YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

A GUIDELINE PROPOSAL FOR ACOUSTIC ISSUES IN SUSTAINABLE BUILDING ASSESEMENT TOOLS: OFFICE CASE

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ABSTRACT

A GUIDELINE PROPOSAL FOR ACOUSTIC ISSUES
IN SUSTAINABLE BUILDING ASSESMENT TOOLS:
OFFICE CASE

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Because of the rapid depletion of world resources, sustainability fact that is entered into our life and open-plan offices that are leaded the way with the increase of the working population are most widely used architectural nation in todays. But unfortunately, when designin the open plan offices with concern of sustainability, where is spend most of life, we are not thinking about hearing that is the most important, unobstructed and irreversible part of the human sense. Certification systems are created to support quality of life and energy conservation, but it has been observed that the acoustic requirements are not sufficiently included in the certification systems.

In this thesis, studies have been conducted on the improvement of acoustic issues that appears to be missing in green building certification systems. A check list is prepared in the result of studies that include improvement suggestions and this checklist is compared with the green building certification systems.

The proposal of thesis, that is the strengthening of the acoustic issues in certifications systems.

Key Words: Acoustic Evalution on Sertificate Systems, Sustainable Office Buildings, Room Acoustic in Open Plan Offices

ÖZ

OFİS BİNALARINDA SÜRDÜRÜLEBİLİR BİNA DEĞERLENDİRME SERTİFİKALARI İÇİN AKUSTİK AMAÇLI KILAVUZ ÖNERİSİ

KARA, Dilara
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Kasım 2017

Dünya kaynaklarının hızla tükenmesi sonucu hayatımıza giren sürdürülebilirlik olgusu ve çalışma nufusunun artışı ile ön plana çıkan açık planlı ofisler günümüzde en yaygın kullanılan mimari kavramlardandır. Fakat ne yazık ki sürdürülebilir olması kaygısıyla hayatımızın büyük bir kısmını geçirdiğimiz açık ofis alanlarımız tasarlanırken, insan duyusunun en önemli, engellenemez ve değiştirilemez parçası olan işitme olgusuna yeterli önem verilmemektedir. Yaşam kalitesini ve enerji korunumunu desteklemek adına oluşturulan sertifikasyon sistemleri içerisinde de akustik gerekliliğe yeteri kadar yer verilmediği görülmüştür

Bu tezde yeşil sertifika sistemlerinde eksik olduğu anlaşılan akustik konuların iyileştirilmesine yönelik çalışmalar yapılmıştır. Yapılan çalışmalar ışığında iyileştirme önerilerinin bulunduğu check list hazırlanmış ve hazırlanan bu check list hali hazırda kullanılmakta olan yeşil bina sertifika sistemleriyle karşılaştırılmıştır

Tezin önerisi yeşil bina sertifika sistemlerinde eksik görülen akustik konuların güçlendirilmesidir.

Anahtar Kelimeler: Sürdürülebilirlik sertifikalarında akustik, sürdürülebilir ofis binaları, açık planlı ofislerde akustik

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Dilara KARA

İzmir, 2017

TEXT OF OATH

I declare and honestly confirm that my study, titled "PROPOSAL FOR ACOUSTIC ISSUES IN SUSTAINABLE BUILDING ASSESMENT TOOLS: OFFICE CASE" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Dilara KARA

Signature

…………………………………..

December 14, 2017

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

LEED Structure of Scientific Revolution

BREEAM Normal Science

SBTOOL Extra Ordinary Science

SYMBOLS:

dB Decibel.

NC Noise Criterion.

RT Reveberation Time.

EDT Early Decay Time.

D50 Clarity of Speech.

STI Speech Transmission Index.

U_t Useful Detrimental.

DL_2 Rate Of Spatial Decay.

Leq Equivalent Sound Level.

Lday Day equivalent level.

Lden Day-evening-night equivalent level.

Ldn Day-night equivalent level.

D_{nTw} Weighted Standardised Level Difference.

Rw Weighted Sound Reduction Index.

Lnw Weighted Normalized Impact Sound Pressure Level.

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CHAPTER ONE
INTRODUCTION

1.1 Litarature Review

<u>National researches / theses</u>

Written by Okten G (2009) in Istanbul Technical Universty *"The Effects of Room Shape and Surface Diffusion on Acoustical Parameters",* master thesis based on multipurposed halls. But, the researcher has made analyses of objective and subjective parameters of acoustical problem in relation with architectural design. The thesis stands on acoustical parameters as revebaration, clarity, loudness, liveness. Then the author gives us the exactly decisions made on the use of hall its geometry and typology, surface materials which are used. The study has been examined in terms of better interpretation of objective acoustic design parameters.

Written by Yüce M.Y. (2009) in Istanbul Technical Universty, the master thesis "*An Acoustıcal Evaluatıon Model For Open Plan Offices"*that give detailed information about acoustic and architectural requirements of open plan offices. The study based on privacy and intelligibility and first ıt examines parameters of this topic. Then, a scale model (1/10) are prepared of open-plan office and measurements were made in anechoic laboratory conditions. The height of the barrier between the two employees and the absorptiveness of the ceiling were changed in the meausurements that made on the workstation model. Thus, Barrier height and ceiling absorbtion effect on intelligibility has been measured. Sound transmission loss performances of barrier and ceiling materials combination (that are results of the measurements), was used in calculation of the intelligibility index. After the calculation of the intelligibility index is performed for all combinations, the privacy ranges are determined for employees.

Written by Yazıcı G. (2016) in Istanbul Technical Universty, the master thesis "*Sustainability and Acoustic: One Hotel Example"* examine the problems that caused by the sustainable design concept on the examples. Acoustic conditions and scores of LEED, BREEAM and DGNB certification systems was explained in the next stage. Acoustical calculations are carried out witht the BREEAM direction on a hotel sample that will be received BREEAM Certificate and efficiency of certification systems is examined on this sample. In terms of acoustical analysis, especially the research based on building noise control, also invastigated the revebaration time for the room acoustic. The result of the study, BREEAM Certification system is found inadequate in terms of acoustics.

The Article written by Acar B. ve Akdağ Y. N. (2008) in Yıldız Technical Universty and published in *YTU Architecture. Faculty Journel*, that named "*Acoutic problems and Control Measures in open plan offices: Evaluations on an Example*" is examined, a open plan offices that owned a lighting company in İstanbul Kartal. Noise level measurements is made to assess the current situation of open-plan office. On simulation model of the area has been examined the terms of "different partition element heights" and "different surface absorbers". Thus, relationship between the partition element and acoustic comfort is revealed in open offices.

International articles / congresses

Presented by Rindel J H. (2012) in congress of Acoustic 2012 Hong Kong "*Prediction of Acoustical Parameters for open plan offices according to ISO-3382-3*" that is defined acoustic criteria for open plan offices and is focused on a set of new parameters for subjective evaluation. These new parameters are speech privacy and distraction distance that are derived from Speech Transmission index. The purpose of the simulation is how to apply these new parameters on the acoustic simulation model. As a result, the parameters change according to amount of sound absorption, the applications of screens between the work stations, and level of backround noise.

Prepared by Pop and Rindel (2005) in Brezilya, the research that is “Inter-noise” kongresinde sunulan *“Perceived Speech Privacy in Computer Simulated Open-plan Offices”* is examined relationship between subjective acoustic parameters and speech privacy. A real office model was developed by using ODEON software. As a result of the study, the STI value must be 0.45 for supply conditions of speech privacy in office spaces. If it is required to be partially better, STI should be under 0.30 value. In this context, if DL_2 parameter higher than 4db, it is assumed that speech privacy has been provided.

Prepared by Nilsson and Hellström (2009) in Scotland congrees of “Euronoise” the article that name is “Room Acoustic design in open-plan offices”. According to the study, the acoustic conditions were examined in five different open planed offices. In this context, reverberation time (T20), early decay time(EDT), clarity (C50), speech transmission index (STI), speech intellebility index (SII), privacy indeks (PI) ve Rate Of Spatial Decay (DL_2) parameters are used for the research. As a result of the review, two offices are improved of both them and then the study has been verified with surveys.

Presendent by Che D. N, Jalil N, Keumala N. ve Razak A. (2014) in congress of “Internoise” , the research that name is “Acoustic investigation of open-plan offices in green building : simulation experiment” that is examined two open plan office area in a green office building in Malaysia. The author has made field measurements primarily in the offices examined. Later, different settlements and surface quantities have been modeled and transferred to the Odeon program and the result of RT, STI parameters were examined and compared. As a result, detail of model and amount of surface are investigated the terms of effect on acoustical parameters.

Represented by Boglev D. (2008) in Acoustic 2008, the research “Acoustic Design Practices For Sustainable Buildings” emphasized on HVAC systems in sustainable buildings and contribution of these systems to the acoustics. ultimately, information about the masking system and settlement angles is given as a solution recommendation.

The "Acoustical Evaluation of Six Green Buildings" article published by Hodgson M. in the "Journal of Green Buildings", six different green office building has been observed that have got Leed certificate four of them. In the survey, first of all, the users of the office buildings were surveyed and it was found that the users in the green buildings were more uncomfortable in terms of gore acoustics. On the other hand, the buildings were tested in terms of background noise level, reveberation time, speechtransmission, speech intelligibility and sound insulation, and green buildings could not reach the required parameter values.

<u>Reviewed Other Sources</u>

Tezin şekillenmesinde ve konuların kavranmasında rol alan diğer tüm araştırma, makale ve kitaplar şu şelilde sıralanabilinir.

Bayazıt T. N., (1999). "*A Geometric Design Method For Acoustic Evaluation Ofv Regtengular Cross-Sectioned Concert Halls,"*

Cowan, J. (2000). *Architectural Acoustics Design Guide,*

Everest, F.A., Pohlamann, K.C. (2009*). Master Handbook of Acoustics*,

Ermann M. (2015). *Architectural Acoustics Illustrated*,

Jianxin P., Chengxun B.(2010) "*Prediction of Chinese speech intelligibility using useful to detrimental sound ratios based on auralization"*

Karaman Ö.Y., &Üçkaya N.B. (2015). "*Acoustic Comfort in Lectures Hall; The Dokuz Eylül University Faculty of Architecture*";

Kurra, S. (2009). "*Çevre Gürültüsü Ve Yönetimi"*.

Long, M. (2006). "*Architectural Acoustics."*

Ozkartal N. E., (2011). "*Analyse Of Acoustical Comfort Parameters Concert Halls with A Case Study*",

Vural A., (2009). "Acoustical evaluation of four concert halls in İstanbul"

Yılmaz Demirkale, S. (2007). "*Çevre Ve Yapı Akustiği"*

Result of literature review, another study has been found about sustainable open office building that is exemined in detailed from enviromental noise control till room acoustic parameters and then result of examination comparing with sustainable certificate systems. Especially, DL2 and U50 are current acoustical parameters which are important and necessary for open office areas are included to this research and it shows that; this is the biggest difference for preparing the steps of environmental noise analysis and noise control of the entire building up to this point in time.

1.2 Review Of Acoustic Simulatıon Programs

Current measurement equipments and acoustic simulation programs were used to obtain the results of the necessary acoustic parameters during the examination of case of study.
In the first step, the noise level of the area,where the building will position, was determined by industrial noise measuring equipments. Then the building and its enviroment have been modeled and enviromental noise levels that obtained at different times during the day have been processed into the SoundPLAN software.

In the second step the building is modeled in the SONARchitect program for providing noise control within the buildingThe INSULL program was used to find the sound reduction coefficients of the building's construction elements. and the values that obtained from INSUL, were processed into the SONARchitect program.

ın the last step, the open plan office that is purified from enviromental noise and building noise sources have been transffered to Odeon Software that is room acoustic similation program. Technical literature, odeon library and SoundFlow program have been used to obtain the sound absorption coefficients of the surfaces in the open plan office. Thus, the acoustic parameters have been acquired. Because of these reasons, calculation methods and properties of acoustic simulation softwares and measurement equipments that are used during the research will be examined in this section..

1.2.1 Measurement Equipments

- NTI Audio XL_2 Hand Analyzer (IEC 61672-1 Electroacoustics) (SNo.A2A-05241—E0,FW3.03)
- NTI Audio MA220 Type 1 Measurement Microphone (User calibrated 2016-08-23 07:00)
- Norsonic type 1251 Sound Calibrator
- Mic Sensitivty: 22.9mV/Pa
- Range : 30 – 130dB ‘dir

1.2.2 SoundPlan Industrial Acoustic Simulation Program

When the first standards were introduced for acoustic calculations, computers were not available for daily noise calculations. For this reason, the equations are simplified. Over time, researchers measured noises and developed different interpretations of cause and effect.. Thus, the equations have become more complicated to demonstrate the complex nature of the sound propagation.
The fact that calculations are so complex and time-consuming, have been increased the importance of computer use.. Calculations that made with tables and formulas are rough estimates compared to reality and simulation programs. For this reason, SoundPLAN program have been used to calculate the environmental noise analysis.

SoundPLAN, which has the most users in the world in noise simulation software, was released to the market in 1986. The complete integration of indoor factory noise, transmission through walls and the noise propagation into the environment make this software the ideal tool for engineers working in the fields of noise planning, noise in the workplace, noise mapping and as part of general environmental assessment studies. [30]
SoundPLAN follows an approach based on noise standards. The software may run in accordance with the regulations that is location of the building to be built. More than 50 regulations have been implemented by SoundPLAN for road noise, train noise, building sound, general industrial noise and aircraft noise. [30]
Because of it has got comprehensive environmental noise analysis and best recognized environmental noise simulation program,Soundplan have been used in environmental noise analysis of the research. [30]

1.2.3 SONarchitect Acoustic Simulation Program

SONarchitect that make calculation according to ISO is the most powerful building noise control software. The SONarchitect gives information about airborn sound insulation values according to ISO 12354-1, the impact sound levels according to ISO12354-2, the front sound insulation values according to ISO12354-3, the noise emission levels according to ISO12354-4 and reverberation times according to ISO12354-6. It makes automatic and quick evaluations based on the relevant sound insulation requirements, while making possible to analyze the whole project..

Sound transmission losses and noise isolation are calculated between all volumes or floors in the building . Thanks to the auralization function, it is possible to listen to the loss of sound transitions between all the volumes in the structure. [31]
Drawings that is dxf format are transferred into the program. Thus, architectural design is quickly processed in SONarchitect.
The appropriate structure material can be found in the library of program as well as if necessary, the material is prepared in and INSUL software and have been transferred to SONARchitect. Sound insulation values of walls, ceiling-floors, windows etc. other details that are designed specially, can be processed into the project.. This gives the flexibility to calculate the acoustic comfort of the design with local and original solutions. On the other hand, the SONarchitect provides great convenience about design and reporting for ECO material selection of LEED and BREEAM certifications or green buildings. [31]
Also, it gives great advantage that files of sonarchitect export to ODEON which is the best room acoustic simulation program. The building sound insulation can be analyzed with SONARchitect ISO, the 3D model can be transferred to Odeon and the acoustic environment can easily be designed for each room. For all these reasons, the SONarchitect program has been preferred in order to provide building noise control.

1.2.4 INSUL Acoustic Calculation Program

INSUL is calculation program for foresee the sound insulation of walls, floors, roofs, ceilings and windows. The programme make estimates of the Transmission Loss (TL) or Impact Sound (Ln) in 1/3 octave bands and Weighted Sound Reduction Index (STC or Rw) or Impact Rating (IIC/LnTw) for use in noise transfer calculations. [32]
Desired separation elements are created with layer such as gypsum board, concrete, glass, sound insulation materials that is founded in the program library and the data that prefered format , are transferred to the acoustic simulation programs or reports. Thus, the sound reduction values of the building elements are calculated by INSUL. INSUL does not replace any measurement but when compared to the actual results, it is seen that the values obtained from the INSUL software give reliable results up to the difference of ±3 dB. [32] For this reason, INSUL software has been used when the sound reduction coefficients of the building components were calculated, for the case of study section of thesis..

1.2.5 AFMG Soundflow Acoustic Calculation Program

AFMG SoundFlow is a simulation software for calculating the absorption, reflection, and transmission of sound by multi-layer structures like INSUL. The difference between the two programs, the INSUL calculate sound reduction index of separator construction elements but SoundFlow calculate sound absorption coefficient of covering materials. Ceiling and wall materials are modelled at SOUNDFLOW by specifying the layer and thickness, and the results are obtained in the desired octave band and graphic. [33]

"The calculation engine of AFMG SoundFlow is an accurate implementation based on the theory of sound absorbers developed by Mechel, Bies and others. Various computational models are available including the calculation according to the ISO 12354 standard." [33]

When calculating the sound absorbtion coeifficient of surface materials, the advantage of SoundFlow according to formulas is more complex layers can be used. The software's database allows rapid modeling of multiple layers and calculation of the absorbation value.. The software gives absorption graph based on frequency. [33] For this reason, SoundFlow software has been used to calculate surface absorption values in room acoustic simulation.

1.2.6 Odeon Software Acoustic Simulation Program

Odeon has been created in 1984 by a team from the Danish technical university and a group of consulting companies to achieve reliable forecasting software for room acoustics. The first versions of the Odeon has been aimed solving acoustic problems in concert and opera halls. So, the software has been taken its names from old Greek odeon. The odeon, which has been invested to be easy to use and dependable at development of years, nowadays is used for a wide range of applications. [34]

Calculation Algorithms

ODEON hesaplama sırasında hibrit yansıma yöntemini kullanır. "*Hybrid reflection method: A combination between the image source method, raytracing and ray radiosity. Early reflections are defined by image sources and ray-radiosity. Late reflections are defined by a special ray-tracing/radiosity method. The transition order decides at which reflection order the reflections goes from early to late reflection method."* [34]

Reflection has been defined that depending on the sound scatter value and sound bounce from the limited surface size (diffraction). [34]
Accordingly, properties of room surface are determined in the simulation program. Surface features:

-Absorbtion conficient :the sound absorbtion is defined as 0 to 1 in 1octave band (63-8000hz)

-Scattering coefficient: The value defined between 0 and 1, which is related to the shape, smoothness and texture of the surface .

-Transparency: defines between 0-1 that the surface is permeable or 100% absorbent.

-Sound reduction index For simulating sound transmission a user defined sound reduction index R, in 1/3 octave-bands (50-10.000 Hz) can be specified. Can be imported directly from the Insul software or Excel. [34]

Below several ways to handle 3D models for use in ODEON are illustrated:

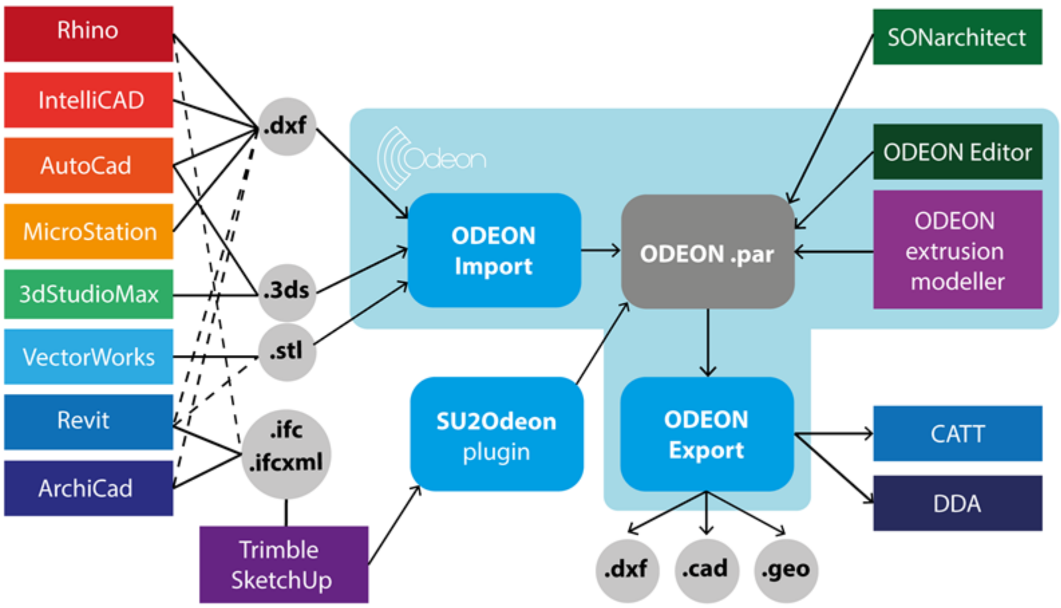

Figure 1. 3D models for use in ODEON [34]

Also, Odeon software has a text editor in itself that supports parametric modeling. The program can identify many sound source types such as multiple sound sources, human voice, omni sound source as well as in real life.

The results that enable us to examine acoustic parameters can be presented in many different ways. These ;

*“**Quick Estimate:** Fast estimate of reverberation time, and effect from different absorbing materials, based on diffuse field assumptions (Sabine, Eyring, and Arau-Purchades).*

***Global Estimate:** Estimate of reverberation time taking room shape, position of absorbing materials and sources into account.*

***Single point response:** Detailed results of acoustical parameters and auralisation option for a selected receiver.*

***Multi point response**: Acoustical parameters for a specified number of receivers.*

***Grid Maps:** Map of room-acoustical parameters and statistics for the grid receivers.*

***Grid Maps of Direct Sound:** Fast displayed grid map of direct sound to check the loudspeaker coverage before the room acoustical parameters are calculated.*

***Reflector Coverage:** 1st and 2nd order reflector coverage.*

***Ray-Tracing:** Dynamic display of raytracing from selected source.*

***3D billiard:** Interactive display for visualisation of wavefronts to demonstrate scattering, flutter echoes, focusing and coupling effects”* [34]

Acoustic datas can be export in current usage formats such as jpeg png gif,pcx, wmf, emf, bmp. [34]

The Odeon Software Acoustic Simulation program was chosen during the research because of all these; ease of use,compatibility with many modeling programs, as well as proven reliability and realistic results.

1.3 Subject and Aim

It is very important for human life that the buildings have various comfort criteria such as ventilation, lighting, sound, heating-cooling in psychological and physical terms since a large part of human life passes through the interior. Various building certifications have been formed to increase the quality of the time spent inside the building and to measure and qualify it. These building certifications include many criteria that will affect the comfort of life such as energy and water efficiency, air quality, material selection. One of the important criteria that affects indoor comfort is acoustic and many researches on sustainable building certifications have indicated that many comfort criteria are improved but the improvements in acoustic comfort are inadequate and sometimes the acoustic comfort is reduced. Karaman and Üçkaya (2015) pointed out that it is great importance to consider the acoustical conditions of all the buildings required auditory communication and to provide auditory comfort. [1]

The subject of the thesis is acoustical values required for office buildings and the place of these values in sustainable certificate systems. In this study, It has been investigated how noise levels, acoustic reflections and problems affect the quality of the place and so the quality of life, how much this situation is included in the main building certification systems and what the necessary improvement suggestions might be.

The aim of the thesis is set as follows: a check list will be composed in support of sustainable certification systems, especially in open plan office buildings, with the characteristics of the building elements to be used, in line with the required acoustic parameters. This checklist will be made on odeon software program on samples according to different office types. For this reason, this study will help to understand the conditions for the issuance of sustainability certificates and their adequacy in terms of the quality of space and will bring new solutions to them.

1.4 Method

Following the literature research, The hypothesis of the study was composed by basing on the problem of inadequacy of acoustical evaluation and implementation in newly established sustainable office areas..

In the first part of the research, the acoustic parameters and requirements used for the criteria of the office areas have been examined in order to understand the acoustic evaluation. Thus, the relationship between the open office space and the sounds at the speech level and then the results created by these sounds have been evaluated. Impact of each parameter on the occurrence of spatial acoustic problems examined in this section has been determined.

In the third chapter, the relation between acoustic problems and architectural status has been revealed. The origin, reasons and solutions of these problems have been researched..

At the next part of the study, to what extent acoustical requirements are included within the LEED and BREEAM sustainability certification models, respectively, used in developed countries such as the United States and the United Kingdom, has been examined.

In the last part of the thesis, sample of office project was made and then problems and requirements were practically examined from analysis environmental noise to selection of inter office materials. For this purpose, the problem that first started within the office volume was related to the building and environment dimension. In the next stage, the current office volume which was provided with environmental and interior noise control and the improved volume which was recommended were compared by making acoustic simulation samples with Odeon Acoustic Software program. Lastly, open office volume variables were examined by being kept constant the environmental and building noise control criteria of the comparative samples.

Sustainability certificates were compared with the output of the sample of office project where the acoustic problems were examined and the acoustic criteria that should be evaluated were evaluated. At the end of our study, an acoustic requirement list, which must be applied, has been composed and the thesis has been completed.

. CHAPTER TWO
ARCHITECTURAL ACOUSTIC
FOR OFFICES

2.1 Sound and Acoustic

Acoustic which means phonics is subdivided various branches such as psychoacoustic (the psychological effects of sound on people), physiacoustic (the physical effects of sound on people), bioacoustics (the usage of sound waves in the medical diagnosis), noise control and architectural acoustics. [2]

The sound control which is the main topic of this thesis, stands for the control of desired and undesired sound. Hence, the regulations about volume acoustic and sound quality in indoors will be examined on a sample which will be used in building acoustic and sound insulation oriented sound control.

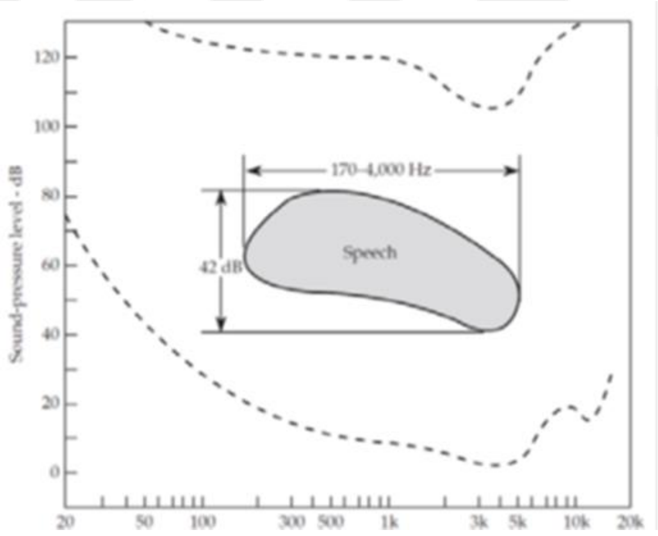

Figure 2. Hearing range for speech voice [3]

Speaking is involved in a small part of the hearing capacity and located in a center of hearing range (Figurel 2). Because, excessive low or excessive loud frequency sound waves is not used during the speech.

It is necessary to know the physical characteristics of sound such as rise of sound, reverberation of sound, refraction of sound and etc in order to understand the procedures of sound control. Each of these characteristics can affect the sound waves to turn into another energy or to go out. In other words, thanks to these characteristics of sound waves, sound level control or noise control can be provided in the environment.

2.2 Behavior Of Sound

2.2.1 Sound Frequency

Frequency is a measurement of a incident's repetiton in a unit of time. Sound is made of beats .Each time a high-pressure wave of molecules impinges upon the listener, it's heard as a beat, and measured in hertz (Hz), or cycles per second. If the beats come one per second, it is said they have a frequency of one hertz. One hundred beats per second, or pressure waves per second, measures one hundred hertz. [4]

A human's sense of hearing ranges between 20 and 20 000 Hz. And the most sensitive range is between 2000 to 6000 hz. This aspect is shown below on loudness contours. These contours show that the human hearing system is rather sensitive to sounds in 4 kHz and sensitivity relatively decreases in frequencies that are lower or higher than this.

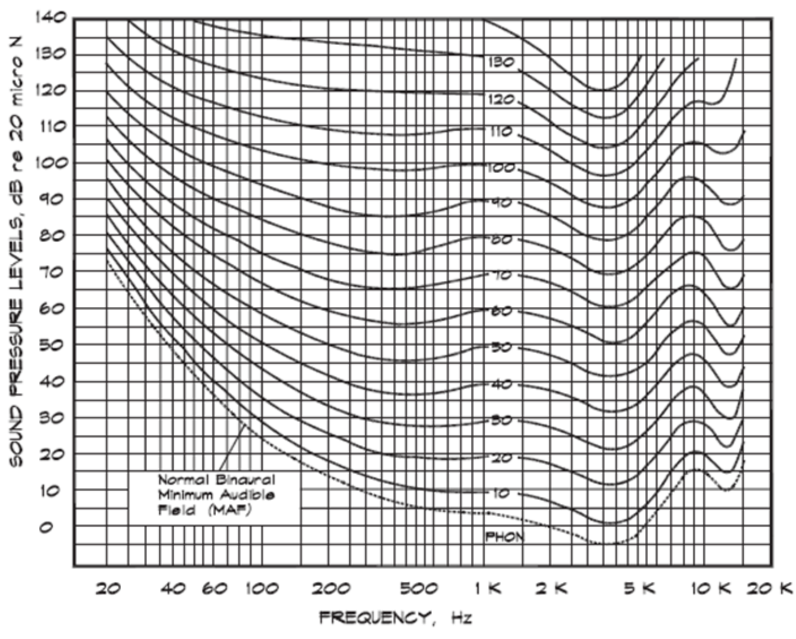

Figure 3. Normal Loudness Contours for Pure Tones [7]

Sounds have a sound intensity related to a frequency and defining a sound quality as a decibel without indicating its frequency content is an incomplete definition If the whole energy centers on only one frequency during hearing, it is called pure tone. Sounds like honk can be shown as examples of pure tone. However, the sounds produced by musical instruments and have a frequency pattern, are characterized as harmonic sounds. Sounds such as daily speech, traffic sounds, etc., which have varying levels of sound along the sound frequency spectrum, are also called complex sounds. [4]

These complex sounds which are the sounds heared constantly and daily, are taken part as background noises in our research

2.2.2 Octave Bands

It is very effortful to be able to define the sound volume of each frequency in the frequency spectrum where the human ear can hear a wide range between 20 and 20000 Hz. For example, to explain a sound in the absence of a sound graphic, a sound level in each hz like 130 hz in 70 dB, 131 hz 71 dB, should be identified. Moreover, even in this detailed level the decibel value between the exact number frequency values might be skipped. For example, 88 decibels are 160.5458 Hz.For this reason, the octave band, which simplifies the content of the sound spectrum, is used.

"Grouping frequency ranges into bands with upper and lower limits on the frequency domain, octave bands allow for the definition of loudness across the frequency spectrum, divided into finite and practical-to-use groupings of frequencies. To better account for the way human brains perceive pitch, individual octave bands (each described by the frequency of its geometric center) encompass unequal ranges of frequencies". [4]

"Each successive octave band's center point frequency is set at twice the frequency of the previous octave band's center frequency: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz. These are the octave bands with which architectural acoustics concerns itself". [4]

Therefore, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz ,4000 Hz which are defined as 1/3 octave band in this research, have been investigated.

2.2.3 Direct Sound

The sound that arrives at the receiver without interference and reflection between the receiver and the source is called direct sound. The direct sound that the audience firstly hear, is the most important sound in a volume and it defines the shortest path between the source and the audience.

The direct sound generally decrease proportional to the geometric width and distance, as it goes away from the audio source (when the distance doubles each time, 6 dB or 25% percentage of it). The human senses often use direct sound to identify direction, recognize the sound, and know what the source of the sound is. It is an important advantage to be in the direction of source of sound or the audience. It is efficient to provide such subjective acoustic parameters like the loudness, clarity and presence of perceived sound. [5]

2.2.4 Reflection

The sound waves start to move in a radial motion in each direction, when the sound is activated in a room. These sound waves interfere with the obstacles and surfaces such as walls etc. and then change their direction. This is called reflection.

Sound follows the same rule as light, the angle of incidence is equal to the angle of reflection.

"The sound pressure on a surface normal to the incident waves is equal to the energy density of the radiation in front of the surface. If the surface is a perfect absorber, the pressure equals the energy density of the incident radiation. If the surface is a perfect reflector, the pressure equals the energy-density of both the incident and the reflected radiation". [3]

2.2.5 Absorption

The sound energy can spread in any environment and at the same time it can be reduced for various reasons. When sound waves hit an object, high frequency sound waves reflects from the object. At this time, however, some of the sound waves are absorbed by the object. This is called absorption. Sound absorption is the main source of sound attenuation in a place. On the other hand, spreading, scattering and sound transmission also cause the sound attenuation.

Although architectural acoustics is an integral part of structural design of at least 200 years, this subject was placed on a strong scientific structure by Wallace Sabine at the beginning of 20th century. First of all, Sabine found out that there are various absorption values based on the type of the material and the angle of the sound on impact to the material and this can be maximum 1. According to Sabine, an open window is regarded as a perfect absorber, because the sound that passes through it never comes back to the room. An open window, by definition, would have 1 absorption rate and all other sound waves that go to all other surfaces will be evaluated as less than 1.0 because that will reflect back. Based on this, when calculating the total sound absorption of a room, all the materials/objects in that room and the places that they are placed on should be included in the total absorption..

$\Sigma A = S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \ldots$

where S_1, S_2, S_3 . . . = surface areas, sq ft or sq m

α_1, α_2, α_3 . . . = respective absorption coefficients

Moreover, the average absorption coefficient can be calculated by dividing the total absorption by the total surface area: $a_{avarage} = \frac{\Sigma A}{\Sigma S}$

Especially at open planned offices, the most preferred type of sound absorption is seperator barriers. Once a sound wave met with a barrier, part of a wave is intercepted. Intercepted waves run into the barrier and part of the wave pressure spread into the area inside the barrier. The absorpsion value of the barrier is defined as the sound absorption coefficient.

The sound absorption coefficient of the materials are obtained by examining the laboratory results of the tested construction materials. Absorption coefficient tables are usually given for the range between 125 to 4000 frequencies in the 1/3 octave band.

A single number that summarizes performance on octave bands is sometimes requested to quickly compare the absorption values of different materials. This single number note, which includes speech frequencies, is called noise reduction coefficient (NRC). This value is rounded up to the nearest 0.05 after taking the average of the sound absorption coefficients in the four octave band from 250 Hz to 2,000 Hz. [4].

2.3 Acoustic Parameters for Office Spaces

2.3.1 Reveberation Time (RT)

The elapsed time in term of second in order to the sound level decrease below 60 decibels from its highest value after the audio source is turned off is called reverberation time the volüme. The reverberation time is directly proportional with the volume of the media and It is inversely correlated with the sound absorption coefficient of the surfaces of the materials in the environment. [6]

The general equation of the reveberation time which is found by W.C. Sabine as follows:

RT = 0.161 V / A (2.1)

RT : [sn] Reverberation time

V : [m3] Volume of the room

A : [sabin] Total absorption coefficient

Regarding to the equation, reveberation time is a parameter which depends on volume and volume absorption. RT60 is the elapsed time for 60 seconds decrease, but after various researches it is revealed that the first echos reached to the human ear are important and the reveberation time must be calculated regarding to the first 10-20 and 30 dB decrease curve (EDT, T20, T30)

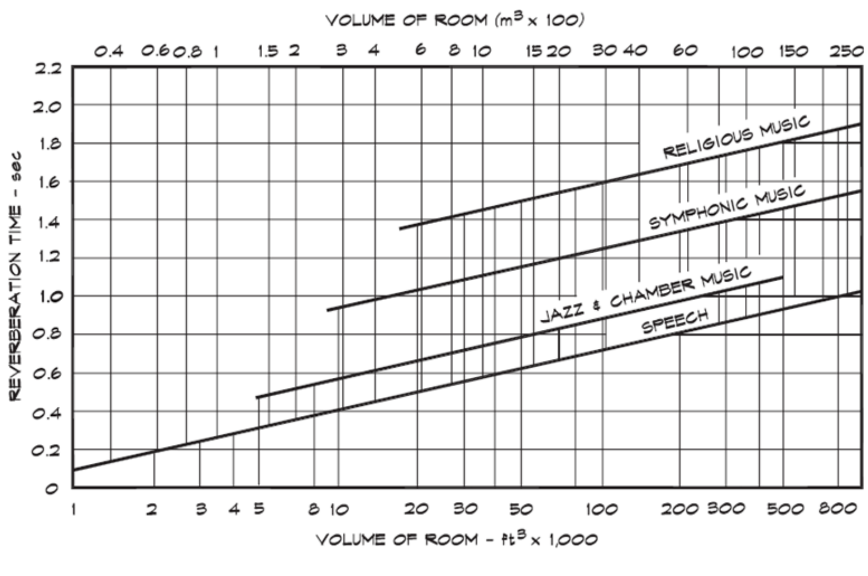

Figure 4. Reveberation time graphic based on volumetric size [7]

It is necessary that absorption should be higher and the resonance period should be shorter than the music fields for a variety of reasons such as speech subjectivity at the office areas, causing physical fatigue and attention disturbance, forming many sound sources at the same time. According to the graphic above, the average reveberation time required for open office areas that includes speech intention varies between 0.1 and 1.1 regarding to the size of volume of the areas. **The size of the volume to be applied and the speech curve should be crossed in order to clarify reverberation time. For example, the reverberation time of an office volume which is 30 meters to 20 meters and a ceiling height of 3,5 meters, should be approximately 0.7 seconds according to the graphic.**

2.3.2 Early Decay Time (EDT), T20, T30

The early decay time is also a parameter of the reveberation time and It is calculated by using 10dB decrase curve that is between first 5dB and 15dB decrease range.

The early decay time corresponds to 6 times of the resonance time measured above the first 10dB decrease. The early decay time, which analyze the effect of the volume geometry in detail thanks to first reflections that is obtained from each receiver points, gives a more subjective assessment in comparison with reveberation time. The early decay time as a parameter of resonance is calculated for each octave band and It is expressed as ms [8].

EDT value is introduced by V.L. Jordan and is calculated by the equation below [8]

EDT = t10x6

t10: [sec] The elapsed time for the first 10 dB decrease of sound.

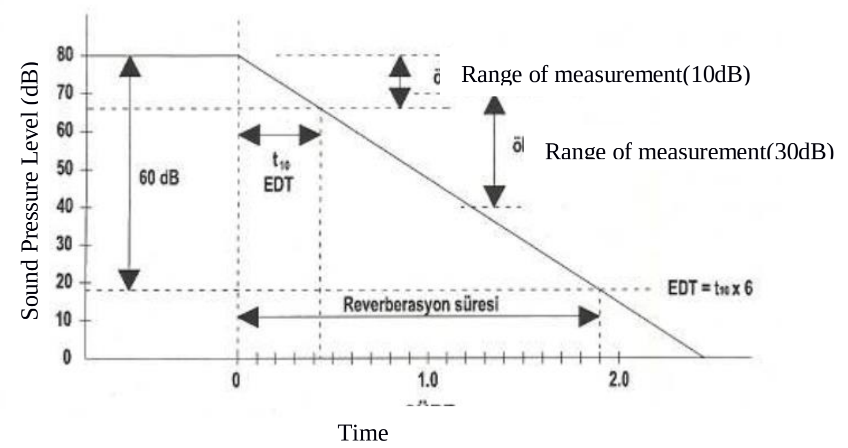

Figure 5. Determination of EDT and T in the Curve Of Decrease [9]

EDT is less dependent on fullness of the area than RT, and is measured in an environment without audience. In Beranek studies, It is revealed that there is an approximately 0,3 sec difference between EDT in empty saloon and RT60 in full saloon among 52 saloons. [7]

EDT=RT60 ±0,3 sn

T20 and T30 are also calculated in the same way as EDT. The T20 parameter is obtained by making straight line from the decay curve of 20 dB of sound by regression analysis and then completing it to 60 dB with the same inclination. The While T20 parameter is obtained from 20dB decay curve at the first 5dB - 25dB decrease, The T30 parameter is obtained from 30dB decay curve reaches 60dB at the first 5dB - 35dB decrease.

