Speech Transmission Index (STI) were measured by the help of ODEON 9.2 Auditorium Acoustics Software as computer simulation of the Bilkent Roll House.

ODEON is a prediction software tool for indoor acoustics. It simulates acoustics of buildings that is actually ideal for analyzing large rooms like concert halls. Despite the fact that it is good at large scales, small scaled rooms can also be modeled like atria or classrooms. The software has a large material library that makes it easy to assign properties of materials to the surfaces (Brueel & Kjaer, 2010).

In order to simulate Bilkent Roll House by using ODEON 9.2, the 3D model of the space was drawn and saved in DXF format by using AutoCAD 2008 with face modeling technique (See Figure 5.1.). Each material and surface was layered to make possible to assign materials in ODEON 9.2. The saved DXF file was imported to ODEON 9.2, and 3D model of Bilkent Roll House was ready for analyzing. The next step was assigning the materials in ODEON 9.2 by using its own material library and additional materials. Accordingly, the sources and receiver positions are determined. Figure 5.2. and 5.3. shows the views from the sources and receiver.

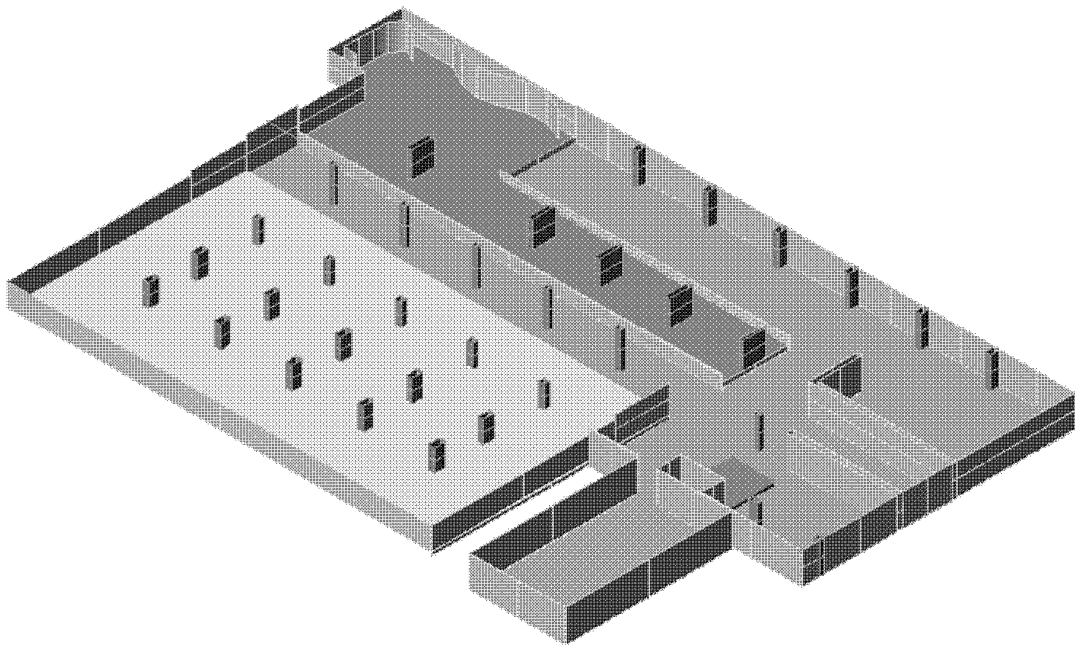


Figure 5.1. 3D model of Bilkent Roll House in AutoCAD 2008.

In order to being sure on the reliability of calculations, the geometry of model was checked to be sure that there was no sound escape. Hence, the ray tracing tool of ODEON 9.2 was used to check the 3D geometry. To get acoustical parameters, grid response was used.

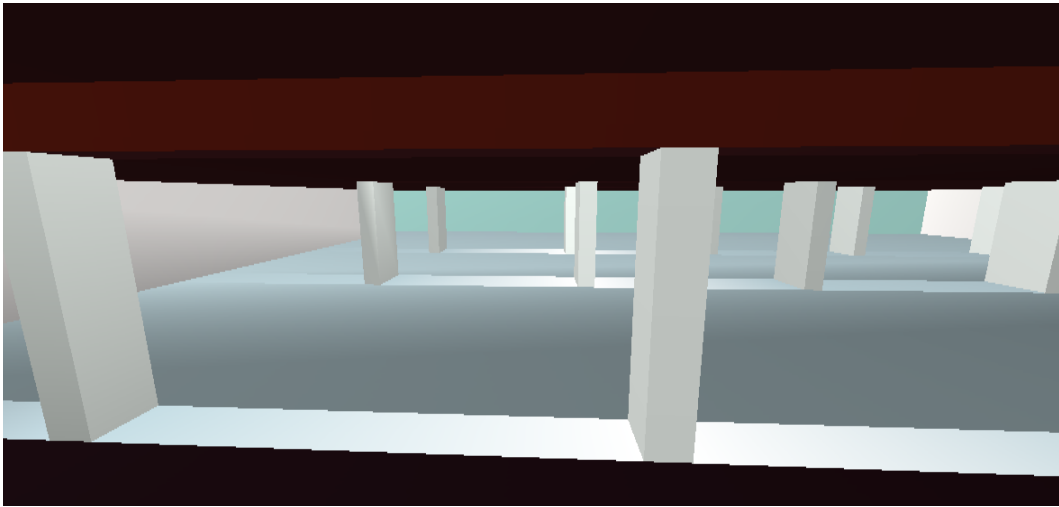


Figure 5.2. The 3D view from receiver in ODEON 9.2.

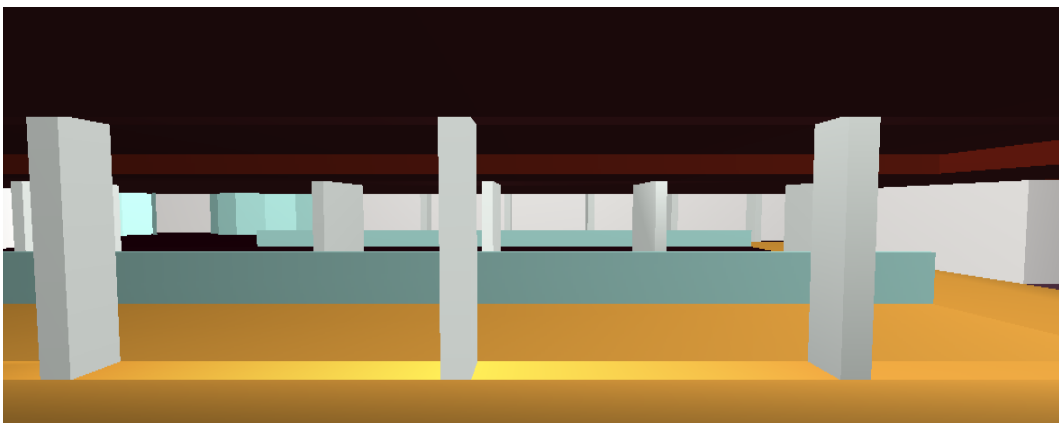


Figure 5.3. The 3D view from sources in ODEON 9.2.

5.2. Simulation of the Bilkent Roll House for fully occupied condition

For this study, it is preferred to measure Reverberation Time (RT) and Speech Transmission Index (STI) by using real-size measurement tools that is DIRAC 3.0. Although it is not difficult to measure RT by DIRAC 3.0. at unoccupied condition (See at Appendix C), it is very hard in fully occupied condition of Bilkent Roll House, because of the high background noise level of Bilkent Roll House that is 88.7 dB A . Firstly, it was simulated by using ODEON 8.5. room acoustics software, however, because of wrong attached background noise level, the simulation were repeated (Gezginer & Yilmazer, 2011). Therefore, second part of the simulation was organized and assumed as an occupied. It was planned to measure Reverberation Time (RT) and Speech Transmission Index (STI) in occupied condition by using ODEON 9.2 that is computer simulation software.

In order to measure acoustical parameters by using ODEON 9.2, the twelve column type sources of Bilkent Roll House and a receiver point that is in the middle of dining area were determined (See at Figure 5.4.).

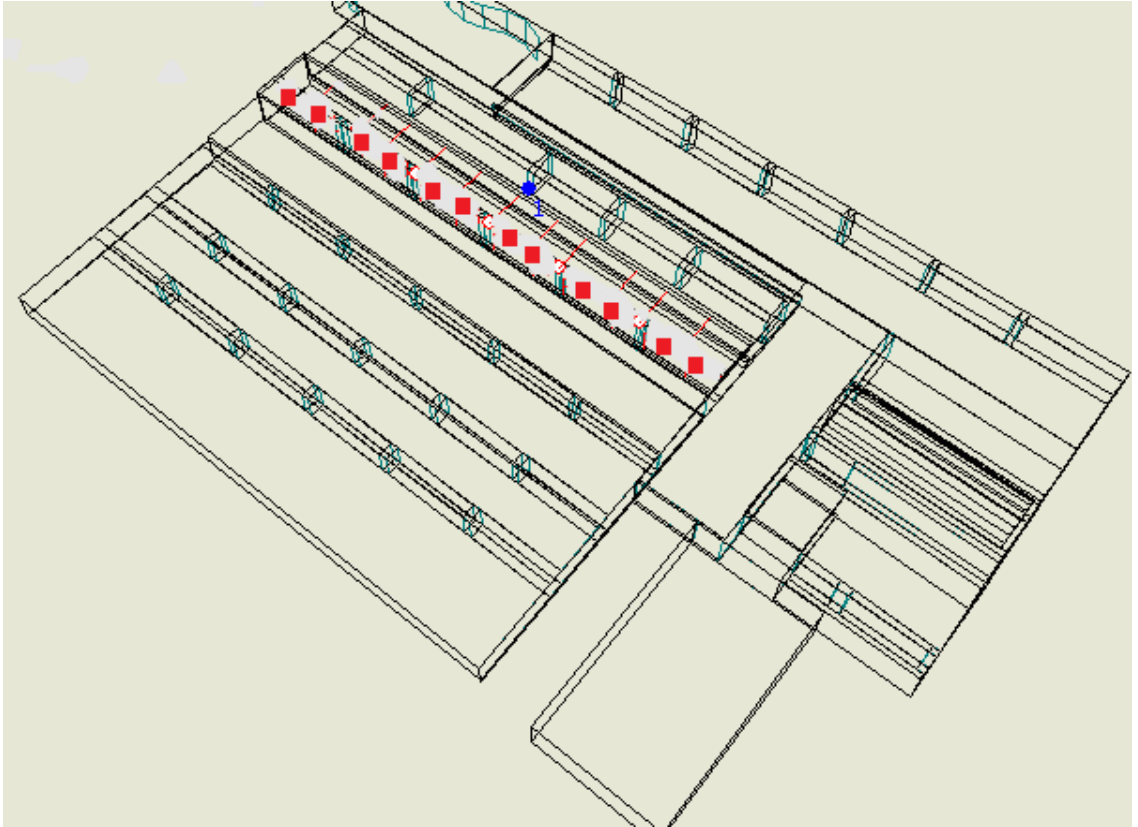


Figure 5.4. The sources and receiver positions in ODEON 9.2.

(●: Receiver, ■: Speakers)

5.2.1. Reverberation Time (RT)

Reverberation time is one of the most important factors in room acoustics that affects speech communication. Hence, absorption coefficients of selected material is very important because if the reverberation time is longer than a room requires, the negative effects of reverberation time can be seen in terms of intelligibility (Rettinger, 1988). Figure 5.5. shows absorption coefficients of Roll House finishing materials. It is expected that reverberation time should be at preferred value in a room.

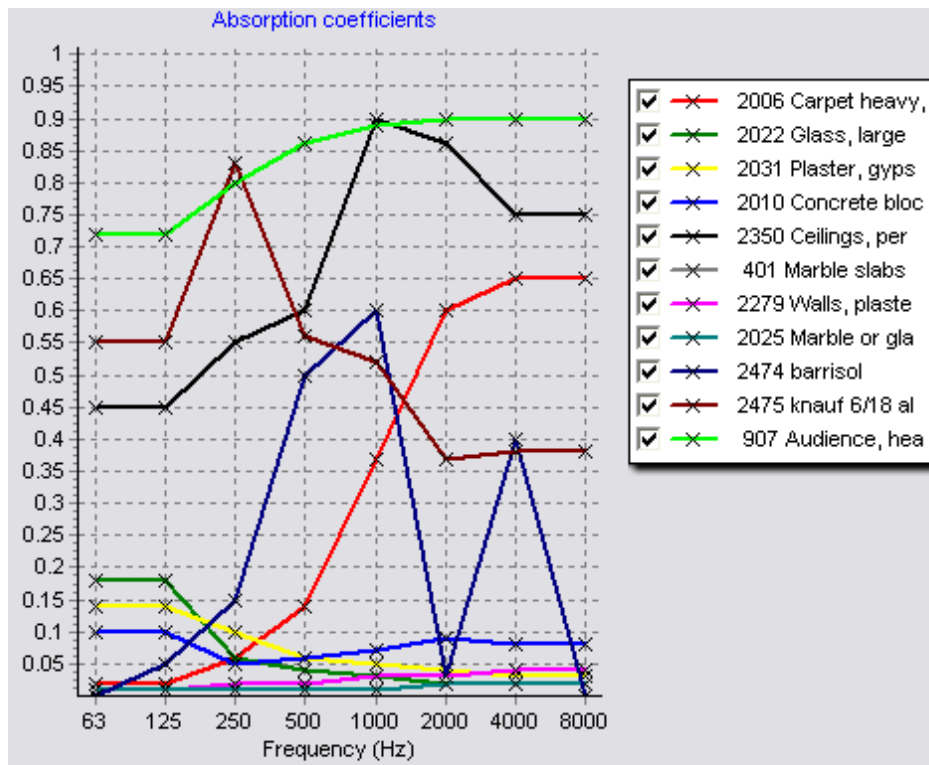


Figure 5.5. Absorption coefficients of Roll House' finishing materials.

