EFFECTS OF SPEECH INTELLIGIBILITY ON COMPUTER-BASED TASK PERFORMANCE IN OPEN-PLAN OFFICES

A THESIS
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By
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May, 2008

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ABSTRACT

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M.F.A. in Interior Architecture and Environmental Design

Supervisor: Assist. Prof. Dr. Semiha Yılmazer

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The aim of this thesis is to find out the effects of speech and speech intelligibility on computer-based task performance in open-plan offices. The research was conducted in a real open-plan office environment to include the open-office experience of subjects to the analysis. STM Bilkent Office was selected as the case, and 40 available open-office occupants were participated to the study. The experiment consists of three main phases. In the first phase, real-size measurement of selected open-office area within STM Bilkent was analyzed to understand effects of divider panels on acoustical situation of the room, and to check the reliability of the computer simulation. In the second phase, acoustical simulation of the site was done, to derive distribution graphs for speech related room acoustics parameters. In the last phase, occupants computer-based task performances were tested under three different sound environments, which are continuous noise, speech and masked speech. According to statistical analysis of performance test, and acoustical properties of the case STM, suggestions for renovation were discussed and tested in computer simulation. It was found that, effects of intelligible speech on occupants task performance is only psychological, because it is significant that there is no difference between results of performance test. However, all of the occupants respond to the questionnaires that speech sound environment was the most distracting one. Proposal for renovation was given to minimize the effects of intelligible speech on occupants for preventing the long-term effects on occupants' health.

Keywords: Room Acoustics, Open-Plan Office, Task Performance, Speech Intelligibility, Speech Privacy, Acoustical Simulation

ÖZET

KONUŞMA ANLAŞILABİLİRLİĞİNİN AÇIK OFİSLERDE BİLGİSAYAR TABANLI İŞ VERİMİNE ETKİSİ

Kıvanç Kitapcı

İç Mimarlık ve Çevre Tasarımı Bölümü, Yüksek Lisans

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Bu çalışmanın amacı, anlaşılabilir konuşmanın açık ofis çalışanlarının bilgisayar tabanlı iş verimi üzerindeki etkilerini incelemektir. Araştırma, çalışanların açık ofise alışkanlık etkisinide göz önüne almak amacı ile gerçek bir ofis ortamında gerçekleştirilmiştir. STM Bilkent ofisinde gerçekleştirilen çalışmaya, bu ofisi kullanan 40 kişilik bir grup katılmıştır. Araştırma üç ana aşamadan oluşmaktadır. İlk aşamada STM Bilkent binasından seçilen açık ofis alanının yerinde akustik ölçmleri, bölücü panoların ofis alanının akustik özellikleri üzerindeki etkisini anlamak ve akustik benzetimin güvenilirliğini sağlamak amacıyla gerçekleştirilmiştir. İkinci aşamada, mekanın akustik benzetimi, konuşma ile ilgili oda akustiği değerlerinin dağılım grafiklerini elde etmek için yapılmıştır. Üçüncü aşamada katılımcılara konuşma, maskelenmiş konuşma ve sabit gürültü olmak üzere üç farklı ses ortamı altında bilgisayar tabanlı çalışma verimi testi uygulanmıştır. Test sonuçlarının istatistiksel çözümlemesi ve akustik ölçümlerden alınan sonuçların ışığı altında, STM açık ofis alanı için çözüm önerileri sunulmuştur. Verim testinin sonuçlarına gore, konuşmanın açık ofis çalışanları üzerindeki etkisi sadece psikolojiktir. Fakat, test sonrasında verilen anketlere gore, katılımcılar en çok rahatsız oldukları ses ortamını konuşma olarak belirtmişlerdir. İç mekandaki değişiklik önerileri, stresin çalışanlar üzerinde yaratabileceği uzun vadeli etkileri düşünülerek sunulmuştur.

Anahtar Sözcükler: Oda Akustiği, İş Performansı, Konuşma Anlaşılabilirliği, Konuşma Gizliliği, Akustik Benzetim

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1. INTRODUCTION

Today, open-plan offices are the most popular office type, mostly because of organizational and economic reasons. An early explanation of open-plan offices was given by Oldham and Brass as, "…it is generally characterized by the absence of interior walls and rooms, which, in conventional 'multi-cellular' offices, define private work spaces" (1979, p. 267). Brennan, Chugh and Kline (2002) list different types of office designs, private offices to open offices. They also divide design complexity as the 'bull pen' in that the desks are arranged in neat rows to 'landscaped' offices, which include systems furniture and dividers. Open-plan offices generally consist of workstations, which can be separated by screens or divider panels. They decrease the required area per occupant, leading to economical savings, and changing the layout of the space is easy to carry out. Organizations cover the economic arguments for choosing an open-plan office by emphasizing the other features of open-plan offices, for instance spaciousness, refreshing and modern architectural design, improved communication and relationships, better flow of information, greater sense of work involvement, and shorter distances to common spaces (Hongisto, 2005).

There are three key elements that affect occupant satisfaction in office environments: thermal comfort, lighting and acoustics (Wang and Bradley, 2002a). According to Venetjoki, Kaarlela-Tuomaala, Keskinen and Hongisto (2006), work performance can decrease because of office noises. Mostly, environmental effects on work performance caused by poor acoustical conditions, poor speech privacy and difficulties in concentration caused by unwanted speech, are not taken seriously because the expected economic and organizational benefits are so evident in open-plan offices (Hongisto, 2005).

Coexistence of activities with various noise emission and need for quietness or privacy in the same area can distract open-plan office occupants in high levels. Dividers in an open-plan office contribute to a good acoustical comfort and improved speech privacy. Also, by using an absorbent ceiling, the noise between two adjacent working places can considerably be reduced. They contribute to obtain a short reverberation time, too (Desarnaulds, 2007).