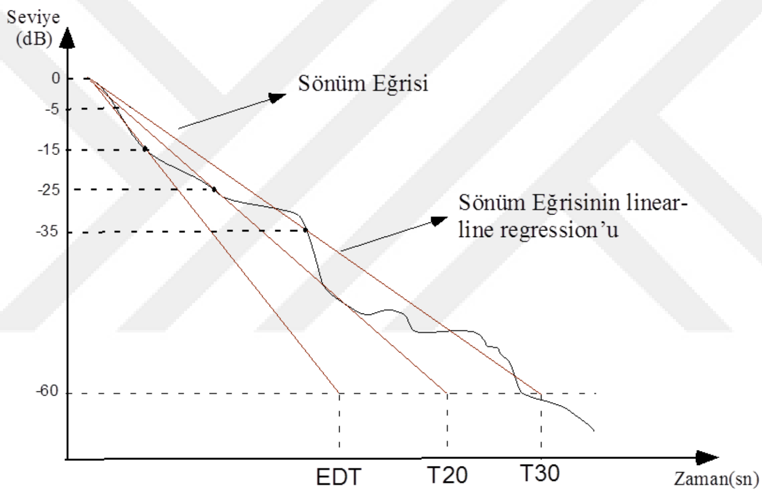

Figure 6. Determination of EDT and T20 and T30 on the curve

2.3.3 Defination (D50)

Practical parameters such as the simple early-late ratio (ELR), speech transmission index (STI), room acoustic speech transmission index (RASTI) have been developed to measure speech clarity. ELR is widely used from these parameters. The ELR is the ratio of the early sound to the late at the signal-to-noise ratio. The D50 parameter is used to measure the clarity syllables at a speech and also a song. In the calculation of clarity, the 50 ms rate is valid at the function of the speech for ELR. D50 parameter is found by the ratio of the sound energy that arrives in 50 ms after the sound that reaches directly to the receiver to the total sound energy that reaches that point. [8]

The clarity parameter of the speech is the ratio of the sound energies that arrives to the receiver in first 50 ms period to total sound energy that arrives to the receiver and is formulized as below:

$$D50 = \frac{\int_0^{50} p^2(t)dt}{\int_0^{\infty} p^2(t)dt}$$

D50: [-] Clarity

$p^2(t)$: [Pa] Sound pressure

In other words, the more sound reflections that reaches to the receiver in first 50 ms the more clarity of speech. It should be noted that the result should be bigger then 0.5 while the D50 parameter is being evaluated.

2.3.4 Speech Transmission Index (STI)

The main purpose of usage of the open office areas contains speech depending activities, so that intelligibility of the speech within the place is crucial in terms of preferred functionality of the volume. Intelligibility of the speech can be measured in the void by three metric values: speech intelligibility index (SII or SI), speech transmission index (STI) or room acoustic transmission index (RASTI). Currently, The articulation index (AI), an old metric value, is rarely used, because the reverberation is not considered effectively. In our country, the speech intelligibility is determined by the parameter of speech transmission index which is calculated regarding to IEC 60268-16, 2003 [4]

Background noise criteria is crucial about investigating the results of STI parameter. Increasing of the sound intensity that is called the background noise which is formed by natural or mechanical methods makes intelligibility difficult

It is considered sufficient to intelligibility of the speech in a circle of only 2 meters diameter around the sound source in the design of the open offices when the STI parameter is examined, while designs are made to provide the voice orientation and transmission with the ceiling and wall panels with the aim of reaching of the speech to the audience clearly in all hall. This is because in office areas it is expected that only dual conversion is easily comprehensible and sounds does not reach to another working area.

The subjective scale of STI is given below:

Table 1. Reletionship with STI Parameters –Subjective Scale [4]

Intelligibility and its inverse, (Speech Privacy)	**Speech Transmission Index (STI) or Rapid Speech Transmission ındex (RASTI)**	**Speech Intelligibility Index (SII or SI)**
Perfect intelligibility (no privacy)	1.0	100%
Excellent intelligibility	≥0.80	≥98%
Very good intelligibility	0.65–0.80	96%–97%
Good intelligibility	0.50-0.65	93%–95%
Fair intelligibility (poor speech privacy)	0.40-0.50	88%–92%
Poor intelligibility	0.30-0.40	80%–87%
Bad intelligibility (good speech privacy	<0.30	<80%
Completely unintelligible (confidential)	0	0%

2.3.5 Speech Privacy: Signal to Noise Ratio (U_t)

In a volume, if speech intelligibility is low, speech subjectivity rises, but in open office areas it is intended that speech intelligibility is high in a 2-meter-diameter area and as for speech subjectivity is low out of this diameter.

In an office area with a goal of speech privacy, the desired signal / noise ratio can be achieved in a various way. Briefly, It can be expressed it as follows: [7]

Source sound level – Sound Attenuation (Reduction) – Masking sound level = Signal to noise ratio (privacy)

In office areas STI value should be 0.45 to fully ensure the conditions of the speech privacy conditions, and as for STI value should be below 0,30 to partially improve the speech privacy. The relationship between the speech privacy parameter (U50) and the speech intelligibility parameter (STI) is given in the following graphic.

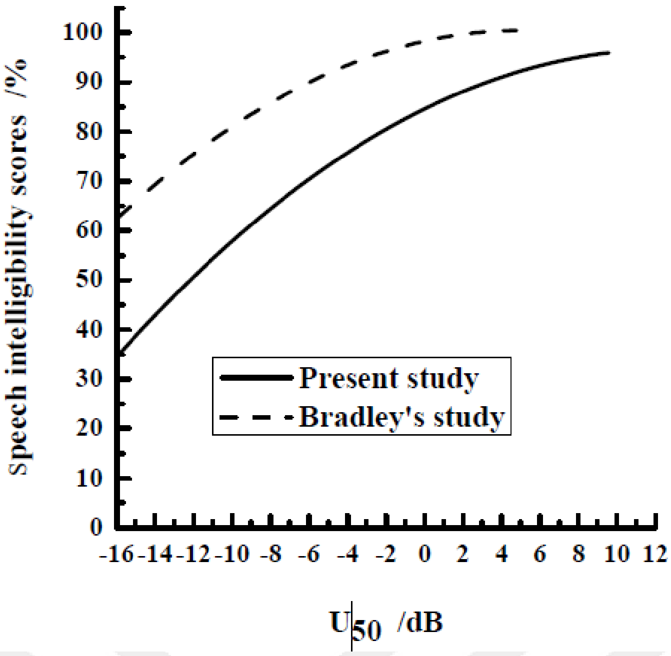

Figure 7. Relationship Between Speech Intelligibility and Speech Privacy

The relationship between intelligibility and subjectivity is shown below in Table 2:

Table 2. Criterion of Signal to Noise Ratio [7]

Articulation index	Signal to noise ratio	%sentences understood	Intelligibility	Privacy
> 0,4	> 0 dB	> 90	Very Good	none
0,3	−3 dB	80	Good	poor
0,2	−6 dB	50	Fair	transitional
0,1	−9 dB	20	Poor	normal
< 0,05	−12 dB	0	Very Poor	confidential

"Speech Transmission Index (STI) combines both a room acoustics and a signal-to-noise ratio component into a single objective index for speech intelligibility in rooms." [10]

It is important to simultaneously provide both the speech clarity and the speech quality in an open office volume. Therefore, the U parameter that was formed by taking table 2 above as the basis, in acoustic design criteria, it is anticipated to maintain the speech quality at normal levels while providing speech clarity. Therefore, for the sample work it is identified as -6dB for U50 parameter criteria

2.3.6 Rate of Spatial Decay (DL_2)

Speech is the most disturbing sound signal in an open planned office, and necessity of reducing the speech between different working groups is of utmost importance for acoustic planning in open-planned offices.

Regarding to IS0 14257, 2001, spatial deterioration ratio is deterioration of sound pressure level per folding distance. It is possible to evaluate the efficiency of the surface treatment and thus the acoustic quality of a volume from the spatial deterioration ratio. DL2 parameter is composed in order to help characterizing of the speech subjectivity performance of the working areas.. [11]

"The logic behing the parameter is formulized as follows:

$$d_c = 10^{0.3(Lspeech + DL_f + Lc)/DL_2}$$

where:

dc is the distance of comfort,

Lspeech is the level of speech

Lc is the acceptable speech level at the work place.

This (comfort) distance gives an indication of how to proceed in the acoustical design work concerning absorbing materials, screens, furnishing etc. and act as a useful tool for the architects". [12]

Spatial deterioration value is started to investigate after the sound is out of the source and then proceed 2 meters. Hence, while the results are obtained by the acoustic simulation programme, it is necessary to place the receivers at distances of 2 and 16 meters away from the source. Besides, It is recommended that the receivers are aligned in a logarithmic distance between them.. [13]

"The values to be expected for the DL_2 parameter is; 1 - 3 dB for reverberant rooms and 2 - 5 dB for ideally treated rooms. The design criterion for DL2 is set to 3.5 dB or better according to ISO 11690-1, 1996". *[13]*

2.3.7 Noise Criteria (NC)

The initial point of volume acoustics is the determination of the background noise within the volume. Background noise refers to constant noise caused by ventilation and other similar building services..

Technically speaking, the background noise refers to the total remaining sound in a given location and situation, When the actual sounds examined in an environment are suppressed. [14]

NC curves (based on the highest noise level in the room) are used in the standards that are valid in our country among the determined criteria such as NC, RC, NCB, PNC curves used in the expression of the noise level in the environment. The NC value is measured in the 1/3 octave band and it provides sensitivity of noise to be reduced at low frequencies. The numerical definition of the NC curves given in the graph is the arithmetic mean of the sound pressure levels at 1000, 2000 and 4000 Hz..

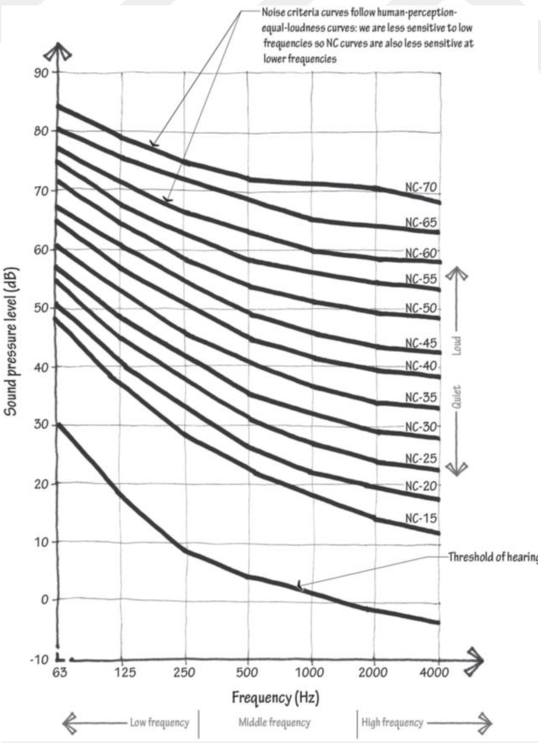

Figure 8. NC criteria curves based on Frequency and Sound Pressure

The graph in Figure 4 shows the noise pressure value of each frequency of the background noise source determined at the NC value. Thus, it is determined that how many dB of constant noise at low, medium and high frequencies.

The NC values that must be required to be composed in order to prevent the noise sensitivity in the volume are categorized as follows:

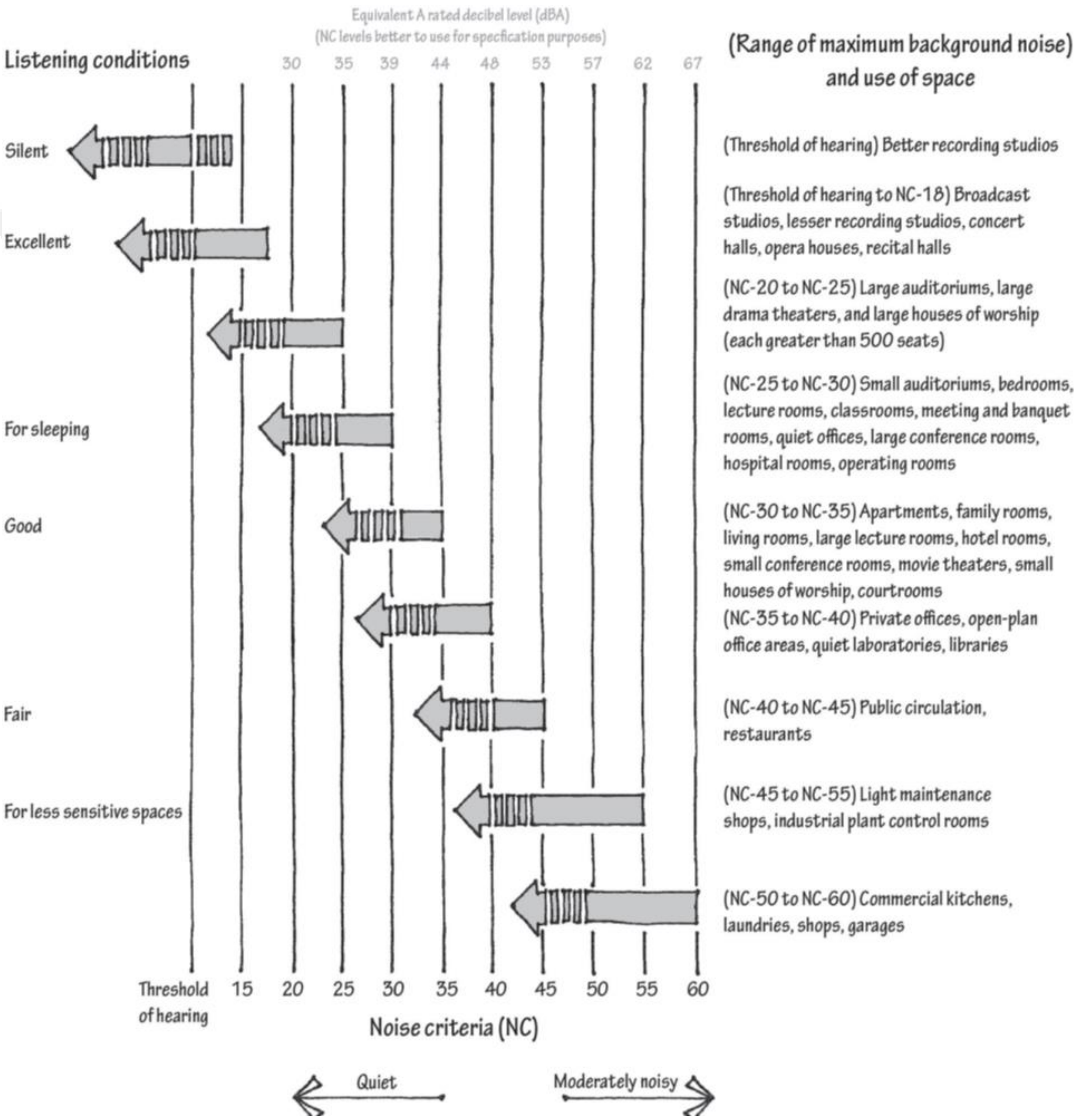

Figure 9. NC Curves accordint to Room Type [4]

As shown in the table above, the background noise curve of the office areas can be characterized NC30 NC35 or NC40 according to the usage of space and size of the office.

2.3.8 A Weighted Sound Pressure Level (Leq)

A weighted sound pressure level is A contour filtered sound intensity. Filter arranges the measurement value by taking account of the way of to various sound frequencies. Sound sensivity of the human ear is depends on the sound frequency. People hear some of the sound frequencies much better then the others. A filtered arrangement's main effect is featured less because it is on the low and higher frequencies at the standard decibel scala. It is generally used in enviromental noise measurement. At the A weighted sound pressure level, during the period of interest, equivalent sound level is abbreviated as Leq. [7]

Sound level should be measured three different time intervals of a day as in the morning, in the evening and at night for measurement of noise level. The equivalent sound level which is measured within the day is referred as Ld, in the evening is referred as Le and at night is referred as Ln.

Acceptable noise level limit values of interiors are defined in Regulation on the Assessment and Management of Environmental Intensity, Annex VII in Table 3

Table 3. Maximum Noise Level

<table>
<tr><td colspan="2" rowspan="2">Usage Area</td><td>Closed Window Leq dBA</td><td>Open Window Leq dBA</td></tr>
<tr><td colspan="2">The values that is no activity in the usage areas</td></tr>
<tr><td rowspan="4">Public institutions</td><td>offices</td><td>45</td><td>55</td></tr>
<tr><td>labratuary</td><td>45</td><td>55</td></tr>
<tr><td>Meeting Rooms</td><td>35</td><td>45</td></tr>
<tr><td>Computer Rooms</td><td>50</td><td>60</td></tr>
</table>

2.3.9 Weighted Standardised Level Difference (D_{nTw})

Either in one of the two rooms, the reference value of the reverberation time in the receiver room equaled to the difference between the location and time average of the pressure levels of the sound that is produced by one or more sound source in these two rooms. [15]

For instance, it is assumed that 70 Db sound is occured in a waiting room and background noise might be 30 dB in the open office area next to this waiting room.

Level difference of sound between these two rooms is 40 dB and this situation prevents the healthy working in this office area. Standardization of the level difference of sound is stated in ISO 140-4-1998 as follows:

D = L1 - L2

where

L1 is the average sound pressure level in the source room;

L2 is the average sound pressure level in the receiving room.

DnT= D + 10log T/T0

D is the level difference;

T is the reverberation time in the receiving room;

T0 is the reference reverberation time; for dwellings, T0 = 0,5 s.

NOTE 1 The standardizing of the level difference to a reverberation time of 0,5 s takes into account that in dwellings with furniture the reverberation time has been found to be reasonably independent of the volume and of frequency and to be approximately equal to 0,5 s. With this standardizing, DnT is dependent on the direction of the sound transmission if the two rooms have different volumes.[15]

2.3.10 Weighted Sound Reduction Index (R_W)

Rw is weighted sound reduction index of the wall and it defines the sound insulating power of the construction element by air. It is a measurable value in a laboratory as identified in ISO717 Part 1. Larger measurable value means that more powerful sound insulating power of the construction element. Rw value is measured in the frequency range of 100 and 3150 Hz. [16]

2.3.11 Weighted Normalized Impact Sound Pressure Level (L_{NW})

In constructions, insulation assesment for the impact sounds on the floor is performed same as weighted sound reduction index. Weighted Normalized Impact Sound Pressure Level used on floor defined as Lnw and it indicates the transmission level of the standard sound source noise to the ground floor. Hence, the lower Lnw value desirable.

CHAPTER THREE

ACOUSTICAL COMFORT CONDITIONS FOR OFFICES IN GREEN BUILDINGS

Nowadays, The demand for energy and natural resources is rapidly increasing as population and globalization rapidly increase. The considerable amount of reduction of non-renewable energy sources has led to an increase in the interest of the society in renewable energy sources, as well as has created anxiety about leaving a viable environment to the next generations on society.

The concept of sustainability has influenced our living spaces for the first time by coming into our lives in this way. Sustainability has provided buildings which designs with environmental responsibility comprehension, is named ecological, green building etc. names, is appropriate to the weather and conditions, produces their own energy to enter into our lives.

The aim of designing green buildings is to increase the energy efficiency of the buildings, to provide using renewable energy and to increase the life quality of interior. Main requirements such as thermal comfort, enlightenment value with day light, air quality, usage of natural materials are essential for providing the quality of interior with sustainable ways. Providing of these requirements by natural methods causes various negativities in terms of acoustic. These negativities and their solution suggestions are explained in the next section.

3.1 Acoustical Comfort Conditions For Offices In Sustainable Certification Systems

3.1.1 Leed's Acoustic Criterias For Office Spaces

It is the first official point scoring system that is developed by United States Green Buildings Council (USGBC) in the year of 2000 on the purpose of increasing the speed of development and construction of the green buildings and providing the environmental sustainability. In 1998, LEED which starts to be used with pilot scheme for the new buildings is not only used in United States, but also used in many countries in worldwide. Regarding to GSA, commonly used assesment system is LEED. [24]

In LEED system, acoustic subject is collected under the concept of indoor air quality.

The subject is stated with the main lines as follows:

- *room noise levels*
- *sound isolation performance of constructions,*
- *limiting reverberation time and reverberant noise buildup*
- *paging, masking and sound reinforcement systems*
- *speech privacy analiysis*

Yet, speech privacy is a requirement only for hospital buildings, it is not expected to be in office buildings. Hence, it will not analyzed in the concept of our study.

3.1.1.1 Backround Noise

Mechanical system and background noises should be reduced in termms of 2011 ASHRAE Handbook. Hereunder, background noises for office areas might be as follows:

Table 4. Design principles for HVAC – background noises in rooms [25]

Room Types		Oktave band analysis	Approximate inclusive sound pressure level	
		NC / RCb	dBAc	dBCc
Office Structure	Corridors, lobbies	40	45	65
	Service and support areas	40	45	65
	Administrative and special offices	30	35	60
	Conference room	30	35	60
	Teleconference room	25	30	55
	Open plan offices	40	45	65
	Corridors, lobbies	40	45	65

3.1.1.2 Sound Insulation

In the concept of Leed, during the phase of building noise control, STC criterion is used for sound reduction concept of the seperative construction elements. In our country, related value is defined as Rw. The difference between these two criterions based on the the different way of calculation. There is no calculation way to establish a connection between STC and Rw. In Insull which is a construction element sound transmission measurement programme, each two values should be calculated seperately. Accordingly, STC values in the concept of Leed as follows::

Table 5. Maximum composite sound transmission class ratings for adjacent spaces [25]

Adjacency combinations		STC_C
Residence (within a multifamily residence), hotel or motel room	Residence, hotel or motel room	55
Residence, hotel or motel room	Common hallway, stairway	50
Residence, hotel or motel room	Retail	60
Retail	Retail	50
Standard office	Standard office	45
Executive office	Executive office	50
Conference room	Conference room	50
Office, conference room	Hallway, stairway	50
Mechanical equipment room	Occupied area	60

3.1.1.3 Reverbaration Times

In the concept of Leed, in order to establish the reverberation time requirements, the table below stated is taken into account. If there are areas that changing with the applications or unspesified in the table, it is recommended that standard criterions or the valid criterions for the closest functional area type in the table to be used. According to Leed, the required reverberation time for the office areas as follows

Table 6. Reverberation time requirements in Leed [25]

Application	T60 (sec), at 500 Hz, 1000 Hz, and2000 Hz
Executive or private office	< 0.6
Conference room	< 0.6
Teleconference room	< 0.6
Open-plan office without sound masking	< 0.8
Open-plan office with sound masking	0.8

3.1.1.4 Paging Masking and Sound Reinforcement Systems

Sound reinforcement systems are one of the desired criterion for conference halls and auditoriums for over 50 people. For the reason that required criterion for open office areas are not mentioned in concept of leed, it will not examined in concept of the study.

For masking systems, the criterion is only the system used is not being over the 48 db. Coverage zone of the loudspeakers provide an uniformity of +/–2 dBA and speech sprectrums should be masked efficently..

3.1.2 Breeam‘s Acoustic Criterion For Office Spaces

BREEAM:,It is developed by Building Research Establishment(BRE) in England and BREEAM- Building Research Establishment Environmental Assessment Method which is put into practice in the year of 1990 is the first of the green building assesment systems.

Acoustic requirement subjects are indicated inside the various Bream certification parts as follows:

- • BREEAM International New Construction-Health&Welfare-HEA05 (Acoustic Performance) and Pollution -POL05(Noise Pollution Reduction)
- BREEAM International Refurbishment- Health & Welfare- HEA05 (Acoustic Performance) and Pollution -POL05(Noise Pollution Reduction)
- BREEAM Communities-Social&Ekonomic Welfare-SE04 (Sound Pollution)
- BREEAM In-Use International-Building Administration -HEA20(Acoustic Conditions)

For our open office sample in the concept of BREEAM International New Construction part, it is evaluated in two sections as noise pollution reduction and acoustic performace. The aim in the concept of noise reduction: reduction of the noise probability that is resultant of the fixed wiring in the new building and affects the surrounding noise sensitive buildings. Hence, it does not cover the required criterions in the concept of acoustical assesment of open office areas. The standards that are determinated in acoustical performance part are analyzed in detailed as follows.

3.1.2.1 Acoustic Performance

Herewith this part, acoustic performance of the building (including sound insulation) fits with the certain standards is intended.These standards are examined under these subject headings below.

Interior Noise Level

In order to estimate the mechanical ventilation systams originated internal noise/ sound levels, generally NR curves are used. But in the concept of BREEAM, alongside of the internal noise originated mechanical ventilation system, closed ambient noise level criterion including ambient noise that is transmitted through external and frontage, L_{AeqT} is used. L_{AeqT} is obtained by using this formulation with NR values: L_{AeqT}~ NR+6 dB

In the concept of Breeam, indoor sound level criterions of the areas related to their vacancy status where might be located in the office buildings as follows:

Table 7. Backround noise crition inBreeam [26]

Function of spaces	Sound level of interior spaces
Public area (resting room, toilets)	≤ 40 dB L(AeqT)
Private offices	≤ 40 dB L(AeqT)
Common offices	40-50 dB L(AeqT)
Convention room	35-40 dB L(AeqT)
Receptions	40-50 dB L(AeqT)
Offices designed for speech (education and training, seminar and conference halls)	≤ 35 dB L(AeqT)
Concert hall, theatre or auditorium	≤ 30 dB L(AeqT)
Cafe and canteen areas	≤ 50 dB L(AeqT)
Catering kitchens	≤ 50 dB L(AeqT)
Restaurant areas	40-55 dB L(AeqT)
Private areas	50-55 dB L(AeqT)
Manuel studios	≤ 55 dB L(AeqT)
Library areas	40-50 dB L(AeqT)

When the sound level intervals are indicated and confidentiality is not seen as a problem by the consumer, lower limit of the interval can be neglected and sound level criterion can be acceptable as lower than upper limit or equal to the upper limit.

Breeam stated in the case of inadequate speech privacy for Interior noise level as follows:

"Unless calculationsfrom the suitably qualified acoustician or mechanicalservices engineer confirm otherwise;the contribution to the indoor ambient noise level from mechanicalservicesfor the privacy index should be assumed to be lessthan 35 dB, LAeq,T, regardless of the upper limit during the design stage of the project.

To increase the ambient noise level, where privacy isrequired or the ambient targetsinclude a minimum as well as maximum limit, an artificialsound source or *sound masking system may be required. Any artificialsound source or sound masking system should be installed and in operation at the time of the acoustic testing to demonstrate compliance."* [26]

Reverberation Times

The part of the reverberation time inside Breeam, determines the parameters of reverberation, sound absorption and sound transmission index control of the applied office. In respect to this, Breeam's requirements that refer to BS 8233:2014 part 7 are briefly as follows:

Table 8. Reverberation time requirements in Breeam [26]

Room Volume(m^3)	Reveberation time	
	Speech	Music
50	0.4	1.0
100	0.5	1.1
200	0.6	1.2
500	0.7	1.3
1000	0.9	1.5
2000	1.0	1.6

Besides, there is an another criterion as <0.8s for open office areas . The parameter of sound transmission index is determined as follows:

Table 9. STI requirements in Breeam [26]

Performance	Speech Transmission Index(STI)
Education or critical listening activity in a group	≥0.6
Inter groups (During critical listening activity)	≤0.3

3.1.2.2 Sound Insolution

In this part, as well as outer noise and noise originating from interior service area, requirement of controlling the noises originating from adjacent volumes is discoursed. Hereunder, there is a precondition that the sound difference between two volumes should follow the table below:

Table 10. DnTw requirements in Breeam [26]

privacy requirement	activity noise of source room	noise sensevity of receiving room		
		low sensivity	medium sensivity	sensitive
confidential	very high	47	52	57
	high	47	47	52
	typical	47	47	47
	low	42	42	47
modarate	very high	47	52	57
	high	37	42	47
	typical	37	37	42
	low	no rating	no rating	37
no private	very high	47	52	57
	high	37	42	47
	typical	no rating	37	42
	low	no rating	no rating	37

NOTE Background noise can also influence privacy. A) DnTw 55 dB or greater is difficult to obtain on site and room adjacencies requiring these levels should be avoided wherever practical. [26]

3.1.3 Sbtool's Acoustic Criterias

SBTool created by developed countries into lay the foundations for an environmental assessment method for buildings in 1998. SB Tool is a general evaluation framework that is not implemented directly on buildings. The purpose of tool is adapting to regional conditions that using by this framework. [27].

performance categories of based on the evaluation:

"(A) Site regeneration and development, urban design and infrastructure,"

"(B) Energy and resource consumption,"

"(C) Environmental loading,"

"(D) Indoor environmental quality,"

"(E) Service quality,"

"F) Social, cultural and perceptual aspects,;"

"(G) Costs and economic aspects." [28].

Acoustic criterion is evaluated under the tittle of "Acoustic comfort" in the categories of "Indoor environmental quality".

According to SBTool, the acoustic behavior of the building is determined by the calculation of the building's acoustic comfort level (P_{CA}).. PCA refers to the general behavior of the building in terms of sound insulation. the system based on comparing performance of acoustic isolation that provided by each building element..

The system goes through, the determination of the solution value by joint calculation of standard value given by RRAE (Regulation of Acoustic Requirements of Buildings) and best value given by SBTool itself .

According to this, SBTool system wants to calculating the steps on below

- *Quantification of the level of acoustic comfort to air conduction sounds between the outside and rooms or sitting areas of the building"*
- *"Quantification of the level of acoustic comfort to air conduction sounds between compartments of a fire and rooms or sitting areas of another fire"*

- *“Quantification of the level of acoustic comfort to air conduction sounds between locations of common circulation of the building and rooms or sitting areas of a fire”*
- *“Quantification of the level of acoustic comfort to air conduction sounds between locations of the building destined for trade, industry, services or entertainment and rooms or sitting areas of a fire”*
- *“Quantification of the level of acoustic comfort to percussion sounds between floors of a fire or locations of common circulation and rooms or sitting areas of another fire”*
- *“Quantification of the level of acoustic comfort to percussion sounds between locations of the building destined for trade, industry, services or entertainment and rooms or sitting areas of a fire”*
- *“Quantification of the level of acoustic comfort to noises of collective equipments” [28].*

By the standardization method, level difference are calculated between the different spaces that are wanted requriements in above and foudns P_{CA} value of building. The acoustics performance value of the building that is determined to according to PCA value is like the following table. [28]

Table 11. Acoustic Performance Levels in SBTool [28]

Level	Conditions
A+	$P_{CA} > 1{,}00$
A	$0{,}70 < P_{CA} \leq 1{,}00$
B	$0{,}40 < P_{CA} \leq 0{,}70$
C	$0{,}10 < P_{CA} \leq 0{,}40$
D	$0{,}00 < P_{CA} \leq 0{,}10$
E	$P_{CA} < 0{,}00$

Accordingly, the building performance measures are scored between -1 and 5.

3.2 Sustainable Offices and Acoustic

3.2.1 Design Requirements And Solution Offers Affecting Acoustic In Sustainable Offices

3.2.1.1 Enviromental Noise Control

Sounds with specific characteristics are perceived as noise by people. For instance, if the sound is trapped in narrow bands, this sound is perceived as louder than the sound which has the same energy but is expanded into wider bands. Another example is related to uprising period of sound. The sound which one is uprising faster is perceived as louder than the other one with the same energy. Irregular unstable sound is perceived louder than stabile sound [17].

Acoustic satisfaction of indoor should firstly be assessed in the open air. The design elements of the building should be compatible with the sound levels of its location in order to prevent noise transmission. Besides, the compatibility between function of the building and function of the other existing buildings in that area, provides that the noise is more easily controlled. For instance, when an office project that is planned to be constructed in the industrial zone is compared to an office project that is planned to be constructed in the areas with low noise ratio, it would be both more costly and impossible to prevent noise completely. Hence, in the zones of loud areas (airport, highway, plant, railway etc.) it should be avoided from constructing buildings such as hospial, office, educationl etc., that are not suitable for these functions [18] If the building was firstly built in the region, it is also important to determine the functions of other buildings planned to be built in this area in the future. If the buildings to be built are not acoustically compatible, significant improvement precaution must be taken in order to bring interior sound ambient to an acceptable level [[18]

When the improvement of the acoustic ambient is the general purpose, noice control and acoustic landscape (sound universe) design are the two main perspectives about sound control in the ambient. [16]

In terms of acoustic landscape, more than one design target being in a single application example is been supportive about design characteristics of the sustainable buildings. For instance, soil barrier which is composed of plants with low growth rate and drought-tolerance might act as a noise barrier, correspond with sustainable development principles and help to safety requirement between buildings. [18]

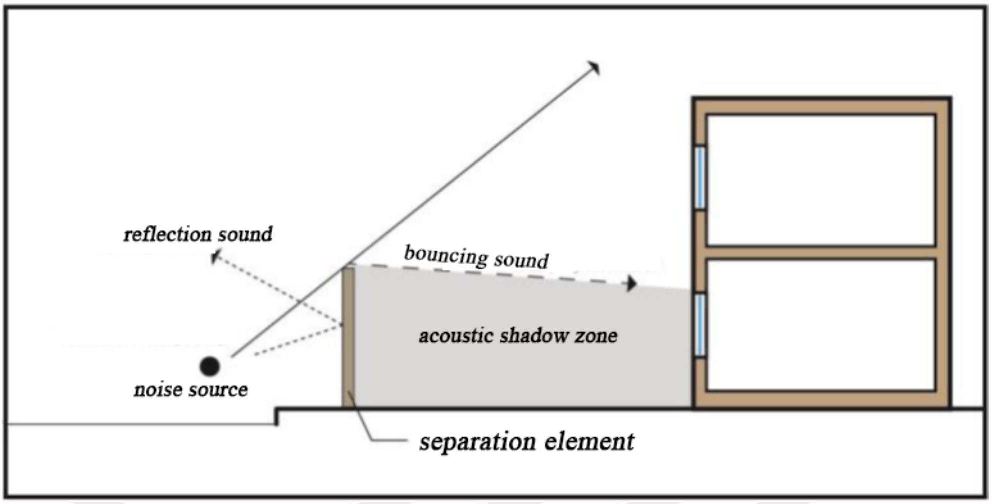

Figure 10. Acoustic Problem and Solution Regarding To Building Orientation [20]

During the design of the noise barrier, the barrier source must be made as close to the barrier source as possible, so that the building stays within the barrier in an easier way.

Glass surfaces and huge gaps should be constitute on the surface of the buildings in order to obtain energy efficiency by reducing the enlightenment and electricity and also in order to improve the quality of enlightenment by taking maximum benefit from daylight These glass surfaces increase the transmission of daylight into the building, reduce the sound insulation between the interior areas and increase the level of exterior noise. The insulation of glass surfaces is less then the opaque wall and roof element. . Special acoustic qualified transparent products are not preferred by reason of their high prices and also having lower level of sound transmission (RW) in comparison with opaque elements.

So that, the construction materials of the building, which will be built on noise level reduced area with acoustic barrier, should be selected in accordance with the existing acoustic condition. Having appropriate sound transmission coefficients (RW) of floor and wall materials will prevent the performance degradation of employees in the volume because of the noise which is come from outside such as transportation, industry, road and building construction, entertainment and commercial etc.

It is necessary to firstly perform the environmental noise analysis of the construction which of noise control will be provided in order to determine the Rw values of the construction components to be used in the facade. Therefore, an A weighted sound level measurement must be conducted in the area on which it will be placed

The noise simulation maps that are created as a result of environmental noise measurement enables us to determine the noise that will come to the building facade. Sound Plan Essential is the most widely accepted one within the noise simulation programs which are currently the most preferred method for this.

In the noise analysis software, determining the essential sound receiving points is important in terms of interpreting the results accurately. Facade Noise Receivers: In order to measure the sound pressure levels that come to the façade surface, a receiver must be designated to each floor based on the Environmental Noise Evaluation and Management Regulations. These receivers must be designated to be 2 meters away from the façade of the building. The reason for this is to prevent remeasuring the reflections that will arise from the façade on the receiver points.

The A weighted sound pressure level values that are measured in various hours are imprinted on the modelling. The imprinted measurement must be made in three different time frames in the morning, evening and at night. This is important to learn how the noise status of the environment changes within the day. The noise and the noise reflections that come from the other buildings are inspected with the designated receiving points and the sound pressure levels that will come to each floor are determined.

Temperature, pressure, humidity, and wind status must also be taken into consideration during the measurement. In addition to sound being propagated in a fast or delayed manner based on the weather conditions, the road emulsion will also show a difference based on the weather being rainy or sunny. The required tolerance values must be generated based on this.

Based on environmental noise evaluation and regulations, environmental noise exposure categories of a building are defined as follows:

a) Category A (in terms of Ldaylight < 55 dBA) Area: Maximum level of the noise in this category is not obtrusive Noise is not evaluated as a determinant factor, while planning decision is given..

b) Category B (in terms of Ldaylight 55-64 dBA) Area: The noise in this category is obtrusive but level of the noise is taken into account in planning decisions. Planning decisions are given by taking the necessary precautions against noise.

c) Category C (in terms of Ldaylight 65-74 dBA) Area : The noise in this category is pretty obtrusive. Planning decision of the new housing zones are not generally given. Nevertheless, the precautions against the noise is taken by taking into account the level of background noice in the case of necessity of public welfare and being allowed is an obligation due to the lack of a quieter location.

d) Category D (in terms of Ldaylight >74 dBA) Area: The noise in this category is excessively obtrusive. The planning decision of new housing zone is not given in these areas. Planning decision of is given by taking precautions against the noise of , working area [14]

Based on the categories of the environmental noise exposure, permeability values (RW value) of the construction elements of the office buildings which are constructed in these areas are given in Table 12:

Table 12. Sound insulation values in order to provide noise control [14]

Class of Noise Level	Interval of the Related Noise Level	Rw values of External Construction Elements for Offices (Db)
A	Until 55 dB	-
B	From 55 dB to 64 dB	30 db
C	From 65 dB to 74 dB	35-40db
D	Higher than 74 dB	40 ve üzeri db

Considering today's city life, the noise level of many areas on the road side is higher than 55 dB. This situation incapacitates the absorbency values of some distinct construction elements.

3.2.1.2 Orientation of spaces and building noise control

Another point that needs to be examined acoustically is the positioning of the building on the land in the beginning of architectural design. Environmental noise criterion is not generally take into consideration, while the buildings are positioned in consideration of many criteria such as land condition, weather condition, sun direction, landscape. In this case, problems can arise that can not be solved even if the construction elements are strengthened acoustically.

For instance, a building model which has a courtyard and whom major side is located on a main road cause all the noise coming from the road to rise due to its reflection from the courtyard facade wall. This model prevents to be protected from the noise and moreover the model cause the noise to increase and the echo problem to occur. The façade walls of the courtyard is considered quite negative in terms of acoustic comfort. Instead of this model, a building model whom backplane side is located on a main road will not cause the echo problem and it also provide to minimize the noise transmission within the building..

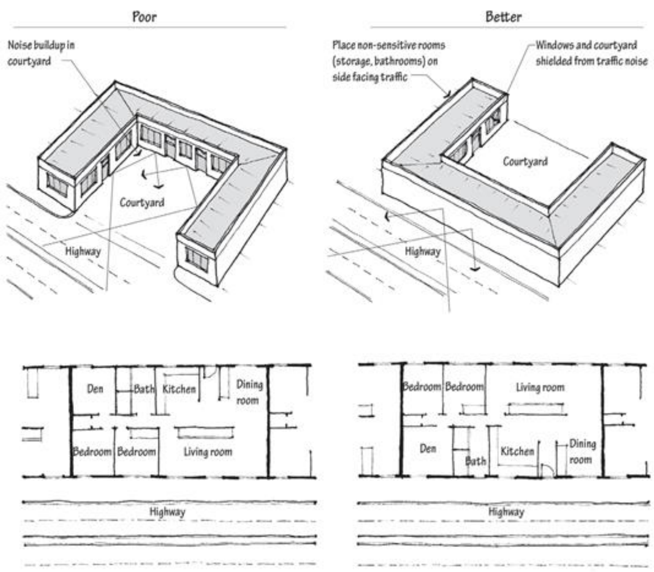

Figure 11. Building Orientation related acoustical problem and solution example. [19]

As well as controlling the outside noise sources of the building, each noises which are called as indoor noise sources such as neighborhood noises in the residential buildings, mechanical device and equipment noises, electrical system noises, circulation system noises, variable special noises related to the building usage should be examined seperately and investigated how they spread out [16]

The building shape and volume organization should be arranged in a way that protect the noise-sensitive volumes from noise sources. Therefore, firstly, noise sources of exterior and interior and routes of sound transmissionshould be determined.