The simulation results include global decay curves which are the quick estimation calculations. According to quick estimation calculations, the simulated results at occupied condition are given in the Figure 5.6. and Figure 5.7.

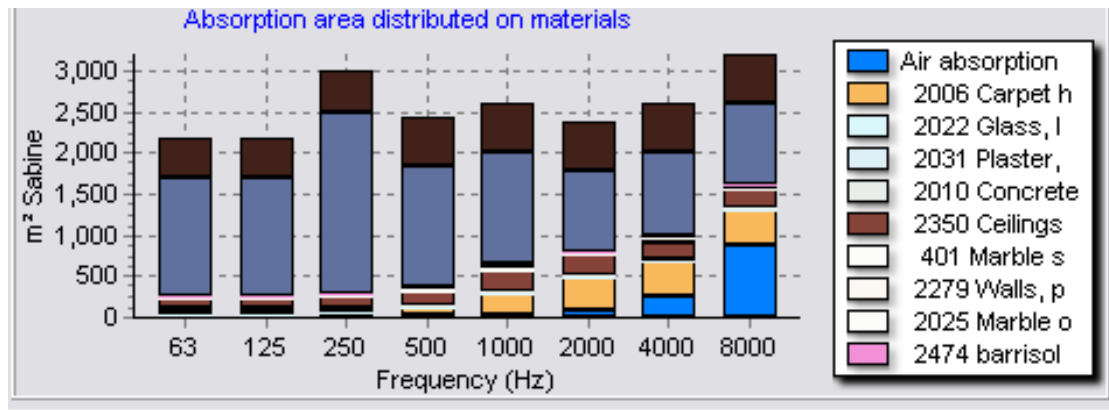


Figure 5.6. Material overview for occupied condition

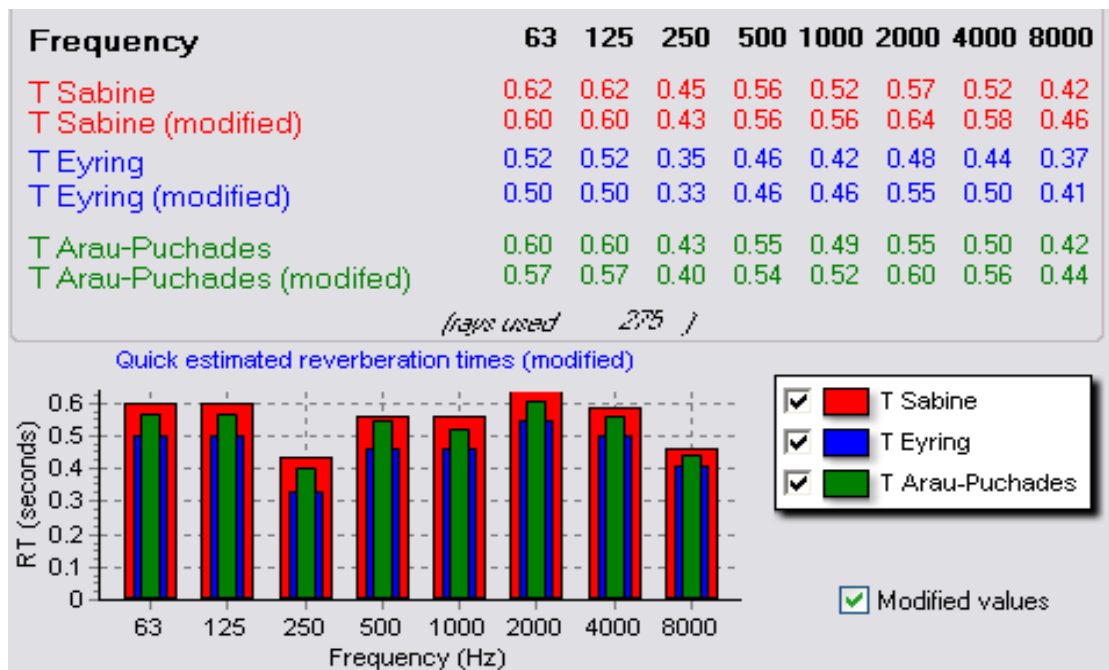


Figure 5.7. Estimated reverberation times of quick estimate for occupied condition

Considering the material overview graph, it can be seen that the sound absorbing materials are again distributed in a balanced manner at occupied condition. The graph implies that the audiences and gypsum board

suspended ceiling material are the much absorptive at all frequencies. The carpet is also absorptive at high frequencies whereas it is reflective at low frequencies (See at Figure 5.6.). The quick estimation calculations show that the reverberation times for the occupied condition are distributed in a balanced manner to all frequencies (See at Figure 5.7.).

The second global decay curve is the global estimate. This energy curves are based on the ray tracing and it takes into account the room shape and the absorbing material (Brüel & Kjaer, 2010). The result of the global estimate energy curve and free path distribution map were placed at Figure 5.8. and Figure 5.9.

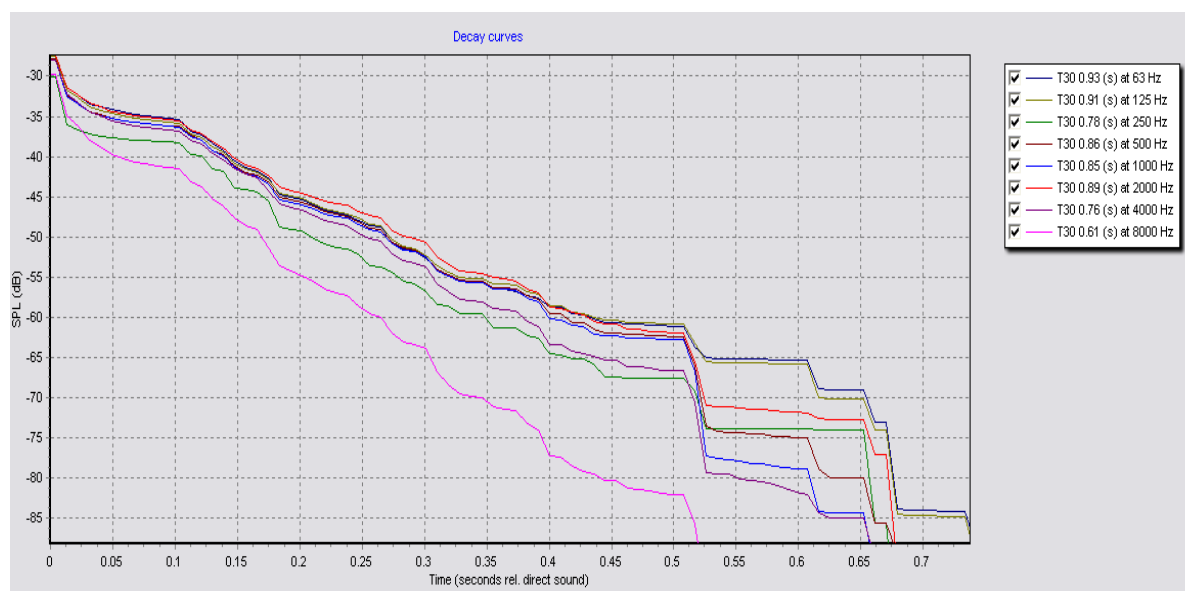


Figure 5.8. Energy Curves for occupied condition

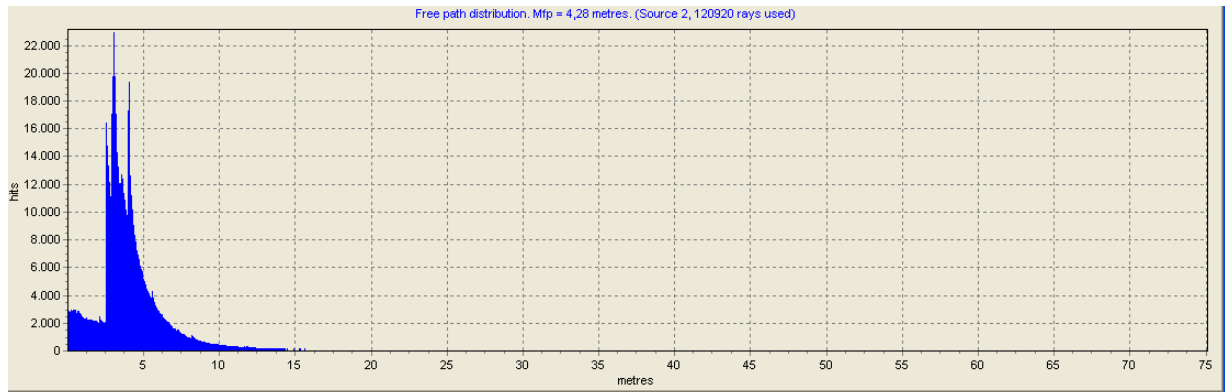


Figure 5.9. Free path distribution map of T30 at occupied condition.

Reverberation requirements in such a space contains multi-activities are between 0,9s. and 1,3s. for T60 (Clark, 1991). The grid response result of reverberation time value at different locations was found in between 0,85 to 2,13 second for occupied condition in Bilkent Roll House at 1000Hz which is at the optimum range. When the results are evaluated in terms of speech intelligibility, it is seen that RT values are in the limit for this kind of multi-activity space. Additionally, when the grid response of T30 is taken into account, it shows that the parameter is not homogeneous in the whole area due to the different surface reflections (See Figure 5.10.). Additionally, cumulative distribution function graph and the fractiles and average values are indicated in Appendix D.

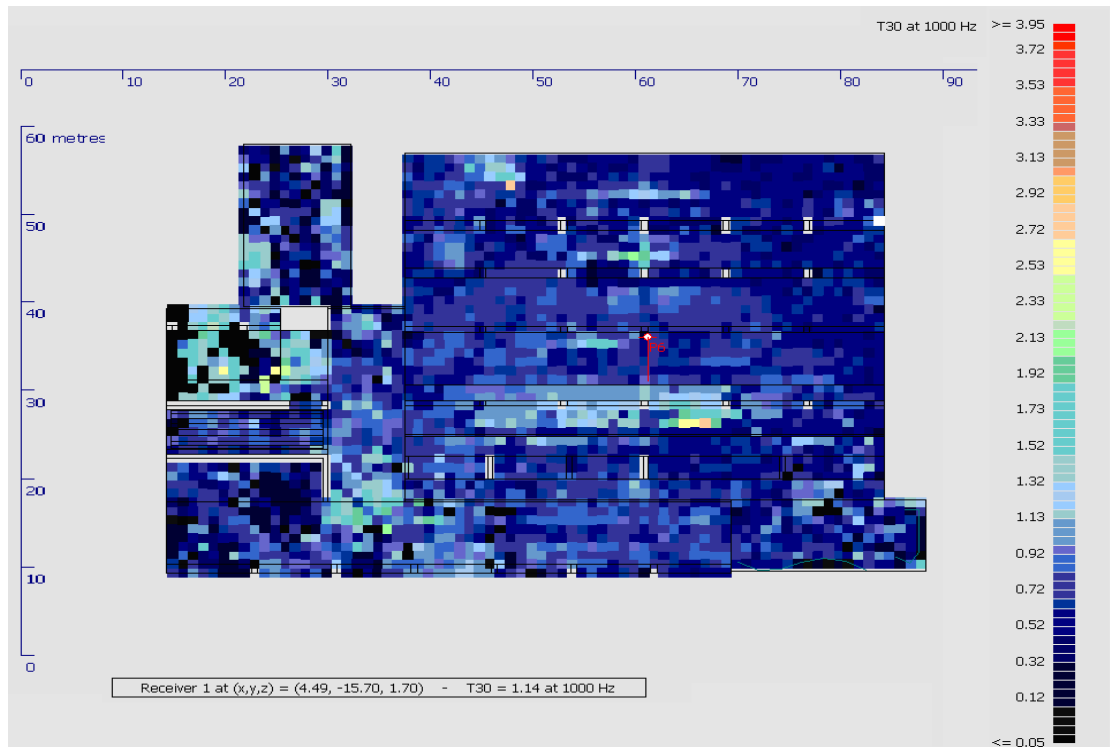


Figure 5.10. Reverberation Time distribution map for occupied condition at 1000 Hz

5.2.2. Speech Transmission Index (STI)

The speech transmission index that is an important parameter for speech intelligibility was simulated and found 0.00 range in Bilkent Roll House (See at Figure 5.11.) which corresponds to an unsatisfactory intelligibility rating and requires high vocal effort. The background noise and the reverberation time have highly important effect on STI. The reverberation time values were found at the required range, however, the background noise level of Bilkent Roll House was measured by using B&K Sound Level Meter Type 2230 and 88 dB A which is really high. This value of

background noise level poorly affects the STI in the area. Hence intelligibility scores decreases.



Figure 5.11. Speech Transmission Index distribution map at occupied Condition

6. REAL-SIZE MEASUREMENTS

In this chapter, acoustical measurements were implemented to analyze acoustical parameters of the selected multi-activity leisure space in terms of speech interference again for occupied condition by using both real size measurement tools. The real-size measurements were applied at the most crowded day of the week, on Friday from 18:00 to 21:00 that is tournament time for occupied condition to get Equivalent Continuous A-weighted Sound Level ($L_{eq\ A}$), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Speech Interference Level (SIL).

6.1. Equipments and Method

Real-size measurements of Bilkent Roll House were performed by using one of the B&K products that is DIRAC 3.0. Room Acoustic Software Type 7841 and Sound level meter Type 2230. Dirac 3.0. measures acoustical parameters by using a PC with soundcard and microphones (Briel & Kjaer, BE 1685-12, 2003). It calculates the frequency spectrum and many acoustical parameters from the impulse responses.

For the measurements of Bilkent Roll House by DIRAC 3.0, B&K Omnipower Sound Source Type 4296 (See Figure 6.1.) was used as a sound source. It uses 12 loudspeakers that are connected in a series-

parallel network. To acquire maximum sound source (signal) power, B&K Power Amplifier Type 2716 (See Figure 6.2.) was used that drives the Omnipower sound source which are connected to each other via AQ 0622 bridging cable and at the same time, power amplifier was connected to the PC from Input of the amplifier to the output of the PC (Briel & Kjaer, BB1078-14, 2003). B&K Sound Level Meter Type 2230 (See Figure 6.3.) was used as a receiver that was connected to the PC from the AC output of the device with 9-pin to 25-pin interface cable AO. Calibration of the sound level meter was adjusted at 94 dB.



Figure 6.1. B&K Omnipower Sound Source Type 4296 (Briel & Kjaer, BB1078-14, 2003).

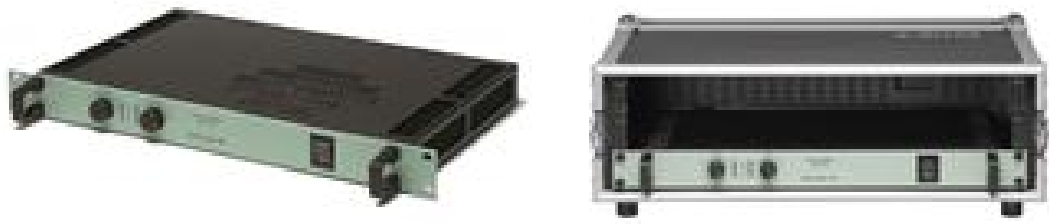


Figure 6.2. B&K Power Amplifier Type 2716 (Bruek & Kjaer, BB1078-14, 2003).



Figure 6.3. B&K Sound Level Meter Type 2230 (Bruek & Kjaer, BB1078-14, 2003).

To evaluate speech interference in the selected space, Speech Transmission Index (STI) and Signal to Noise Ratio (SNR) parameters were measured by using DIRAC 3.0., hence, internal MLS signal was processed by using DIRAC 3.0. for measuring speech parameters. Additionally, Equivalent

Continuous A-weighted Sound level was achieved by using Sound Level Meter Type 2230.

6.2. Measurements and Results

Equivalent Continuous A-weighted Sound level (Leq A) was obtained from the impulse responses of seven measuring points and Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Speech Interference Level are obtained from the impulse responses of five measuring points in Bilkent Roll House at occupied condition. In addition, much detailed impulse responses at occupied condition are given at Appendix D.

6.2.1. Equivalent Continuous A-weighted Sound Level (Leq A)

The Leq A measurements of Roll House was performed at seven different measuring points that are R0, R1, R2, R3, Billiards, Dart and Play Station. As a result from the pilot study, the number of measuring points at bowling and dining area were increased in case study because of the noise levels and user behaviors in dining area (See at 4.3.). Three of these were located in bowling area, one at the same point with previous measurement that is at the middle point of dining area and the others at the billiards, dart and play station area (See at Figure 6.4.).

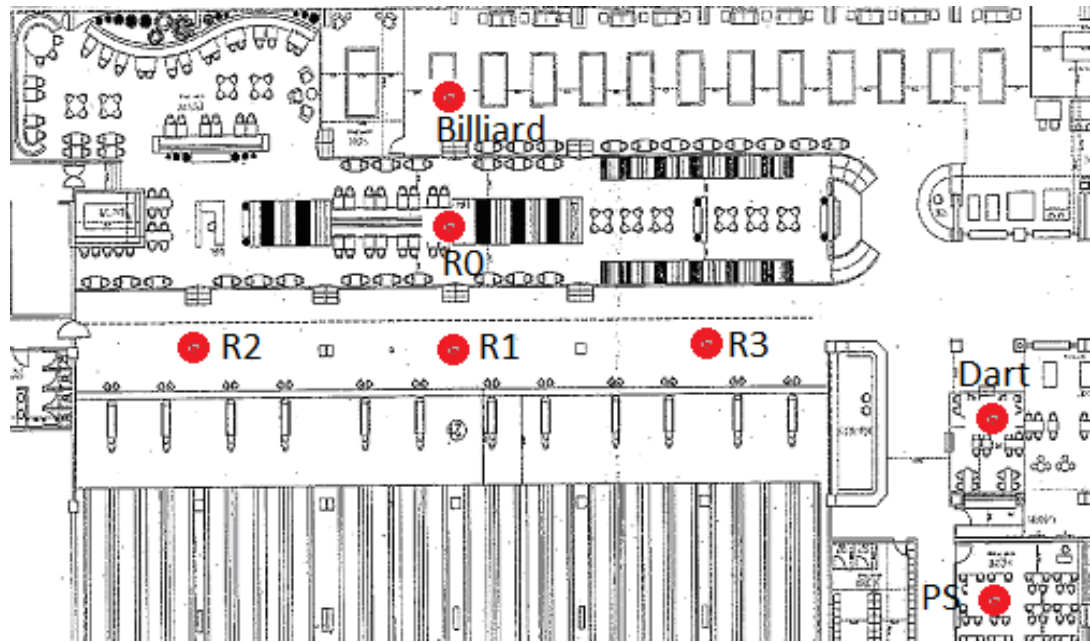


Figure 6.4. Seven measuring points (R0, R1, R2, R3, Billiard, Dart, Plat Station) for Leq A in occupied condition

Leq A was measured on the most crowded day of the week that is Friday from 18:00 to 21:00, in each 15 minutes at seven points. For each identified point, the measurements were taken at ear height that is 1.2 meter by using B&K Sound Level Meter Type 2230 and repeated 2 times on every Friday Figure 6.5. shows the results of Leq A at seven measuring points.

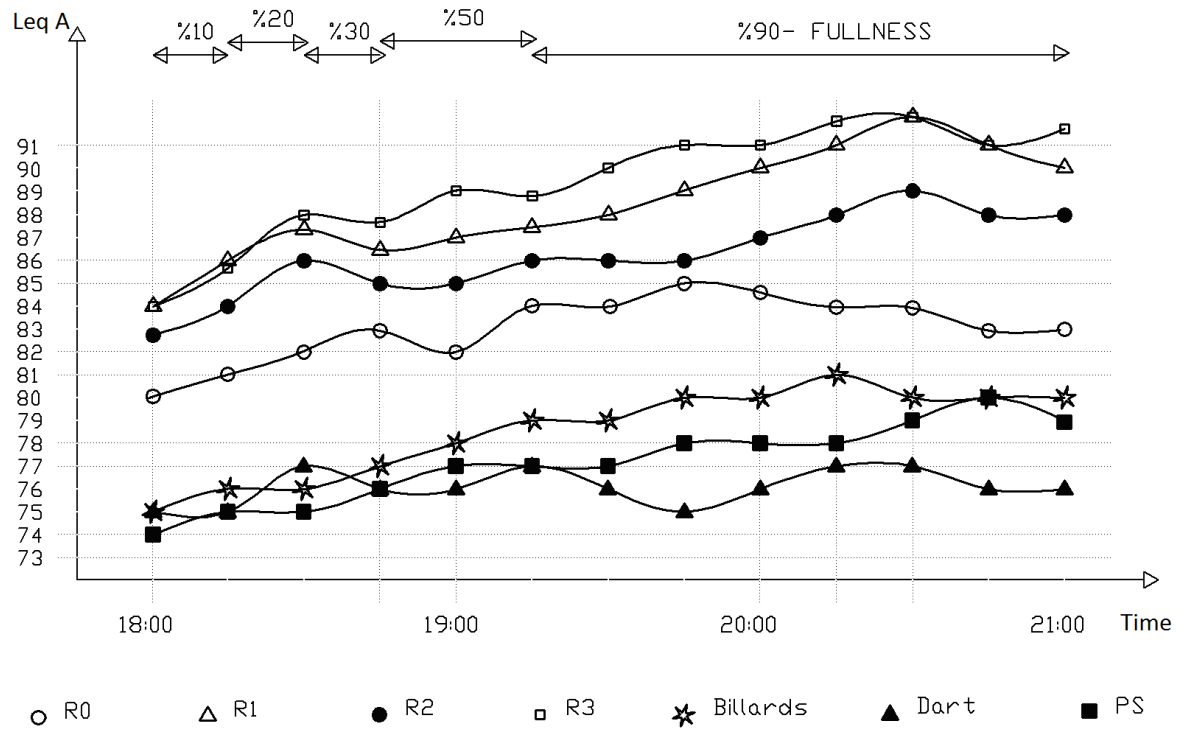


Figure 6.5. Results of Leq A at seven measuring points in occupied condition.

Figure 6.5. shows that noise levels increases when the number of people increase in time. When the dining area's Leq A noise level is handled, it is seen that the noise level stays on time but the others increases slightly on time as in the pilot study. In the light of this information, users have a tendency to change their behavior because of their annoyance from the bowling area that is the most dominant noise in that space, when the main activity of users is dining.

In order to separate A weighted 'ambient noise level', 'conversational noise (speech) level' and 'music noise level' from each other; music was

required to be muted for a time, when the leisure space 90% of full. At that time, the conversational noise (speech) levels of users were measured and found that is 82 dB A.

As a second way, the music noise level that (L_{NA}) was measured at unoccupied condition (due to solely measure music noise level) can be subtracted from the ambient noise of the space at occupied condition by using logarithmic calculation in order to determine conversational noise (speech) level (L_{SA}) (See at 3.1.2.). It was found that the ambient noise was 84 dB A at occupied condition and the music noise level was 75 dB A at unoccupied condition from the receiver position in the middle of the dining area. By the time, music noise level was subtracted from the ambient noise level by using logarithmic calculation;

$$10\log (10^{LN+S/10}-10^{LN/10}) =$$

$$10\log (10^{84/10}-10^{75/10}) = 83$$

It was found 83 dB A as conversational noise (speech) level.

In order to find overlapping speech effort on the ambient noise level of Bilkent Roll House, the Leq A level at unoccupied condition is subtracted from the occupied condition for both dining and bowling area (See at Figure 6.6.)