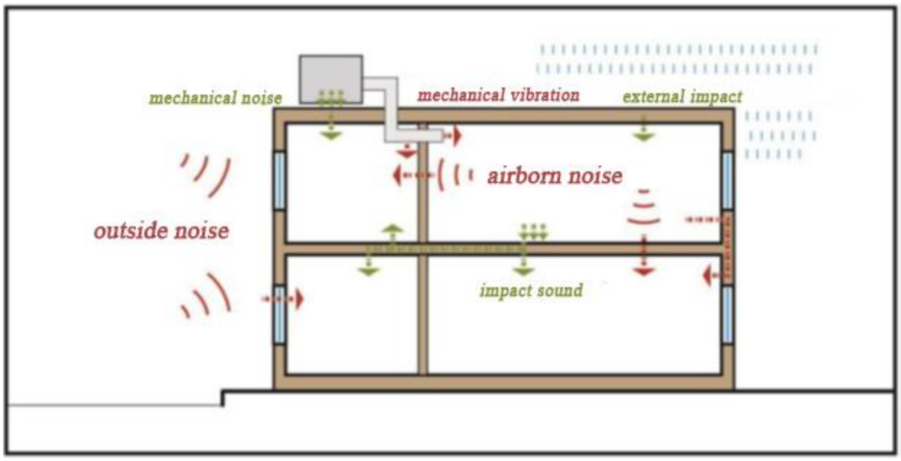

Figure 12. Noise Sources and Sound Differection. [20]

The human originated noises are the primary noises that affect humans negatively . Hence, prevention with the neighbourhood related noise sources such as high heel noises, loud talks, bathroom and kitchen noises seperative construction elements or buffer zones of have an high importance.

Besides, the noise and vibration in technical volumes should be controlled in order to keep the background noise acceptable. Technical volumes are assigned as noise sources in the buildings. The noise forms in these volmes in two ways: air born noises and solid born noises. During the architectural design, these volumes that are assigned as noise sources, should be kept away from the acoustically critical places. The noise based volume should be designed to be kept away from the noise sensitive units in order to control the air born noises and seperative walls of the volume should be determined regarding to characteristics of the noise. If it is not possible to prevent noisy areas such as elevator shaft to be neighbour with noise sensitive volumes, additional acoustic precautions are required. For instance, it is possible to establish buffer zones between these two areas as a precaution in this kind of situation.

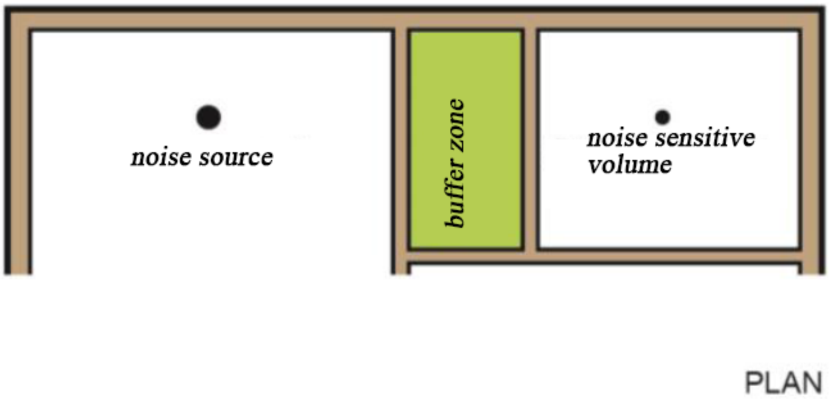

Figure 13. The usage of buffer volume between noisy and sensitive volumes. [20]

In order to identify the seperative elements based on characteristics, firstly spots in the buildings should be included in the main groups. If the relavant building is an office area, thses main groups can be collected under the noise source titles like offices, circulation areas, cafteria, public areas, parking areas, terrace, shaft, stairway and gallery shaft etc. There are required DnTw values between neighbouring spots that we determined with main titles. These values varies with the characteristics of the volumes. It can be explained for office areas with an example table as follows: :

Table 13. The required Dntw values between volumes [20]

Receiving Room Type	Source Room Type	Requirement
Offices	Office	Dntw >45db
	Cafeteria	dntw>50db
	Shaft	dntw>55db
Mechanical volume	Parking Area	Dntw>40db
	Shaft	Dntw>40db
	Stairway	Dntw>45db
Parking Area	Stairway	Dntw>40db
Terrace	Office	dntw>45db
Gallery Shaft	ofis	Dntw>45db
Cafeteria	Genel kullanım alanı	Dntw>45db
	ofis	Dntw>40db
Conference Hall	Offices	Dntw>50db

	Mechanical volume	Dntw>70db
	Public Room	Dntw>55db
	Gallery Shaft	Dntw>55db
Shaft	Office	Dntw>45db
	Public Room	Dntw>45db
Public Room	Office	Dntw>40db
	Conference Hall	Dntw>40db
Stairway	Office	Dntw>45db

Regarding to the table above, The selection of the bearing and the separative construction elements is provided by selecting the weighted sound reduction index (Rw) of the separating elements between the places.

The reduction coefficients of the separator structural elements that will be determined are designed to be +2 dB more from the limit values between the volumes that are determined in the table above. [20]

As well as separating walls, heating-ventilation systems can also create noise bridge. Therefore, while the heating-ventilation project is being carried out, it is necessary that flexible connectors should be used while ventilation duct is transported to the volumes and also sound bridges should be considered It should be performed application with the pipes whom culvert of air intake and suction is flexible in order to prevent transportation of sound formed in a volume to other volumes in the sequent single line ducts. These pipes should end in an obfuscatory way.

Direct contact of these elements to the building structure should be avoided during the wall transitions of the ventilation ducts and the pipes. The transmission of vibration will be reduced to minimum if the transitions is achieved using vibration-absorbing materials. Usage of firestop mortar and firestop brick is suitable for such transitions. Having high density and high flexibility properties of the fire-stop materials ensure that the the noise do not transmit acoustically.

3.2.1.3 Criterion of Room Acoustic and Solutions

Open planned offices are the volumes that includes many noise sources such as employees, machines sounds, stabile mechanical sounds and etc at the same time. Providing enviromental and indoor noise control of an area should not be inferred that acoustical requirements are completed. When the room scale of the construction is considered, each surface that the sound waves in the room encounter has an acoustic meaning. In open offices these surfaces are used to make people hear each other clearly and at the same time they are used to make people not hear each other. Hence, in open planned offices, obtaining the speech privacy and speech intelligibility at the same time is a thin line. In this part, the design factors that affect some parameters which are resonance time, intelligibleness, clearnes and sperech privacy have been investigated.

3.2.1.3.1 Backround Noise

One of the main points of open-plan offices is background noises. In an open-plan office volume where noise control of the building is provided, Factors that might cause background noise heating and ventilation systems, speech sounds, object friction, sound of mechanical instruments (computer, fax, photocopy, coffee maker etc.).

Ventilation and heating systems among these factors are the main sources of the background noise. Unlike the others, ventilation noises are a continuous and measurable noise source.

Sounds of mechanical ventilation and air conditioning system creates a constant but not exhausting preferred noise at a low decibel in the office area. This low level of noise helps employees in the office to hide their private conversations when it is necessary.

Acoustic scientists measure the background noises as “A- weighted” decibel. This odd-numbered measurement calculates the noise heard at the frequency that the human ear is sensitive. It is often used in environmental noise measurements, and it may not be sufficient for criterion a weighted metric indoor noise measurement. Hence, NC value which is measured in the room noise 1/3 octave band is used in the interiors [4].

Background noise in the open planned offices that should be considered is between NC30-NC40.. [4]

The background noise values measured in 1/3 octave band, which reveal the amount of noise in the environment for each Hz in terms of decibels are given in Table 14:

Table 14. Background Noise Curve Values [4]

Oktav bans	63 hz	125hz	250hz	500hz	1000hz	2000hz	4000hz	8000hz
NC 30	57	48	41	35	31	29	28	27
NC 35	60	52	45	40	36	34	33	32
NC40	64	56	50	45	41	39	38	37

In the buildings that have natural ventilation to provide sustainability NC value decrease because of no mechanical ventilation noises. The decrease in this value cause speech privacy problem in open planned offices because it reduces masking of background noises. This situation causes loss of concentration even in the lowest noise in the future.

While two or more sounds are sufficiently different in the environment, it is difficult to perceive the lower sound. This is called masking the silent sound by the loud sound. [21]

A masking system can be used in order to arrange the background noise level which is reduced due to various sustainable design requirements. The masking system is a method that give out a ventilation simulation sound to the offices with neutral background noise. the masking system is formed by loudspeakers located along the ceiling area of the open plan office. The spread of the system is achieved with the reverberation that occurs in the flooring sill by directing the loudspeakers upwards. Thus, a sound field which spreds to cover more areas below is generated. Having the equal coverage zones of the sound is crucial for the office employees to perceive where the sound comes from and not to prevent working. Briefly, The aim of masking systems create background noise in order to provide a high level of speech privacy, as well as imitate the acoustic environment created by conventional conditioning systems.

3.2.1.3.2 Facade and Walls

One of the most important factors affecting energy efficiency, which is the main target in the design of a sustainable building, is facade. The facede is a factor that can change the basic systems of the building, such as heating, cooling, ventilation and lighting. Glass facades are preferred in order to provide energy saving by taking maximum advantage from sun light for heating and lightning, as mentioned before. The glass facades are used for most of the main separating elements forming the volume so that the sun light taken from the facade is desired to be effective to the inside of the building.

Increasing usage of glass is among the factors that affect noise control and volume acoustics. Glass is a reflective material, and in order not to block the daylight, the absorbent material is not covered with acoustic materials, causing high tinnitus in the room. For this reason, glass construction elements create problems, that affect the working environment, such as long ringing times, echo, overlap, sound transmission in open office areas.

The first step for controlling the consisted negative criterion, is that the surfaces which are the reason for reverberation is coated with the acoustically high absorbent materials. However, covering high absorbent materials prevent energy efficiency which is the main design purpose of the glass surfaces. Therefore, the new generation of micro perforated translucent materials has taken the place of classical opaque absorbent elements as high-absorbency materials. These materials, which can hold 400 000 holes per square meter, work on the basis of air absorption.

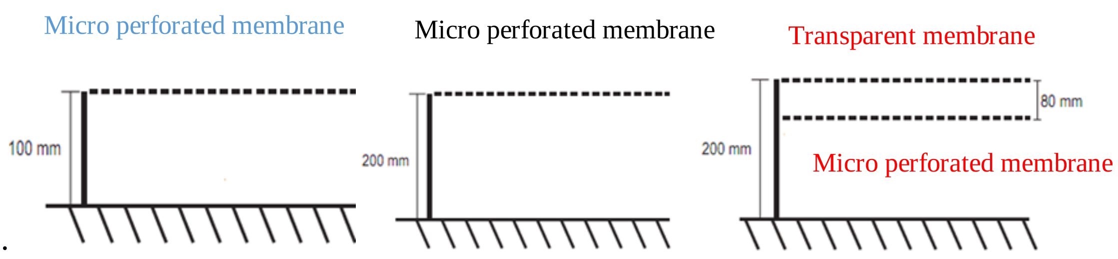

Figure 14. Micro Perforated Absorber Material Application Methods [22]

These materials applied by leaving a space between 10 and 20 cm in the back can be applied with steel tie systems seperately and also can be used as lightning equipment by putting a light behind with a standard transparent membrane.

Absorbency graphs obtained only with air and not applied any absorbent felts behind the micro perforated transparent materials are shown in Figure 12.

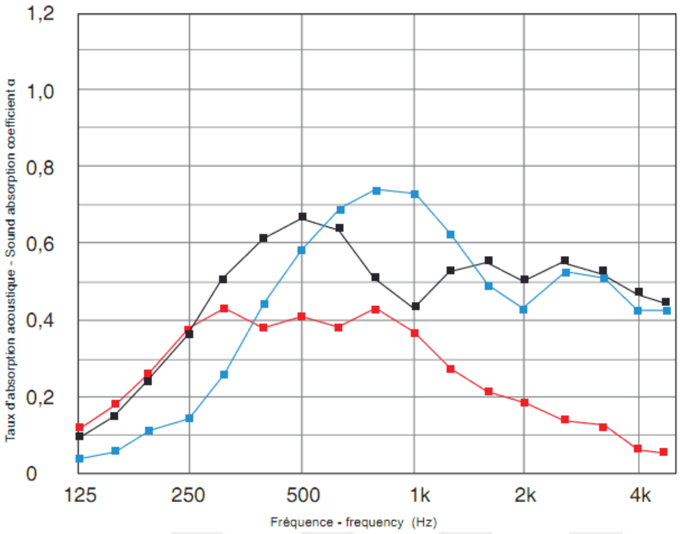

Figure 15. The aborbency values of the micro perofrated absorber materials [22]

Figure 16. Application of Micro Perforated Absorber Material [22]

Another surface coating material that is an alternative of an acoustic membrane is acoustic covers. The material, which is also designed to be transparent, can be applied with normal cover or stretch system. Thus, when the daylight and the heat are taken in, it forms the necessary absorbency values within the volume.

Figure 17. Transparent Cover Application

In addition, if it is not desired to coat the glass surface area with any material, rather than large flat glass surfaces, gnarled or faulted surfaces might be preferred. These surfaces will prevent the reberverations to transit big gaps because of reducing the focussing of sound on one point, even if these surfaces does not provide any absorbency in the volume. In this case, the necessity of the absorbent material in the volume should be supported by other elements.

3.2.1.3.3 Seperation elements

The seperative panels are main elements of the open office areas which are used in either to provide concentration by visually unlinking or to reduce the sound transmission by providing the sound wave refraction and absorption inside the office. The logic behind the inter office seperation elements is generally based on the sound barriers that are used for establishment of environmental noise control.

When a plane wave encounters a barrier, the lower portion of it is cut off leaving the rest to propagate over the wall. The high and low-pressure regions of the wave impinge on the quiescent fluid in the shadow zone and propagate into it. In this manner the wave diffracts or is bent into the space behind the barrier. The greater the diffraction angle the greater the attenuation. [7]

For this reason, the part of the barrier that refracts the waves is being made of absorber material has an high importance in order to provide neutraliation of the encountered waves inside the barriers. But, acoustic felt and wool content materials with high absorbency ability are unfavourable because they have an opaque quality and cut the lightning transmission off. With the worry of natural lightning and energy saving seperative panels that are made of transparent or translucent reflactive materials are only used for visual unlinking.

In this case, transparent micro perfore panels might be used in seperation elements. The other method is designing the absorber upper part of 120 cm ear lenght of the seperation elements from glass etc materials. This obtains the required sound absorbency between working areas and also does not prevent the sun light transmission. [23]

Another topic that should taken into account about seperative elements is the height of the barrier. As we mentioned above, the bigger diffraction angle of the sound barrier the lower sound transmission. This shows that direct proportion between height of the barrier and loss of sound transmission. Hence, the panels, which have the height until 120 cm that is accepted as head level insitting position of the employees, can not function. Because, refraction will start after the level of the sound source exit (after the head level). Yet, it won't give best results because of the minority of the refracting angle in the parts between 120 and 155 cm. If it is desired that to get the best acoustical performance from the seperative panels, attention should be paid for the height is over the 155 cm..

3.2.1.3.4 Floor and ceiling mateials

In open planned offices, ceiling areas creates a huge reverberation area in terms of having the biggest uninterrupted surface. Hence, good absorbency ratio of the ceiling area whereas providing the speech privacy by cutting up the whisperer surface effect in the volume, also reduces the reveberation time. Thus, both a comfortable working area is established and also speech intelligibility in dualogs between 1,5-2 meters range is provided. But by enabling the natural orientation, it is thought that ceiling system that is exposed to the heat and light from glasses will support both natural lightning and also passive heating and cooling. On the other hand, sustainability concept which does not support the usage of surplus material carries on in the direction of writing off the ceiling systems..

As a matter of course, this brand new design approach bring along the new acoustic materials. The primary of these materials is fire control sprays. Fire line generated with exposed ceiling system and fibrous cement applied over the steel elements or some of the cement plasters are produced as to provide acoustical absorption. The absorbency value of these kind of sprays are around 0.75-0.85.

Another frequently used material type is acoustical felt or roof panel system with fibreglass filling and wood wool panels. This material can be used as well as on the ceiling with hanger elements or closed system, and also can be used on the wall by installing on the structure system.

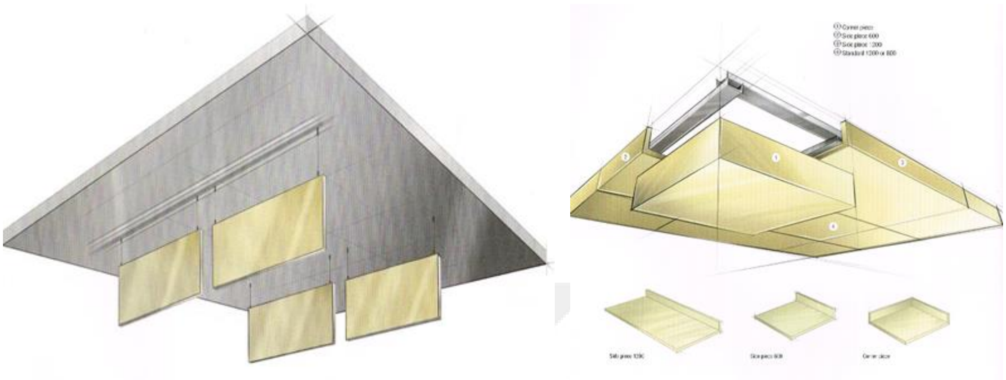

Figure 18. Wood Wool Applications Types

The concrete application is performed frequently also on the floor in order to apply radiant heating and cooling easily and provie low energy level. This case, as well as it is one of the factor that increases the reverberation surface in the volume, it also causes impact related noise transmission to the adjacent volumes. On the purpose of controlling the reverberation time, carpet treatment which is a positive method in open office areas, if it is not preferrable linoleum over the screed to prevent impact noise or under screed impact preventer materials – if only gross concrete is used- should be used.

3.2.2 Prerequisites ve Guideline For Acoustic Performans Criterion

3.2.2.1 Prerequisites

Because of the environmental sound control will differ based on the area where the building will be placed, it is mandatory to include a specific criterion value. First of all, prerequisites must be created to be able to evaluate this section. These prerequisites can be listed as follows:

1- When the premises are being selected as it is detailed in Section 3.2.1.1, the function of the building to be in a harmonic function with the existing building in the area must be taken into consideration. It is prerequisite to prepare a report regarding that this was taken into consideration.

2- If it is necessary and possible, noise barriers must be made between the space that the building will be located and the main noise source as it is detailed in Section 3.2.1.1. It is prerequisite to prepare a report regarding that this was taken into consideration.

3- In order to rate the level and category of the noise, the noise measurement of the environment must be made as it is detailed in section 3.2.1.1. It is prerequisite to prepare a report regarding that the environmental noise measurement has been made.

3.2.2.2 Guidelines

3.2.2.2.1 Building Noise Control Guidelines

<u>1-Determining the Noise Reduction Coefficients of the Façade Elements</u>

In order to be able to select the façade elements, first of all a noise simulation must be conducted. The noise analysis requirements that are indicated in section *3.2.1.1 Environmental Noise Control* must be taken into consideration while conducting a noise simulation.

The highest sound pressure level that will come to the building façade must be calculated sticking to the emission measurement that was conducted and to the simulation results, and façade elements that are suitable for this must be created.
You must be careful to select the sound permeability values (RW) of the façade elements that will be created to be 2 dB more than the maximum noise level that comes to the building façade.

2-Determining the Target Values (D_NT_W) Between Spaces

The sound level differences that we define as D_NT_W between adjacent neighborhoods which are explained in detail in Section 3.2.1.2 table 5 must be determined. Therefore, in regard to provide noise control in the best and cost-effective way, it is important to primarily determine the space types in the building in accordance with the noise criteria and provide space orientation of the coherent space types to be side by side.

3-Creating the Wall and Floor Details That Will Meet the Target Values

Subsequent to determining the sound level differences between the volumes, separator structure elements that will prevent penetration of this sound level difference must be created. As it is indicated in Section 3.2.1.2, the sound reduction coefficients of the separator structure elements that will be determined must be designed as it will be +2 dB more than the limit values between the volumes that are determined in the table above.

4-Providing Vibration Control in Mechanical Volumes and Elements

When the problem in question is solid-borne noise transmission, the noise reduction value of the separator element that is created for air-borne noise prevention will not be sufficient. Therefore, as it is explained in section 3.2.1.2, in mechanical volumes, the impact noise of the mechanism must be known and the connection between the solid and the device that will create the impact must be cut and the vibration transmission must be prevented

3.2.2.2.2 Room Acoustic Guidelines

The evaluation rules for the volume acoustic that is required for an open office space reveal the main idea of the research and the short-coming areas in the evaluation criteria in the sustainability certificates. According to this, the guideline points that are suggested to be present for the volume acoustic are as follows:

1-Setting the Background Noise Values

The background noise level of a volume must be determined as it is explained in detail in section 2.3.7. The noise level that is required to be continuously present within a volume according to the purpose of the volume is explained in figure 8 in accordance with the literature. If the background noise level within the open office volume will be more than the literature criteria, the sound entries must be prevented, and mechanic noise must be reduced by stopping them as it is explained in 3.2.1.2, if it will be less, it will be increased with sound masking systems as it is explained in section 3.2.1.3.1 Background Noise in the required level.

2-Determinig the Design Criteria of the Early Decrease Time

As it is explained in section 2.3.2 the early decrease time which is a reverberation time parameter, early reflections give more subjective results for human ears. First reflections are important for the open office volumes where the resonance time is especially required to be low. Therefore, EDT must be determined based on the RT – volume- function graphic in figure 3 and EDT=RT60 ±0,3 dB correlation that indicates the maximum resonance time difference that is required to be in between the EDT and RT must be taken into consideration.

3-Determining the T20 Design Criteria

The T20 design criteria that are considered as secondary reflections must also be determined based on the EDT and RT as it is explained in section 2.3.2 and must be taken into consideration when reviewing the result of the design.

4-Determining the T30 Design Criteria

The T30 design criteria that are considered as secondary reflections must also be determined based on the EDT and RT as it is explained in section 2.3.2 and it must be reviewed whether an accurate graphic is created with EDT and T20 or not when reviewing the result of the design.

5-Determining the RT60 Design Criteria

The RT criteria that are defined as delayed reflection must be determined as it is explained in section 2.3.1. Determining the RT criteria is important in terms of determine criteria for first reflections and creating a straight inclined graphic between these.

6-Reviewing the Speech Clarity

The D50 definition must be reviewed as it is explained in detailed in section 2.3.3 volume acoustic criteria and in accordance the way the design criteria are determined.

7-Reviewing the Speech Transmission Index

STI parameter which is important for open office spaces in terms of transmission of conversation to one another must be evaluated as it is explained in detail in section 2.3.4 and as it is indicated in table 1.

8- Determining the Sound Distortion Rate

Suitability of the volume that is being used must be evaluated as the ISO criteria is determined as it is explained in detail in section 2.3.6 for the DL2 parameter that determines the distortion rate of the sound per distance.

9- Providing the Personal Speech Privacy

The U parameter that is also quite related to the DL2 parameter and defines providing the speech privacy must be evaluated as it is explained in detail in section 2.3.5.

10-Concreating the Above Volume Acoustic Criteria and the In-Volume Material Selections

The effective point in providing all these volume acoustic parameters that are indicated above are the surfaces that provide dispersion or absorption of the sound within the volume. As it is explained in detail in 3.2.1.3 Room Acoustics Criteria and Solutions Section, the absorption or dispersion values of the surfaces within the volume must be adjusted and the simultaneous results of these with the abovementioned acoustic parameters must be reviewed on the acoustic simulation program. As a result of this, the material combinations that will provide the indicated values of all the acoustic objective parameters that are anticipated to be required for the open office spaces above must be created by using Odeon.

3.2.2.3 Guidelines Checklist

Table 15. Acoustic requirements for working spaces - Design criteria

Acoustic requirements for working spaces		Design criteria
Building noise control requirements	Determining the sound reduction coefficients of the façade elements	Environmental noise analysis and prerequisite report regarding determining the noise amount that come to the façade.
	Target values between spaces	After determining the space types, orientation and noise criteria of the space types, based on the acoustic design application and inspection manual [20]
	Creating the wall and floor details that will meet the target values	The D_NT_W value that is determines in accordance with the acoustic design application and inspection of buildings manual is +2dB
	Providing vibration control in the mechanical volume and elements	
Volume acoustic requirements	Adjusting the background noise values	NC 30-40 range
	Determining the early decrease time design criteria	To be between 0.1 to 1.1 range based on the size of the speech functional volume
	Determining the T20 design criteria	To be between 0.1 to 1.1 range based on the size of the speech functional volume
	Determining the T30 design criteria	To be between 0.1 to 1.1 range based on the size of the speech functional volume
	Determining the RT60 design criteria	To be between 0.1 to 1.1 range based on the size of the speech functional volume
	Speech clarity	≥0.00s
	Speech transmission	≥0.60s

	Providing the speech privacy in the open office space	≥ -6 dB
	Determining the sound distortion rate	≥ 3.5 dB
	Determining the absorbtion value of the material	Based on the acoustic design criteria and Odeon software acoustic simulation program

CHAPTER FOUR
THE CASE OF STUDY: ACOUSTIC DESIGN OF OPEN PLANNED OFFICES OF KONAK MUNICIPALITY SERVICE BUILDING

In this section, open-plan offices of the new Service Building to be built under Konak Municipality, which is aimed at being sustainable, will be studied from an acoustic perspective. The main purpose of choice; the building is being an office building that is design with the concern for sustainability. The building on which we easily see the acoustic problems that the finish surfaces that are selected to make it sustainable is can be intervened with due to being in the project phase. Therefore, the building, of which we will review the solution offers to acoustic problems will utilize the review while it is being put into effect.

To do this, firstly, environmental noise maps will be generated via the Sound Plan software by measuring the building area in Izmir, Yesildere. Hence, the noise level of Yesillik Street, which is located next to the building, and how much the building would be affected from it will be established.

Secondly, via the Insul software, which generates air-born sound reduction index of construction materials; technicalities of seperator elements will be determined in order to prevent the building being affected by the identified noise levels. Additionally, via the SONarchitect software, interactions of various rooms inside the building, especially the open-office areas, will be studied; then, with a view to reduce this interaction to a minimum, orientation of workspaces inside the building and sound absorption levels of seperator elements will be examined. Material suggestions will be given to prevent noise-bridges from air-conditioning systems.

Finally, sustainably designed dividing and seperating elements of an open-office space, of which, sound interaction with surrounding volumes and environmental noise permeability is reduced to a minimum, will be modelled. The modelled room will be transferred to the acoustic simulation software, Odeon; where parametres such as background noise levels, reverberation times, clarity of speech and speech privacy will be evaluated..

4.1 Service Building Environmental Noise Control Analysis

4.1.1 Location of Project and Noise Measurement

The new service building of Konak Municipality to be built is located in Yesildere region of Karabaglar district in Izmir. Yesildere region, by location, has a heavy traffic flow, being positioned on one of the main junction points of Izmir. Therefore, noise measurements of this heavy traffic area are carried out initially.

Figure 19. Project Location and Measurement Area Sattelite View

On the 3rd March 2017, at 07:00 – 19:00, 19:00 – 23:00 and 23:00 – 07:00 respectively, A-weighted equivalent noise level – Leq' measurements have been carried out in a single spot around the project site, at three different time periods, for five minutes. Measurement location is given below.

Figure 20 Image from Measured Position

Equipments used during measurement:

- NTI Audio XL_2 Hand Analyzer (IEC 61672-1 Electroacoustics) (SNo.A2A-05241—E0,FW3.03)
- NTI Audio MA220 Type 1 Measurement Microphone (User calibrated 2016-08-23 07:00)
- Norsonic type 1251 Sound Calibrator
- Mic Sensitivty: 22.9mV/Pa
- Range : 30 – 130dB .

On the day of the measurement, the existing weather conditions were recorded as rainy and between 7 to 15 degrees celsius. Humidity ratio was %76, wind were at 3km/hr. A graph has been provided below with more detailed information on the weather conditions.

Figure 21 Weather Conditions in Measuremets Day

Noise measurements have been carried out on a single spot along the main road edge, which is the project boundary, at three different time periods, for five minutes to determine the road emission capacity correctly. Measurement results are as follows:

L_{day} results of the measurement:

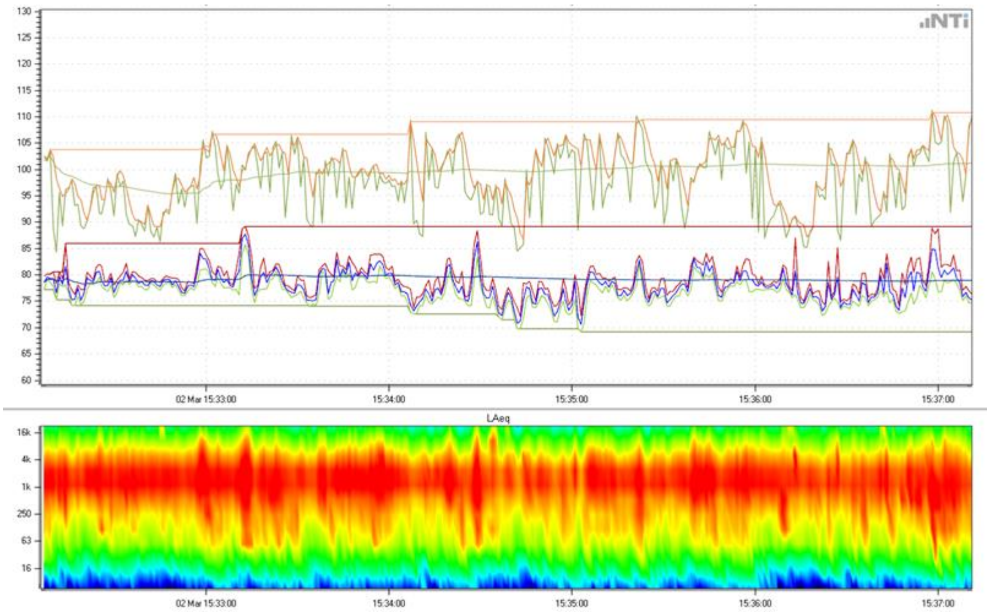

Figure 22 L_{day} Garphic of Measurement Results

Type	Start Date and Time	Duration	LAeq [dB]	LAFmax [dB]	LAFmin [dB]	LCPKmax [dB]	LZSmax [dB]	LZeq [dB]
Recorded		**00:05:05**	**78,9**	**89,2**	**69,2**	**120,4**	**110,8**	**101,3**
Project Result		00:05:05	78,9	89,2	69,2	120,4	110,8	101,3

Figure 23 L_{day} results of the measurement

L_{day} measurement result was measured as 78.9 dB (A). Once the results have been assessed, the highest noise level have been observed to be 89.2dB(A.

$L_{evening}$ results of the measurement:

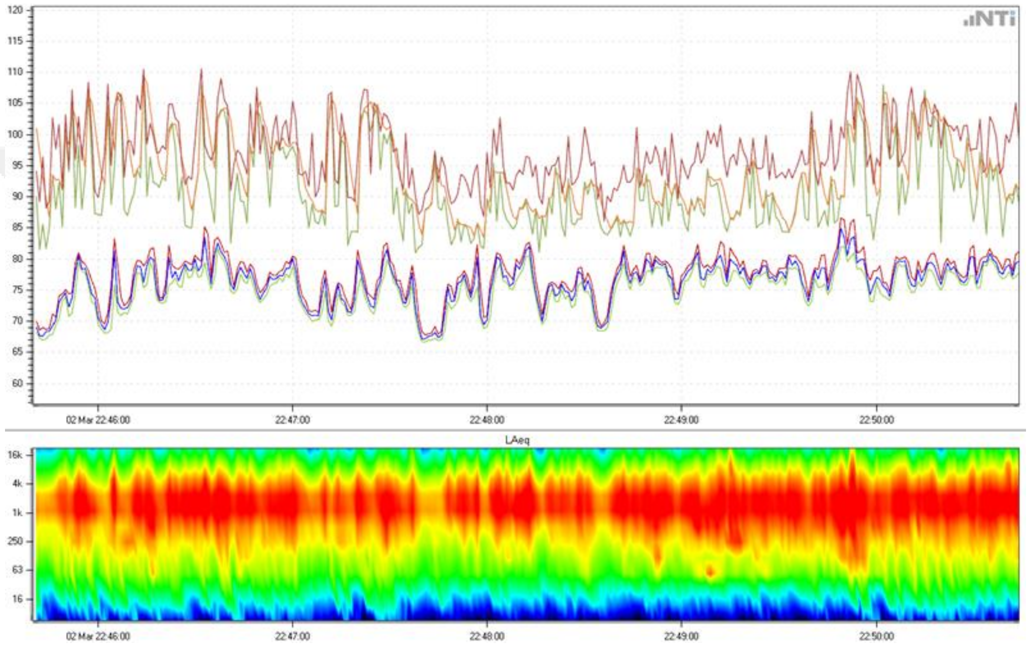

Figure 24 $L_{evening}$ Garphic of Measurement Results

Type	Start Date and Time	Duration	LAeq [dB]	LAFmax [dB]	LAFmin [dB]	LCPKmax [dB]	LZSmax [dB]	LZeq [dB]
Recorded		**00:05:04**	**77,5**	**86,6**	**66,7**	**110,6**	**109,4**	**96,8**
Project Result		00:05:04	77,5	86,6	66,7	110,6	109,4	96,8

Figure 25 $L_{evening}$ Results Of The Measurement

$L_{evening}$ measurement result was measured as 77.5 dB. Once the results have been assessed, the highest noise level have been observed to be 86.6 dB(A).

L_{night} results of the measurement:

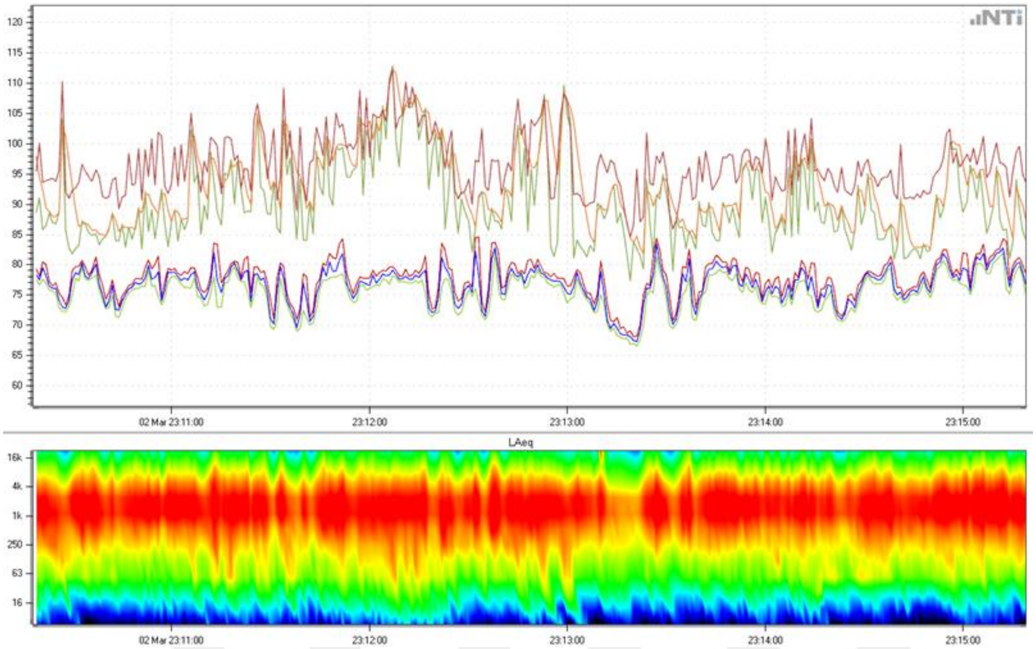

Figure 26 L_{night} Garphic of Measurement Results

Type	Start Date and Time	Duration	LAeq [dB]	LAFmax [dB]	LAFmin [dB]	LCPKmax [dB]	LZSmax [dB]	LZeq [dB]
Recorded		**00:05:01**	**77,6**	**84,6**	**66,6**	**112,2**	**112,4**	**97,1**
Project Result		00:05:01	77,6	84,6	66,6	112,2	112,4	97,1

Figure 27 L_{night} results of the measurement

L_{night} measurement result was measured as 77.6 dB. Once the results have been assessed, the highest noise level have been observed to be 84.6dB(A)..

4.1.2 Noise Simulation

For the noise simulation, firstly, three dimensional modelling of the building and its surroundings has been performed in the noise analysis simulation software. When modelling, ground height curves and topography have been transferred from the Google Maps programme. The satellite view was taken of the field at a height of approximately 810m and transferred to the programme. (This modelling has ±30cm tolerance.)

Figure 28 Satellite Image of Noise Analysis Zone

4.1.2.1 Modelling the Field and Its Surrounding Structures

Modeled in the SoundPlan noise analysis software, the three-dimensional model's view on the terrain and the plan view are as follows. Components such as buildings, land heights, highways and bridges have been modelled roughly for it being an industrial package software. When carrying out noise mapping on large areas, the positions and heights of the buildings are entered the software approximately. Zoning plan is taken from the municipality for the field where noise mapping is to be carried out. According to the plan, the heights and positions of the buildings are obtained correctly. The relationship between the building's surroundings and the constructions is as shown in figure 28.

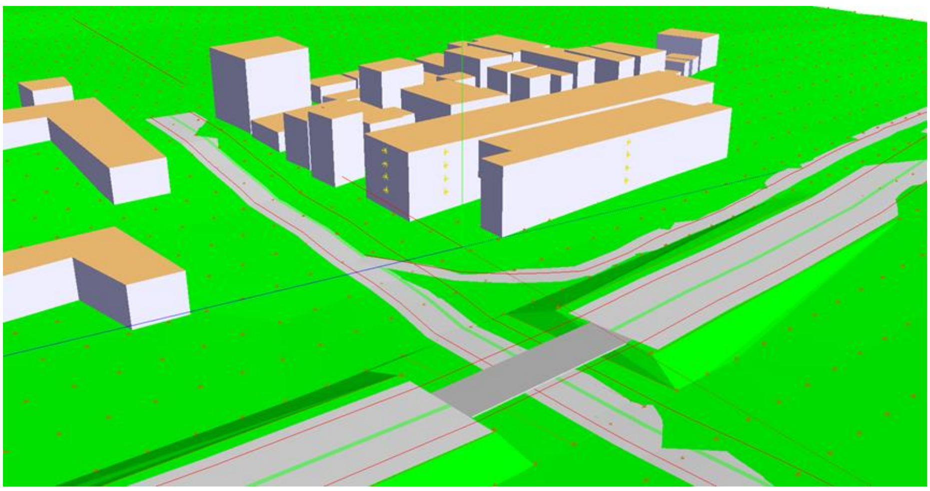

Figure 29 Simulation Model Of Noise Analysis

Figure 30 Noise Analysis Simulation Model Plan View

4.1.2.2 Facade Receiver Layouts and Features

Identification of needed sound receivers in noise alalysis software is important for interpretation of the results. The building surfaces that are faceing the highways will be the reference for interpretion of result. The receivers were placed on the three facedes that shown in figure 29. On the other hand shown in Figure 30, each receiver on facede represent a floor.

Types and positioning of the receivers are as follows:

1th receiver point is 150 m high (A-1, B-1, C-1)

2th receiver point is 450m high ((A-2, B-2, C-2)

3th receiver point is 750 m high ((A-3, B-3, C-3)

4th receiver point is 1050 m high ((A-3, B-3, C-3)

Facade Noise Receivers: For the measurement of sound pressure levels on the surfaces of the facades, receivers are assigned at each floor according to the Environmental Hazard Assessment and Management Regulation. These receivers are assigned to be at a distance of 3m from the facade of the building. The reason for this is to prevent the frontal reflections from being recalculated at the receiver points.

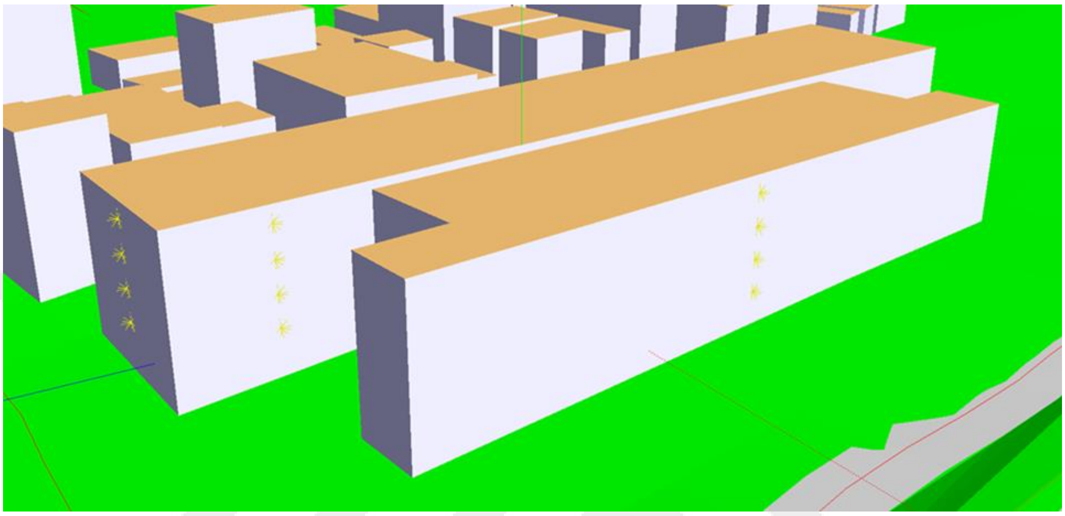

Figure 31 Figure of noise receivers in front of building

As well as the receiver points shown below on the plan, noise reflections from the surrounding buildings have also been studied. To check the noise from the highway, together with its reflections from the surrounding buildings, noise mapping has been done along the area indicated red on the image below.