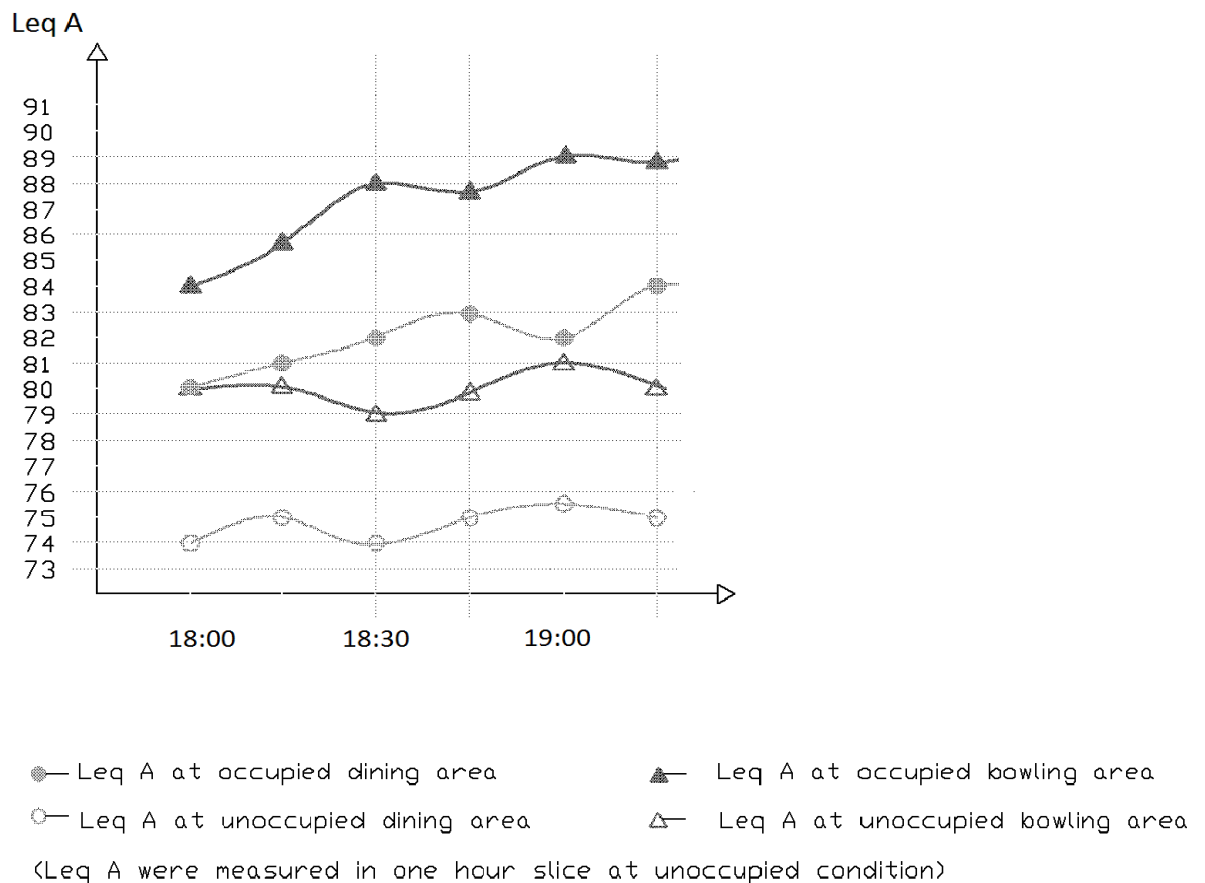


Figure 6.6. The noise levels in bowling and dining area at occupied and unoccupied

6.2.2. Speech Transmission Index (STI)

In order to measure Speech Transmission Index (STI), DIRAC 3.0 was used as a Real-Size measurement tool. According to Lazarus (1986), STI values can also obtained from the speech intelligibility tests. As a result of real-size measurements, STI is near the range of 0.26 at R0, 0.1 at R1 and R2, 0.04 at R3 and 0.24 at Billiards (See at Table 6.1.) It was focused on 5 measuring points because of the changes of noise levels in bowling and dining area (See detailed results at Appendix D).

Table 6.1. The STI impulse responses at five points for occupied condition

	R0 (Dining)	R1 (Bowling)	R2 (Bowling)	R3 (Bowling)	Billiards
STI	0.26	0.10	0.10	0.04	0.24
Intelligibility rating *	unsatisfactory	unsatisfactory	unsatisfactory	unsatisfactory	unsatisfactory
Vocal effort **	High	High	High	High	High
SII***	<40%	<10%	<20%	<5%	<40%

* Volberg et al, 2006, 408. (See at Table 3.5.)

** Lazarus, 1987, 250. (See at Table 3.3.)

*** Lazarus, 1986, 246. (See at Table 3.2.)

For good speech communication, many researchers (Beranek, 1947, Kryter, 1946, Lazarus, 1986 etc) mentioned that STI should be more than 0.5.

Table 6.1. indicates that speech transmission index in Bilkent Roll House at occupied condition ranges from 0.04 to 0.1 at the front seats of bowling area. This range is defined as unsatisfactory in literature (See at Table 3.4.). At the dining area and billiards, the STI value is 0.24 to 0.26 which is better than the front seats of the bowling area, but still corresponds to an unsatisfactory intelligibility rating.

6.2.3. Signal to Noise Ratio (SNR)

To obtain SNR in occupied condition, DIRAC 3.0 was used at 5 measuring points that are R0, R1, R2, R3 and Billiards. According to literature, SNR results are correlated and can be evaluated by the other parameters of speech intelligibility that are Articulation Index (AI) and Speech Transmission index (STI) (Lazarus, 1986). As a result of DIRAC 3.0. results, SNR values are shown at Table 6.2. (See detailed results at Appendix D)

Table 6.2. The SNR impulse responses at five points for occupied condition

	R0 (Dining)	R1 (Bowling)	R2 (Bowling)	R3 (Bowling)	Billiards
SNR_A in dB	-3	-11	-7	-14	-3
Intelligibility rating *	unsatisfactory	unsatisfactory	unsatisfactory	unsatisfactory	unsatisfactory
Vocal effort **	High	High	High	High	High
SII***	<40%	<10%	<20%	<5%	<40%

* Volberg et al, 2006, 408. (See at Table 3.5.)

** Lazarus, 1987, 250. (See at Table 3.3.)

*** Lazarus, 1986, 246. (See at Table 3.2.)

The SNR average of Bilkent Roll House is in the range of unsatisfactory.

Table 6.2. shows that Signal to noise ratio in Bilkent Roll House at occupied condition range from -7 to -14 at the front seats of bowling area. This range is also defined as unsatisfactory in literature (See at Table 3.5.). At the dining area and billiards, the SNR value is -3 which is better than the front seats of the bowling area, but still corresponds to unsatisfactory intelligibility rating. This is because of the distance from the sound source as STI.

6.2.4. Speech Interference Level (SIL)

In order to obtain Speech Interference Level, it is needed to interpret SIL curves. Figure 3.3. shows SIL–Distance Diagram, and in order to find out the Speech Interference Level of a listener in 1 meter distance from speaker (face to face communication) in Bilkent Roll House, this diagram should be taken into consideration.

The highest $L_{eq\ A}$ values in the Roll House are 84 dB in the dining area and 92 dB in bowling area. When these values are placed on the diagram it shows 76 dB in dining area and 84 dB Speech Interference Level at 1 meter distance.

In addition to these, Speech level intensity characterizes the speaker's vocal effort to produce speech" (Lazarus, 1987, 250). Table 3.3. shows the speaker's effort and the hearer's impairment. When the SNR values are interpreted according to Table 3.3., it shows that the speech communication in dining and bowling area of Roll House are insufficient with -3 SNR in dining and -14 in bowling area which requires very high vocal effort, more than 78dB speech interference level.

7. DISCUSSION

In this study, a pilot and a case study were applied by using questionnaires/ intelligibility tests, computer simulations and real-size measurements to put forth the acoustical characteristics of the selected space, Bilkent Roll House, in terms of speech interference. As a pilot study Leq were measured upon the questionnaire application and AI contours of the dining area were prepared by using intelligibility tests. As a case study, RT was measured by using ODEON 9.2. and Leq A, STI and SNR were measured by using DIRAC 3.0. The results show some similarities and differences with literature.

As a result of pilot study, when the bowling, billiards and play station areas' noise levels increase slightly on time, dining area's noise levels are stable on time. However, the annoyance ratings in dining area are also increase slightly in time. These findings showed differences with literature, users of Roll House get in a common behavior psychologically; they adjust their vocal noise that they create. Additionally, AI contours showed that far parts of the dining area has better intelligibility than the fore part of the dining and bowling areas.

As a result of the case study, reverberation time (RT) at different locations was measured in between 0,85 to 2,13 seconds for occupied condition in Bilkent Roll House at 1000Hz which is at the optimum range. This result shows similarities with other studies on the reverberation requirements in multi-activity spaces. According to those studies, Reverberation times are between 0,9s. and 1,3s. for T60 (Clark, 1991). In literature, it was mentioned that higher RT values reduce the intelligibility scores of speech (Egan, 1988). When the Roll House's RT result is evaluated in terms of speech intelligibility, it shows that RT value is at required limit for this kind of multi-activity space. Hence, the intelligibility scores of speech are at the required range. Additionally, when the grid response of T30 is examined, it shows that the parameter is not homogeneous in the area due to different surface reflections (See Figure 5.9.).

Additionally, the Equivalent Continuous A-weighted Sound Level (Leq A) values were obtained in Bilkent Roll House by one-minute measurements from seven different measuring points (See at Figure 6.4.) at the most crowded day of the week, Friday in between 18:00. to 21:00. Measurements were made every 15 minutes, and taken from ear height.

The results of Equivalent Continuous A-weighted Sound Level (Leq A) values showed that (See at Figure 6.5.), noise levels of bowling, dart, billiards and play station activities increase when the number of people increases in time. Originally, there is the ambient noise level of the space. In addition to this, human voice level overlaps the ambient noise level of the space. These human voice levels (overlapping noise) increase the noise level of the selected space. This result showed similarities with the study of Bronkhorst (2000) which states ambient noise of a space increase in time, when the number of people and their vocal effort increase.

As the dining area's Leq A noise level is handled, it has been seen that the noise level remains stable through time, but the others increase slightly. This result can be evaluated as that, no overlapping human voice occurs in the dining area of Bilkent Roll House even if the number of people increases in time. In the light of this information, it can be argued that, users have a tendency to focus on their own activity instead of increasing vocal effort when the main activity is dining in Bilkent Roll House. These results show differences with previous researches which demonstrated that, when the ambient noise increases, users should increase their vocal effort, repeat the words, look the lips of speaker and accept the uncomfortable

communication (Bronkhorst, 2000, Navarro & Pimentel, 2007, Zaheeruddin & Jain, 2008) that is called 'cocktail party phenomenon'. In Bilkent Roll House, it is seen that, users are affected by the ambient noise, change their behavior and instead of increasing their voice level, they prefer to decrease their vocal effort to provide speech intelligibility in multi-activity spaces. Ambient noise level in the area is stabilized by users unconsciously because of their noise annoyance from other activities and high level of background noise. Although it changes user behavior, cocktail party phenomenon continuously occurs in the area because of the high level of background noise that decreases the intelligibility score of the environment.

When the bowling, billiard and play station areas Leq A were examined, it was seen that, the noise levels in the areas goes slightly high in time.

People increase their vocal effort because of their interference ratings.

These results showed similarities with Volberg et al.'s (2006) study, in which it was mentioned that if the noise level of the area more than 78 dB, people suffer from the speech interference (See at Table 3.5).

Essentially, background noise level should be between 55– 65 dB at 1000 frequency for good speech communication in ambient public environment

(Zaheeruddin & Jain, 2008). Hence, the noise level in the space is more than required.

As mentioned above, according to Volberg et al. (2006), if the noise level of the area more than 78 dB, people suffer from the speech interference. Thus, speech parameters were needed to measure at the activities that noise level more than 78 dB A. Table 3.5. shows that the noise levels in bowling, dining and billiards areas are more than 78 dB A.

In order to separate A weighted ‘ambient noise level’, ‘conversational noise (speech) level’ and ‘music noise level’ from each other, logarithmic calculation method was used to determine conversational noise (speech) level (L_{SA}) (See at 3.1.2.). As a result, conversational noise (speech) level was found as 83 dB A which equals to a shouting level. According to Lazarus (1986), normal vocal effort level near the range of 60–70 dB at one meter distance (See at Figure 3.3.). In the light of this information, it is seen that conversational noise level in Roll House is higher than required, because of the tendency of increasing vocal effort against the background noise level.

To determine STI, DIRAC 3.0 was used at 5 measuring points that are R0, R1, R2, R3 and Billiards in order to evaluate STI of different activities of the space in occupied condition. The results showed that STI of the activities (bowling, dining and Billiards) in Bilkent Roll House are ≤ 0.26 (See at Table 6.1.), and therefore, are insufficient and unsatisfactory for speech communication. Additionally, it was observed that when people are away from the bowling area, STI values increase and show better ratings than the bowling area.

For good speech communication, many researchers (Beranek, 1947, Kryter, 1946, Lazarus, 1986) mentioned that STI should be more than 0.5. Additionally, Kuttruff (1991), Egan (1988) and others imply that if the speech transmission performance is more than 50% (0.5), speech transmission is satisfactory to hear the words and sentences separately, and is insufficient for speech communication, if it is less than (0.5).

Furthermore, to obtain SNR in occupied condition, DIRAC 3.0 was once more used at 5 measuring points that are R0, R1, R2, R3 and Billiards. The results showed that SNR of the activities in Bilkent Roll House are ≤ -3 (See at Table 6.2.), and consequently are insufficient for good communication. In literature, it was mentioned that >7.5 SNR is best for

good quality of communication. If it is lower than -3 , SNR becomes unsatisfactory (Volberg et al. 2006). In such situation, SIL diagrams are needed to be used for the determination of SNR (Lazarus, 1986).

Additionally, whenever people are away from the bowling area, SNR values increase and show better ratings at far points of Roll House as STI. Yet, these results differed from the studies on SNR that are dealt with the required SNR range for good communication.

It can be concluded that, reverberation characteristics and unoccupied condition measurement results shows that the acoustical characteristics, design and material selection of Bilkent Roll House is at desired range. However, except dining area, noise level of each activity increases slightly in time when number of people increases which causes speech interference. Although the noise level is stabilized by users (especially in dining area), it is not good enough for speech communication quality. This is because; the speech parameters (STI & SNR) also showing unsatisfactory ratings due to high background noise level. If all these points are taken into consideration, it is seen that background noise level of the environment activates the cocktail party phenomenon.

8. CONCLUSION

The aim of this study was to analyze the speech interference of multi-activity public leisure spaces. In this context, Bilkent Roll House, which involves the activities of bowling, dining, darts, computer games and billiards, was studied, and the acoustical parameters of the selected space were examined.

Although there are many studies that deal with the speech interference in public leisure spaces with one-activity, it was seen that, speech interference in multi-activity enclosed leisure spaces was almost neglected. Therefore, this study aimed to put forth the effects of speech interference in public leisure spaces with multi-activity.

In the course of the study, questionnaires/intelligibility tests were made as a pilot study and both computer simulations and real-size measurements were fulfilled to evaluate acoustical parameters of Bilkent Roll House. In order to analyze speech interference within the selected space, four different room acoustic parameters were analyzed: Reverberation Time (T_{30}), Speech Transmission Index (STI), Signal to Noise Ratio (SNR) and Equivalent Continuous A-weighted Sound Level ($L_{eq A}$).

Acoustical characteristics of Bilkent Roll House were found to be at the required range. However, it was observed that, the speech parameters (STI & SNR) results are unsatisfactory in terms of speech communication for occupied condition due to the high background noise level which triggers cocktail party phenomenon.

According to literature survey, there is a tendency of people to increase their vocal effort as the other talkers increase the ambient noise of the environment in one-activity leisure spaces. Such attitude is explained as the 'cocktail party phenomenon' (Bronkhorst, 2000). In this study, it was found that the noise level (Leq A) of the activities in Bilkent Roll House increases slightly in time. However, the results of Leq A at the dining area of Bilkent Roll House indicate that, users are affected in an informal way by the speech interference, and instead of increasing their voice level, they prefer to focus on their own activity to provide speech intelligibility in multi-activity spaces. In this regard, it can be argued that, users change their behaviors and ambient noise level in the area (dining area) is stabilized by users unconsciously because of their noise annoyance from other activities, and low values of speech parameters (STI & SNR) and high level of background noise.

For further studies, the annoyance ratings, interference levels and behaviors of users can be examined in laboratory condition with recorded noise samples, listening difficulty tests and intelligibility tests. Additionally, it is expected that the background noise level of this kind of leisure space is minimum 80 dB A. Hence, some structural elements can be added like partitions, parapets etc. or spatial organization of the selected space can be reorganized in order to decrease speech interference level of the area.

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APPENDIX A



Figure A.1. Entrance of Bilkent Roll House



Figure A.2. Billards area of Bilkent Roll House



Figure A.3. Bowling area of Bilkent roll House



Figure A.4. A view from Dining area



Figure A.5.ilkent Roll House

APPENDIX B

Bilkent Üniversitesi
İç Mimarlık ve Çevre Tasarımı
Gürültü Denetimi Anketi

1. Cinsiyetiniz:

☐ K ☐ E

2. Yaşınız:

☐ 15–25 ☐ 25–35 ☐ 35–45 ☐ 45–65

3. Eğitim Durumunuz:

☐ İlkokul ☐ Lise ☐ Üniversite ☐ Yüksek Lisans ☐ Doktora

4. Rollhouse’a geliş sıklığınız nedir?

☐ Her gün ☐ haftada 2’de fazla ☐ Haftada 1 -2 ☐ Ayda 1 -2

5. Rollhouse’a hangi “boş zaman etkinliği” için geliyorsunuz? (birden fazla işaretlenebilir)

☐ Bowling ☐ Dart/ Langırt ☐ Bilardo ☐ Yemek ☐ Bilgisayar Oyunları

6. Rollhouse’da geçirdiğiniz süre ne kadardır?

☐ 1 saat’ten az ☐ 1 -2 saat ☐ 3 -4 saat ☐ 5’den fazla

7. Rollhouse’daki gürültü seviyesini değerlendiriniz.

Az

1	2	3	4	5

Çok

8. Rollhouse’da yemek yeme sürecinde gürültü sizi ne kadar etkiler?

Az	1	2	3	4	5	Çok

9. Rollhouse’da arkadaşınızla karşılıklı sohbet ederken gürültü sizi ne kadar etkiler?

Az	1	2	3	4	5	Çok

10. Şu an hangi etkinliği yapmaktasınız?

- ☐Bowling ☐ Dart/ Langırt ☐ Bilardo ☐ Yemek ☐Bilgisayar Oyunları
- ☐ Çalışıyorum ☐Diğer.....

11. Şu an yapmakta olduğunuz aktivite’nin gürültüsü ilginizi dağıtacak kadar sizi rahatsız ediyor mu?

- ☐ Evet ☐ Hayır

Gürültüyü değerlendiriniz.

Az	1	2	3	4	5	Çok

12. Bu mekânda bulunan boş zaman aktivitelerinin gürültü seviyelerini değerlendiriniz.

Az

Çok

	1	2	3	4	5
Bilardo					
Dart/ Langırt					
Yemek Alanı					
Bilgisayar Oyunları					
Bowling					

Articulation Index Word List

Case Study: Evaluation of Speech Intelligibility in "Bilkent Rollhouse"

Table No:	Name - Surname	SPL (dBA)

	Words		Words		Words		Words
1	Demir	26	Tüp	51	Yaz	76	Kurt
2	Şut	27	Mum	52	Bul	77	Muz
3	Kör	28	Hava	53	Gel	78	Göz
4	Muz	29	Pil	54	Zar	79	Masa
5	Kapı	30	Taş	55	Dal	80	Bal
6	Efe	31	Su	56	Ana	81	Ses
7	Nane	32	Müze	57	Kare	82	Kuzu
8	Göz	33	Kıplı	58	Koş	83	Nur
9	Sınav	34	Kadı	59	Riçe	84	Füze
10	Keçi	35	Kova	60	Bez	85	Kır
11	Göl	36	Fizik	61	Kuş	86	Süt
12	İşçi	37	Adem	62	Mal	87	Nar
13	Yalı	38	Paşa	63	Gap	88	Üzüm
14	Spor	39	Dağ	64	Ütü	89	Saf
15	Dört	40	Terzi	65	Baba	90	Halı
16	Dizi	41	Topuz	66	Köp	91	Elma
17	Kese	42	Musa	67	An	92	Karga
18	Müzik	43	Şal	68	Van	93	Boş
19	Tüp	44	Dur	69	Saz	94	Ela
20	Kuru	45	Mavi	70	Ev	95	Cem
21	Nem	46	Krom	71	Tuz	96	Şap
22	Çakı	47	Dev	72	Ay	97	Para
23	Kan	48	Cam	73	Dede	98	Sopa
24	Camlı	49	Sır	74	Yer	99	Hap
25	Zil	50	Köy	75	Düz	100	Kale

APPENDIX C

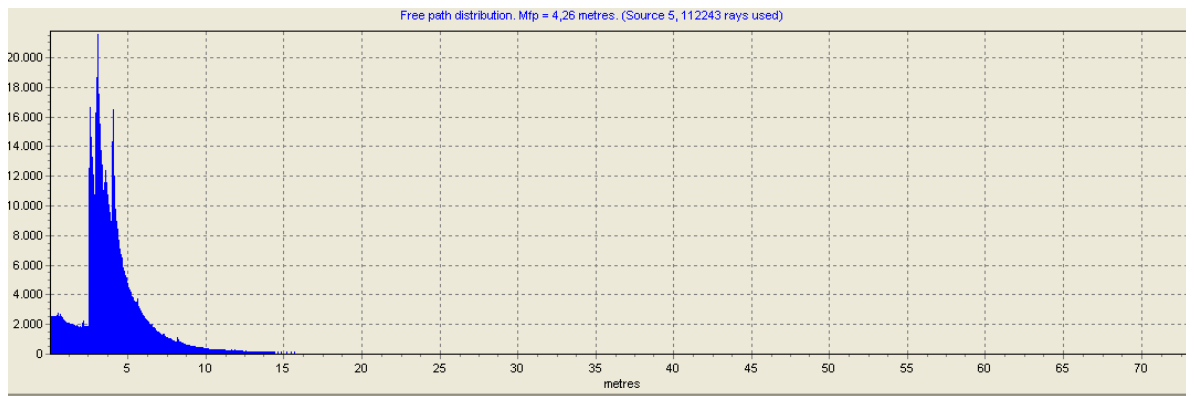


Figure C.1. Free path distribution map of T30 at unoccupied condition.

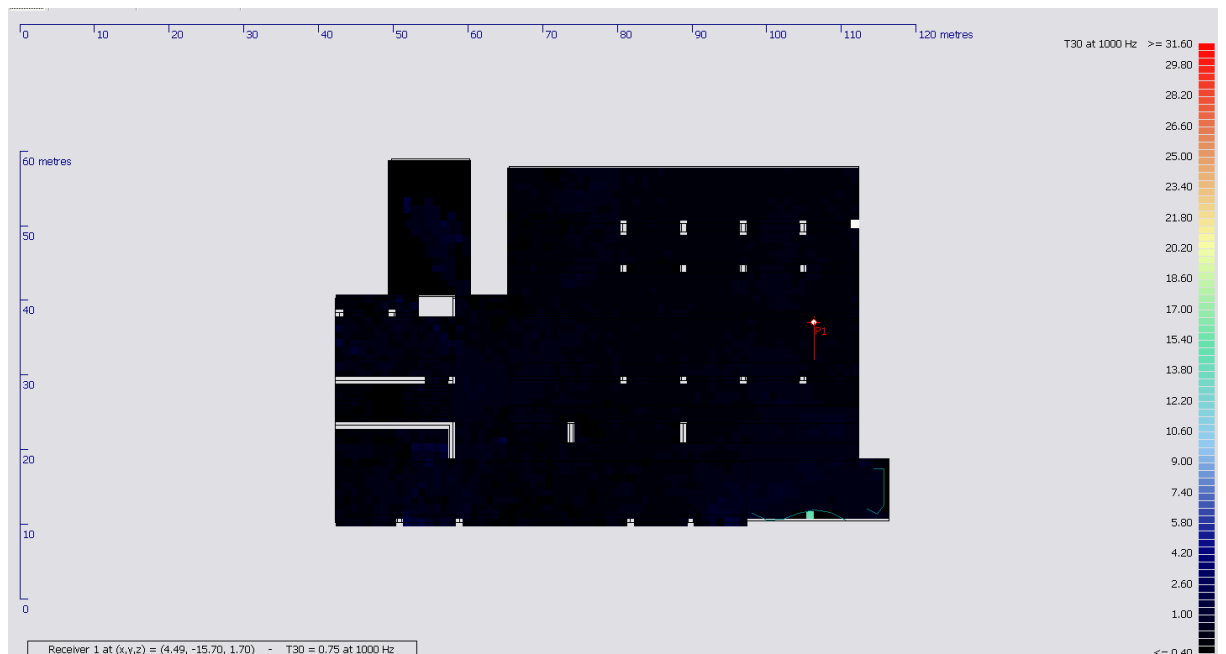


Figure C.2. T30 distribution map for unoccupied condition at 1000 Hz by ODEON 9.2.

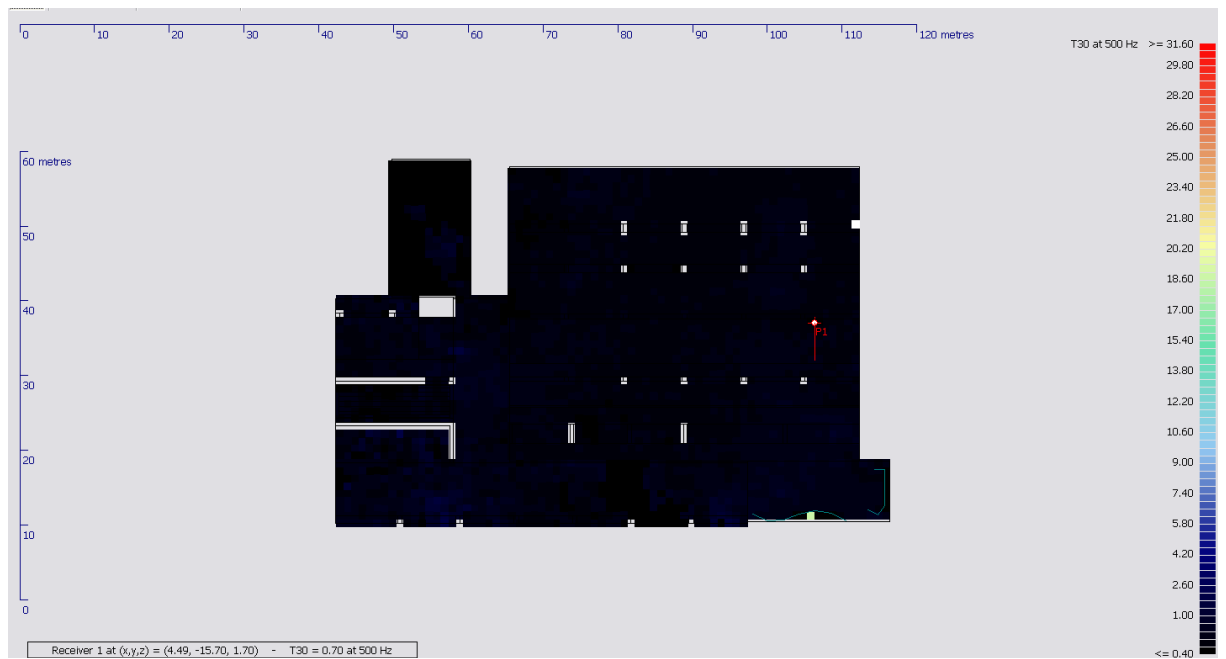


Figure C.3. T30 distribution map for unoccupied condition at 500 Hz by ODEON 9.2.