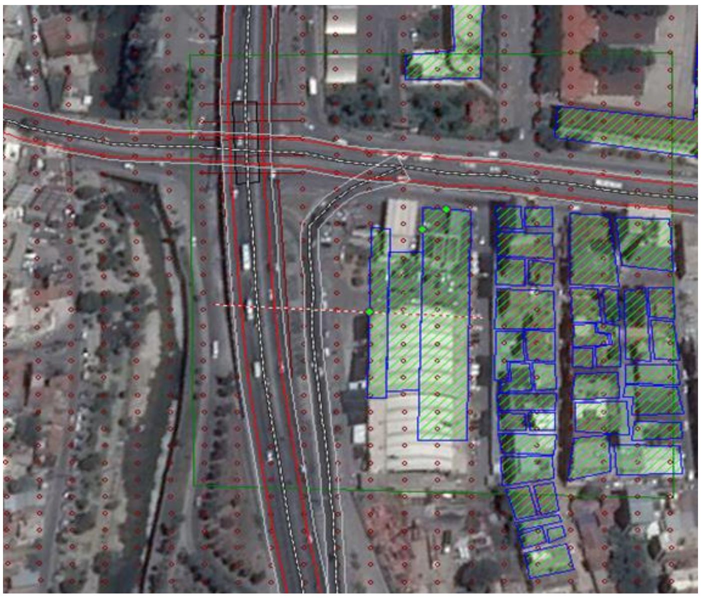

Figure 32 Demonstration of Grid Noise Map Limits on a Plan

Figure 33 Facade Noise Receiver Points

The sound pressure levels corresponding to each floor obtained from the simulation are given in Table 15. The noise maps obtained are given in Appendix 1.

Table 16. Sound Pressure Levels on Each Floor

		dB(A)			
		Ld	**Le**	**Ln**	**Lden**
A CEPHESİ	**Zemin**	*63.3*	*61.9*	*62.1*	*68.6*
	1. Kat	*63.0*	*61.6*	*61.8*	*68.3*
	2. Kat	*62.5*	*61.2*	*61.3*	*67.8*
	3. Kat	*62.1*	*60.7*	*60.8*	*67.4*
B CEPHESİ	**Zemin**	*58.8*	*57.5*	*57.7*	*64.2*
	1. Kat	*59.5*	*58.2*	*58.4*	*64.9*
	2. Kat	*59.9*	*58.5*	*58.7*	*65.2*
	3. Kat	*59.7*	*58.4*	*58.5*	*65.0*
C CEPHESİ	**Zemin**	*59.8*	*58.7*	*59.0*	*65.4*
	1. Kat	*60.3*	*59.0*	*59.2*	*65.7*
	2. Kat	*60.3*	*59.0*	*59.2*	*65.7*
	3. Kat	*60.3*	*59.0*	*59.1*	*65.6*

4.1.3 Results of Simulation

In conseration of the simulation results and the emission measurements made along the highway, the highest sound pressure level on the building has been taken as 63.3dB(A). In order to determine the acceptable noise level inside a room, the dimension of the glass on the facade (5m2) has been entered, and the minimum preferred Rw value (Weighted Sound Reduction Index) on the glass has been reached. The preferred noise level with the glass panels closed, is given to be 35dB by the Standards (see Table 2). The noise level inside the room would be 25 dB when the glass Rw value is minimum 41dB.

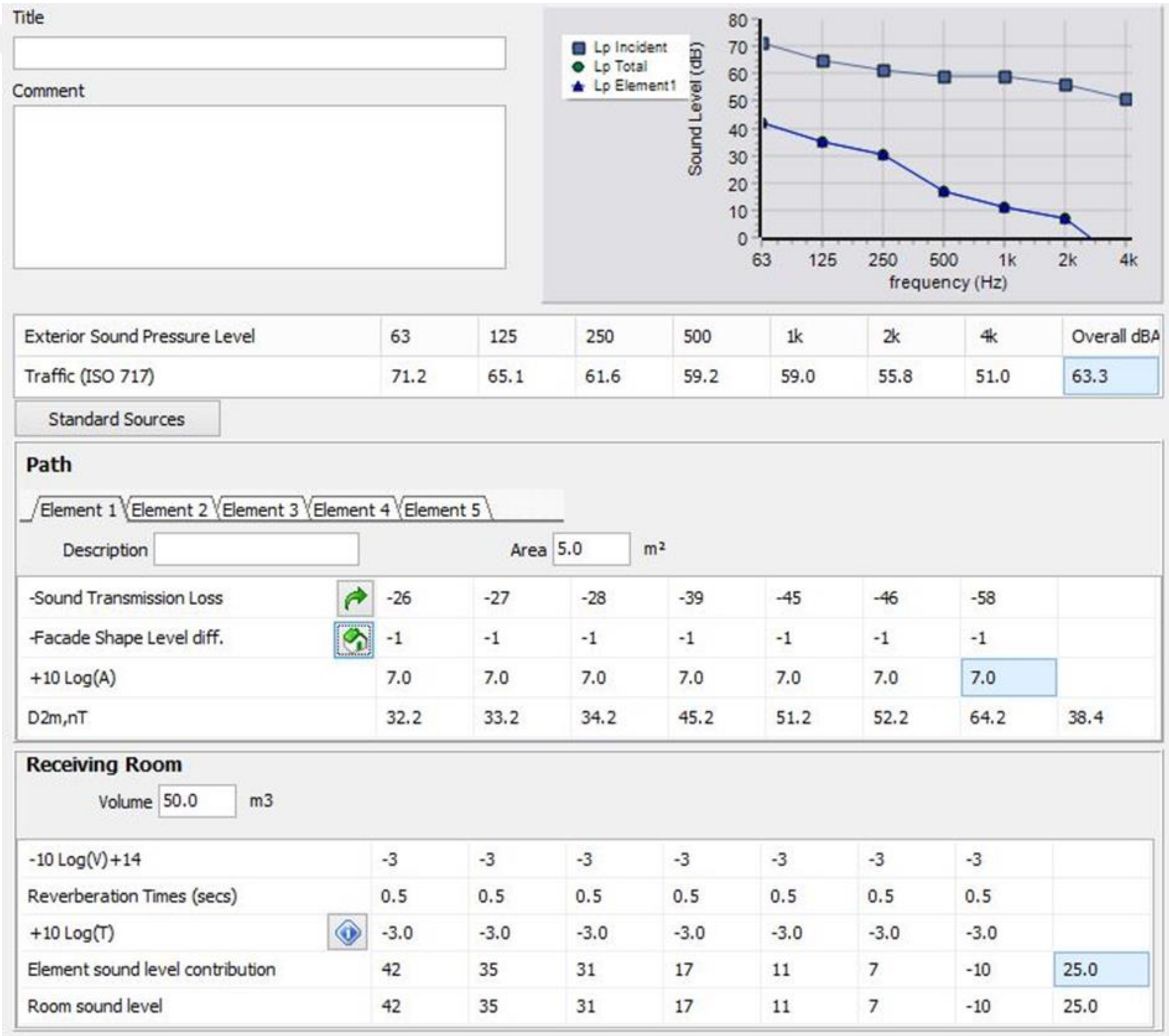

Figure 34 Required R_W value for facede

4.2 Building Noise Control

In the previous section, a peripheral noise map for the highway has been generated, outside noise levels have been found and the sound insulation value of the building has been determined. The facade detail with this insulation value has been created via Insul and given below.

Noise forming inside a building among its rooms must also be controlled, as well as the noise from without the building. It has already been stated that when carrying out building noise analysis, space types inside a building and their respective requiremets should firstly be determined. While determining these requirements during the acoustical assessment of Konak Municipality Service Building, sound interactions among the rooms have been defined as Weighted Standardised Level Difference – DnTw, therefore; the specific requirements of each type of room have been decided. Descriptions used to identify the different types of spaces are shown below:

4.2.1 Space Types

Assembly meeting room: Meeting area for special purpose

Dining Hall / Cuisine: All food and service areas

Gallery Space: For examining the vertical axis voice

Auction and Council room : Special purpose collection area

Offices : All open and closed offices

Technical Room: All fields including mechanical receptacles and equipment (for examining sound passages of mechanical units)

General service area: washbasins, toilets

Special Service Area : Archives, terraces, tea stoves

Shaft: Shaft blanks (for examination of vertical axis voice transitions)

Elavator: elevator gaps (for examining the vertical axis voice transitions)

Corridors: All circulation areas

Stairs: Stairways

Parking : All car parks

Storage Areas: Shelters and depots

Positions of the plan types categorised for requirements on the project, and their relations with each other, are given below via SONarchitect, the building noise analysis software. While the adjacency relations of the volumes were being reviewed, attention was paid for the mechanic volumes not to be adjacent to the volumes that will be required to be sensitive in terms of noise as it is indicated before and if so the wall type to be determined and baffle gaps to be created in between.

Figure 35 2. Basement floor space types.

Figure 36 1. Basement floor space types.

Figure 37 Ground floor space types.

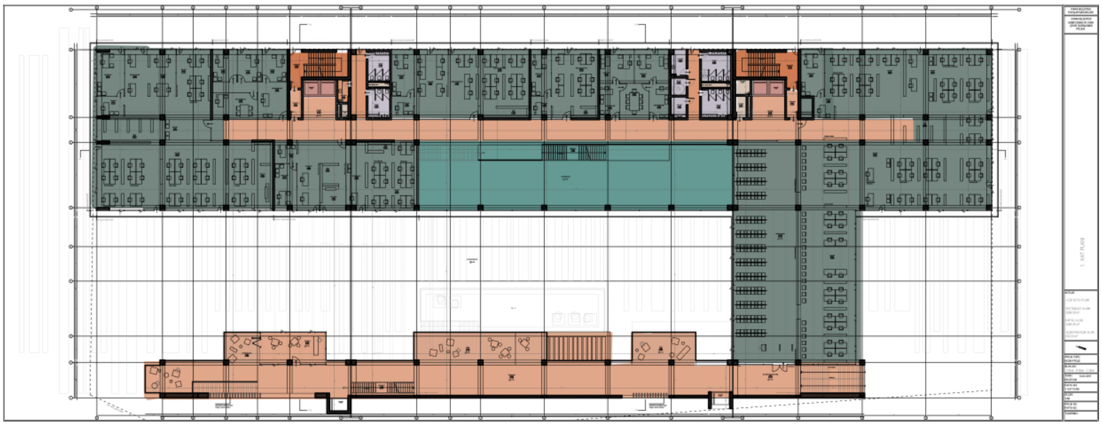

Figure 38 First floor space types.

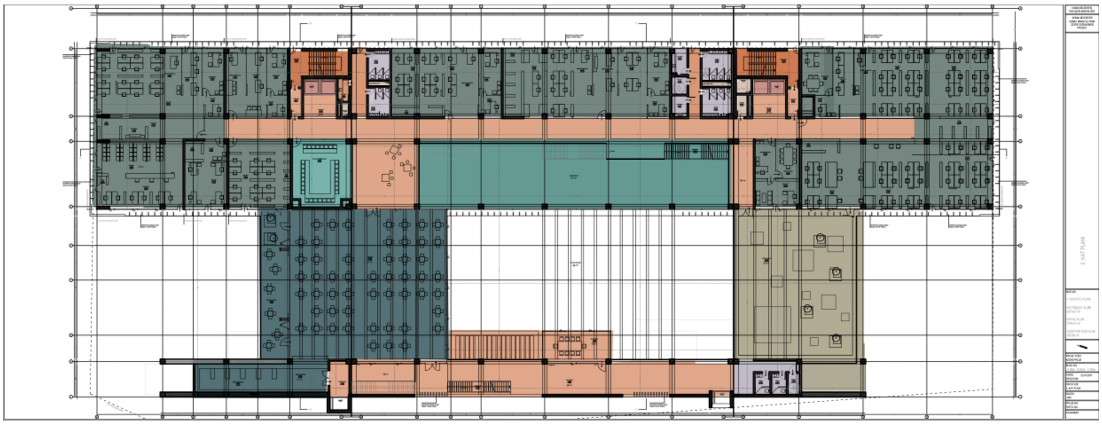

Figure 39 Second floor space types.

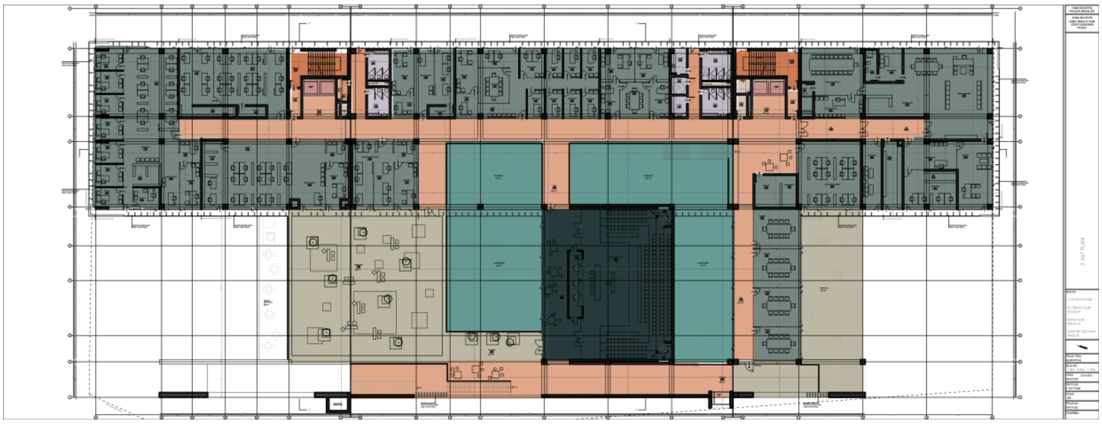

Figure 40 Third floor space types.

4.2.2 Weighted Standardised Level Difference

In the previous section; The air-born sound reduction index values between the rooms created, and the definitions used, are determined in accordance with the ISO standards. Below are given the neighboring rooms and their standardised level differences required for their room types.

Table 17. Weighted Standardised Level Difference of Rooms

Adjacent Areas		DnTw Değeri (dB)
Assembly meeting room	Special Service Area	40
	Gallery space	40
	Corridors	40
Auction and Council room :	Offices	35
	Dining Hall	50
	Corridors	40
Offices	Offices	35
	Shaft	40
	Technical volume	50
	Stairs	45
	Dining Hall	50
	Corridors	35
	General service area	40
	Special Service Area	40
	Gallery space	35
Dining Hall	Corridors	35
	Gallery space	35
Technical volume	Shaft	50
	General service area	50
	Parking	50
	Corridors	50
General service area	Shaft	50
	Stairs	40
	Corridors	40
Special Service Area	Corridors	40
	Stairs	40
	Shaft	40
	Gallery space	40
	Parking	40
	Storage Areas	35
Shaft	Stairs	40
	Elavator	40
	Shaft	40
	Corridors	40
Elavator	Corridors	50
	Stairs	50
Corridors	Parking	35
	Stairs	50
Stairs	Parking	45
	Storage Areas	35
Parking	Storage Areas	40
Storage Areas	Elavator	40
	Corridors	35
	Shaft	35
	General service area	30

4.2.3 Types of Wall

The sound reduction index of inter-location constructional components are identified according to the inter-location sound level difference indicated above. While identifying the sound reduction index of the construction elements, it has been demanded that it is +3 dB higher than the necessary DnTw values between room types. The technical details of wall typess used are shown in order below.

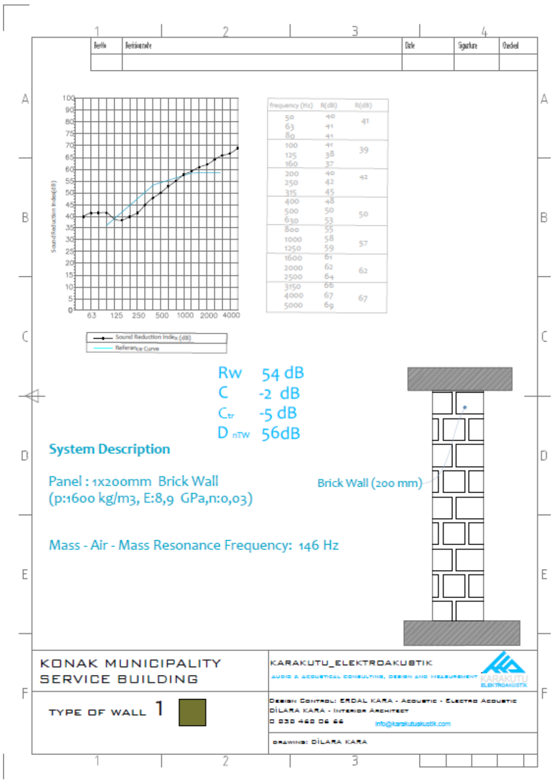

Figure 41 20 cm Brick Wall Detay and Criterion

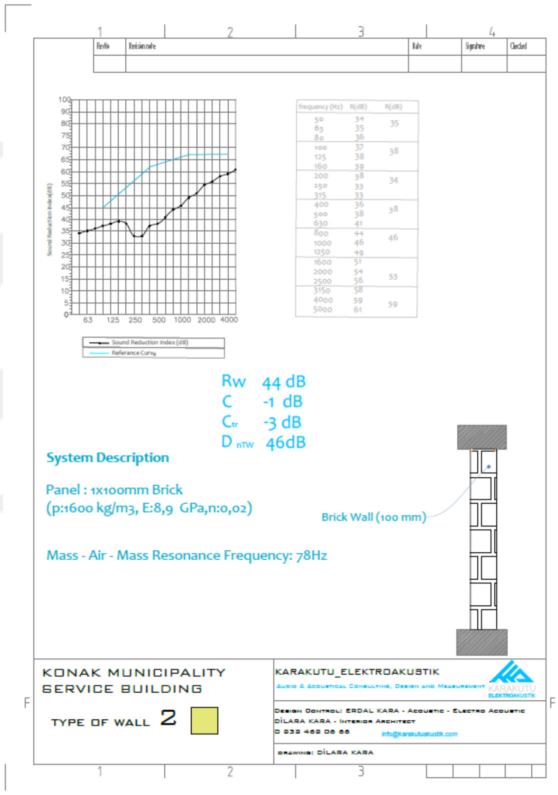

Figure 42 10 cm Brick Wall Detay and Criterion

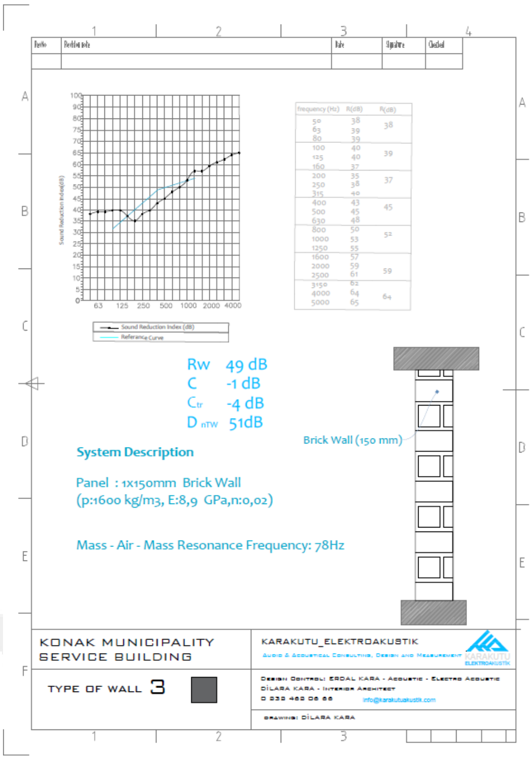

Figure 43 15 cm Brick Wall Detay Criterion

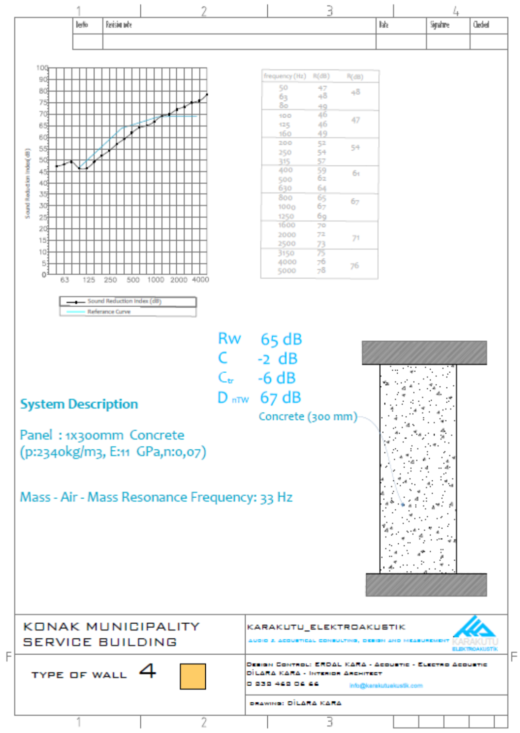

Figure 44 30 cm Concrete Wall Detay Criterion

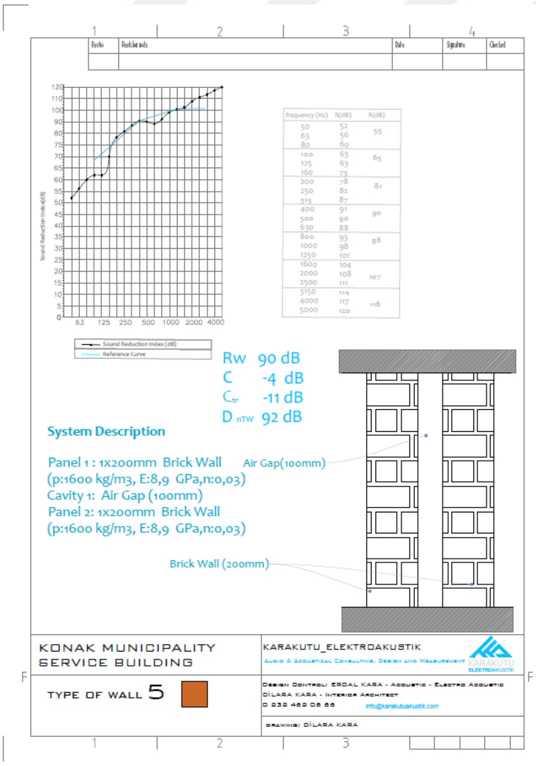

Figure 45 20+10+20 System Detay Criterion

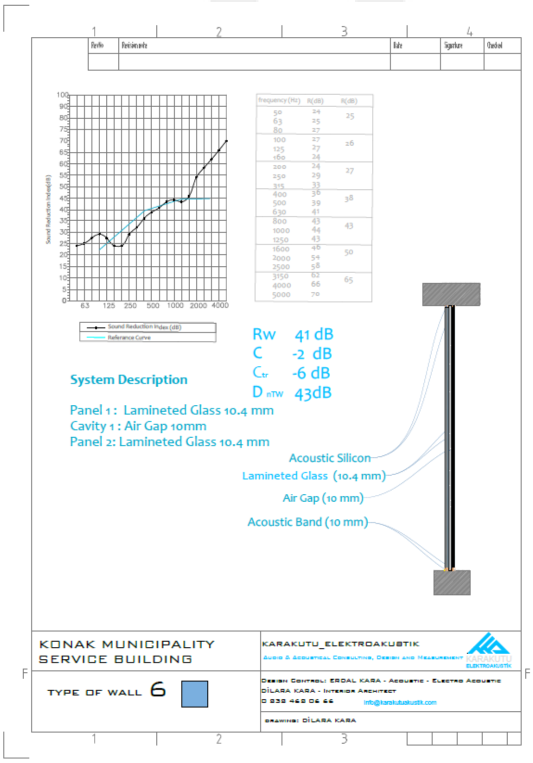

Figure 46 34mm Glass Wall Detay Criterion

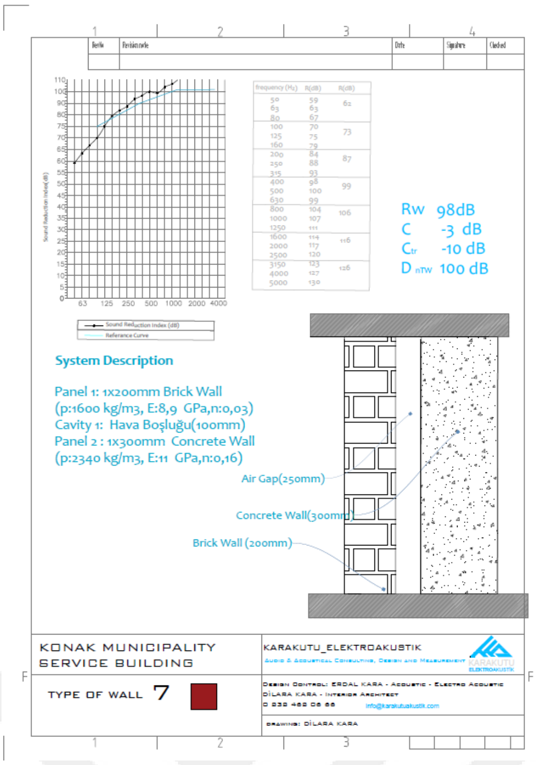

Figure 47 20+10+30 SystemWall Detay and Criterions

4.2.4 Locations of the Types of Walls on the Project

The types of walls with the necessary sound reduction values are located on the project as shown by the images below, together with the legend concerning the colours of the types of walls.

10 mm firebrick

150 mm firebrick

200 mm firebrick

300mm reinforced concrete wall

38mm duplex laminated glass

200 mm brick + 100mm space + 200mm firebrick

300mm reinforced concrete wall+ 100mm space+ 200mm firebrick

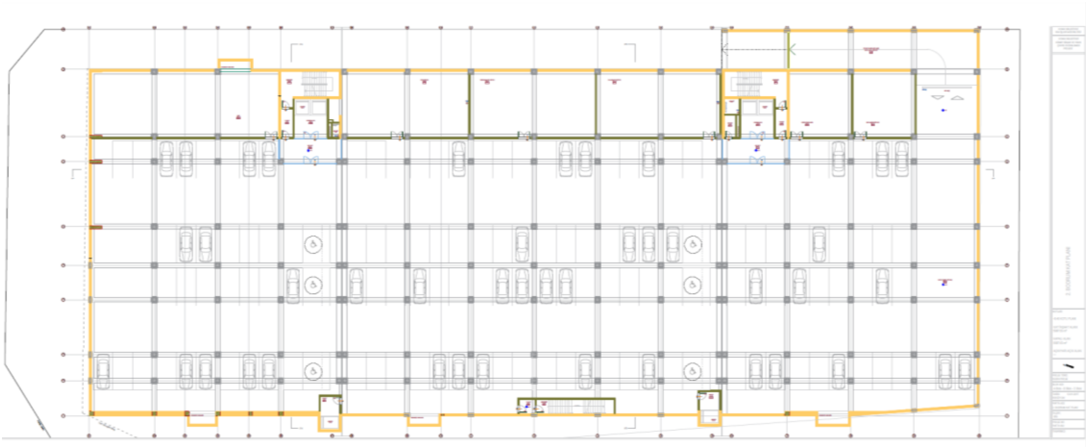

Figure 48 2.Basement Wall Plan

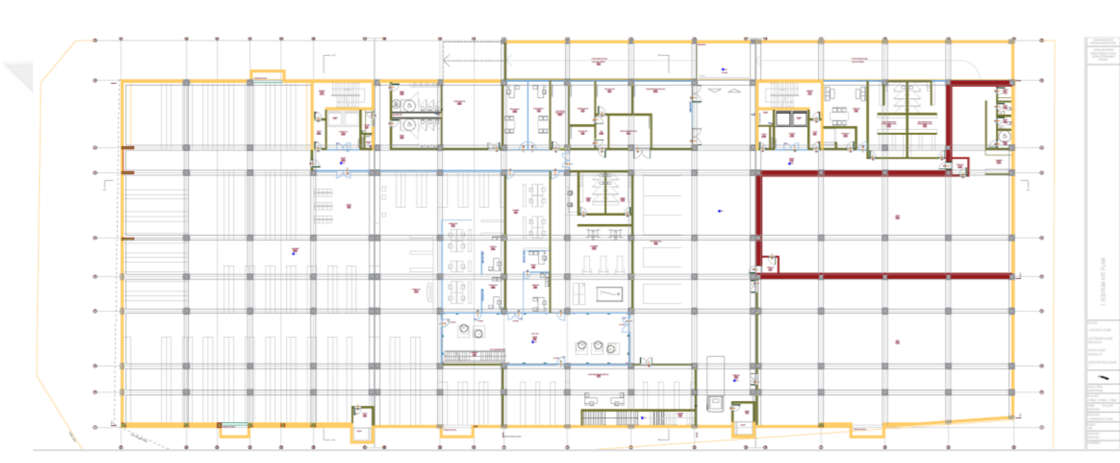

Figure 49 1. Basement Wall Plan

Figure 50 Ground Floor Wall Plan

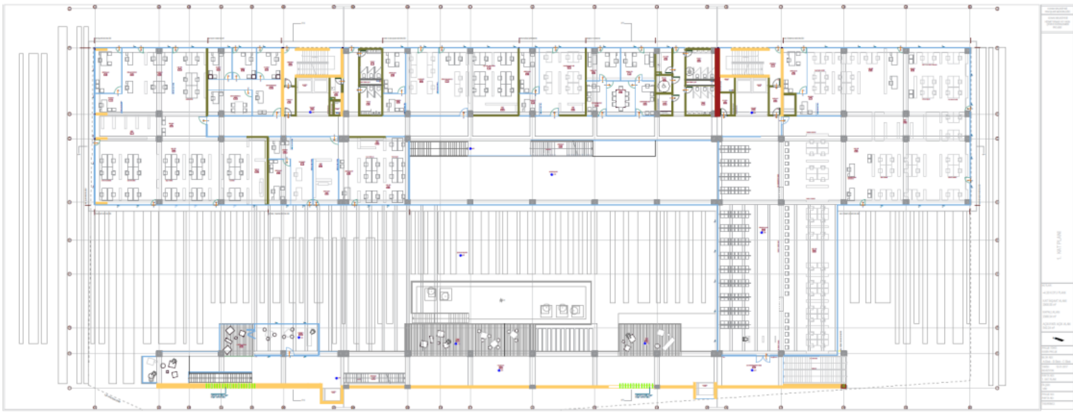

Figure 51 1. Floor Wall Plan

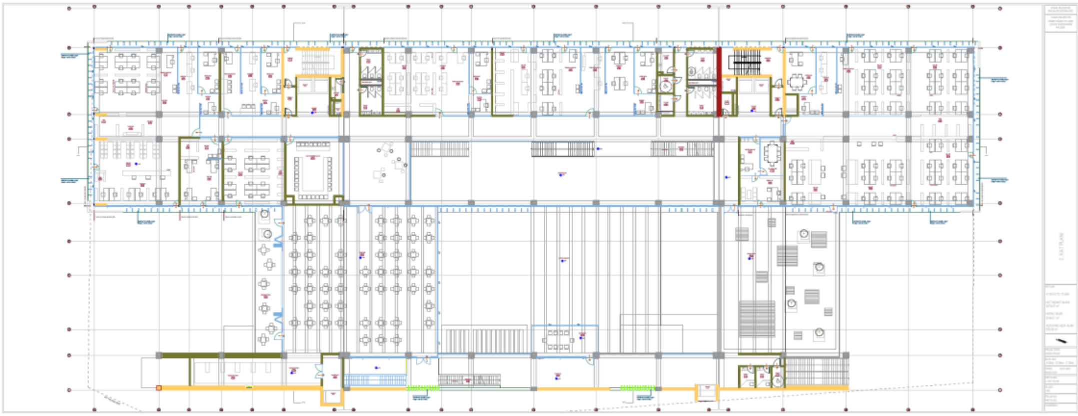

Figure 52 2. Floor Wall Plan

Figure 53 3. Floor Wall Plan

4.2.5 Building Acoustics Similation Results

After the necessary wall, flooring, tiling, door and window details are transferred to the acoustic simulation model, results are obtained via the SONarchitect building noise simulation programme. The programme analyzes each room with its surrounding rooms, seperation elements and junction points, and decides whether the absorption values are sufficient. Below are given location assessment target values and results table of some sample acoustically significant types of spaces.

Table 18. Weighted Standardised Level Difference of Rooms and Project Result Values

Source Room Type-Room Code	Receiver Room Type-Room Code	Required D_{NTW} Value	Results Rw Value
Corridor-**142**	Auction and Council room **-145**	40db	42 db
Office-**144**	Auction and Council room **-145**	35 db	57 db
Dining Hall **-141**	Auction and Council room **-145**	50 db	57 db
Gallery Space **-215**	Assembly meeting room **-216**	40 db	72 db
Corridor **-209**	Assembly meeting room **-216**	40 db	50 db
Gallery Space **-112**	Office **-131**	35 db	55 db
General service area - **154**	Office -155	40 db	59 db
Corridor **-142**	Office **-143**	35 db	46 db
Stairs **-147**	Office **-143**	45 db	70 db
General service area - **164**	Office **-173**	40 db	53 db
Office **-139**	Office **-143**	35 db	60 db
Shaft **-171**	Office **-173**	40 db	81 db
Technical volume **-32**	Office **-33**	50 db	51 db
Dining Hall **-141**	Office **-144**	50 db	64 db
Stairs **-50**	Parking **-35**	45 db	77 db
Corridors **-19**	Parking **-35**	35 db	61 db
Technical volume **-44**	Parking **-35**	50 db	64 db
Technical volume **-32**	General service area **-29**	50 db	57 db
Technical volume **-32**	Corridors **-19**	50 db	56 db
Technical volume **-32**	Shaft **-28**	50 db	62 db
Elavator **-22**	Shaft **-24**	40 db	54 db

As seen above, the walls of the critical room types, whose location codes are given beside them, are designed to respond to the necessary values. Both air-born and solid-born building noise control is facilitated between rooms. The D_{NTW} value required to be present between some sample location coded volumes, and the Rw value of the generated wall type detail, do not have close values. The reason for that is that, a different type of wall room with same function but different location code had been used in the current project. The reason for this is that in the current project, a different type of wall had been used in a volume with the same function but a different location code. For example, the seperator elements between office and office rooms are glass walls in some instances, and 20cm brick walls in others. As long as the types of walls of the current project complies with the required DNTW value, and since minimum intervention on the project is wanted, the sound transmission value of the 20cm brick wall on the office and office seperator elements, would be higher compared to the D_{NTW} value. Yet, at no point of the project, it is adjusted so that it never falls below the D_{NTW} values specified by ISO.

The results for inter-location air-born sound insulation measurement, whose table has been given above, are provided in Appendix-2.

4.3 Room Acoustic

This section covers the acoustical design of open office spaces between 2.49 - 2.59 Area Codes planned within Konak Municipality Services Building. The design results were obtained using the industry standard Odeon 14.02 Auditorium software.

The software, which has been recognized to be highly practical and accurate in evaluating the acoustical conditions of a room in full condition, and offering improvement recommendations if necessary; provides us with parameter values which can not be obtained by actual on-site measurement with the present possibilities. [5]

The aforementioned acoustical design, will define the interior surface materials and placements suitable for the acoustical conditions of the offices in the direction of their intended use, according to the results obtained from the simulation.

In this section, an acoustical simulation will be carried out based on the current situation. Later, improvement proposals will be introduced before remaking the simulation, and finally, the results will be compared.

4.3.1 Making Simulation Model of Open Plan Offices Layout

Simulation method is a preferred method today because it facilitates gathering acoustical information at designated receiver points, hence, enables one to see acoustic results of various alternative designs before construction by simulating the sound phenomenons that can occur in a room modeled in the computer environment.

The simulation model for the Odeon progamme is based on the acoustic parameters of a real open-plan office, and is modelled in order to recreate the sound definition in a room. On an area which is designed on a 1/1 scale, every surface that may cause echoing and absorption of sound should be drawn. This includes floor, walls, ceiling as well as seating areas, desks, dividing separators, and even the number of people who will use the area. Additionally, each surface made of a different material should be transferred to the programme under a different layer.

As examples, the plan of the open office area on the project where volume acoustics simulation is to be carried out and the 3D simulation model are given below.

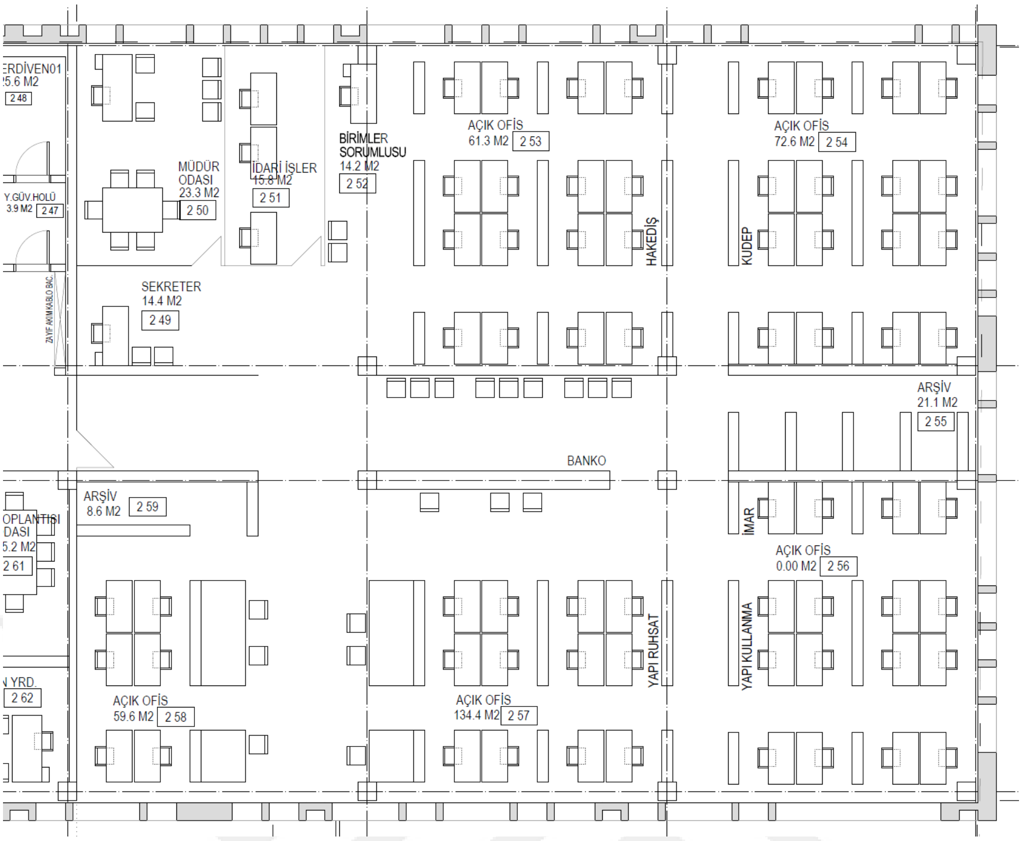

Figure 54 Plan of a Sample Open-Office Area

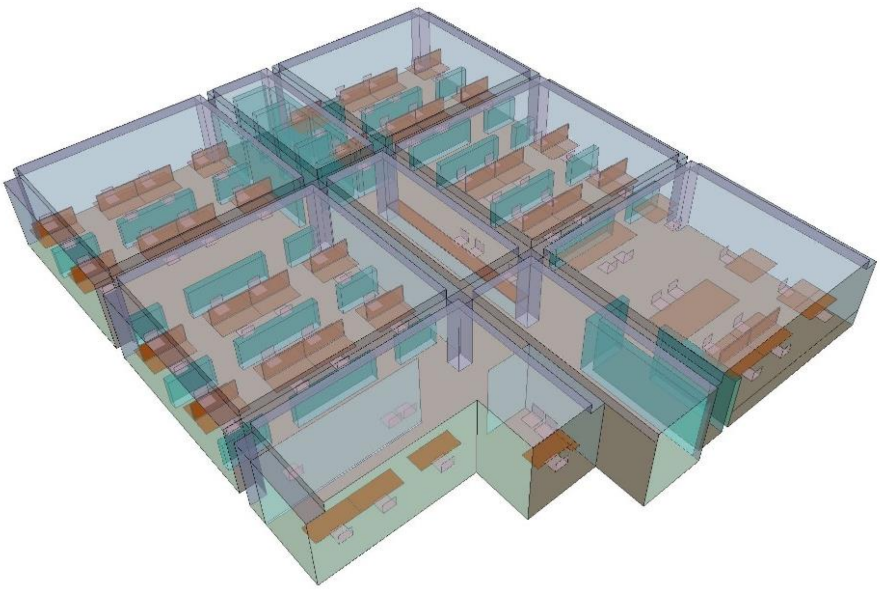

Figure 55 Perspective Drawing of Acoustic Simulation Model

The office space, which is the subject of the study, has been modeled in a CAD programme and transferred to Odeon with a par. extension. As indicated in the manual of the simulation programme, the room is modeled as a general overview with minimum detail.