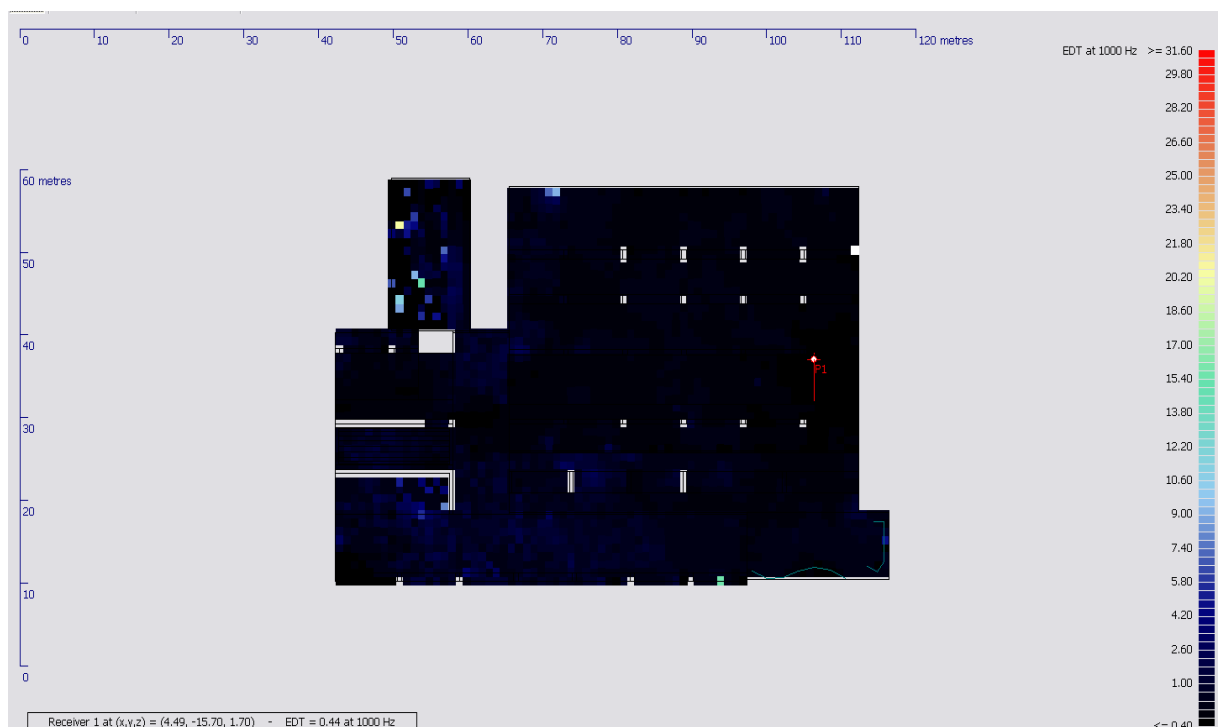


Figure C.4. EDT distribution map for unoccupied condition at 1000 Hz by ODEON 9.2.

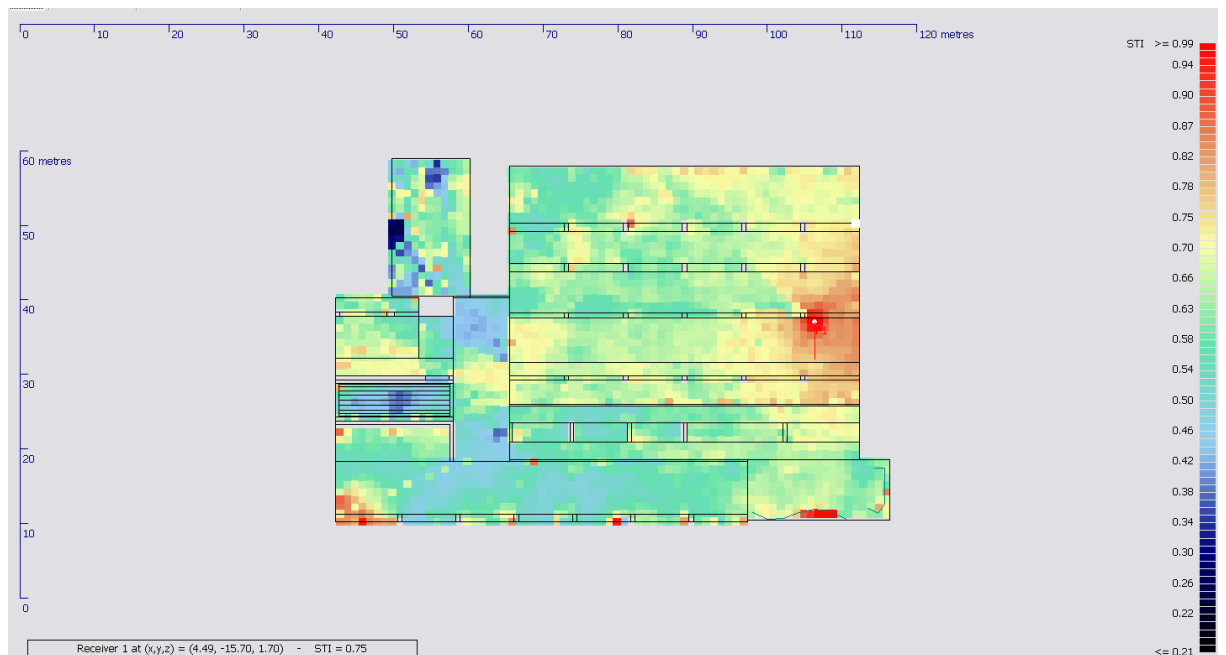


Figure C.5. STI distribution map for unoccupied condition by ODEON 9.2.

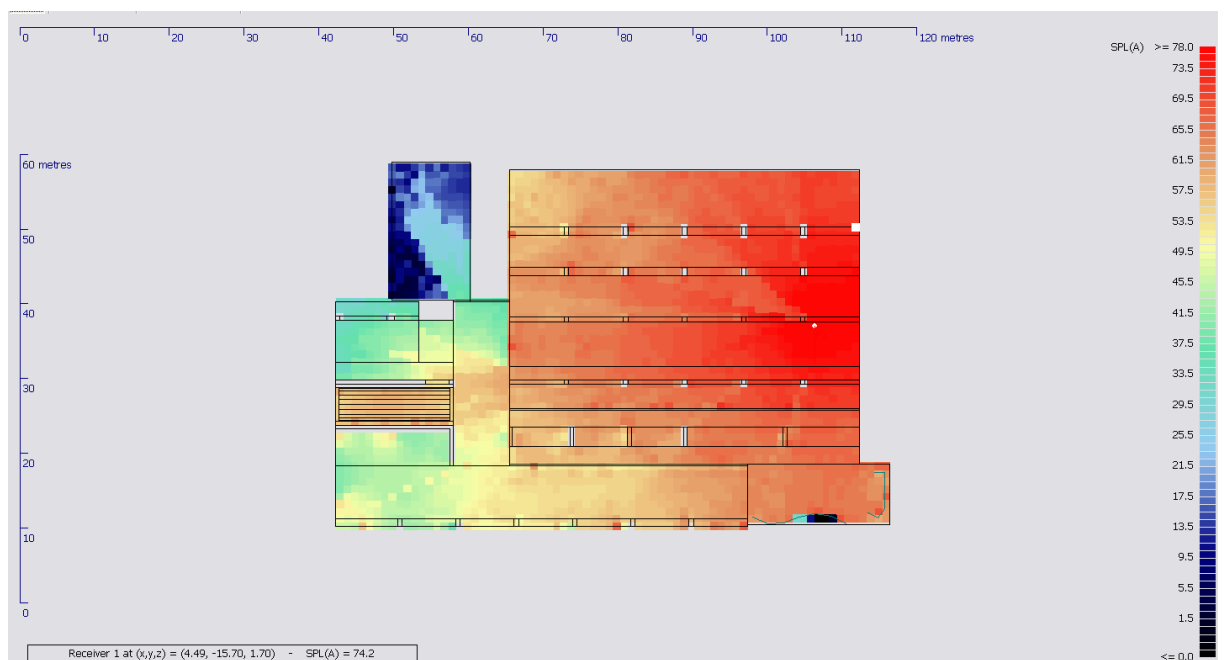


Figure C.6. SPL (A) distribution map for unoccupied condition by ODEON 9.2.

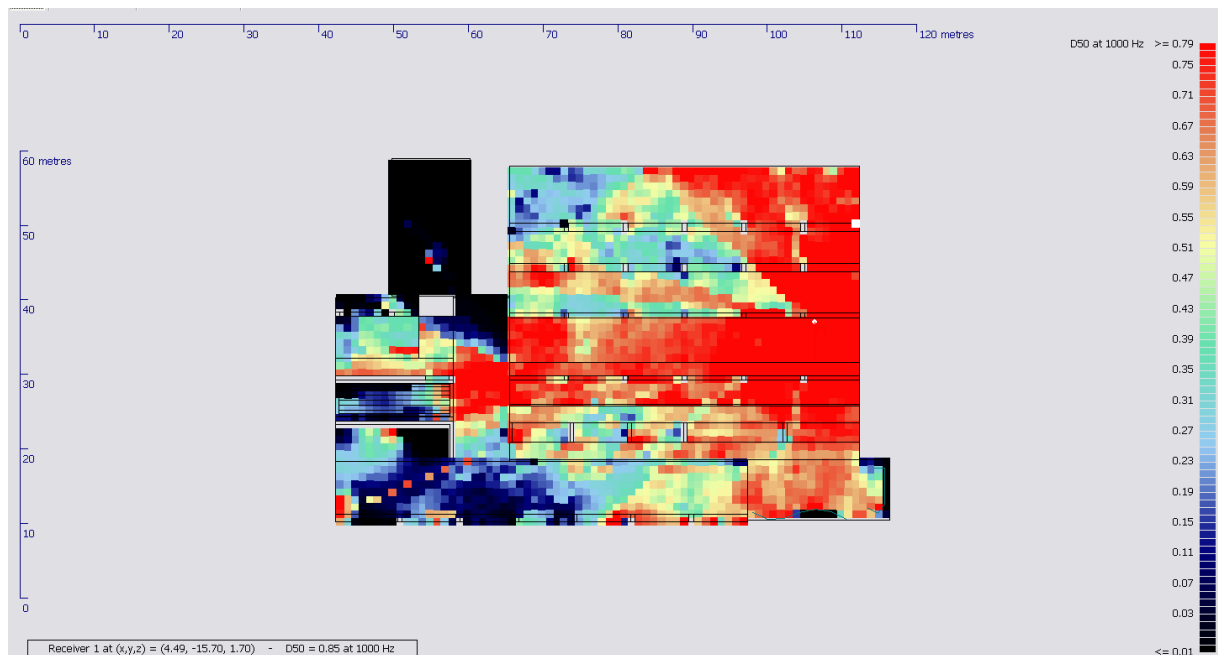


Figure C.7. D50 distribution map for unoccupied condition at 1000 Hz by ODEON 9.2.

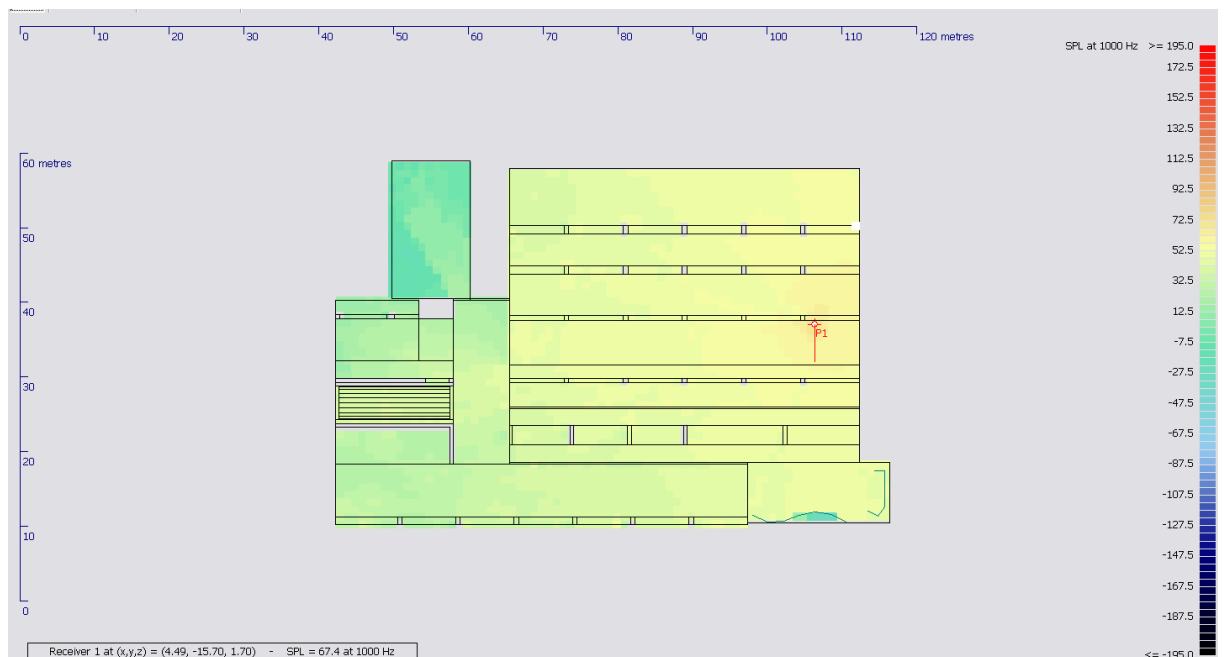


Figure C.8. SPL distribution map for unoccupied condition at 1000 Hz by ODEON 9.2.