The natural lighting property of glass facades designed to provide maximum energy efficiency forms the four major separating surfaces of our office space. The following figure displays the glass application areas on the project.

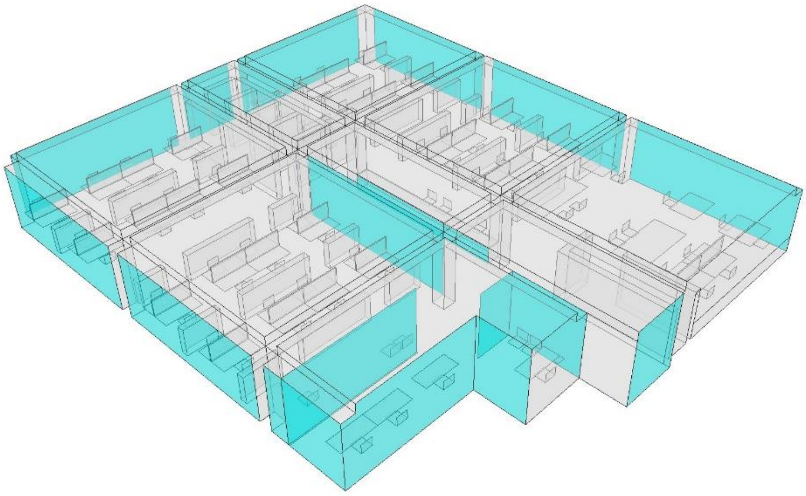

Figure 56 Glass Wall Application Area

The main roof area, which is given as gross concrete in the current project, have been left as open roof system in support of the light entering through the windows. The concrete ceiling application areas of the project are shown below.

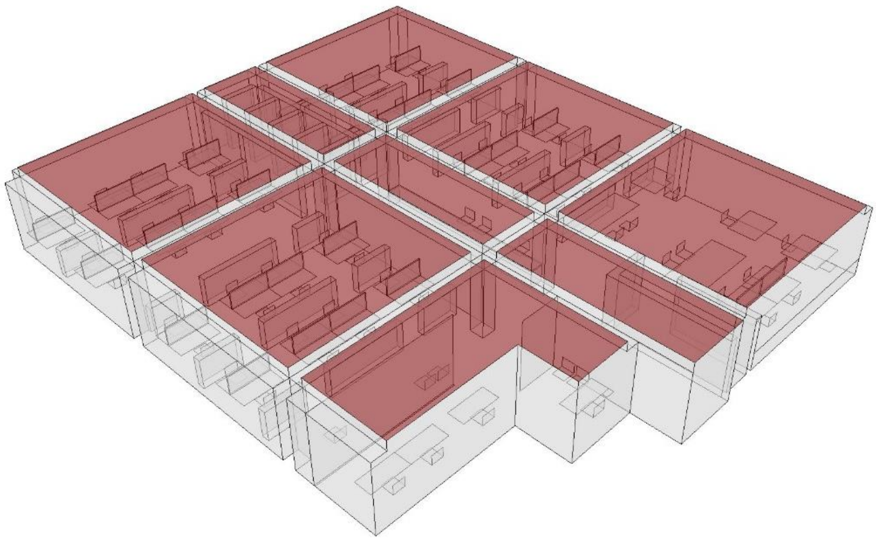

Figure 57 Concrete ceiling Application Area

Again, the column and beam system is designated as gross concrete in the current project. Below are shown the column and beam application areas of the project.

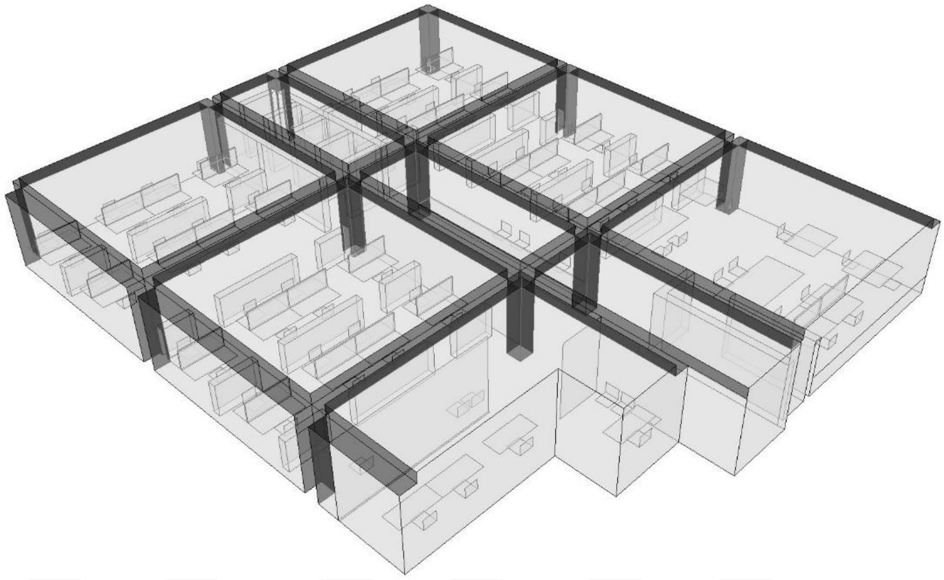

Figure 58 Concrete Colounm and Beam Application Area

The dividing walls facing the entrance area of the project are plaster over a 22 cm brick wall. The solid construction of these walls is important for breaking the acoustic connection with another room. The brick wall application areas on the project are shown below..

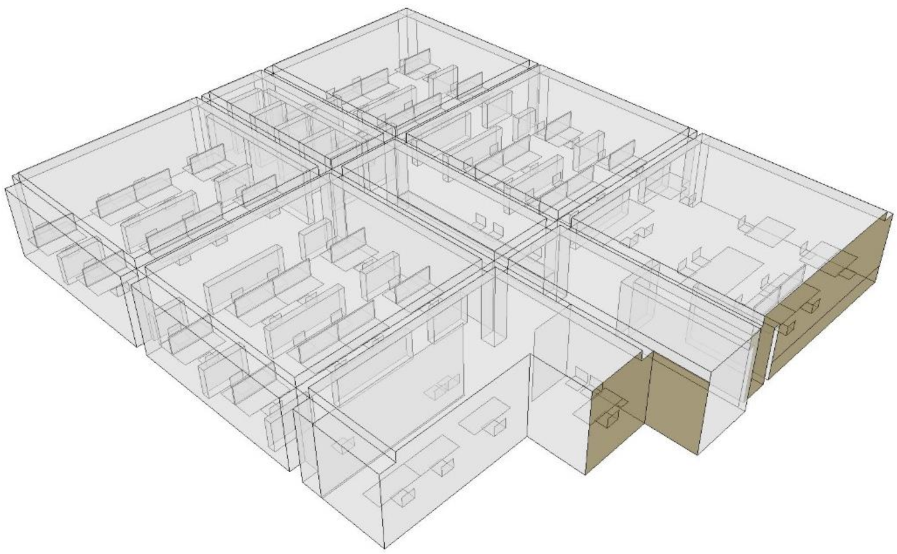

Figure 59 Brick Wall Application Area

The cabinet areas at the back of the working areas are as in the figure. The cabinet material in the current project is taken as plain MDF. Cabinets designed to be 120 cm in height are used as a separating agent in the improvement section to prevent sound transmission. The application areas of cabinets in the project are shown below..

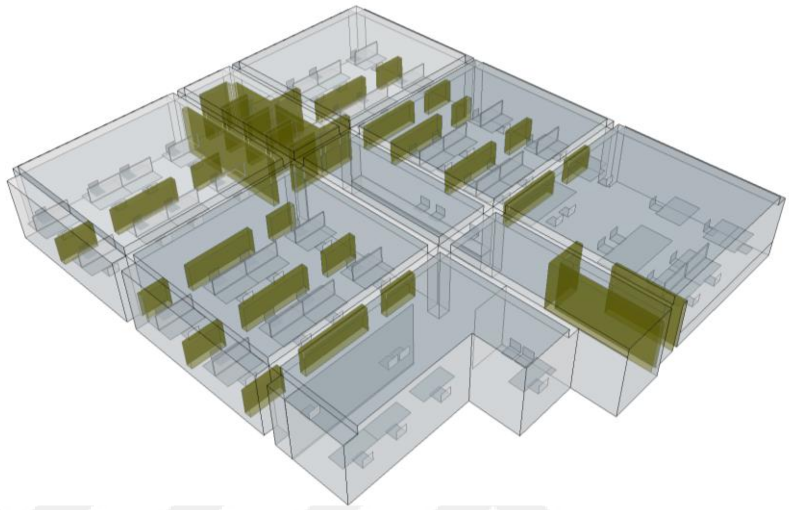

Figure 60 MDF Shelves Application Area

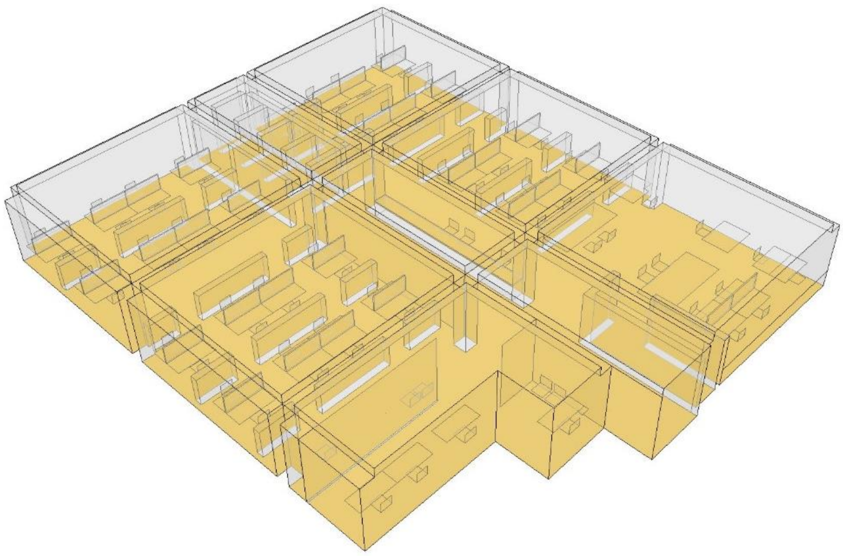

Figure 61 Floor Material Application Area

The existing floor covering material is epoxy. Using epoxy flooring in open office spaces is highly risky, due to the transmission of impact sounds and the continuous rise of reverberation times. Epoxy flooring application areas are shown above.

The application areas of the desks and the separation elements between the desks in the existing project are given below. The improvement proposal for the desks and the separation material with reverberating properties will be given later.

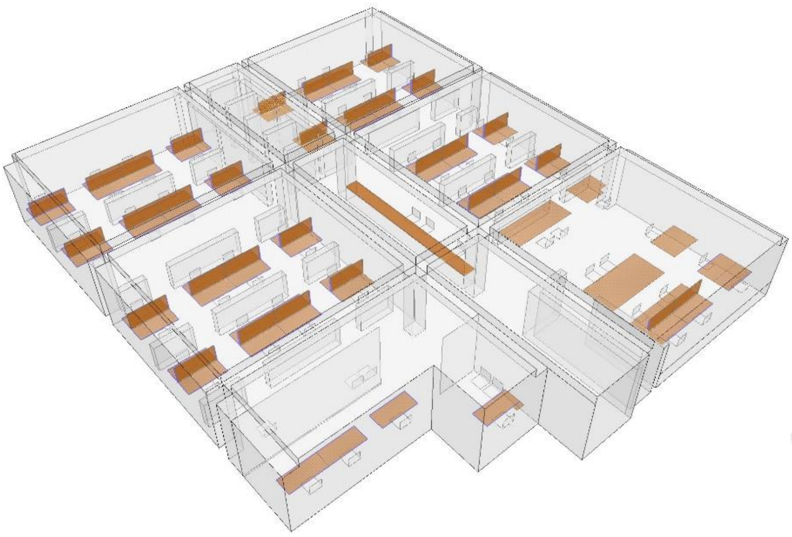

Figure 62 Table Areas

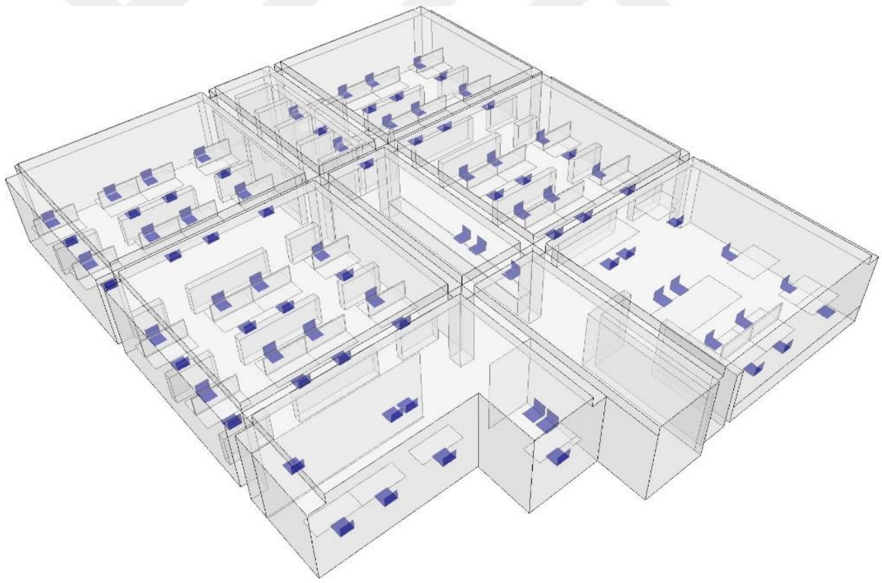

Figure 63 Chair Areas

For acoustic simulation, the positioning of users of the office space in the project, and the material absorptivity of the seating area are also very important. Because the absorption values of an office filled varies substantially compared to an empty office due to the sound absorption of the human factor. The users and their movable chair areas are shown above.

The surface types planned to be present in the room in the current project, and their absorption ratios are as follows:

Table 19. Sound Absorption Cofficient of All Surfaces

	Material Type	Sound Absorption Cofficient, α					
		125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Wall	Glass	0.35	0.25	0.18	0.12	0.07	0.04
Wall	Brick Wall	0.01	0.01	0.02	0.02	0.02	0.03
Column-Beam	Gross Concrete	0.01	0.01	0.02	0.02	0.05	0.05
Ceiling	Gross Concrete	0.01	0.01	0.02	0.02	0.05	0.05
Flooring	Epoxy	0.15	0.12	0.11	0.10	0.07	0.08
Cupboard	MDF	0.19	0.14	0.09	0.06	0.06	0.05
Table	MDF	0.19	0.14	0.09	0.06	0.06	0.05
Chair	Textile Upholstered Wooden	0.16	0.24	0.56	0.69	.081	0.78

4.3.2 Backround Noise Criterion

As mentioned above, there are continuous sources of noise on the background which must remain in the room. If the noise levels of these sources of noise are high, they should be adjusted either by reducing according to the ANSI standards, as explained in the Building Noise Control Section; or by creating artificial noise with a sound masking system.

The noise criterion step of the room acoustics simulation section of our current project is based on the indoor noise level limit values required for office areas according to the Environmental Hazard Assessment and Management Regulation; and the NC 35 chart has been applied according to ANSI. The calculation parameters are under the engineering option. The number of rays to be used in the scan is 10,000 and the scattering method is designated as 'Lambert'. The maximum number of reflections of the beam is 1129, the duration is 1500, and the reflection grade of the virtual sources is 2..

The NC 35 noise criterion value taken as a basis is as in the table below:

Table 20. NC 35– Noise Criterion Curve

NC 35								
Oktav Bandı Merkez Frekansı (Hz)	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Ses Basınç Seviyesi SPL (dB)	60	52	45	40	36	34	33	32

4.3.3 Determination Of Source -Receiver Points

While determining the sound source and the receiver point in the acoustic simulation programme for the open-plan office space, receivers are positioned as on the workstations to ensure that the results are close to reality. Care must be taken to ensure that the receivers are not too close to each other, reflective surfaces or sound sources. Each receiver group is associated with a source and each group must have at least 4 receivers. Preferably 6 to 10 of them could be placed on a line. [27]

The distance of the farthest receiver to the source depends on the size of the office area, but Odeon automatically uses receivers between 2 and 16 meters when determining the spatial decay rate of the talk. The height of the receivers is referred to as the height of the ear on a seated position, which is 1.2 m from the floor. Raised natural is used as the sound source. The source (red point) – receiver (blue points) placement in the sample area is as follows.

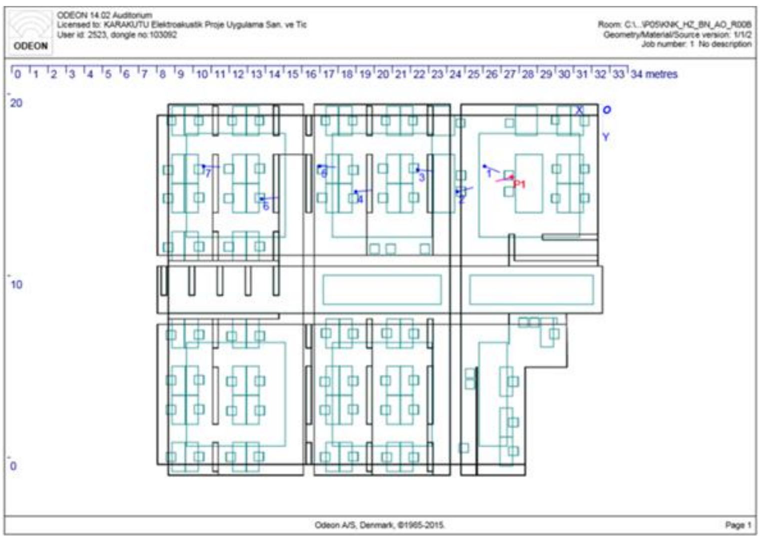

Figure 64 Sources Receiver Points

4.3.4 Simulation Resuls of Current Project

In this section, the graphical and grid results of the acoustic parameters used for open-plan offices given in Chapter 2 of the research will be examined. To summarize the acoustical design criteria mentioned in Part 2 on a table, the acoustic parameter values required for our open plan office space should be as follows:.

Table 21. Open Office Acoustic Design Criterion

Parameter	Design Criteria
T30	< 0.8
T20	< 0.8
EDT	< 0.8
D50	≥ 0.5
STI	≥ 0.6
U	≥ -6 db
DL_2	≥ 3.5 dB

According to this, detailed simulation results of the current project are as follows:.

4.3.4.1 Reverberation time, T30

The T30 average in the 125 Hz to 4000 Hz octave bands is 1.34 seconds. The frequency distribution of T20 values measured at the receiver points is given below. The graph is obtained by averaging the values obtained at all the receiver points

Table 22. Open Plan Office T30 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
T20 (s)	1.00	1.00	1.25	1.38	1.50	1.59	1.35	0.85

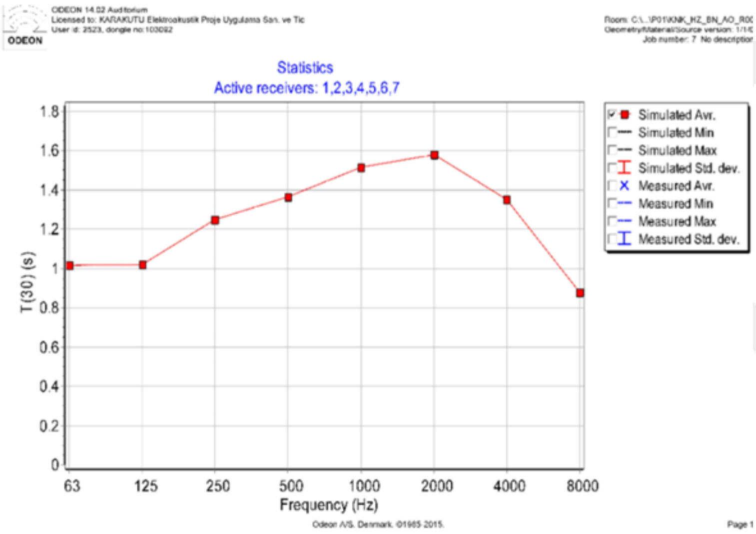

Figure 65 Graphic Of Frequency for T30

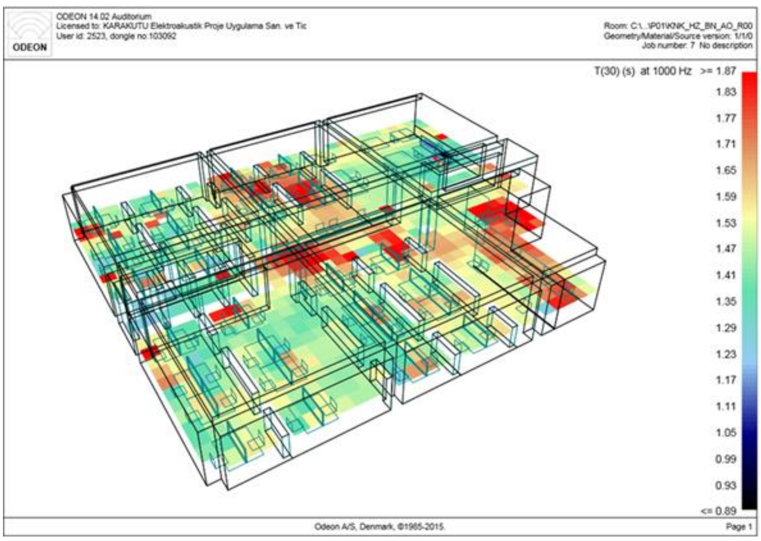

Figure 66 T30 Grid Map @1000Hz

In accordance to the simulation result of the existing status; as it is seen based on the result of the graphic of T30 resonance time (figure 63), it is seen that there is a leap from 1 second to 1,6 seconds in 1000 – 5000 frequency range which is the medium frequency range that the human ear can perceive the best. The curve not going in a straight acceleration and big differences between the frequencies will not be perceived positively by the human ear. So, this means it is a negative result in terms of acoustics.

On the other hand, when we review the T30 dispersion grid (figure 64), regional differences are in evidence. It is seen that the reflections are more and longer in some spaces. Simulation results that do not have a dispersion grid that is close to a homogenous structure, causes negative results in terms of auditory comfort. Therefore, for the simulation result of the existing situation in question, it is seen that the T30 design parameter show negative results due to the leaps it has in the basis of frequencies and also it is in a much higher value than the determined design criteria.

4.3.4.2 Reverberation Time, T20

The T20 average in the speech range of 125Hz - 4000Hz octave bands is 1.37 seconds. The frequency distribution of T20 values measured at the receiver points is given below. The graph is obtained by averaging the values obtained from all the receiver points.

Table 23. Open Plan Office T20 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
T20 (s)	1.05	1.07	1.30	1.39	1.50	1.58	1.39	0.83

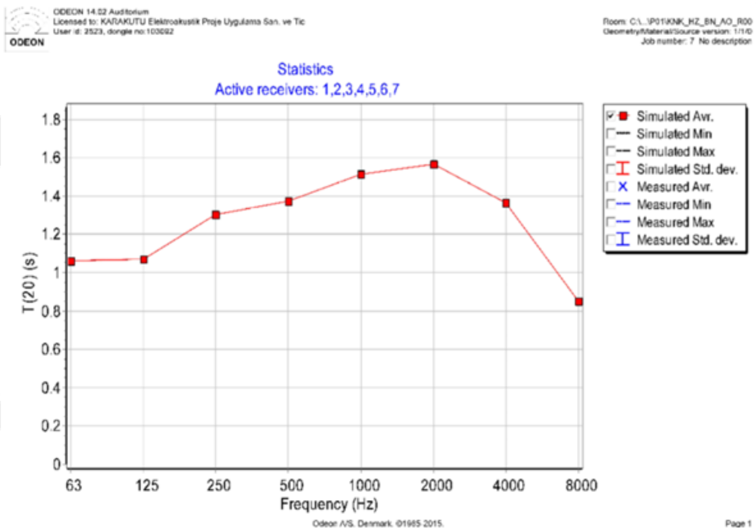

Figure 67 Graphic of Frequency for T20

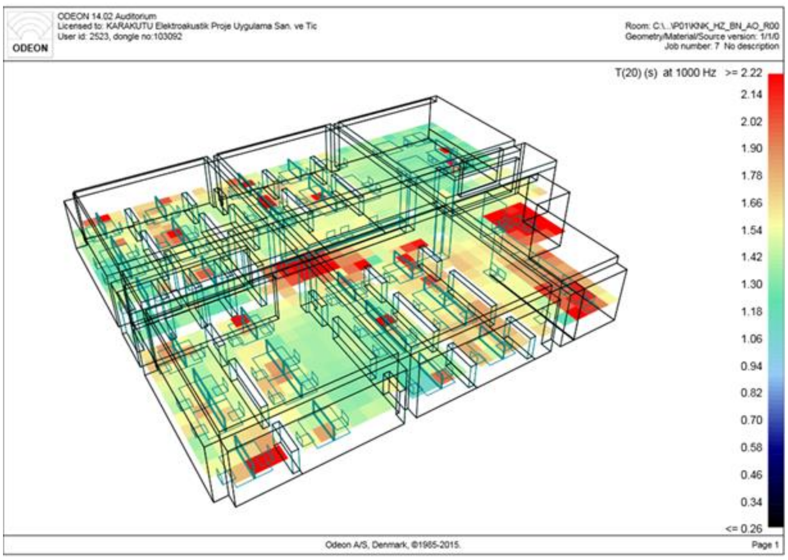

Figure 68 T20 Grid Map @1000Hz

The T20 graphic (Figure 65) of the existing situation's simulation result has uneven second differences between the frequencies as it was mentioned in the previous section. Moreover, the average T20 time of the graphic is at a much higher level than the required design criteria. In addition to this, it is seen that the dispersion grid of the T20 (Figure 66) in 1000hz has results similar to the one above. The leaps that are seen in the dispersion in the single frequency basis shows that the T20 design criteria has also given a negative result.

4.3.4.3 Reverberation Time, EDT

The average EDT in the speech range of 125Hz - 4000Hz octave bands is 1.54 seconds. The frequency distribution of EDT values measured at the receiver points is given below. The graph is obtained by averaging the values gathered at all the receiver points.

Table 24. Open Plan Office EDT Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
T20 (s)	1.15	1.15	1.43	1.58	1.79	1.78	1.52	0.98

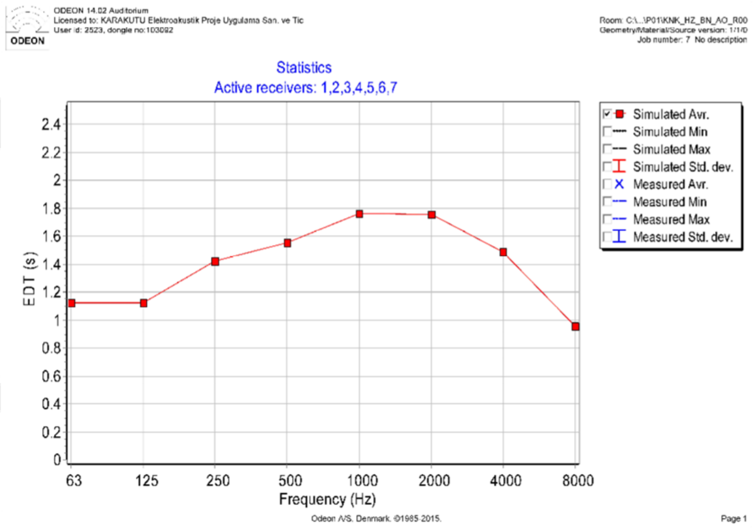

Figure 69 Graphic Of Frequency for EDT

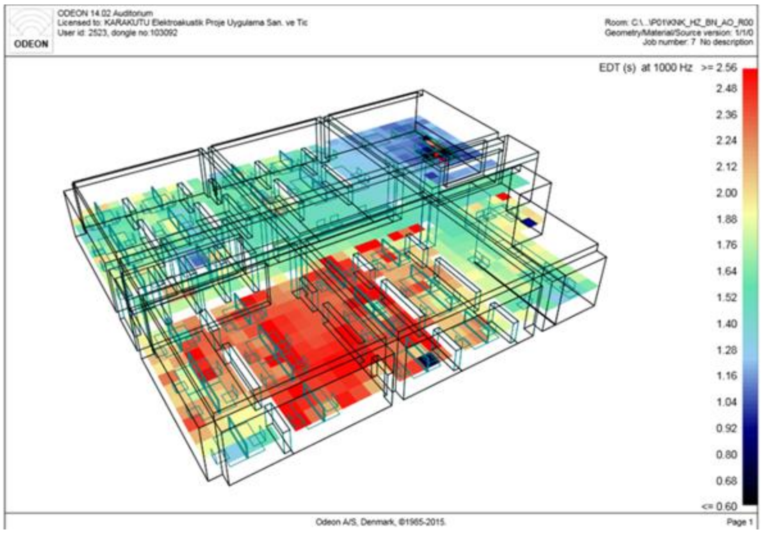

Figure 70 EDT Grid Map @1000Hz

The average EDT time in the graphic has unstable sec diffecences amnong frequencies, plus its expected early reverbation is observed in very high level as it is mentioned in simulation result of current EDT graph (Figure 67) on 4.3.4.1. Beside all that, EDT’s distribution map of 1000hz (Figure 68) gives us a similar result as mantioned above. In the current simulation programme, reverbation’s high results far from the main voice source and in an opposite area, proves that sonic vawes could pass from vast spaces on continuing structures such as, solid wall, floor and ceilings. Beyond all that, the leaps detected on voice distribution map is another proof that the EDT design metric has given a negative result.

4.3.4.4 Defination, D50

At 125Hz – 4000Hz octave bands, the D50 value is 0.30 and the distribution graphs are shown below

Table 25. Open Office D50 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
D50 (s)	0.35	0.34	0.30	0.28	0.25	0.25	0.30	0.35

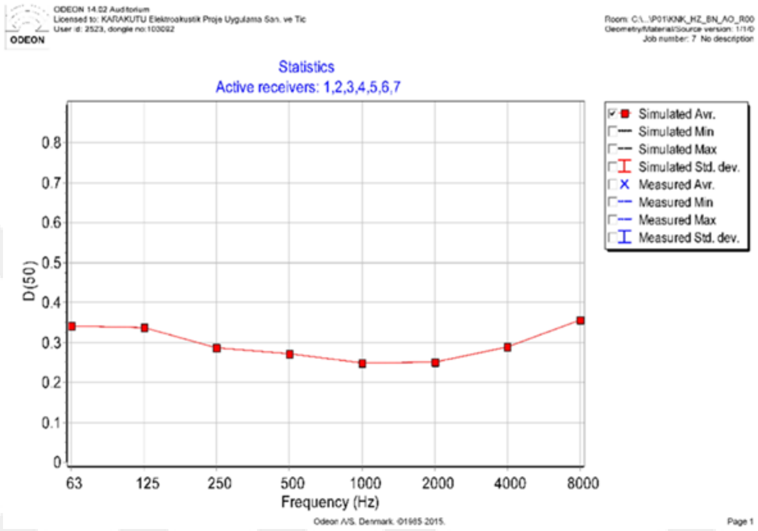

Figure 71 Graphic Of Frequency for D50

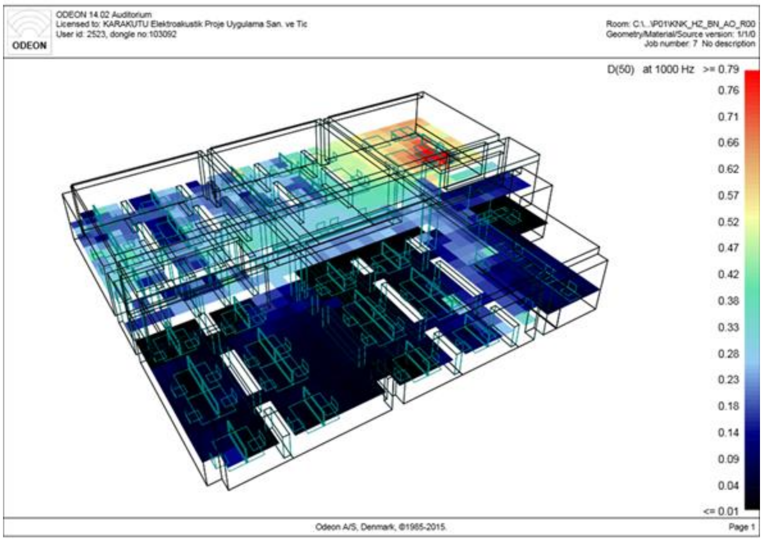

Figure 72 D50 Grid Map @1000Hz

A according to the current result, as long as D50 design criteria had proper frequency curve and homogeneus distribution, it is counted as negatively resulted because it is ranked lower than the design result determined by literature.

4.3.4.5 Sound Transmission Index (STI)

The average STI value obtained in the audience space being 0.44, the distribution map is given below.

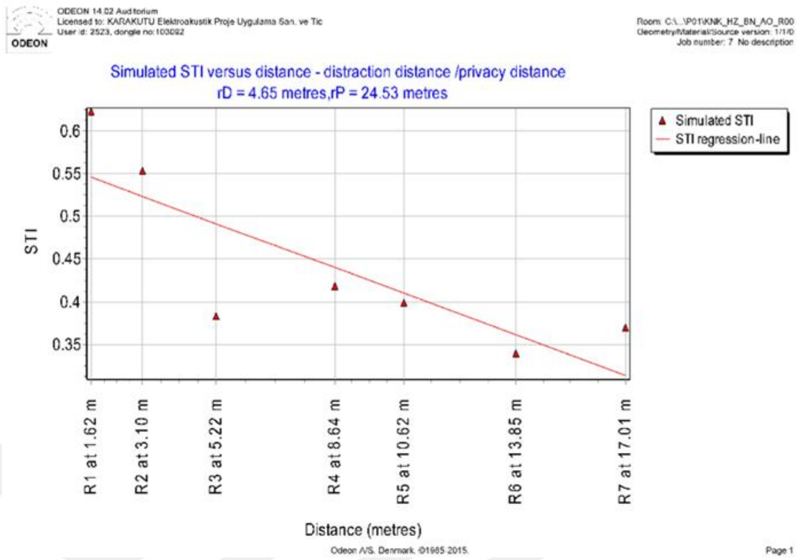

Figure 73 STI Deflection Chart According to Distance

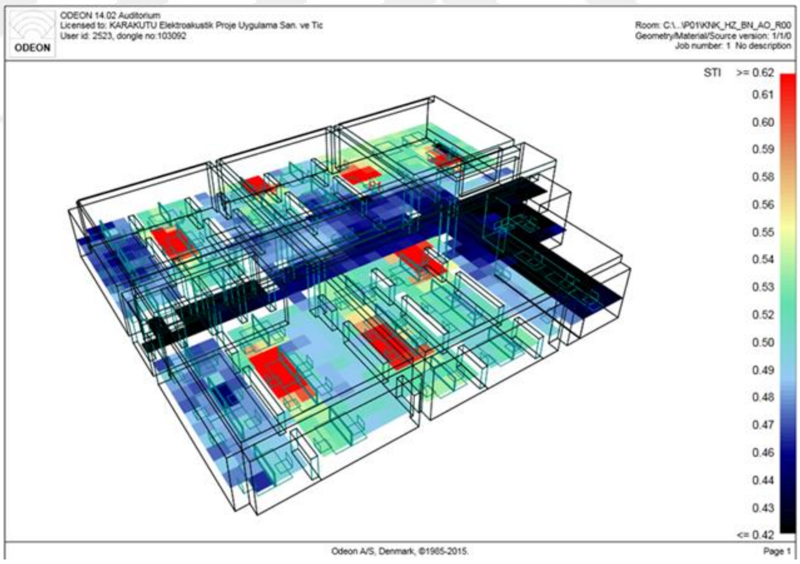

Figure 74 STI Grid Map @1000Hz

According to current situation's simulation results from STI graph (Figure 71), the distance of the receiver situated closest to the source (R1) is 1.6 mt. The speech recognition value for R1 is 0.55. Thus even the closest receiver is given the lover values according to the expected design criteria. In this context, two speaker's interaction in terms of metric scale, is weak and acoustic performance is considered negative.

4.3.4.6 Signal to Noise Ratio (U)

At 63Hz – 8000Hz octave bands, the Signal to Noise Ratio (U) value is -12.27. Distribution graphics are given in the tables and figures below.

Table 26. Open Office U Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
D50 (s)	-24	-17	-9	-7.5	-7.9	-8.5	-9.3	-15

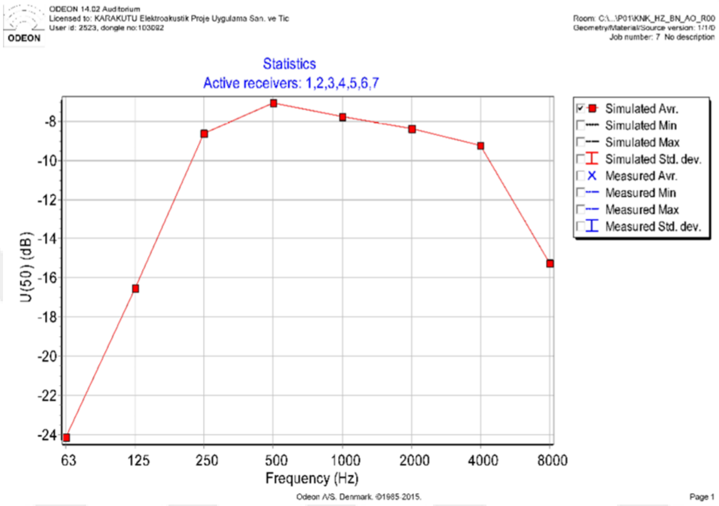

Figure 75 Graphic of Frequency for U50

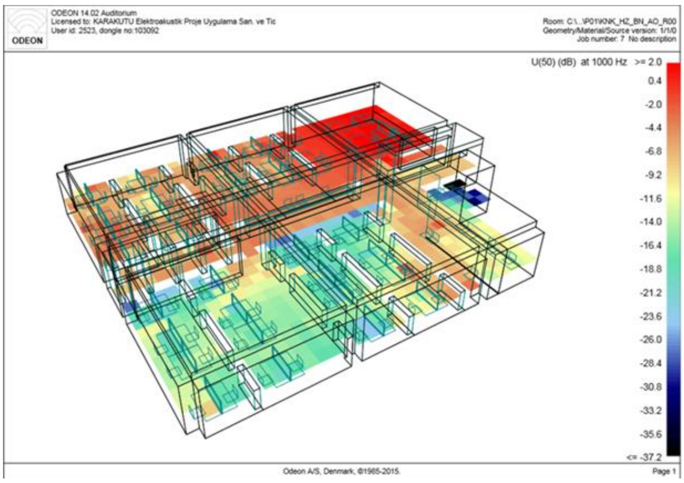

Figure 76 U50 Grid Map @1000Hz

In terms of speech camouflage, the current simulation's signal to noise ratio is reached at satisfying level. But it is mentioned before that, in ofice scales as the speech secreting process occuring, in close distances speech should be understendable either. For that reason the signal to noise ratio is reached to higher level than expected design criteria.