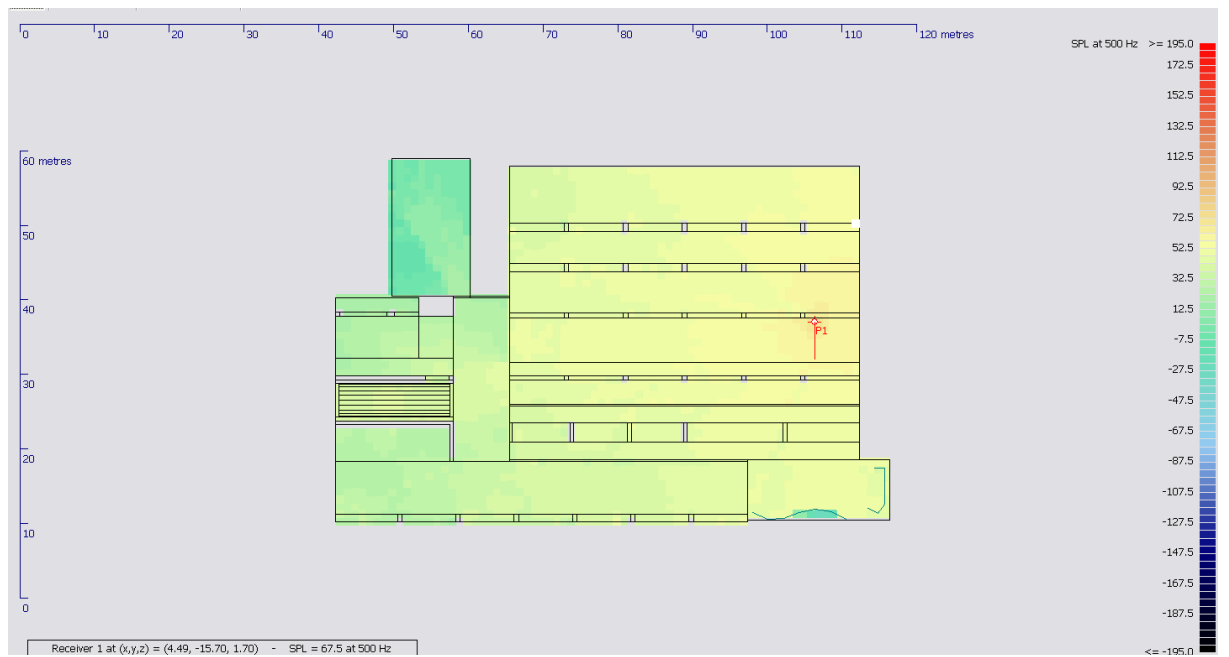


Figure C.9. SPL distribution map for unoccupied condition at 500 Hz by ODEON 9.2.

APPENDIX D

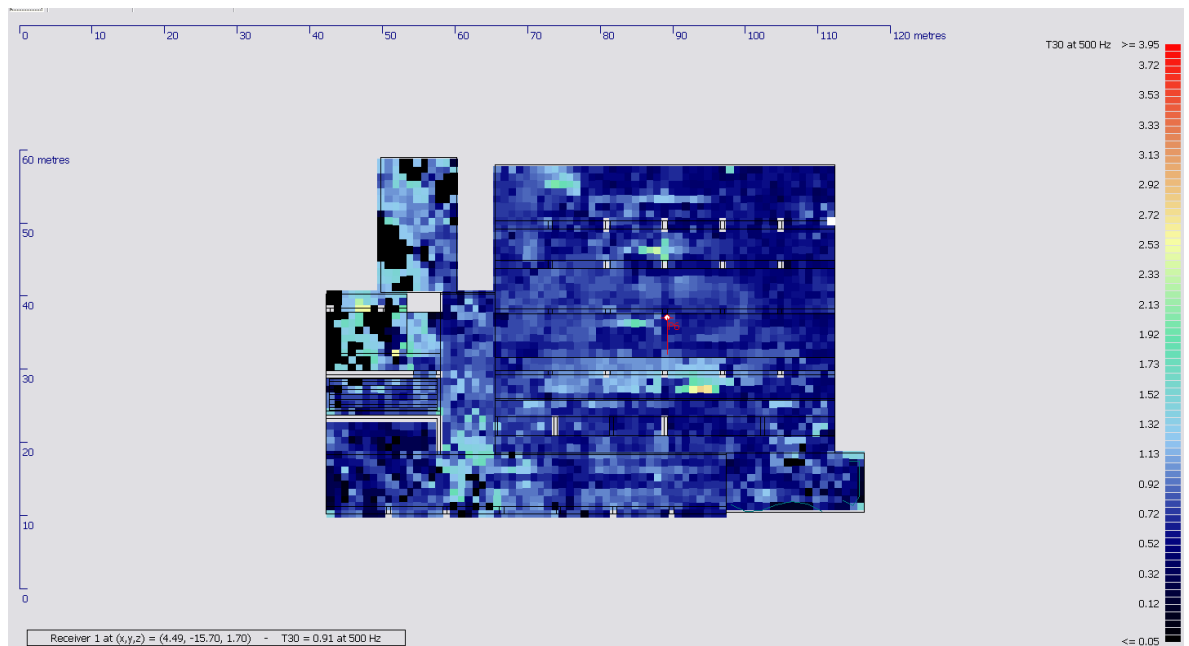


Figure D.1. T30 distribution map for occupied condition at 500 Hz by ODEON 9.2.

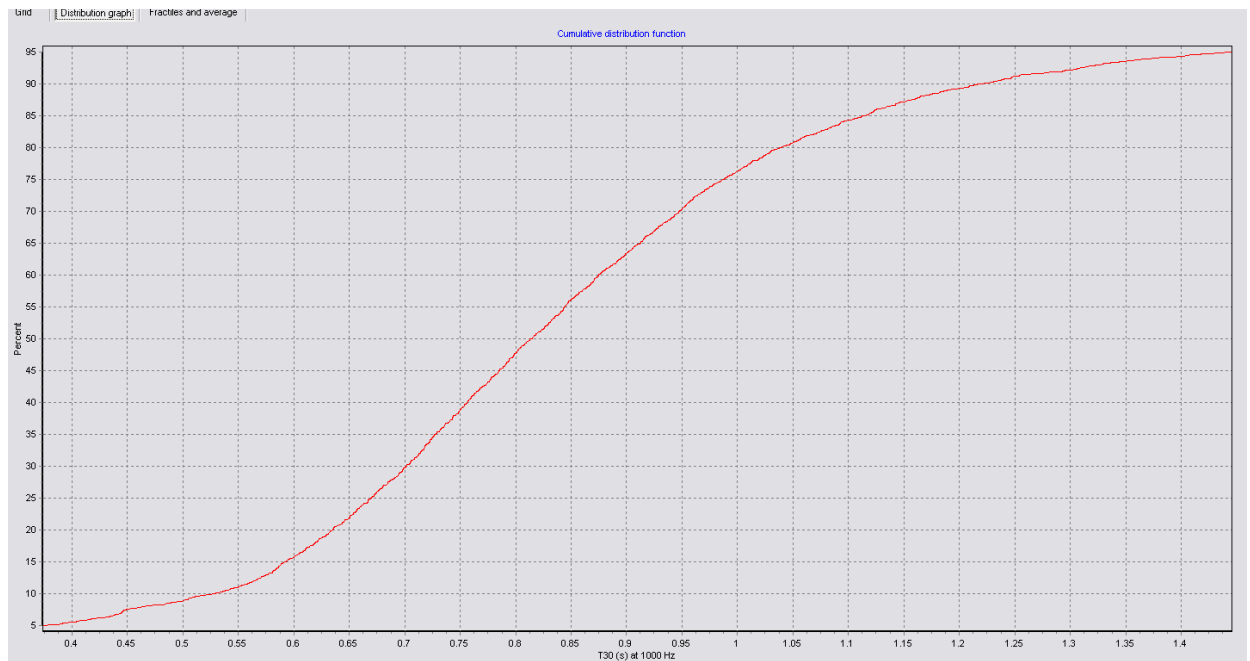


Figure D.2. Cumulative distribution graph of T30 at 1000Hz in ODEON 9.2. at occupied condition.

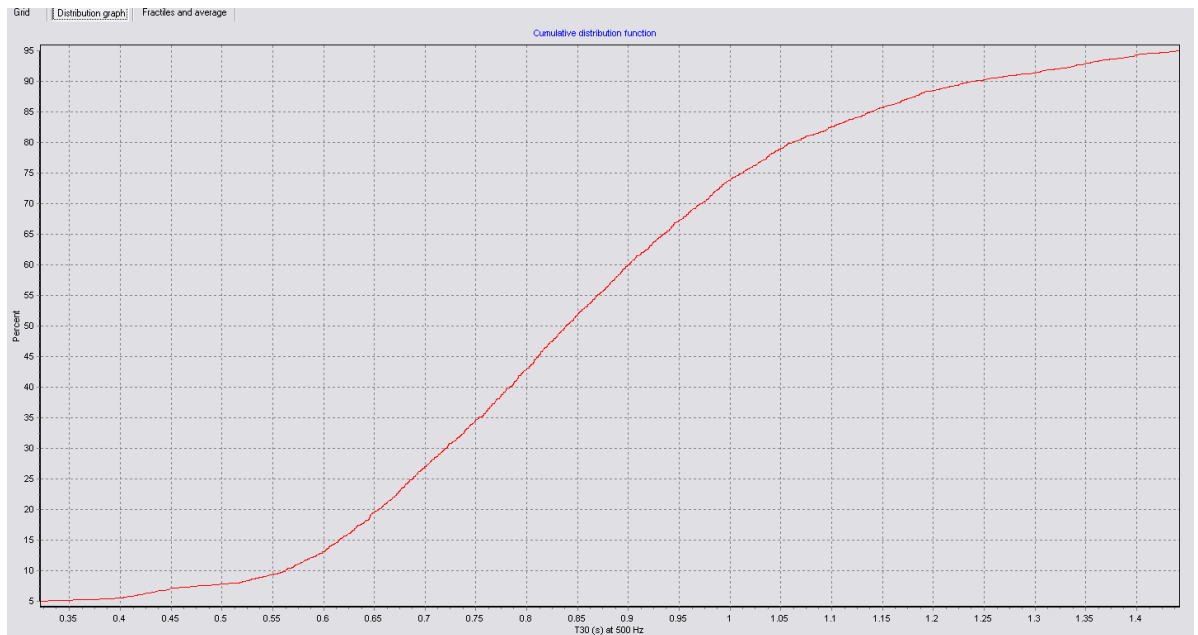


Figure D.3. Cumulative distribution graph of T30 at 500Hz in ODEON 9.2. at occupied condition.

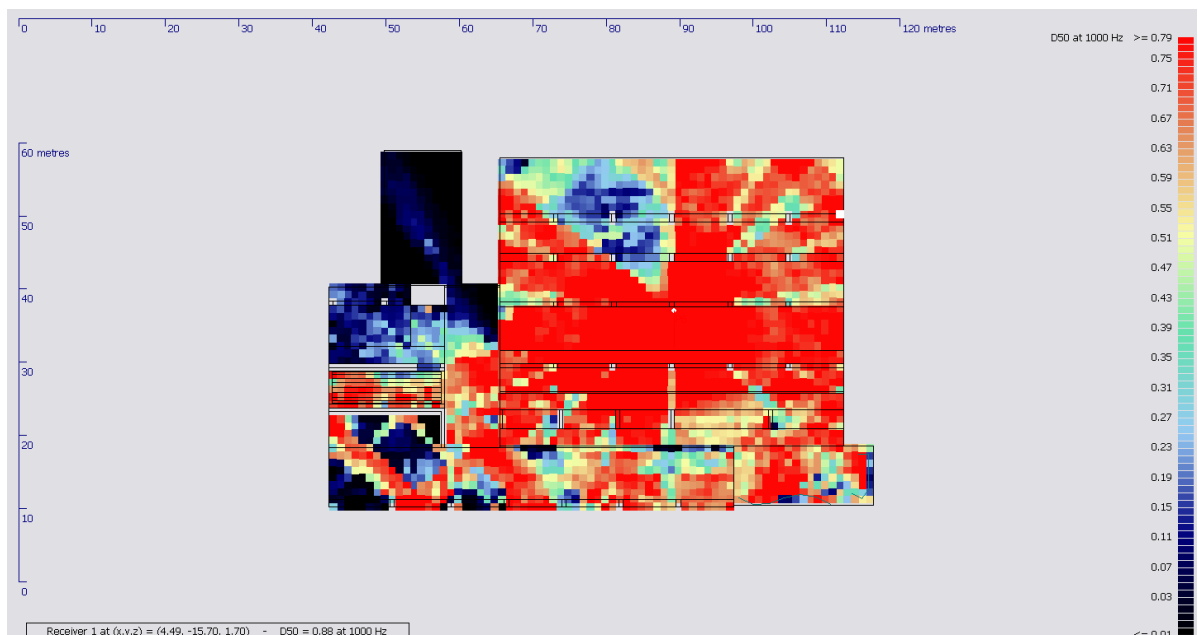


Figure D.4. D50 distribution map for occupied condition at 1000 Hz by ODEON 9.2.