4.3.4.7 Rate Of Spatial Decay DL2

The DL2 values being 2.93, the distribution graphs according to the receiver, are given on the chart below.

Table 27. Open Office DL_2 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
DL_2	3.73	3.68	3.28	3.02	2.84	2.87	3.14	3.82

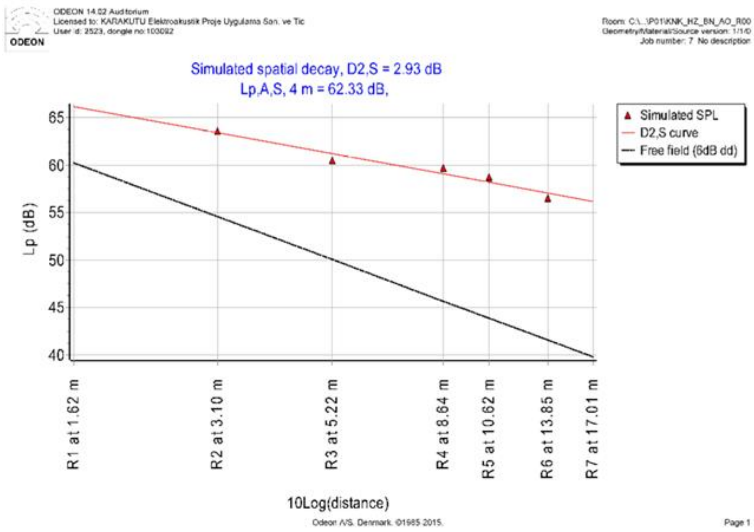

Figure 77 DL2 Ditribution Graphs According to Receivers

When the simulation results of the current situation of the DL2 parameter that is based on the decay rate per meter and examine the nature of speech among different working groups,have been investgated it is seen that the value is 2.93 dB and this value below the design criteria that is specified by litarature. This means that the voices of two independent groups can easily reach each other and their speech is clearly understood. But, this situation is not desirable in open office spaces.

As shown in the graphics, grid and tables of the simulation results, open-space area with sustainable content in the current situation does not conform to the parameters required in terms of acoustics, also the reverberation times raise at the speech frequency intervals. This, in turn, proves unsuccesful in a space where the main aim is to communicate effectively.

4.3.5 Improvement Proposals And Acoustic Results Using Sustainable Materials

As we have seen in the simulation of the present situation of the project to be carried out, it may be extremely difficult to work in office areas built with natural materials with the aim of sustainability. According to research, one-third of occupational diseases are caused by noise and this situation can be overcome by simple sustainable materials.

In this section, measures will be taken to improve the acoustic parameters of the sample office area and the results will be analyzed.

First, the cabinet areas between the working groups, which had previously been 120 cm, will be increased to 165 cm and thus; the direct voice transmission at the ear level will be reduced. In addition, books can be used instead of the front cover of the cabinets, to exploit their absorbtion value. While some of the sound would be scattrered and diverted from its original direction after hitting the bookshlef, the rest would be faded between the air and the pages of the books. This will create a simple sound barrier effect for the office space. The application areas of the libraries to be used in this way are shown below.

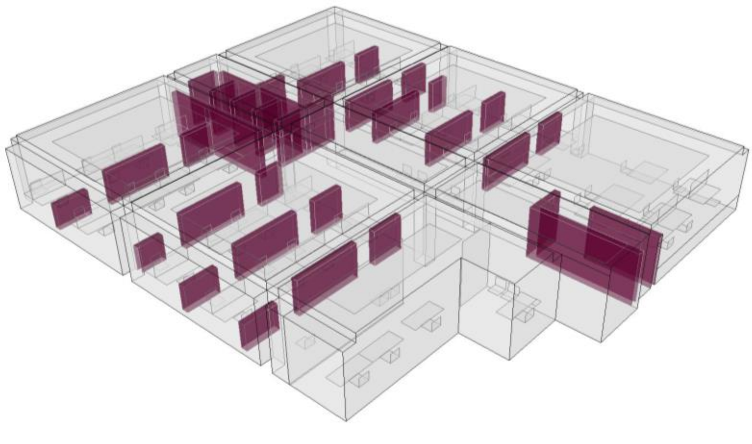

Figure 78 Bookshelf Application Area

The second step would be replacing the materials of visual seperators between desks. Although these are relatively small surfaces on their own, collectively their total area would be sufficient to reduce reverberation times, provided they are designed with an absorber material. An example of this is woodwool, which is sustainable, natural and absorbent. The application area between work tables is shown below.

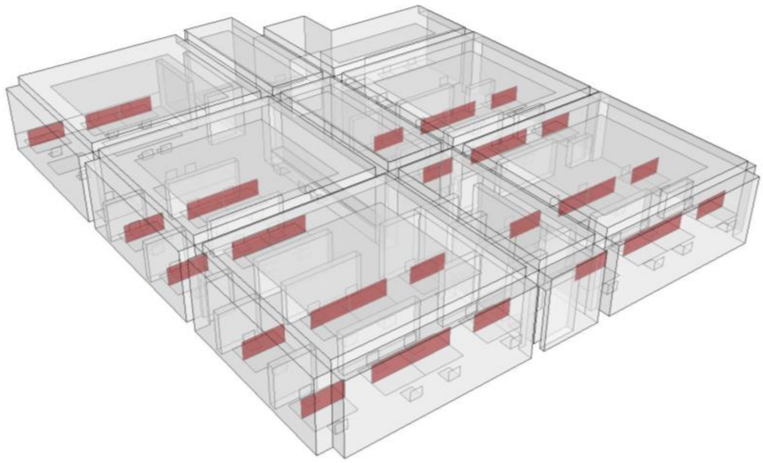

Figure 79 Seperator Application Area

The last application would be the installation of acoustically absorbent materials on the ceiling over the work groups. In the current project, the exposed ceiling system has been used, and as mentioned before, this large uninterrupted reflective area creates long reverberation times and a whispering wall effect. In order to prevent this, the sustainable and absorbent material woodwool, which has also been used between desks; would be covered in mineral wool and mounted to the ceiling with. Therefore, high cost and material wastage would be prevented by using the same type of absorbent material. Size and location of the panels are adaptable according to the interior design, and it has been shown by the results of acoustical measurements that, in total, 160 m2 of panels would be needed for the sample office area. The panels should be distributed according to the location of over the work groups. The woodwool application to the ceiling would be as follows:

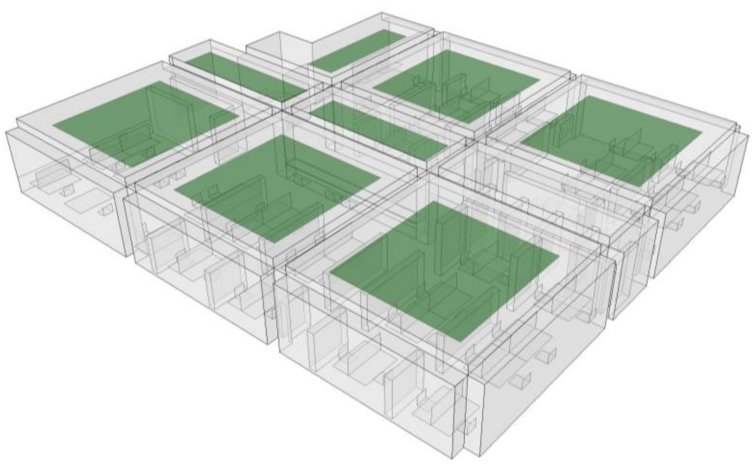

Figure 80 Ceiling Panel Application Area

The absorption index of the applied materials are as in the following table:

Table 28. Sound Absorption Index of All Surfaces

	Types of Materials	Sound absorbtion cofficient, α					
		125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
separater	Woodwool without mineral wool	0.13	0.26	0.31	0.29	0.34	0.40
Ceiling	Woodwool with mineral wool	0.58	0.90	0.85	0.70	0.58	0.81
Bookshelves	woodp	0.40	0.30	0.20	0.17	0.15	0.10

The results of the new acoustic simulation, which is the result of changing materials, are given in detail below.

4.3.5.1 Reverberation Time, T30

The T30 average at 125Hz – 4000 Hz octave bands, which is the speech range, is 0.63 seconds. The frequency distribution of T20 values measured at the receiver points is given below. The graph is created by averaging the values obtained at all the receiver points.

Table 29. Open Office T30 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
T20 (s)	0.54	0.54	0.57	0.68	0.62	0.70	0.72	0.54

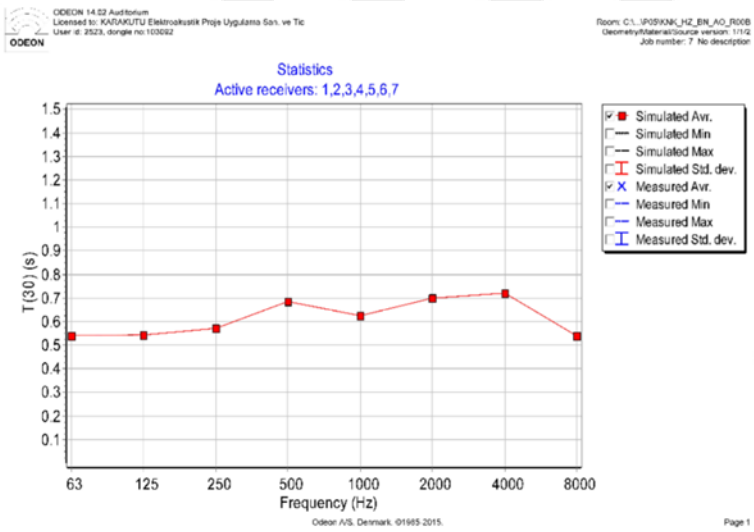

Figure 81 T30 Frequency Graph

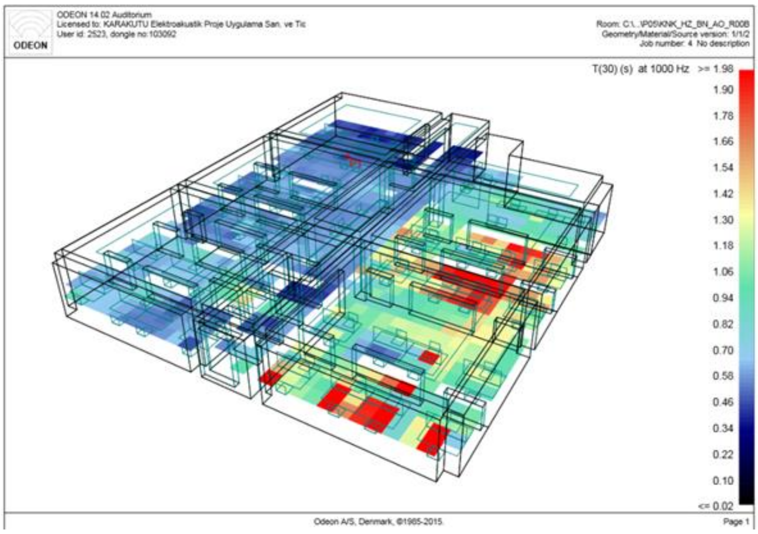

Figure 82 T30 Grid Map @1000Hz

Looking at the result graphich of simulation T30 (Figure 79) after the proposal of sound amplification, 30db reduction, which is high figure compared in volume, has lovered the ringing time as well. In this manner, T30 time is reached the expected design metric and the high second differences among frequencies are all eleminated. By checking the voice distribution map of 1000 hz frequency (Figure 80), it is detected that the distribution between receiver and source among 0.80 and 0.46 seconds is sufficiently balanced. According to that information, the proposals for solving the problem are taken T30 timing under the control and succesfully actualized.

4.3.5.2 Reverberation Time, T20

The T20 average at 125Hz – 4000 Hz octave bands, which is the speech range, is 0.73 seconds. The frequency distribution of T20 values measured at the receiver points is given below. The graph is created by averaging the values obtained at all the receiver points.

Table 30. Open Plan Office T20 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
T20 (S)	0.55	0.55	0.65	0.77	0.81	0.86	0.79	0.55

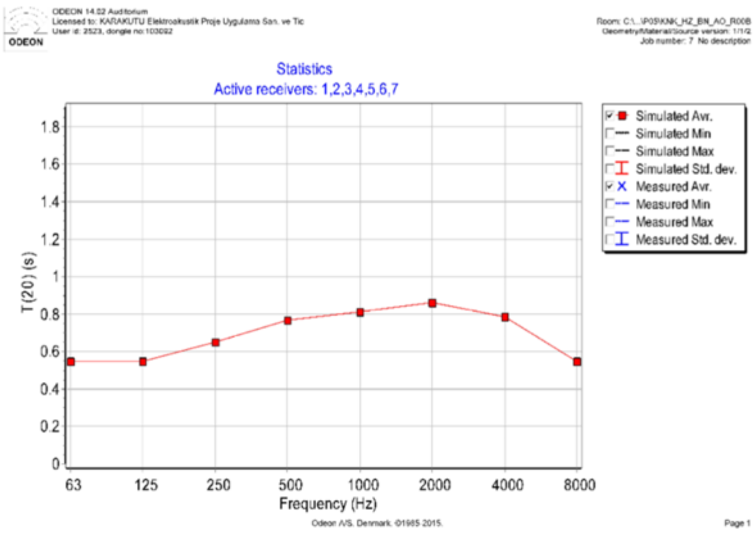

Figure 83 T20 Frequency Graph

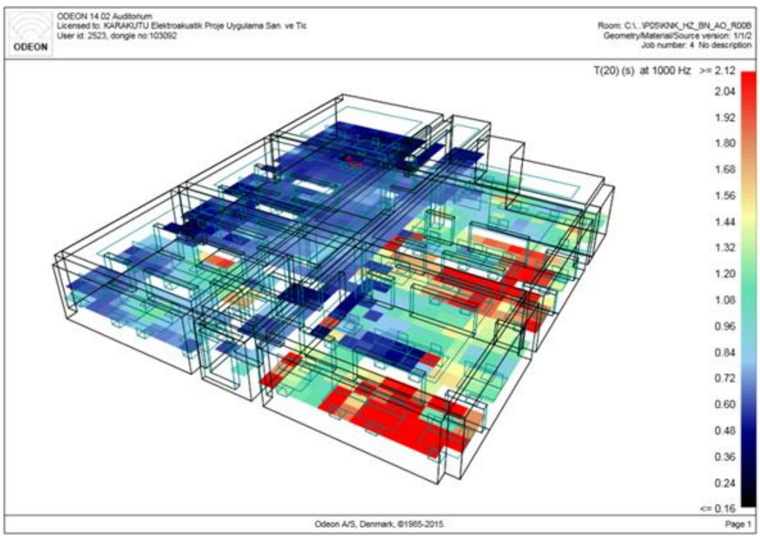

Figure 84 T20 Grid Map @1000Hz

Checking at the result graphic of applied simulation's T20 (Figure 81), the T20 timing which is found high acording to the design criteria is detected lover and acceptable under reasonable levels. Besides all that, the wavy frequency curve detected at the figure 65 under the headline of 4.3.4.2 is impoved and stabilized. The high second differences among frequencies are all disappeared. When the figure 82 is examined, there is a balanced distribution between source and receiver is sighted. According to that information, the proposals for solving the problem are taken T32 timing under the control and succesfully realized.

4.3.5.3 Reverberation Time, EDT

The EDT average at 125Hz – 4000Hz octave bands, which is the speech range, is 0.66 seconds. The frequency distribution of EDT values measured at the receiver points is given below. The graph is created by averaging the values obtained at all the receiver points.

Table 31. Open Plan Office EDT Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
D50 (s)	0.64	0.63	0.64	0.62	0.58	0.60	0.65	0.76

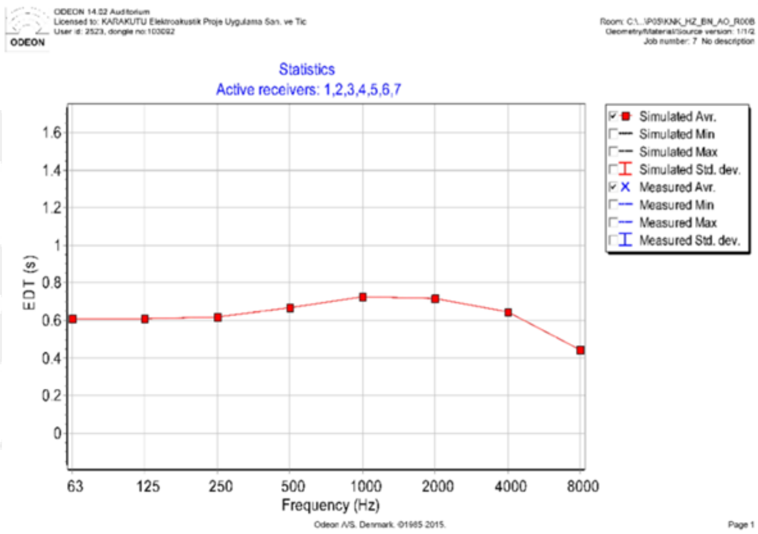

Figure 85 EDT Frequency Graph

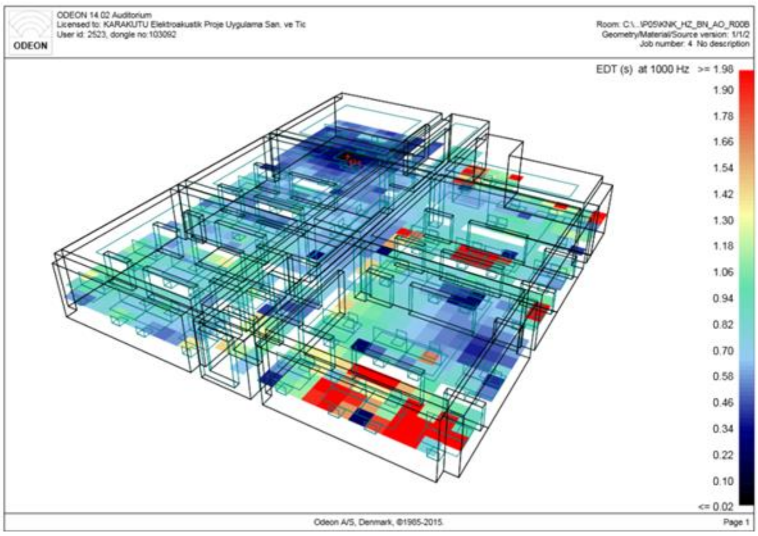

Figure 86 EDT Grid Map @1000Hz

The Early Decay Time which could be defined as the identifier of the first reflections, is dropped to the expected level as in T20 and T30 parameters under the terms of literature and reasonable levels. Besides all that, EDT design criteria's improvement proposal is counted succesfull in terms of showing us a linear and balanced distrubution map.

4.3.5.4 Defination, D50

125Hz – 4000Hz octave bands, the D50 value is 0.63 and the distribution graphs are given below.

Table 32. Open Plan Office D50 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
EDT (s)	0.64	0.63	0.64	0.62	0.58	0.60	0.65	0.76

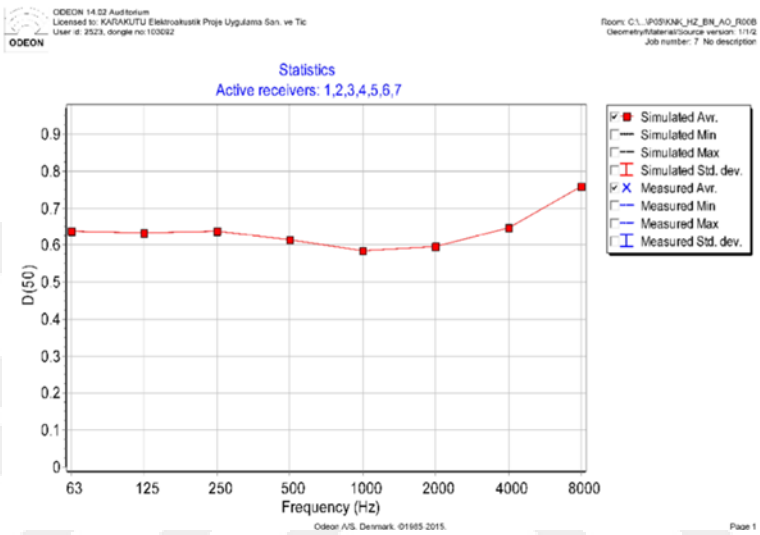

Figure 87 D50 Frequency Graph

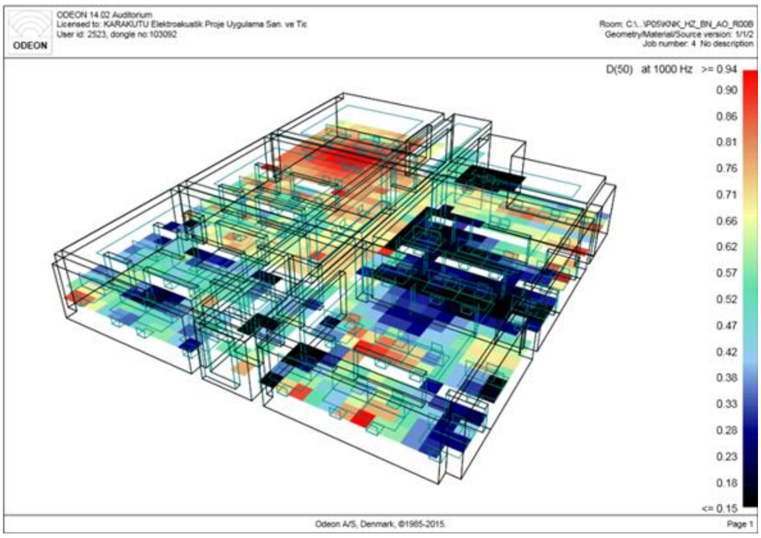

Figure 88 D50 Grid Map @1000Hz

The D50 parameter which is observed lower than design criteria, is reached the expected level with the help of improvement suggestion, which could be counted as succesfully actualized

4.3.5.5 Sound Transmission Index (STI)

The average STI value obtained inside the audience space being 0.66, the distribution map is given below.

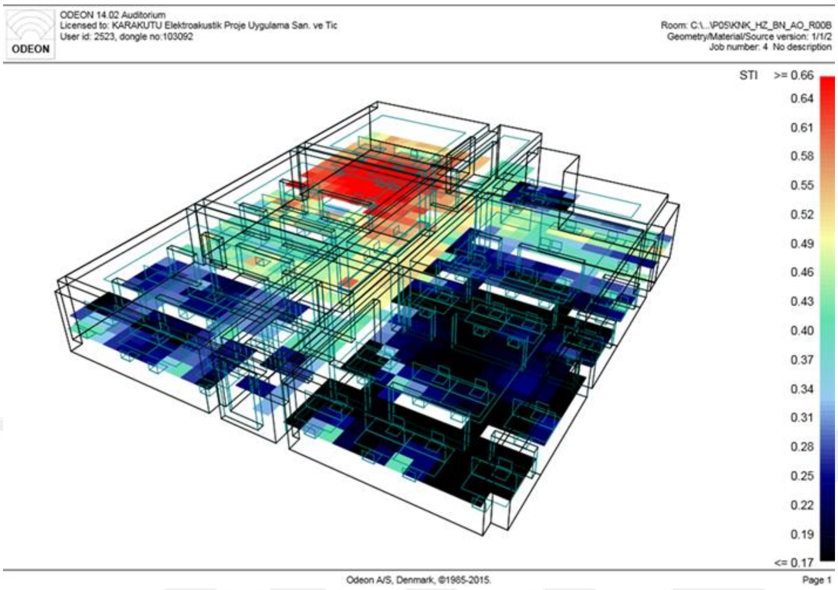

Figure 89 STI Grid Map @1000Hz

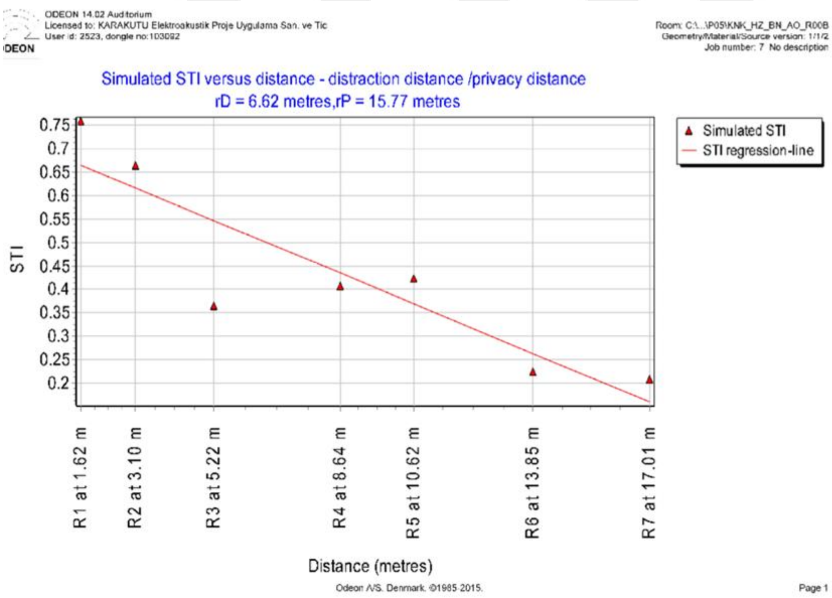

Figure 90 STI – Speech Transmission Distortion Graph According to Distance

According to the STI graph (Figure 88) coming from improvement simulation results, on the receiver closer to the source (R1), speech recongition level is reached to average 0.55 to 0.67 sec. The current state shows that, the speakers interaction, within receivers with his/her two meters radius, is reached to a better level and the acoustic performance could be counted as succesfull.

4.3.5.6 Signal to Noise Ratio (U)

At 63Hz – 8000Hz octave bands The Signal to Noise Ratio (U) value is -5.65. Distribution graphics are given below.

Table 33. Open Plan Office U Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
U50 (s)	-20	-12.8	-3.7	1.4	1.1	0.7	-2.2	-9.7

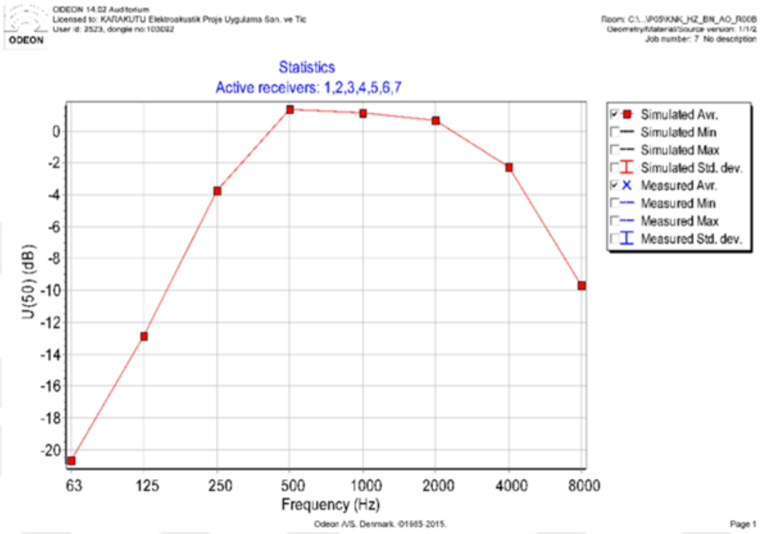

Figure 91 U50 Frequency Graph

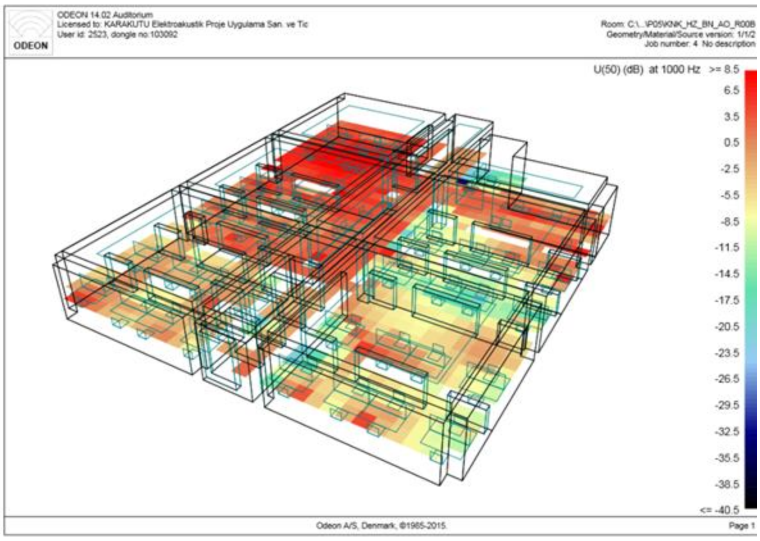

Figure 92 U50 Grid Map @1000Hz

4.3.5.7 Rate Of Spatial Decay DL2

The DL_2 value inside the office area is 6.20. Distribution according to receivers are given below.

Table 34. Open Office DL_2 Results

Frekans (Hz)	63	125	250	500	1000	2000	4000	8000
DL2	X	6.06	6.03	6.60	6.03	5.50	6.21	6.95

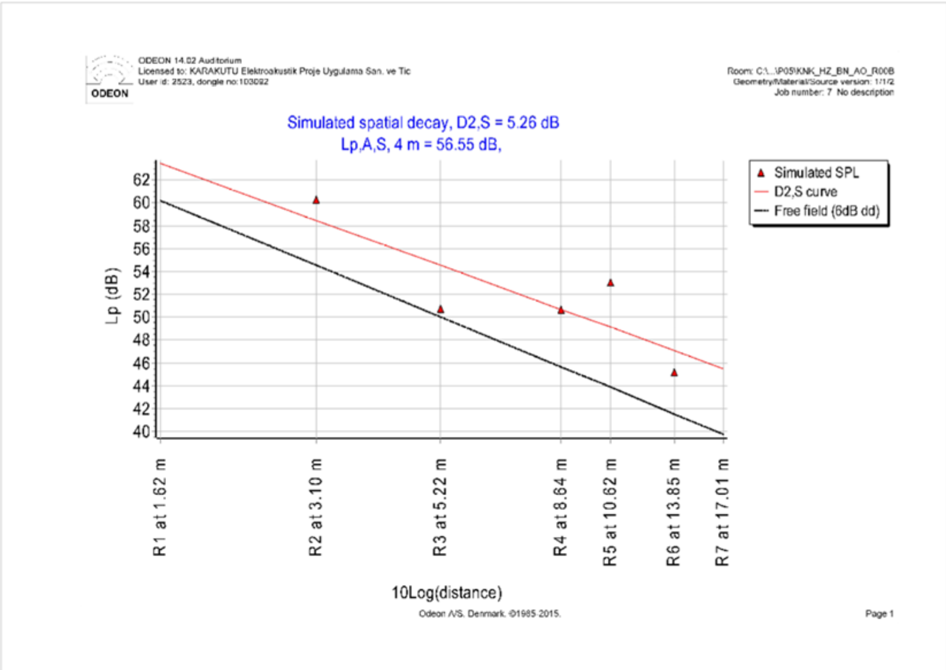

Figure 93 DL_2 Adistribution Graohşcs According to Receivers

When the simulation results of the improvement proposal of the DL2 parameter are examined, it is seen that the value is 5.26 dB and it satisfies the design criteria that determined by litarature. .

4.3.6 Comparison of Acoustic Parameters

As seen in the acoustic simulation results of the open office sample, while the existing reverberation times and other acoustic parameters are quite negative, acoustically healthy workspace conditions are created by simple and sustainable solutions. Below the acoustic condition parameters that are present and which have been proposed for improvement are given comparatively for the sample room.

Table 35. Open Plan Office Vomparative Acoustic Simulation Results

Parameter	Design Criteria	Simulation Result of Current Situation	Improvement Suggestion Simulation Result
T30	< 0.8	1.34s	0.63s
T20	< 0.8	1.37s	0.73s
EDT	< 0.8	1.54s	0.73s
D50	≥ 0.5	0.30s	0.63s
STI	≥ 0.6	0.44s	0.66s
U	≥ -6 db	-12,27db	-5,65db
DL_2	≥ 3.5 dB	2.93db	6.20db

CHAPTER FIVE

DISCUSSION

The importance of the phenomenons of sound and noise, which are amongst the crucial aspects of health and comfort, especilly with regards to working environments where we spend most of our lives, is failed to be addressed sufficiently in the Leed and Breeam certificates; which aim to facilitate the interaction of people with nature in the most efficient way, increase the productivity of them by protecting their wellbeing, and reducing possible negative environmental effects. The reasons for this conclusion can be summarized comparatively in the table below.

Table 36. Comparative Results of Open Office Requirements

Acoustic Requirements for Workspaces		LEED Criteria	BREEAM Criteria	SBTool Criteria	Guideline Proposal
Environmental Noise Control Requirements	Location noise measurement and analysis prerequisites				✓
Requirements for Building Noise Control	Determination of Sound Reduction Index (R_W) of facade elements				✓
	Determining the Target Values (DNTW) Between Spaces				✓
	Creating the Wall and Floor Details That Will Meet the Target Values	✓	✓	✓	✓
	Providing Vibration Control in Mechanical Volumes and Elements			✓	✓
Room Acoustics Requirements	Adjusting Noise Criterion (NC)	✓	✓	✓	✓

	Determination of Early Decay Time (EDT) design measures				✓
	Determination of T20 design measures				✓
	Determination of T30 design measures				✓
	Determination of RT60 design measures	✓	✓		✓
	Clarity of speech (D50)				✓
	Speech Transmission Index (STI)	✓	✓		✓
	Facilitating speech privacy in open office area				✓
	Determination of the rate of spatial decay (DL_2)				✓
	Determination of material absorption values according to criteria				✓
		1 credits	3 credits	Between -1 and 5 point	

According to the table above, the first step of noise control called; "environmental noice control", it is not asked as a prerequisity or restriction for office buildings in Leed, Breeam and Sbtool certificate programmes. In other words, when the environmental noise level is unknown, although the noise reduction parameter criterias for the construction elements used on façade are already determined, the required acoustic efficiency may not be met. Besides all that, in leed, bream and sbtool, there is no article that states the noise conductivity parameter for construction elements. There is only an evaluation for the structure seperator elements for spaces and it only evaluates the noise passage performance without evaluating DNTW value that explains the passage between spaces, that could be concerned as it is evaluated with a general value. This evaluation tells us that; in each building the same noise level occurs and these same performing spaces are situated at the same points. Selection of facade elements without conducting environmental noise measurement, inter-building noise organisation, or creating a buffer zone between noisy and silent rooms; leaves all of the noise burden to the sound reduction values of the main building components. This may increase the cost, as well as result in an acoustically unsuccessful environment.

Another phase of noice control is that, mechanical elements noise control is criticised only by SBTool programme. According to the figure, when the office buildings are discussed, Leed and Bream (they ignore vibration control) have no criteria for noise bridges from air inlets or anything about blocking solid-reasoned noise on mechanic volumes. However, on solid-reasoned noise transmission, without vibration and impact noise conduction preventor materials made from rubber and silicone, the seperating constraction material’s noise reduction ability won’t be sufficient enough.In fact, these phenomena constitute the foundation stone of a work area being affected by noise.

When office scale is concerned, it is found that, on the background noise criteria research, which is the keystone of volume acoustic, is examined by all above mentioned certificate programmes. But among all resonance timing parameters which are EDT, T20, T30 and RT60, only RT60 parameter is entered LEED and BREEAM certification system’s evaluation criterias. As it is mentioned before, when the resonance timing is to be measured with RT60, it may not give actual results for the tested volume area. The examination of the time curve for only the first 60 decibels of sound reduction would cause one to misinterpret the overall volume by ignoring the importance of the initial reflections in the human ear. For this reason, it is more important to examine the first reflection curves and to obtain specific results. On the other hand, checking back the BREEAM resonance timing requirements on page 33, figure 8, we remember that it is not performing reasonable results according to acoustic context. According to Breeam, if it is expected to have speech in a 50 squaremeter volume, the resonance timing would be 0.4 which could be considered as a reasonable level. But for the same volume of space, it is explained that, if the function is about the music the same resonance timing should be 1 second. In a such small volume for a place, such a high level of noise resonance given by BREEAM is a proof that their evaluation criteria is way more different that the ones in academic researches. In LEED's criteria as shown on figure 9 at page 43, for an open-plan office structure, as a general result given such as; RT60 should be smaller than 0.8. This value given without considering the size of volume is not considered reliable in terms of academic approach. Because the volume of 60 m3 and 700 m3 areas may not be expected to give the same results. In SBtool it is understood that it is not covered in their evaluation.

For another volume acoustic criteria known as D50 parameter, it is not considered useful or evaluated by any certification systems. If the parameters that defines syllables relevance in speech are not considered important and added among evaluation criterias for office based areas which includes speach, it may cause negative results in terms of acoustic perspective. When we look at the speech transmission index criteria, we see that this parameter is evaluated properly in terms of academic approach by Leed and Bream. Unfortunately, SBTool as it is not concerned for other acoustic parameters, do not evaluate this parameter either.

The speech privacy parameters such as DL2 and Speech Privacy criterias which are considered highly important for open-office areas are not evaluated by any certificate systems. Up to this line, even the RT60 let us reach reasonable values and results, if the most important problems like speech clarity and speech subjectivity is not uncovered or measured properly then all the work done untill this point will be for no use. Because without a clear hearing of what is being spoken between the receiver and the source at a distance of 2 meters, or hearing the sounds from neighboring working groups after 2 meters too clearly or more than desirable, mean an unsuccessful office space regardless of its infrastructure.

According to the table, the LEED, BREAM which examine the same criteria, and SBTool Certifications that only examine the range of sound isolation along with having a superficial approach to providing acoustical organisation of a building, also cause the acoustics to be ignored by the low credits given in the scoring system.

CHAPTER SIX

CONCLUSION:

AN ACOUSTIC COMFORT GUIDELINE FOR OPEN PLAN OFFICE TYPE

In this study, firstly, acoustic performance parameters for an open office area and the requirements for sustainability certificates are examined. Then, environmental noise measurements were made in a sample office area within the scope of sustainability, building noise control was provided accordingly, and finally, room acoustic parameters of the open office area were calculated.

The results of the different simulations used during these implementation steps show us that a sustainable office space not fulfilling acoustical requirements will produce quite unsuccessful results in many aspects such as facade selection, noise control, mechanical device vibration control, reverberation time, speech transmission and speech privacy.

The guideline has been defined the necessary headings for the detailed examination and the topics that observed to be missing are detailed. It has been observed that even widely used assessment tools have various deficiencies. For example, important values for open offices such as DL2, U50 are not included in assessment tools. In this situation, the open plan office has incomplete and useless atmosphere. In addition, important studies carried out in the international arena suggest that all the parameters alone are not sufficient and should be evaluated together.

As a result, when the research is broadly examined, it is revealed that if a sustainable open office space is to be acoustically highly productive and have a comfortble room acoustic, the following steps must be taken:

1- Determination of noise measurements and design of noise maps during the design phase of the project site

2- Design and orientation of the building according to building noise analysis

3- Determining the spaces that may create noise in the building and avoiding bringing them together with rooms that have critical objectives in terms of silence

4- Application of buffer zones between mechanical or highly noisy rooms

5- Once the aforementioned precautions have been taken in terms of design; determining the Weighted Standardised Level Difference, followed by selection and application of building elements according to these target values

6- Staying within the Noise Criterion levels inside the office room
7- Using sound masking systems or taking measures such as covering the ventilation pipes with acoustic material if the noise level is high
8- Compliance with the more current and appropriate reverberation time parameters such as EDT and T20 for the open office area
9- Determination of the criteria of the speech parameters required for the venue and selection of sustainable materials with suitable absorption value in order to provide them
Within the scope of the study, while intending to raise awareness about the acoustics and importance of acoustical requirements, acoustical aspects of sustainable building certifications are also addressed.
In this study, calculating phases are determined by various simulation programmes. The reason for this is that these simulations are the ones which gives more realistic results and are also wery well known and accepted by academic environment. Plus, at the definition phase of guideline proposal, these programmes are considered within the framework of principal aplication step criteria. However without these programmes, with the help of known formulas macros could be generated and all calculations could be reach enough. On the other side, the calculations based on emprical formulas could take long time but still may not give the expected results close to reality, are not chosen to be applied in case study either.

In the light of created guidelines, when new office buildings are being evaluated:

• Environmental Noise control

• Building noise control

• Room acoustic

it was revealed that it should be examined in 3 main topics and the guideline that prepared about this topic is expected to be a useful for users. On the other hand, It is understood that the office building discussed with the help of the guideline will be examined in detail from the acoustical direction.

The study explains that how to use the guideline on the example in detailed. Firstly, the noise level of area was measured that be positioned in the open office area and than it was ensured that the building was not affected by this noise. In the second step, the properties of the separating building elements were determined so that the noises inside the building did not pass through adjacent volumes and acoustically strengthened measures have been taken. At the last step, the cabinets that are located around the tables in the open office, is raised to prevent the sound waves from passing the long openings, in order to ensure the appropriate acoustic comfort of the open planned office examined. However, by increasing the sound absorption coefficient of the dividing panels, it is possible to prevent the transmission of the speech sound to the adjacent table. In addition to these, the absorption coefficient of the materials in the volume needs to be rearranged. Because the reverberation time parameter is higher than the limit values. Moreover, it has been observed that the reverberation duration parameter alone is not an adequate evaluation parameter.

On different assessment tools, this guideline can be passed on gradually through the three main titles that are betting. The preconditions and conditions that given in guideline may have different score criteria.

Moreover, the scope of this study is focused on only the certificate programme's inadequacy on acoustic at office environment. Improvement of existing office buildings may be the subject of future studies. Also, ıt is found that these above mentioned certificate programmes are not searching their tasks sufficiently in terms of variables for shopping malls, offices, residences or even at school complexes. However, the draft proposal of guideline that helps us evaluate acoustic requirements could be used in any other structure built for any purposes.

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APPENDIX 1 – Enviromental Noise Map

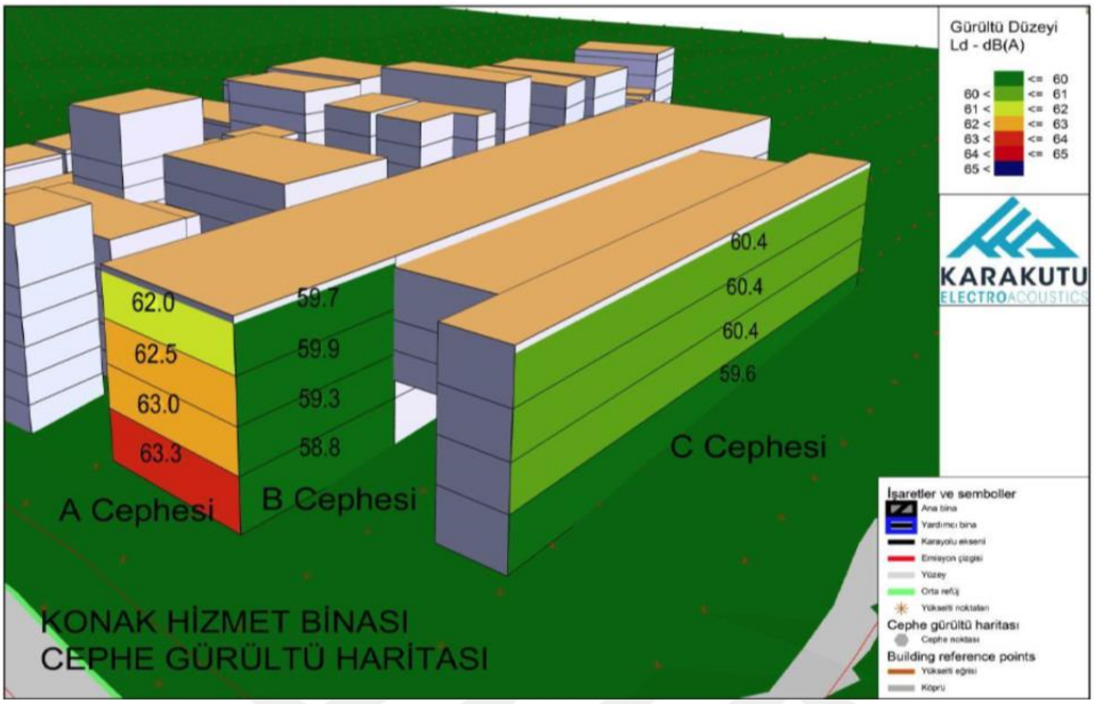


Figure 94 L_{day} Facade Noise Map

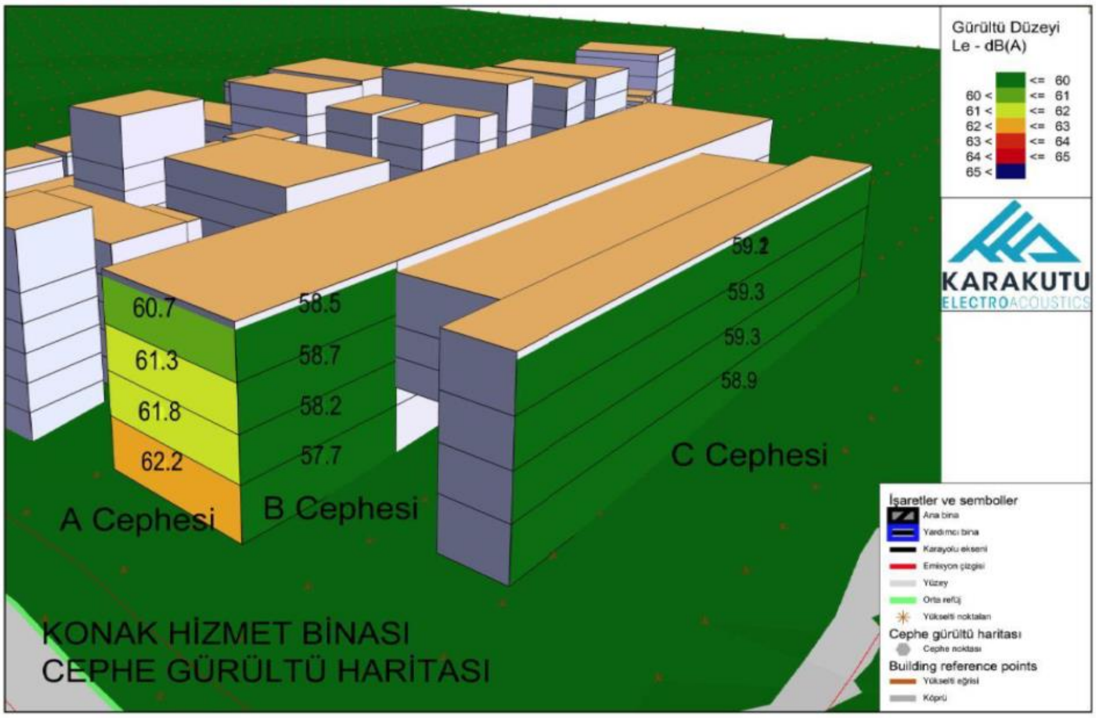


Figure 95 $L_{evening}$ Facade Noise Map

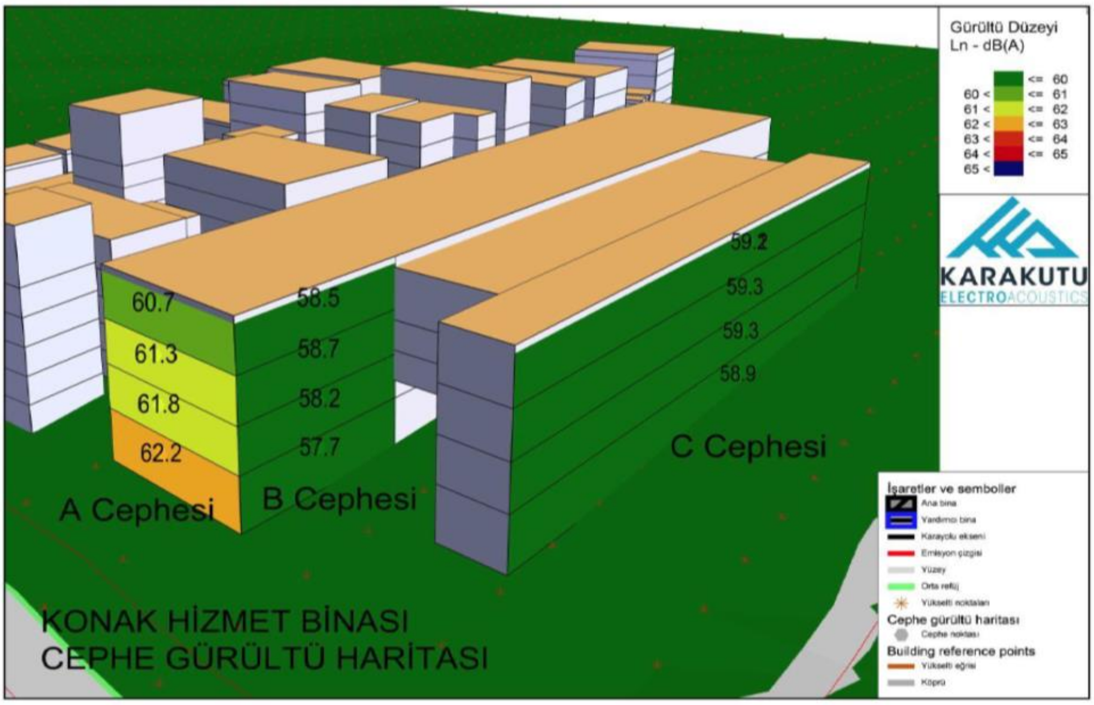


Figure 96 L_{night} Facade Noise Map

1

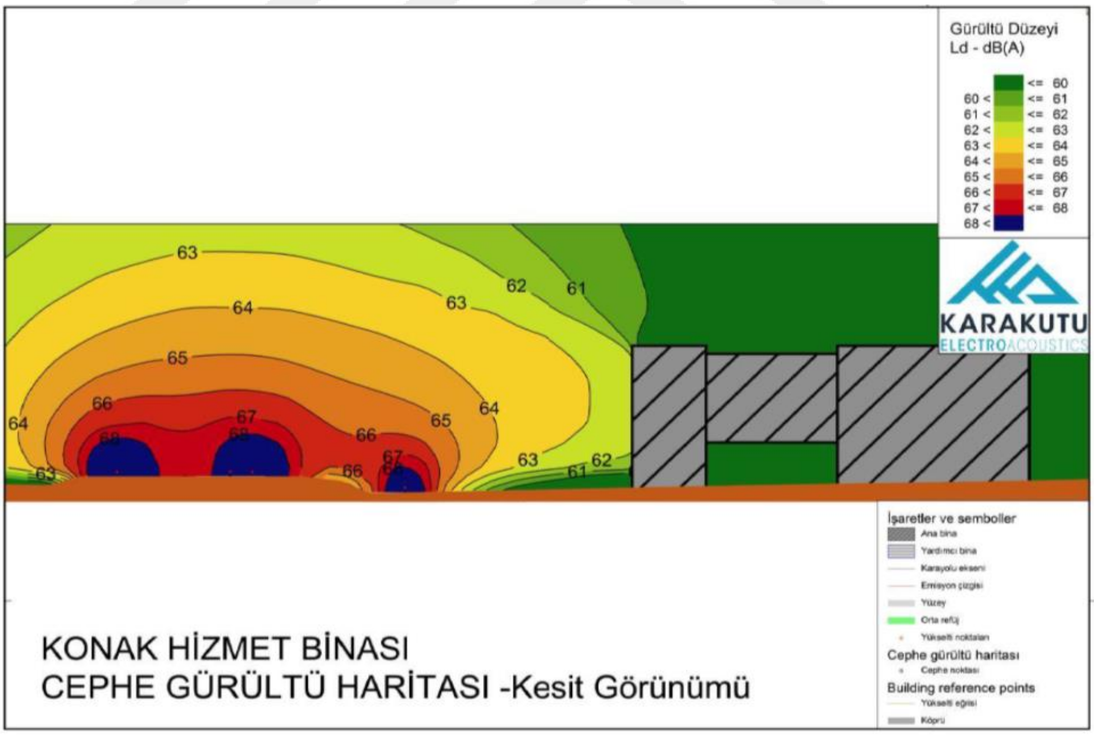


Figure 97 L_{day} Section View of Facade Noise Map

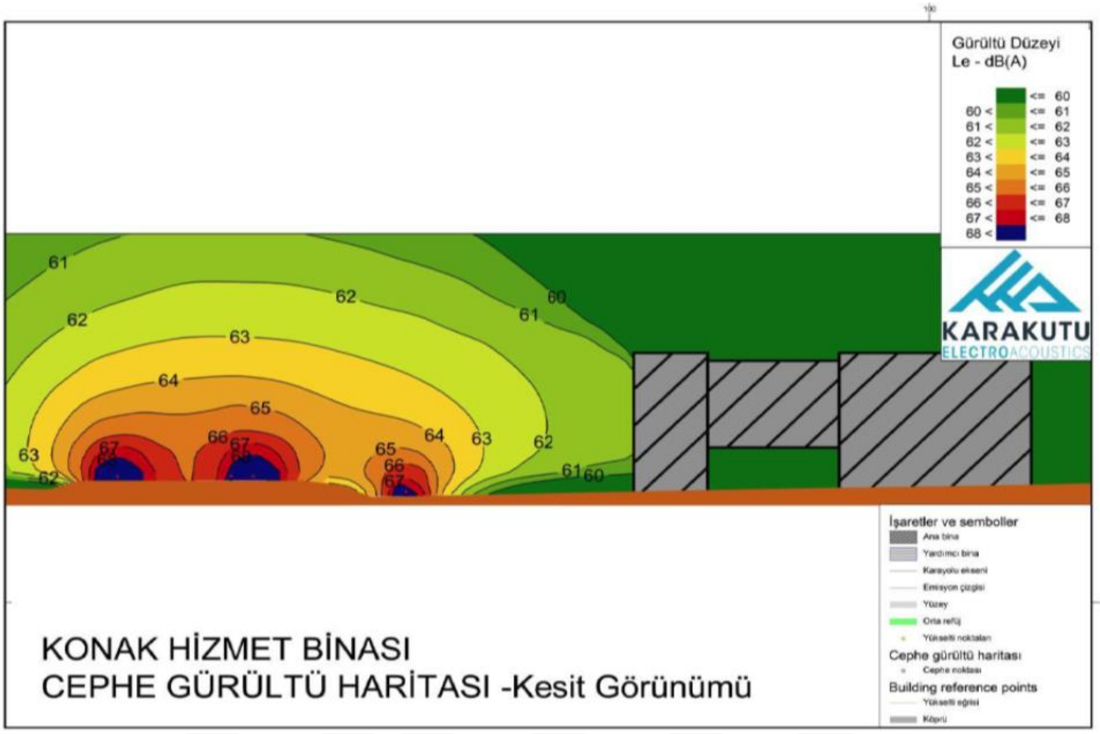


Figure 98 $L_{evening}$Section View of Facade Noise Map

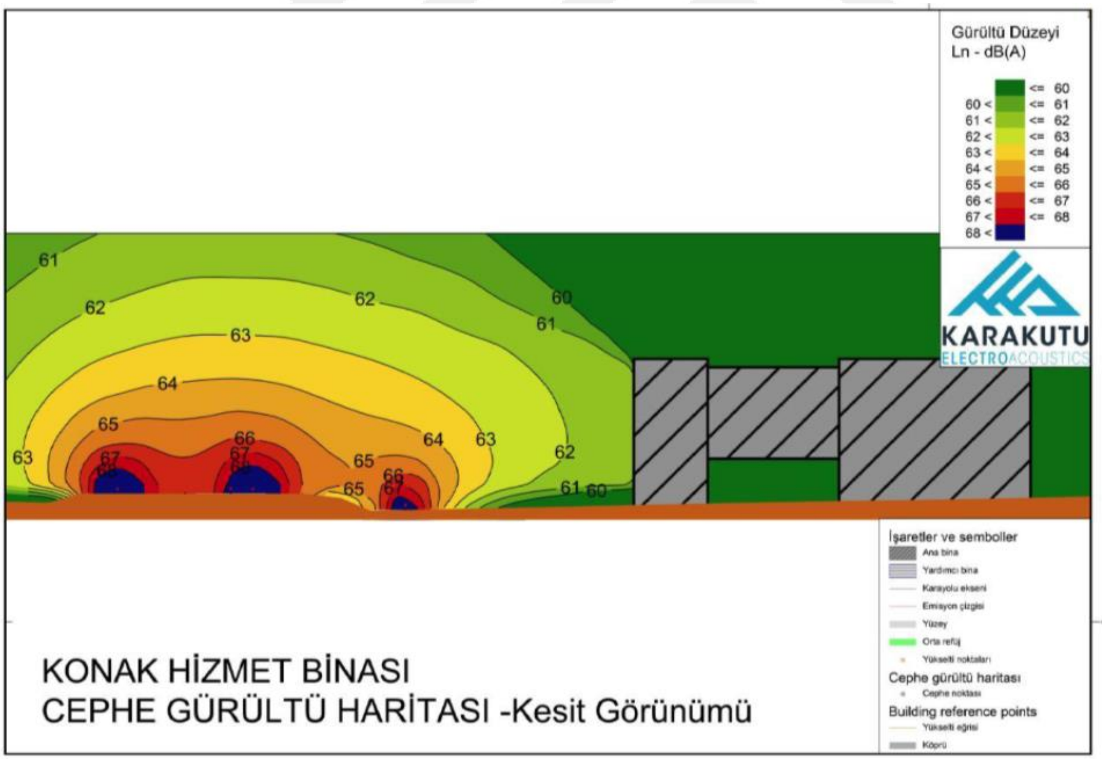


Figure 99 L_{night} Section View of Facade Noise Map

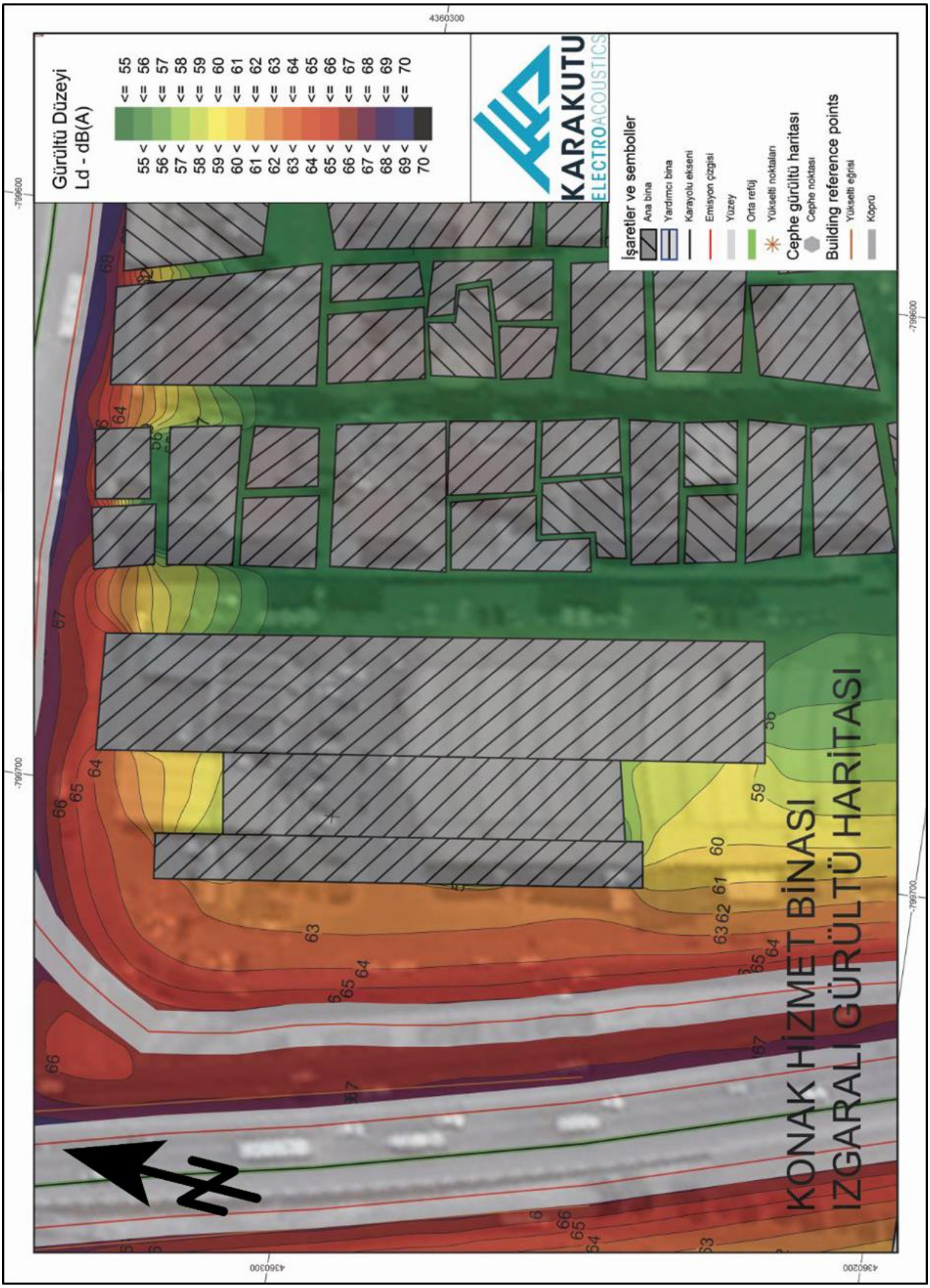


Figure 100 L_{day} Gridal Noise Map

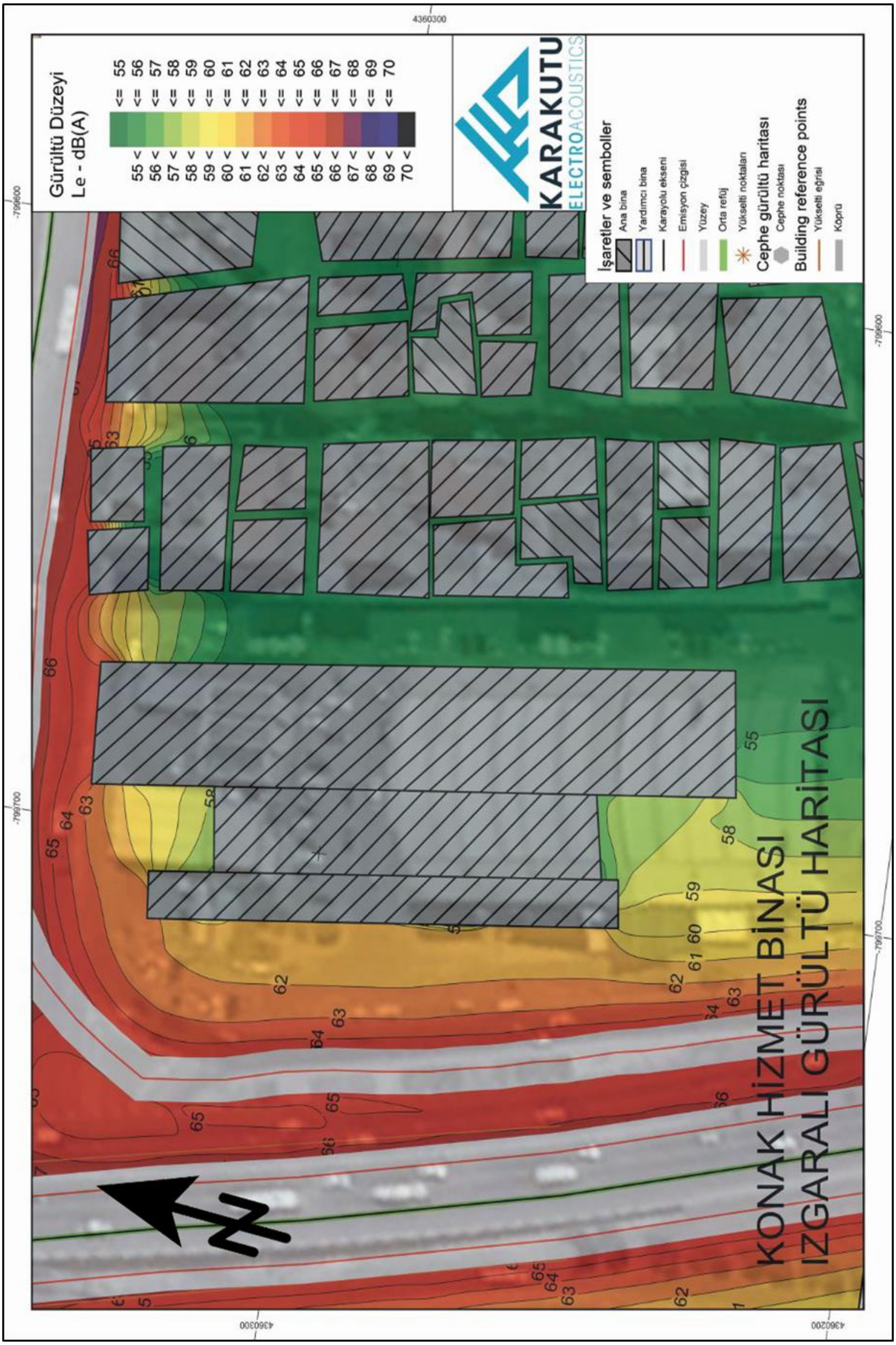


Figure 101 $L_{evening}$ Gridal Noise Map

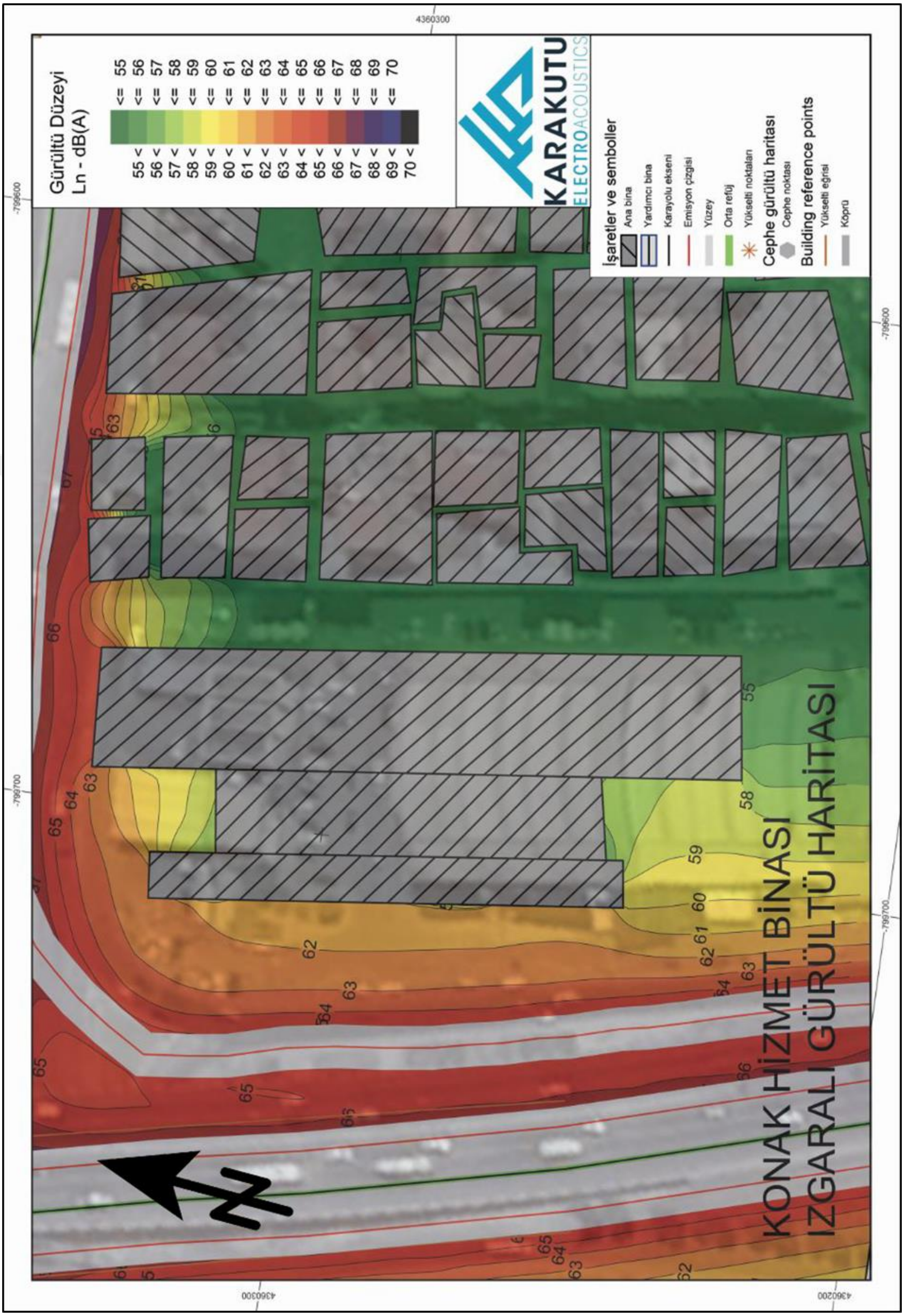


Figure 102 L_{night} Gridal Noise Map

APPENDIX 2 – Sound Insulation Measurement Results Between Spaces

In the below, detailed examples of spaces are presented that are important according to acoustic litarature.

KARAKUTU
ELECTROACOUSTICS

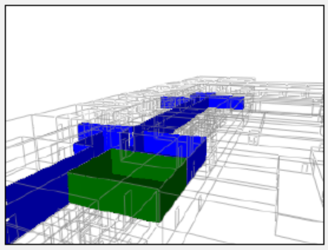
Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3
SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Koridor				
Floor	4	**ID number**	142	**Volume**	1074.30 m³

Receiving Room					
Name					
Unit					
Type	Ihale ve Encumen Salonu				
Floor	4	**ID number**	145	**Volume**	198.91 m³

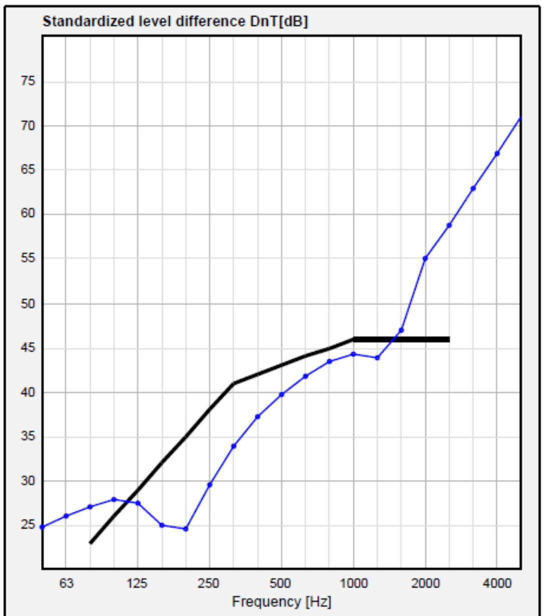


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	26.4
250	28.4
500	39.5
1000	43.9
2000	51.6
4000	66.3

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	42(-2;-6)
50 - 3150 Hz	42(-2;-7)
100 - 5000 Hz	42(-1;-6)
50 - 5000 Hz	42(-1;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	24.9
63	26.2
80	27.2
100	27.9
125	27.6
160	25.0
200	24.6
250	29.6
315	33.9
400	37.2
500	39.8
630	41.9
800	43.5
1000	44.4
1250	43.9
1600	47.0
2000	55.0
2500	58.9
3150	62.9
4000	66.9
5000	71.0



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	42 dB	>	40 dB	MEETS THE REQUIREMENT

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Relationship Between Tender Hall–Corridor

Sound insulation according to EN 12354

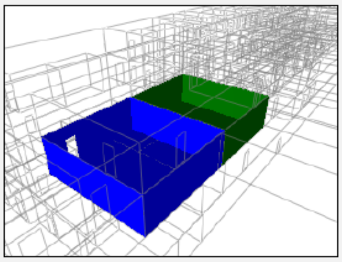
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi			**Ref.**	
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L			**Date**	25.03.2017
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	144	**Volume**	216.27 m³

Receiving Room					
Name					
Unit					
Type	Ihale ve Encumen Salonu				
Floor	4	**ID number**	145	**Volume**	198.91 m³

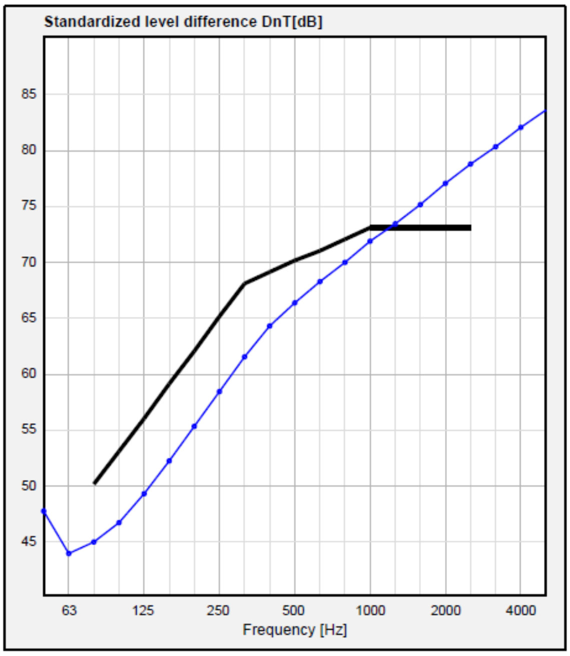


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	49.2
250	58.1
500	66.2
1000	71.7
2000	76.9
4000	82.0

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	69(-2;-7)
50 - 3150 Hz	69(-3;-10)
100 - 5000 Hz	69(-1;-7)
50 - 5000 Hz	69(-1;-10)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	47.6
63	43.9
80	45.0
100	46.6
125	49.3
160	52.2
200	55.3
250	58.4
315	61.4
400	64.2
500	66.3
630	68.1
800	70.0
1000	71.8
1250	73.4
1600	75.1
2000	77.0
2500	78.6
3150	80.3
4000	81.9
5000	83.6



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	69 dB	>	35 dB	MEETS THE REQUIREMENT

Relationship Between Tender Hall–Office

Sound insulation according to EN 12354

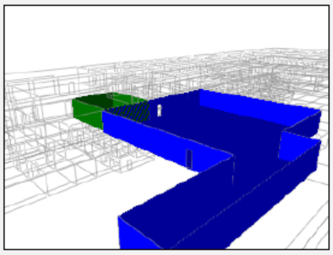
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		Ref.			
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		Date	25.03.2017		
Author		Record	1 of 1	Sheet	1 of 1	

Source Room					
Name					
Unit					
Type	Yemekhane				
Floor	4	ID number	141	Volume	1431.60 m³

Receiving Room					
Name					
Unit					
Type	Ihale ve Encumen Salonu				
Floor	4	ID number	145	Volume	198.91 m³



Airborne sound insulation - Standardized level difference DnT[dB]

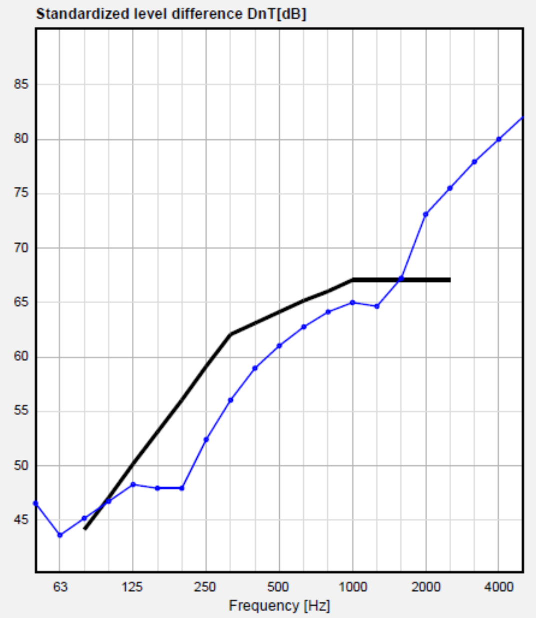
f [Hz]	D_{nT} [dB]
octave bands	
125	47.6
250	51.4
500	60.8
1000	64.6
2000	71.0
4000	79.9

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	63(-1;-5)
50 - 3150 Hz	63(-1;-6)
100 - 5000 Hz	63(0;-5)
50 - 5000 Hz	63(0;-6)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	46.5
63	43.5
80	45.0
100	46.7
125	48.3
160	47.8
200	47.9
250	52.3
315	56.0
400	58.8
500	61.0
630	62.7
800	64.1
1000	64.9
1250	64.6
1600	67.1
2000	73.0
2500	75.5
3150	77.9
4000	80.0
5000	82.0



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	63 dB	>	50 dB	MEETS THE REQUIREMENT

Relationship Between Tender Hall–Restaurant

Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

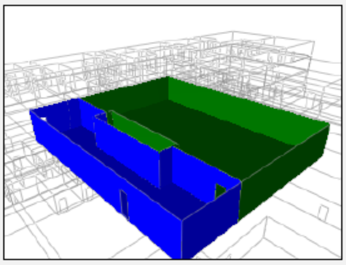
Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room

Name					
Unit					
Type	Nitelikli Servis Alani				
Floor	5	**ID number**	209	**Volume**	251.43 m³

Receiving Room

Name					
Unit					
Type	Meclis Toplanti Salonu				
Floor	5	**ID number**	216	**Volume**	695.01 m³



Airborne sound insulation - Standardized level difference DnT[dB]

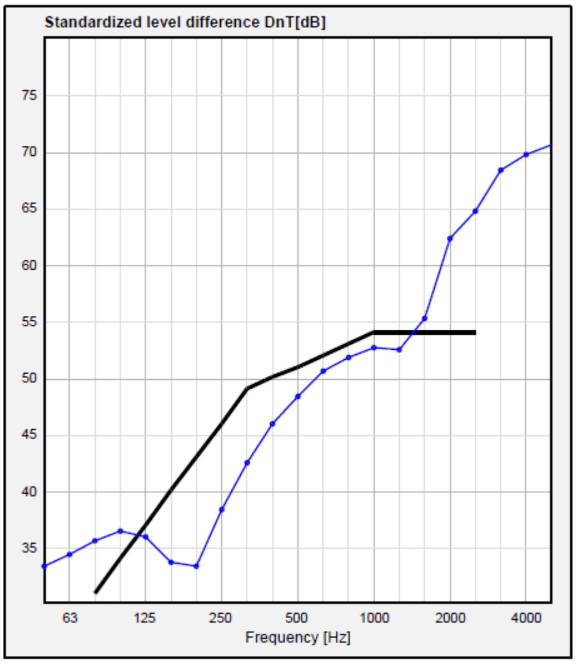
f [Hz]	D_{nT} [dB]
octave bands	
125	35.0
250	37.2
500	48.2
1000	52.4
2000	59.6
4000	69.6

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	50(-1;-6)
50 - 3150 Hz	50(-2;-6)
100 - 5000 Hz	50(0;-6)
50 - 5000 Hz	50(0;-6)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	33.4
63	34.4
80	35.6
100	36.4
125	36.0
160	33.7
200	33.3
250	38.3
315	42.6
400	45.9
500	48.4
630	50.5
800	51.9
1000	52.8
1250	52.4
1600	55.3
2000	62.4
2500	64.8
3150	68.4
4000	69.8
5000	70.6



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	50 dB	>	40 dB	MEETS THE REQUIREMENT

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Relationship Between Council Meeting Room–Special Service Space

Sound insulation according to EN 12354

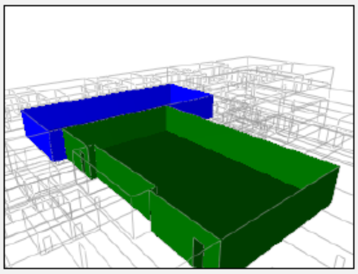
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**			
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017		
Author		**Record**	1 of 1	**Sheet**	1 of 1	

Source Room					
Name					
Unit					
Type	Galeri Boslugu				
Floor	5	**ID number**	215	**Volume**	559.57 m³

Receiving Room					
Name					
Unit					
Type	Meclis Toplanti Salonu				
Floor	5	**ID number**	216	**Volume**	695.01 m³