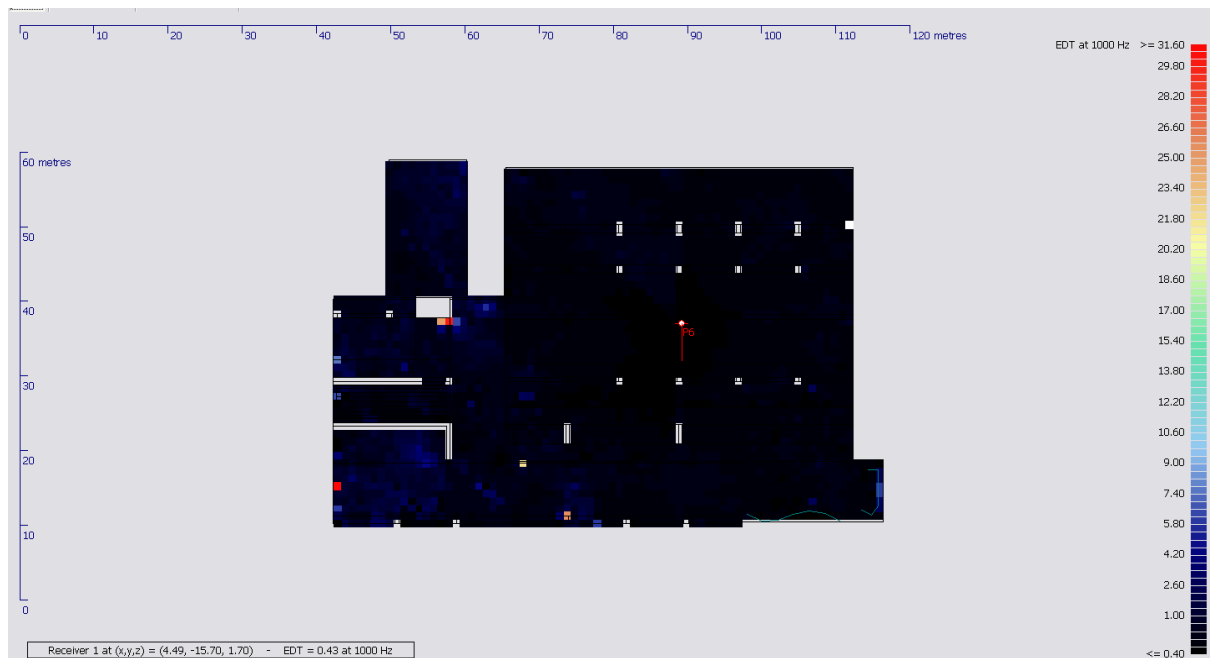


Figure D.5. EDT distribution map for occupied condition at 1000 Hz by ODEON 9.2.

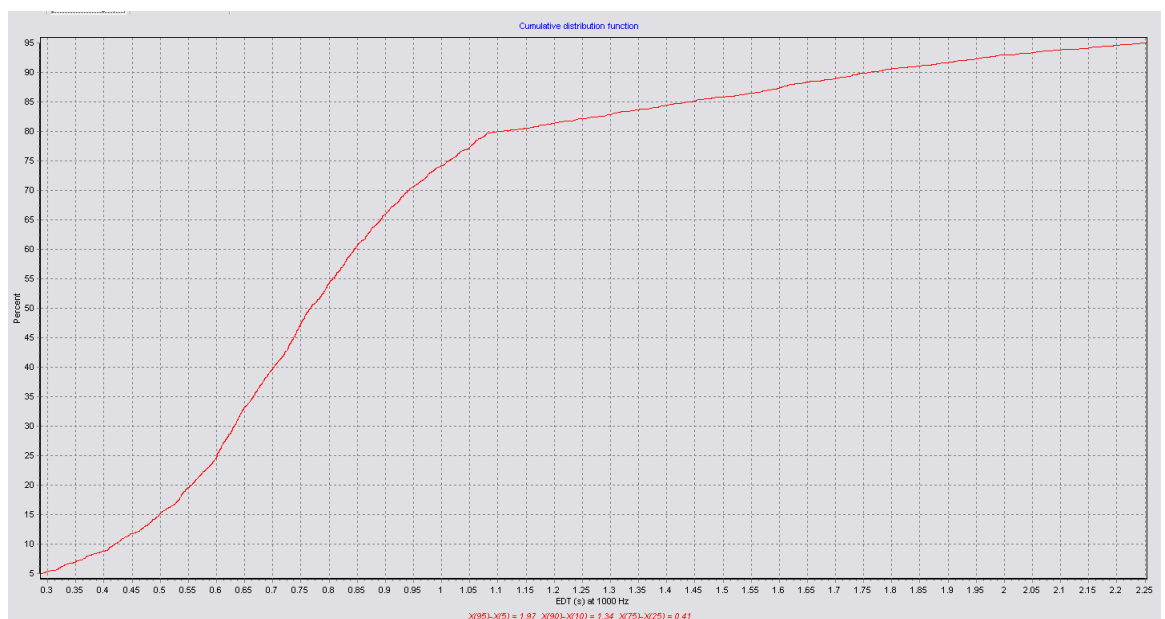


Figure D.6. Cumulative distribution graph of EDT at 1000Hz in ODEON 9.2. at occupied condition.

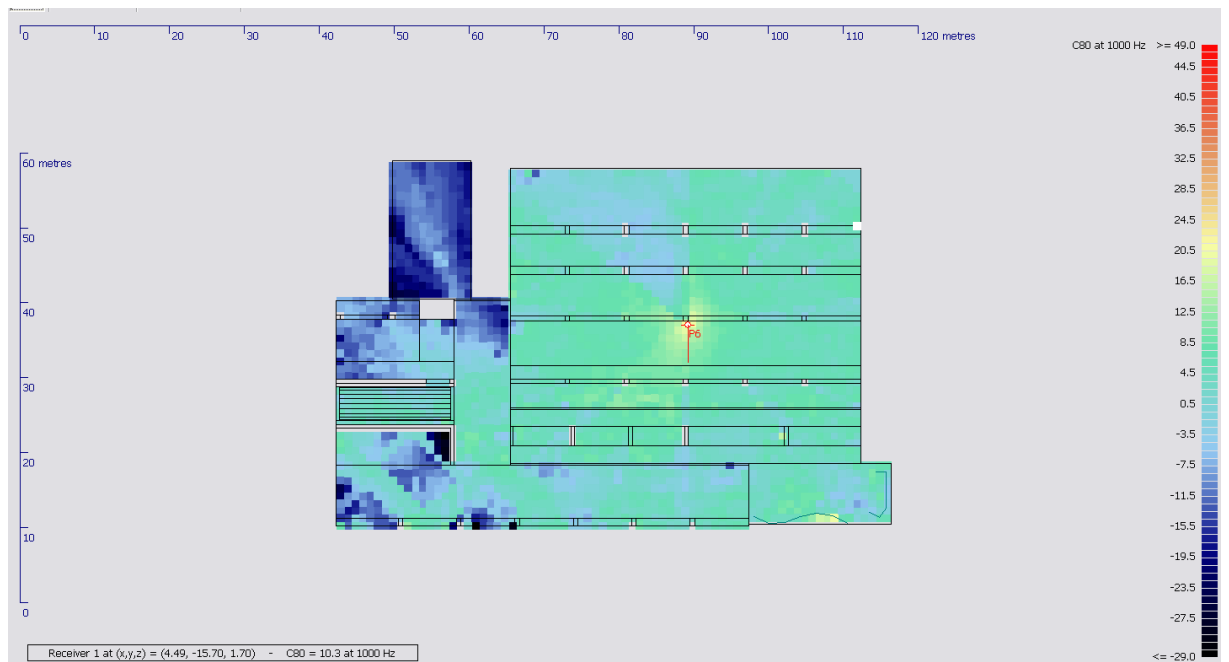


Figure D.7. C80 distribution map for occupied condition at 1000 Hz by ODEON 9.2.

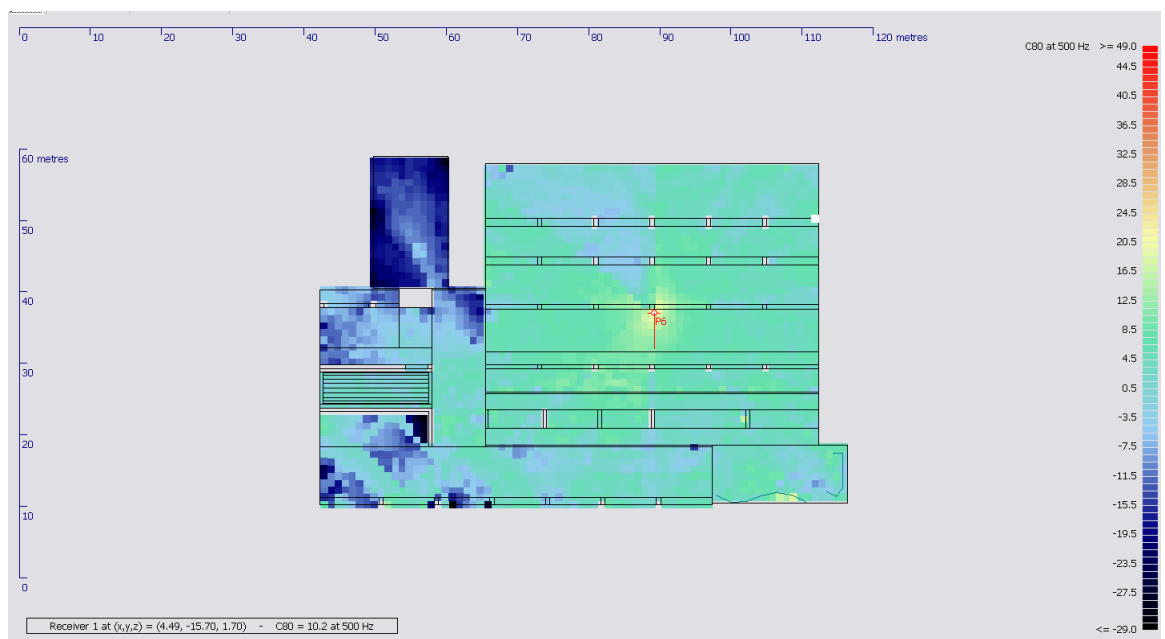


Figure D.8. C80 distribution map for occupied condition at 500 Hz by ODEON 9.2.

Table D.1. STI Value at R0 in occupied condition by using DIRAC

STI female	0,26 : Bad	% ALC	42,7
STI male	0,26 : Bad	% ALC	42,6

Table D.2. STI Value at R1 in occupied condition by using DIRAC

STI female	0,10 : Bad	% ALC	96,9
STI male	0,11 : Bad	% ALC	95,9

Table D.3. STI Value at R2 in occupied condition by using DIRAC

STI female	0,10 : Bad	% ALC	99,3
STI male	0,11 : Bad	% ALC	93,5

Table D.4. STI Value at R3 in occupied condition by using DIRAC.

STI female	0,04 : Bad	% ALC	100,0
STI male	0,04 : Bad	% ALC	100,0

Table D.5. STI Value at Billiards in occupied condition by using DIRAC.

STI female	0,24 : Bad	% ALC	46,1
STI male	0,25 : Bad	% ALC	44,7

Table D.6. SNR Value at R0 in occupied condition by using DIRAC.

	125	250	500	1000	2000	4000	8000
SNR [dB]	-5	-7	-13	-3	-5	-7	-9

Table D.7. SNR Value at R1 in occupied condition by using DIRAC.

	125	250	500	1000	2000	4000	8000
SNR [dB]	-100	-19	-21	-11	-8	-12	-14

Table D.8. SNR Value at R2 in occupied condition by using DIRAC.

	125	250	500	1000	2000	4000	8000
SNR [dB]	-100	-5	-19	-7	-9	-15	-18

Table D.9. SNR Value at R3 in occupied condition by using DIRAC.

	125	250	500	1000	2000	4000	8000
SNR [dB]	-14	-100	-10	-14	-17	-18	-20

Table D.10. SNR Value at Billiards in occupied condition by using DIRAC.

	125	250	500	1000	2000	4000	8000
SNR [dB]	-100	-20	-13	-3	-5	-9	-9