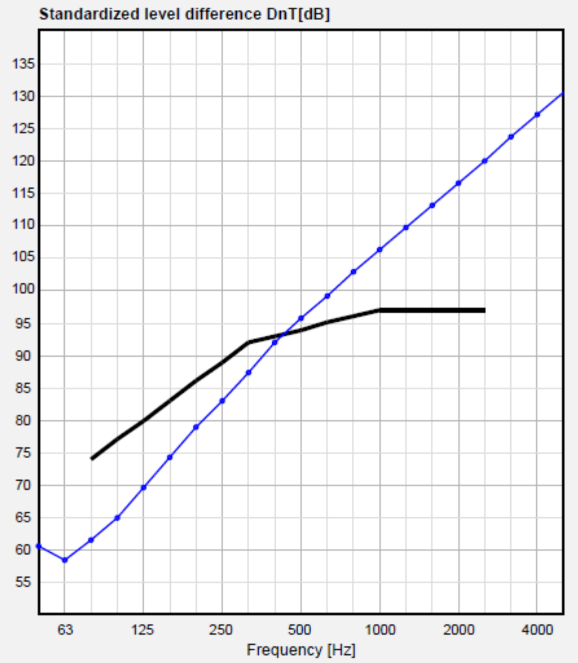


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	68.8
250	82.4
500	95.2
1000	105.8
2000	116.3
4000	126.7

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	93(-3;-10)
50 - 3150 Hz	93(-6;-16)
100 - 5000 Hz	93(-2;-10)
50 - 5000 Hz	93(-5;-16)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	60.6
63	58.5
80	61.7
100	65.1
125	69.6
160	74.3
200	78.9
250	82.9
315	87.5
400	92.0
500	95.7
630	99.2
800	102.8
1000	106.2
1250	109.6
1600	113.2
2000	116.7
2500	120.1
3150	123.6
4000	127.1
5000	130.6



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	93 dB	>	40 dB	MEETS THE REQUIREMENT

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Relationship Between Council Meeting Room–Gallery Space

Sound insulation according to EN 12354

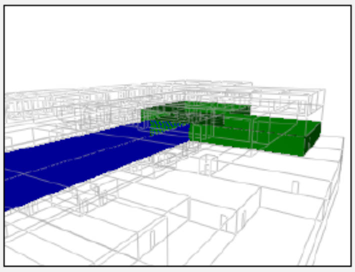
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Galeri Boslugu				
Floor	3	**ID number**	112	**Volume**	1072.00 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	3	**ID number**	131	**Volume**	2529.50 m³



Airborne sound insulation - Standardized level difference DnT[dB]

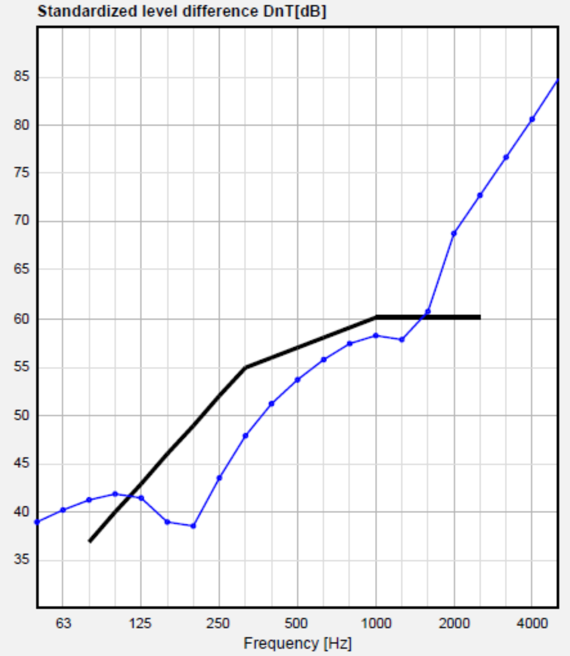
f [Hz]	D_{nT} [dB]
octave bands	
125	40.4
250	42.4
500	53.5
1000	57.8
2000	65.5
4000	80.1

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	56(-2;-6)
50 - 3150 Hz	56(-2;-7)
100 - 5000 Hz	56(-1;-6)
50 - 5000 Hz	56(-1;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	38.9
63	40.2
80	41.3
100	42.0
125	41.6
160	39.0
200	38.6
250	43.6
315	47.8
400	51.1
500	53.7
630	55.8
800	57.4
1000	58.3
1250	57.7
1600	60.8
2000	68.8
2500	72.7
3150	76.7
4000	80.6
5000	84.7



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	56 dB	>	35 dB	MEETS THE REQUIREMENT

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Relationship between Office–Gallery Space

Sound insulation according to EN 12354

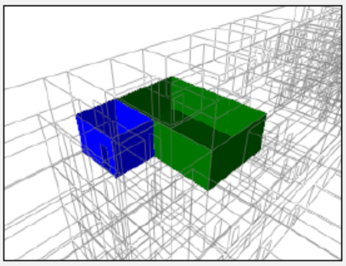
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi			Ref.			
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L			Date	27.03.2017		
Author		Record		1 of 1		Sheet	1 of 1

Source Room					
Name					
Unit					
Type	Genel Servis Alani				
Floor	4	ID number	154	Volume	38.82 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	4	ID number	155	Volume	156.16 m³

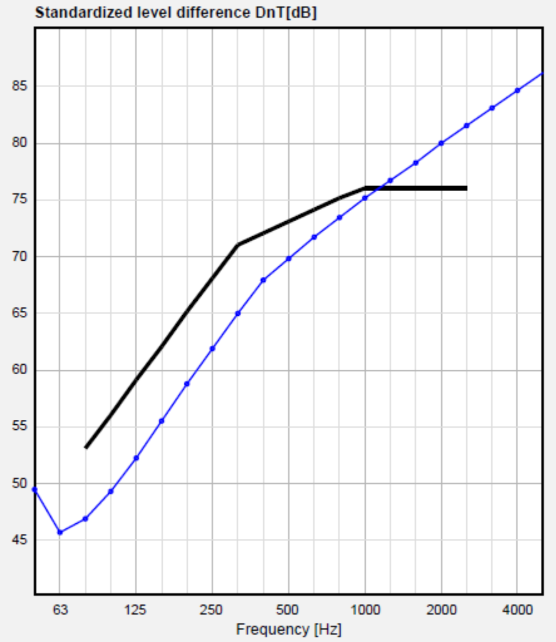


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	52.1
250	61.5
500	69.7
1000	75.0
2000	79.9
4000	84.6

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	72(-2;-7)
50 - 3150 Hz	72(-3;-10)
100 - 5000 Hz	72(-1;-7)
50 - 5000 Hz	72(-1;-10)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	49.4
63	45.6
80	46.9
100	49.3
125	52.2
160	55.4
200	58.6
250	61.9
315	65.0
400	67.8
500	69.8
630	71.6
800	73.3
1000	75.0
1250	76.6
1600	78.2
2000	79.8
2500	81.4
3150	83.0
4000	84.5
5000	86.1



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	72 dB	>	40 dB	MEETS THE REQUIREMENT

Relationship between Office–General Service Space

Sound insulation according to EN 12354

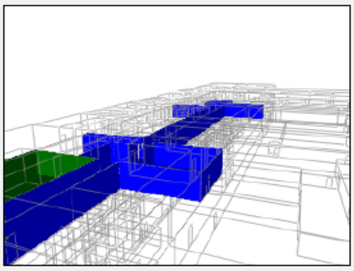
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Koridor				
Floor	4	**ID number**	142	**Volume**	1074.30 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	143	**Volume**	433.98 m³

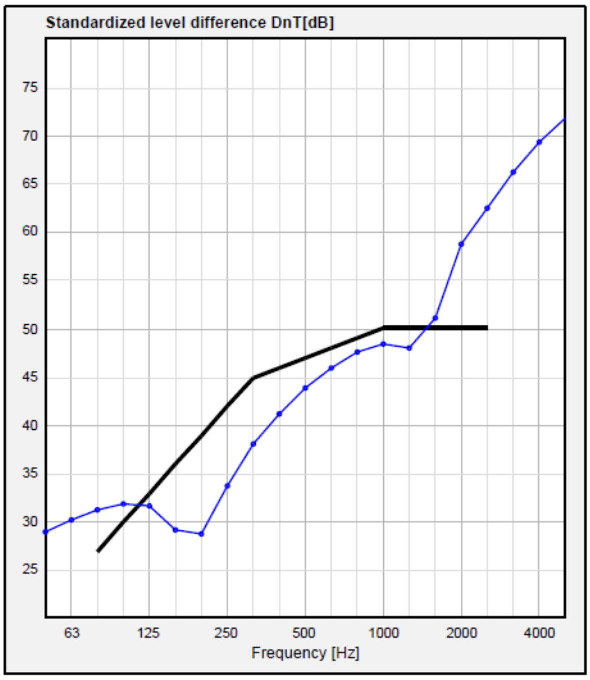


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	30.5
250	32.6
500	43.7
1000	48.0
2000	55.7
4000	69.0

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	46(-2;-6)
50 - 3150 Hz	46(-2;-7)
100 - 5000 Hz	46(0;-6)
50 - 5000 Hz	46(-1;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	28.9
63	30.2
80	31.3
100	32.0
125	31.6
160	29.1
200	28.7
250	33.7
315	38.0
400	41.3
500	43.9
630	46.0
800	47.6
1000	48.5
1250	48.0
1600	51.0
2000	58.9
2500	62.4
3150	66.3
4000	69.4
5000	71.9



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	46 dB	>	35 dB	MEETS THE REQUIREMENT

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Relationship between Office–Corridor

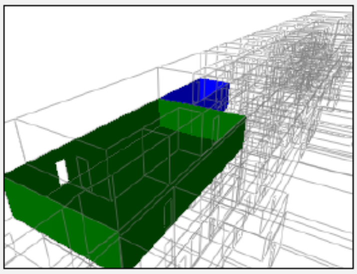
Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3
SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi			**Ref.**			
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L			**Date**	25.03.2017		
Author		**Record**	1 of 1	**Sheet**	1 of 1		

Source Room					
Name					
Unit					
Type	Merdiven				
Floor	4	**ID number**	147	**Volume**	98.04 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	143	**Volume**	433.98 m³



Airborne sound insulation - Standardized level difference DnT[dB]

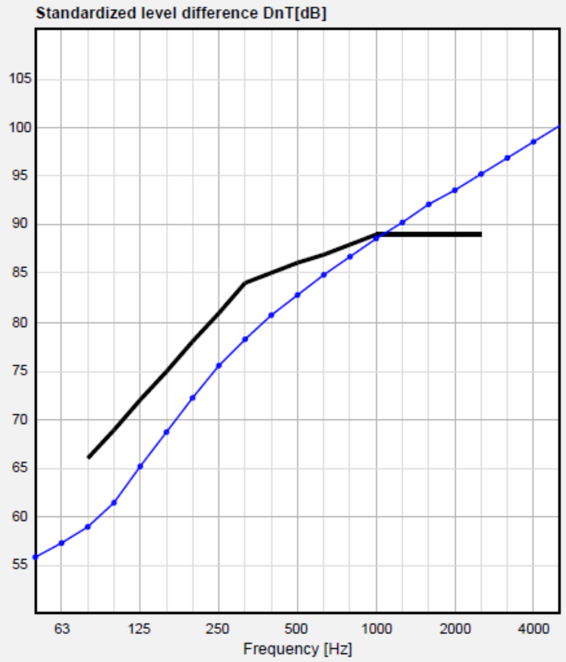
f [Hz]	D_{nT} [dB]
octave bands	
125	64.7
250	75.1
500	82.8
1000	88.5
2000	93.7
4000	98.6

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	56.0
63	57.3
80	58.9
100	61.5
125	65.1
160	68.7
200	72.2
250	75.5
315	78.2
400	80.7
500	82.8
630	84.9
800	86.7
1000	88.5
1250	90.2
1600	92.0
2000	93.6
2500	95.2
3150	96.9
4000	98.5
5000	100.1

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	85(-2;-7)
50 - 3150 Hz	85(-3;-11)
100 - 5000 Hz	85(-1;-7)
50 - 5000 Hz	85(-2;-11)



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	85 dB	>	45 dB	MEETS THE REQUIREMENT

Relationship between Office–Stairway

Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

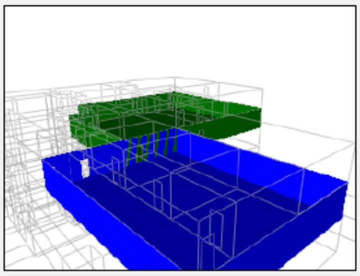
Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room

Name					
Unit					
Type	Nitelikli Servis Alani				
Floor	4	**ID number**	164	**Volume**	903.21 m³

Receiving Room

Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	173	**Volume**	1400.80 m³



Airborne sound insulation - Standardized level difference DnT[dB]

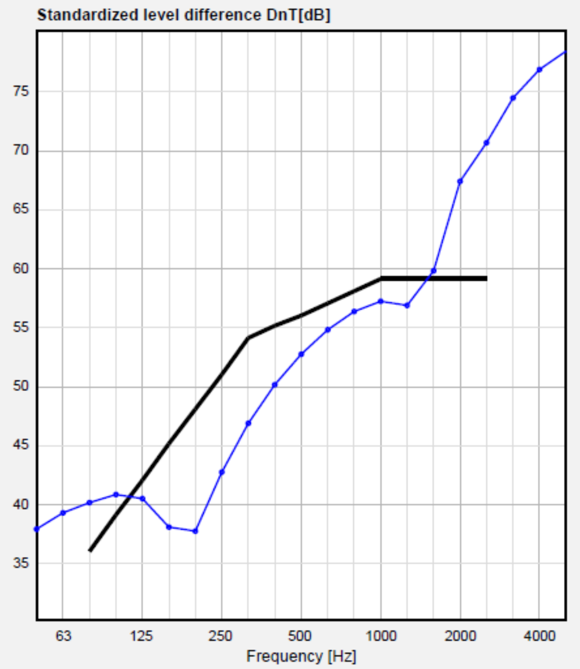
f [Hz]	D_{nT} [dB]
octave bands	
125	39.4
250	41.4
500	52.5
1000	56.8
2000	64.3
4000	76.5

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	55(-2;-6)
50 - 3150 Hz	55(-2;-7)
100 - 5000 Hz	55(-1;-6)
50 - 5000 Hz	55(-1;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	37.8
63	39.1
80	40.2
100	40.9
125	40.5
160	38.0
200	37.6
250	42.6
315	46.9
400	50.2
500	52.7
630	54.8
800	56.3
1000	57.2
1250	56.8
1600	59.7
2000	67.4
2500	70.5
3150	74.3
4000	76.7
5000	78.3



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	55 dB	>	40 dB	MEETS THE REQUIREMENT

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Relationship between Office–Special Service Space

Sound insulation according to EN 12354

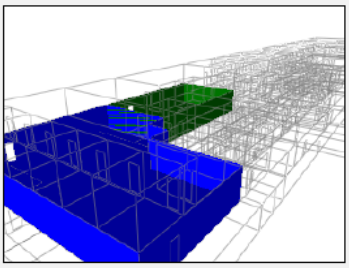
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi			**Ref.**			
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L			**Date**	27.03.2017		
Author			**Record**	1 of 1	**Sheet**	1 of 1	

Source Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	139	**Volume**	831.68 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	143	**Volume**	433.98 m³

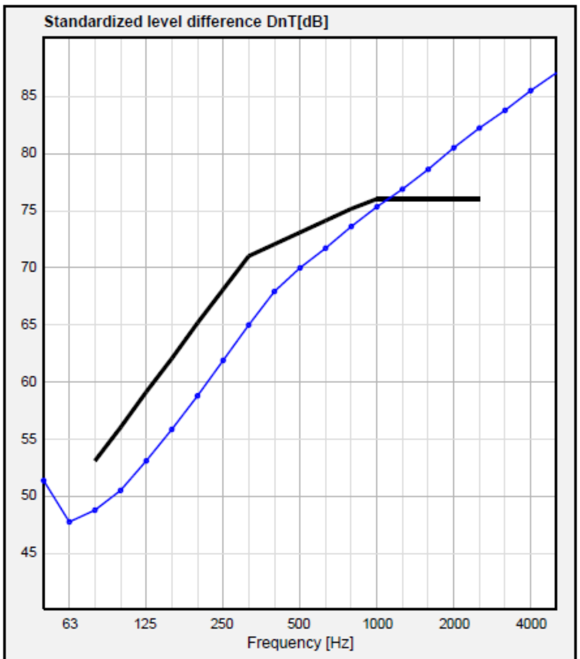


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	52.9
250	61.6
500	69.8
1000	75.2
2000	80.4
4000	85.4

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	72(-2;-7)
50 - 3150 Hz	72(-2;-9)
100 - 5000 Hz	72(0;-7)
50 - 5000 Hz	72(-1;-9)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	51.3
63	47.7
80	48.6
100	50.4
125	53.0
160	55.7
200	58.7
250	61.9
315	65.0
400	67.8
500	69.9
630	71.7
800	73.5
1000	75.3
1250	76.9
1600	78.6
2000	80.5
2500	82.1
3150	83.8
4000	85.4
5000	87.0



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	72 dB	>	35 dB	MEETS THE REQUIREMENT

Relationship between Office-Office

Sound insulation according to EN 12354

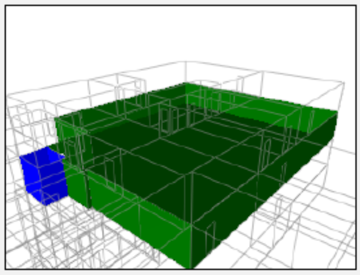
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	25.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Saft				
Floor	4	**ID number**	171	**Volume**	17.61 m³

Receiving Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	173	**Volume**	1400.80 m³

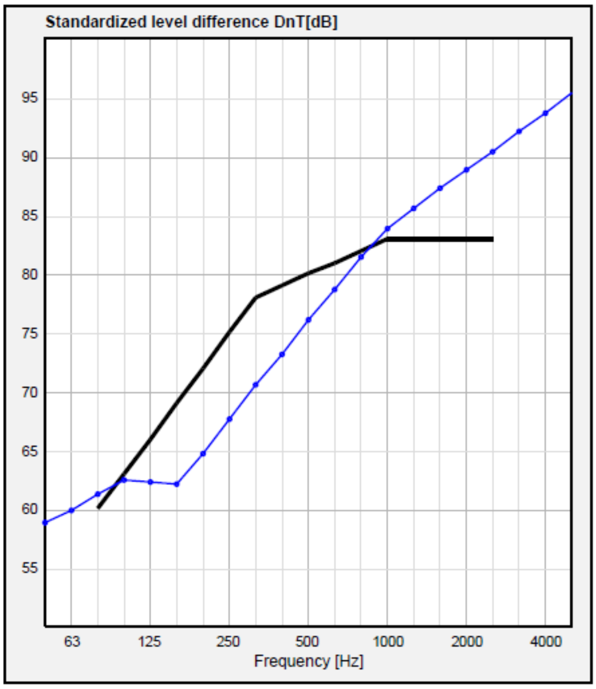


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	62.3
250	67.5
500	75.9
1000	83.6
2000	88.9
4000	93.8

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	79(-1;-6)
50 - 3150 Hz	79(-2;-7)
100 - 5000 Hz	79(0;-6)
50 - 5000 Hz	79(0;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	58.9
63	59.9
80	61.3
100	62.5
125	62.3
160	62.2
200	64.7
250	67.7
315	70.6
400	73.3
500	76.1
630	78.8
800	81.5
1000	83.9
1250	85.6
1600	87.3
2000	88.8
2500	90.5
3150	92.1
4000	93.7
5000	95.4



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	79 dB	>	40 dB	MEETS THE REQUIREMENT

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Relationship between Office–Shaft

Sound insulation according to EN 12354

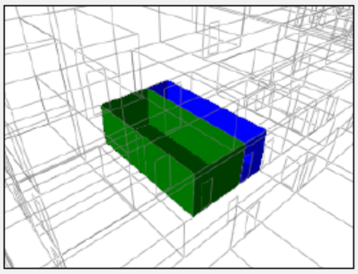
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Ofisler				
Floor	1	**ID number**	33	**Volume**	52.09 m³

Receiving Room					
Name					
Unit					
Type	Teknik Hacim				
Floor	1	**ID number**	32	**Volume**	100.10 m³



Airborne sound insulation - Standardized level difference DnT[dB]

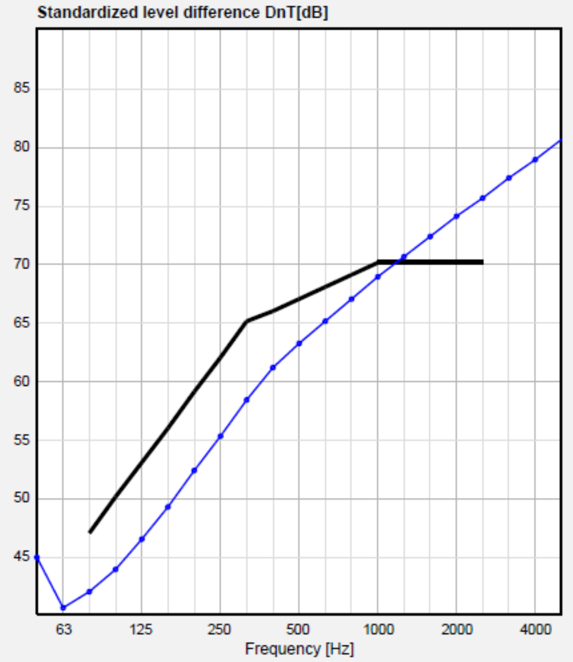
f [Hz]	D_{nT} [dB]
octave bands	
125	46.4
250	55.1
500	63.2
1000	68.8
2000	74.0
4000	79.0

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	44.9
63	40.6
80	42.0
100	43.8
125	46.5
160	49.2
200	52.3
250	55.3
315	58.3
400	61.1
500	63.3
630	65.1
800	67.0
1000	68.8
1250	70.5
1600	72.2
2000	74.0
2500	75.6
3150	77.3
4000	78.9
5000	80.6

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	66(-2;-7)
50 - 3150 Hz	66(-3;-10)
100 - 5000 Hz	66(-1;-7)
50 - 5000 Hz	66(-1;-10)



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	66 dB	>	60 dB	MEETS THE REQUIREMENT

Relationship between Office–Technic Room

Sound insulation according to EN 12354

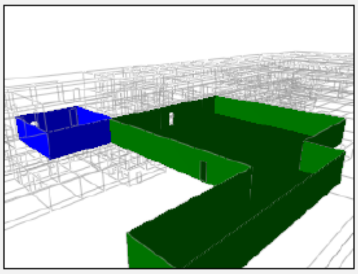
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Ofisler				
Floor	4	**ID number**	144	**Volume**	216.27 m³

Receiving Room					
Name					
Unit					
Type	Yemekhane				
Floor	4	**ID number**	141	**Volume**	1431.60 m³



Airborne sound insulation - Standardized level difference DnT[dB]

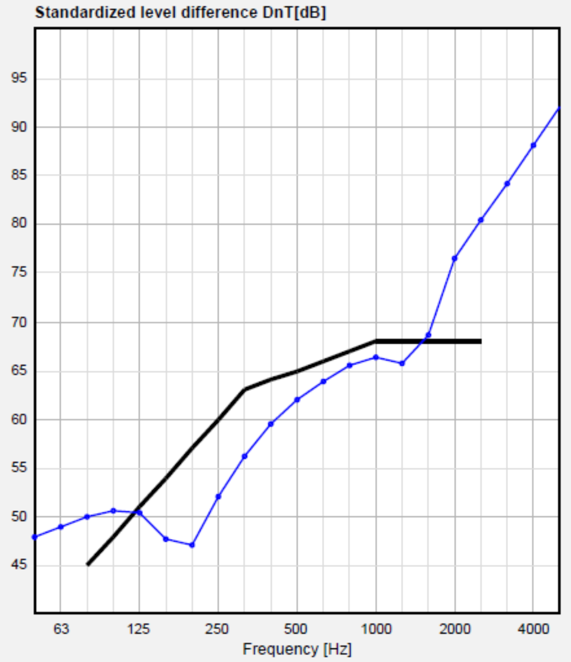
f [Hz]	D_{nT} [dB]
octave bands	
125	49.1
250	51.0
500	61.8
1000	65.8
2000	73.3
4000	87.6

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	47.9
63	49.0
80	50.0
100	50.7
125	50.3
160	47.7
200	47.2
250	52.1
315	56.3
400	59.5
500	62.0
630	64.0
800	65.5
1000	66.3
1250	65.7
1600	68.7
2000	76.6
2500	80.4
3150	84.3
4000	88.1
5000	92.1

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	64(-2;-6)
50 - 3150 Hz	64(-2;-6)
100 - 5000 Hz	64(0;-6)
50 - 5000 Hz	64(0;-6)



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	64 dB	>	50 dB	MEETS THE REQUIREMENT

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Relationship between Office–Restaurant

Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi			**Ref.**	
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L			**Date**	27.03.2017
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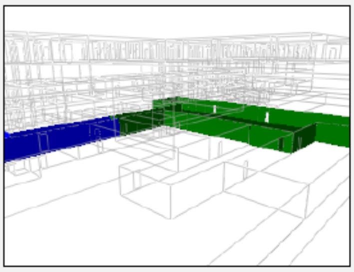
Source Room					
Name					
Unit					
Type	Koridor				
Floor	1	**ID number**	19	**Volume**	229.71 m³

Receiving Room					
Name					
Unit					
Type	Otopark				
Floor	1	**ID number**	35	**Volume**	1788.60 m³



Airborne sound insulation - Standardized level difference DnT[dB]

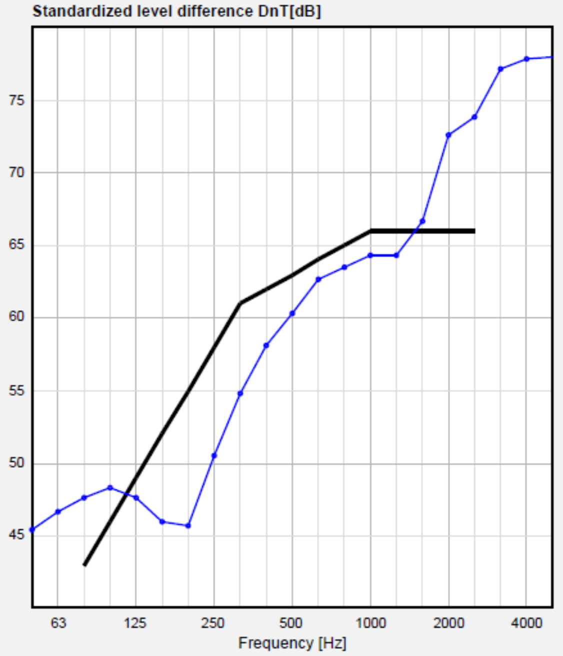
f [Hz]	D_{nT} [dB]
octave bands	
125	47.0
250	49.5
500	60.3
1000	64.1
2000	70.4
4000	77.7

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	45.5
63	46.7
80	47.6
100	48.3
125	47.7
160	46.0
200	45.7
250	50.6
315	54.8
400	58.1
500	60.3
630	62.7
800	63.5
1000	64.3
1250	64.4
1600	66.7
2000	72.7
2500	73.8
3150	77.2
4000	77.8
5000	78.1

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	62(-1;-5)
50 - 3150 Hz	62(-1;-6)
100 - 5000 Hz	62(0;-5)
50 - 5000 Hz	62(0;-6)



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	62 dB	>	35 dB	MEETS THE REQUIREMENT

Relationship between Corridor–Parking area

Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
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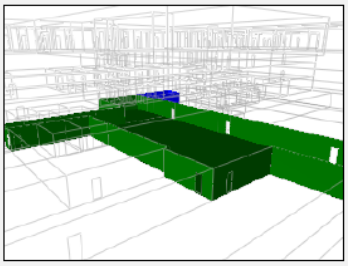
Source Room					
Name					
Unit					
Type	Merdiven				
Floor	1	**ID number**	50	**Volume**	94.62 m³

Receiving Room					
Name					
Unit					
Type	Otopark				
Floor	1	**ID number**	35	**Volume**	1788.60 m³

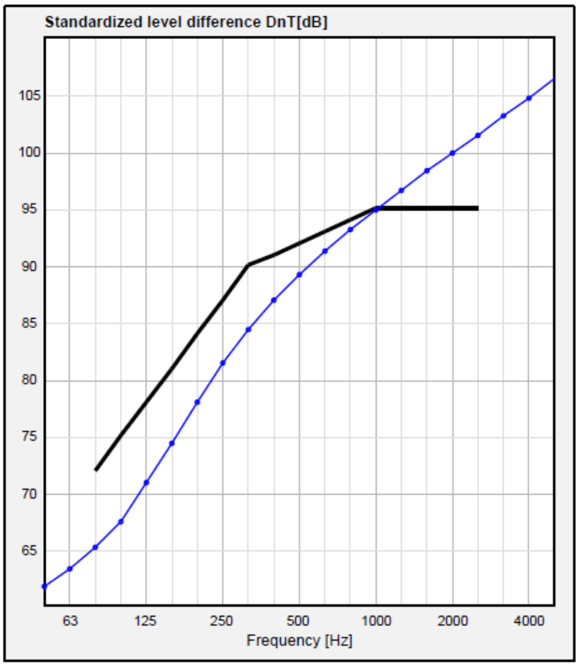


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	70.6
250	81.0
500	89.1
1000	94.9
2000	100.0
4000	104.8

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	91(-2;-7)
50 - 3150 Hz	91(-3;-11)
100 - 5000 Hz	91(-1;-7)
50 - 5000 Hz	91(-2;-11)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	61.8
63	63.3
80	65.2
100	67.6
125	70.9
160	74.4
200	78.1
250	81.5
315	84.4
400	86.9
500	89.2
630	91.3
800	93.2
1000	94.9
1250	96.6
1600	98.4
2000	100.0
2500	101.5
3150	103.2
4000	104.7
5000	106.4



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	91 dB	>	45 dB	MEETS THE REQUIREMENT

Relationship between Stairway–Parking area

Sound insulation according to EN 12354

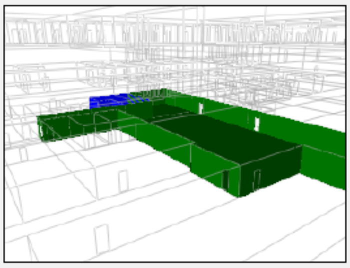
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		Ref.		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		Date	27.03.2017	
Author		Record	1 of 1	Sheet	1 of 1

Source Room					
Name					
Unit					
Type	Teknik Hacim				
Floor	1	ID number	44	Volume	166.85 m³

Receiving Room					
Name					
Unit					
Type	Otopark				
Floor	1	ID number	35	Volume	1788.60 m³

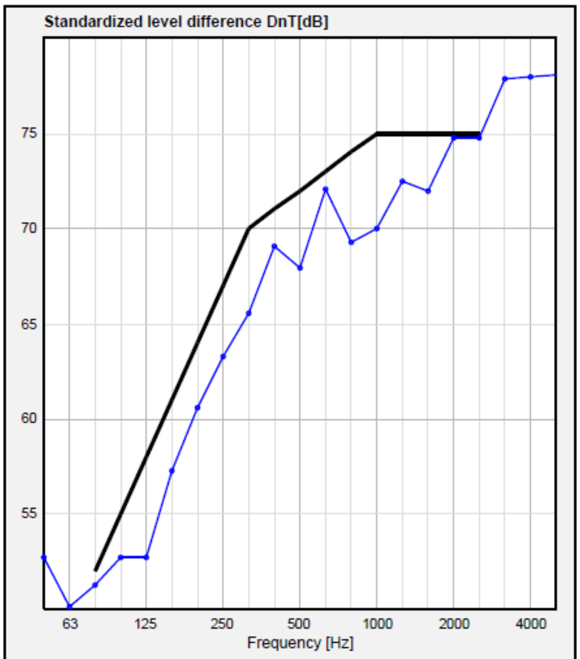


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	54.1
250	63.1
500	69.6
1000	70.6
2000	73.9
4000	78.0

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	71(-1;-5)
50 - 3150 Hz	71(-2;-7)
100 - 5000 Hz	71(0;-5)
50 - 5000 Hz	71(-1;-7)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	52.8
63	50.1
80	51.3
100	52.7
125	52.7
160	57.3
200	60.6
250	63.3
315	65.6
400	69.1
500	68.0
630	72.1
800	69.3
1000	70.0
1250	72.5
1600	72.0
2000	74.8
2500	74.8
3150	77.8
4000	78.0
5000	78.0



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	71 dB	>	55 dB	MEETS THE REQUIREMENT

Relationship between Technic Room –Parking area

Sound insulation according to EN 12354

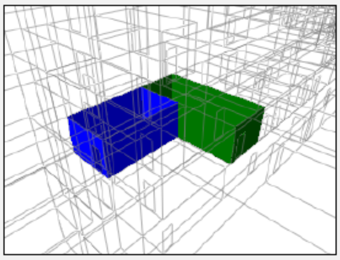
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Genel Servis Alani				
Floor	1	**ID number**	29	**Volume**	79.80 m³

Receiving Room					
Name					
Unit					
Type	Teknik Hacim				
Floor	1	**ID number**	32	**Volume**	100.10 m³

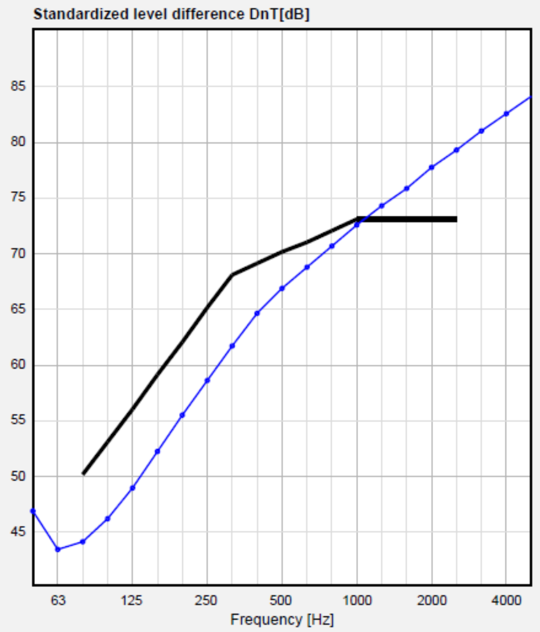


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	48.8
250	58.3
500	66.7
1000	72.4
2000	77.6
4000	82.5

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	69(-2;-7)
50 - 3150 Hz	69(-3;-10)
100 - 5000 Hz	69(-1;-7)
50 - 5000 Hz	69(-1;-10)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	46.8
63	43.4
80	44.1
100	46.1
125	48.9
160	52.1
200	55.4
250	58.6
315	61.7
400	64.5
500	66.8
630	68.7
800	70.6
1000	72.4
1250	74.2
1600	75.8
2000	77.6
2500	79.2
3150	80.9
4000	82.5
5000	84.1



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	69 dB	>	55 dB	MEETS THE REQUIREMENT

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Relationship between Technic Room -General Services space

Sound insulation according to EN 12354

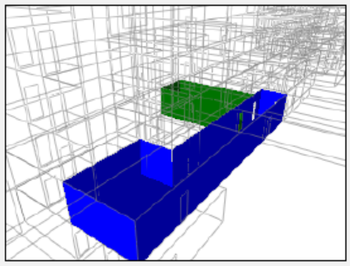
Airborne sound insulation calculation record according EN 12354-1,3

SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Koridor				
Floor	1	**ID number**	19	**Volume**	229.71 m³

Receiving Room					
Name					
Unit					
Type	Teknik Hacim				
Floor	1	**ID number**	32	**Volume**	100.10 m³



Airborne sound insulation - Standardized level difference DnT[dB]

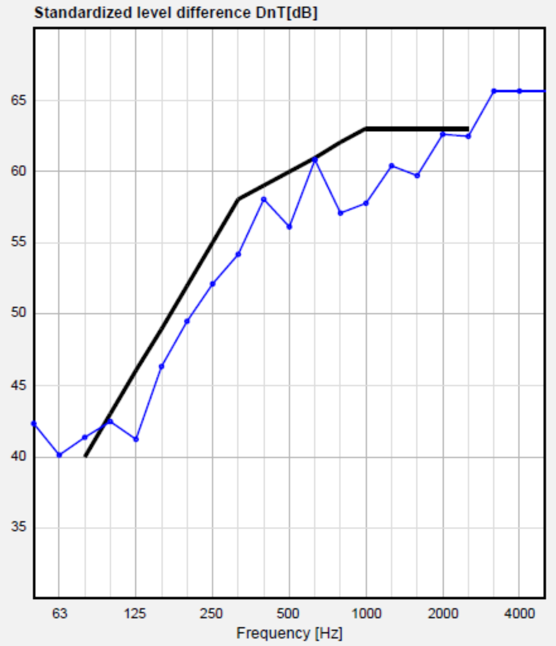
f [Hz]	D_{nT} [dB]
octave bands	
125	43.1
250	51.9
500	58.1
1000	58.5
2000	61.6
4000	65.7

Single-number quantity

ISO 717-1:1996

Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	59(-1;-4)
50 - 3150 Hz	59(-1;-6)
100 - 5000 Hz	59(0;-4)
50 - 5000 Hz	59(0;-6)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	42.3
63	40.1
80	41.4
100	42.5
125	41.2
160	46.3
200	49.6
250	52.1
315	54.2
400	58.1
500	56.1
630	60.9
800	57.2
1000	57.8
1250	60.4
1600	59.7
2000	62.6
2500	62.5
3150	65.6
4000	65.7
5000	65.7



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	59 dB	>	55 dB	MEETS THE REQUIREMENT

Relationship between Technic Room - Corridor

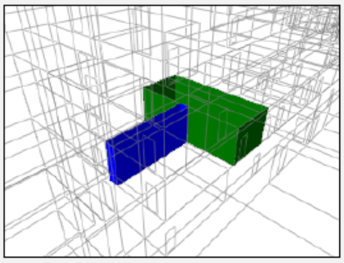
Sound insulation according to EN 12354

Airborne sound insulation calculation record according EN 12354-1,3
SONarchitect ISO Professional v2.4.14

Project	Konak Belediyesi Hizmet Binasi		**Ref.**		
Organisation	KARAKUTU ELEKTROAKUSTIK PROJE UYGULAMA SAN. VE TIC. L		**Date**	27.03.2017	
Author		**Record**	1 of 1	**Sheet**	1 of 1

Source Room					
Name					
Unit					
Type	Saft				
Floor	1	**ID number**	28	**Volume**	14.96 m³

Receiving Room					
Name					
Unit					
Type	Teknik Hacim				
Floor	1	**ID number**	32	**Volume**	100.10 m³

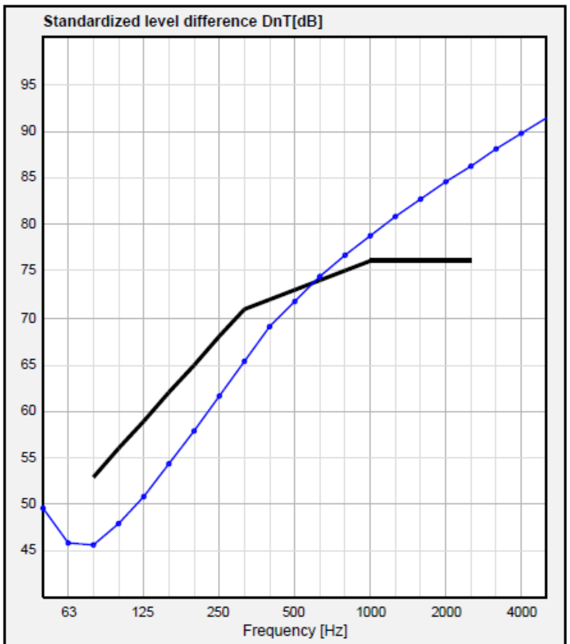


Airborne sound insulation - Standardized level difference DnT[dB]

f [Hz]	D_{nT} [dB]
octave bands	
125	50.8
250	61.2
500	71.6
1000	78.8
2000	84.6
4000	89.7

Single-number quantity ISO 717-1:1996	
Frequency [Hz] Range	$D_{nT,w}$(C;Ctr)
100 - 3150 Hz	72(-2;-8)
50 - 3150 Hz	72(-3;-11)
100 - 5000 Hz	72(-1;-8)
50 - 5000 Hz	72(-2;-11)

f [Hz]	D_{nT} [dB]
one-third octave bands	
50	49.6
63	45.9
80	45.7
100	48.0
125	50.9
160	54.4
200	58.0
250	61.6
315	65.3
400	69.0
500	71.9
630	74.4
800	76.7
1000	78.9
1250	80.9
1600	82.8
2000	84.6
2500	86.3
3150	88.1
4000	89.7
5000	91.3



Fulfilment of requirements

Parameter	Calculation		Requirement	Fulfillment statement
DnTw	72 dB	>	55 dB	MEETS THE REQUIREMENT

Relationship between Technic Room - Shaft