To measure speech privacy, The Articulation Index (AI) and its replacement the Speech Intelligibility Index (SII) are frequently used. Very low speech intelligibility (SII<0.20 or AI<0.15) causes acceptable speech privacy in open-plan offices (Bradley and Gover, 2004). Hongisto explains the difference between speech intelligibility index and speech transmission index, stating that the “speech intelligibility is a subjective measure that has been traditionally measured in rooms by listening tests. During the test, an educated person is talking and listeners write down what they hear. Speech intelligibility is the average percent of correct answers. It is typically different for syllables, words or sentences. The direct measurement of speech intelligibility is time consuming and expensive. Physical measurement methods are developed to avoid the need of real audience, e.g. Speech Transmission Index, STI” (2005, p. 459). Salter, Powell, Begault and Alvarado (2003) investigates designers' point of view to the subject, which those calculation procedures are not widely used among design community. Underlying reasons are given like unfamiliar measurement units and concepts, the specialized testing equipment required for prototype and in stu evaluations, etc.

One way of achieving speech privacy in open-plan office environments is explained by Mohammad, Hassanain and Harkness, so that the "Speech privacy may be readily achieved in private offices. Speech privacy in open-planned offices requires the introduction of carefully specified masking noise. For optimum efficiency, suitable masking noise cannot be assumed to be available from a background hubbub of chatter or from music" (2000, p. 52). Salter, Powell, Begault and Alvarado (2003) support this idea by explaining electro-acoustical solutions for sound masking, which is placing loudspeakers in the ceiling. Masking noise in office environments is called 'white noise', because it covers all frequencies in the sound spectrum, which can override disturbing components of office noise. However, conversations become less intelligible; the use of white noise becomes an additional sound stimulus, which increases sound pressure level of the ambient noise (Loewen, 1992).

Hongisto developed a model using the results of the existing literature for predicting the effect of speech on work performance. The model predicts that the complex task performance can be reduced by 7% when STI is higher than 0.60, but speech does not affect work performance when STI is below 0.2. Three factors should be considered according to Hongisto's predicting model (2005): high room absorption, high screens, and appropriate speech masking. Same rules are used for avoiding noisy activities and achieve speech privacy in open-plan offices. Oldham and Brass focuses on other aspects of acoustical treatments, stating that “However, before any design element is introduced, its relationship to important work outcomes should already have been investigated” (1979, p. 283).

Wang and Bradley (2002a, 2002b) do extended researches, for predicting speech intelligibility in open-plan offices. First study is about single screen dividers and second study is about privacy between two adjacent rectangular workstations. Wang and Bradley (2002a) studied on a mathematical model between two adjacent workstations by using image source technique. Problem is divided into two parts as single screen model and side-back panel model. Those models are investigated in three varying workstation orientation. Results have been tested by an experiment in National Research Council (Canada). This research does not include the effects of furnishing. Second study of Wang and Bradley (2002b) is about predicting the speech intelligibility index behind single screen in an open-plan office. A sound source and a receiver are used for calculating speech intelligibility index (SII). The effect of wall, ceiling and floor reflections on SII is discussed. Again, prepared mathematical model is tested on real situations.

Jones, Miles and Page’s (1990) study finds out that irrelevant speech restricts lower level of analysis performance such as detection of contextual errors in proofreading tasks were not affected by speech; however detecting non-contextual errors are impaired. Longitudinal field study of Brennan, Chugh and Kline (2002) points out that the major problems stated by employees are the lack of privacy and increased noise. Hongisto (2005) listed various tasks of work performance such as proofreading, short-term memory, reading comprehension, etc. In most of those cases, subjects are affected by intelligible speech. Banbury and Berry's (1998) experiment analyzed memory and arithmetic tasks, which are called 'office-related' tasks. Results show that the irrelevant speech reduces memory for prose and mental arithmetic task performance impressively. In the second experiment performance reduced about one-third of the quite environment. Another sequence of five experiments was presented by Salame (1982), which are dealing with phonological similarity effects of irrelevant speech on short-term memory of visually represented digits. However, there is no evidence of testing various task performances in real open-plan office environments that all of the participants are experienced and familiar with the environment.

1.1. Aim and Scope

The aim of the study is to understand the effects of speech and speech intelligibility on computer based task performance in open-plan offices. Examining if the performance of open-office workers differ in variable sound environments such as speech, masked speech, and continuous noise to understand ideal acoustical conditions of an open-plan office in terms of speech and speech intelligibility in a real office environment. Additionally current acoustical situation of the site STM Bilkent Headquarters is analyzed and solutions are discussed under the guidance of task performance test results.

It is expected that there are some significant short and/or long-term effects on occupants of open-plan offices. Also, STM Bilkent Headquarters case allows understanding the direct relation between the experience of working in an open-plan office environment and distraction of speech. The findings of the experiments may show distraction caused by intelligible speech on experienced open-plan office occupants.

Acoustical analysis of the case will provide detailed information on the blocking effectiveness of divider panels, and distribution of direct sound and reflections in a typical open-plan office environment. The difference between derived room acoustics parameters from acoustical simulation of present and renovated open-plan office should give an idea about appropriate open-plan office settings.

1.2. Structure of the Thesis

The thesis is composed of five chapters. First chapter is the introduction, which explains the open-plan office concept, acoustical problems that may occur, ways of occupant satisfaction, and previous studies that are conducted to find the affects on speech on varying task performances. Also, some studies about predicting methods for speech intelligibility were briefly explained.

Second chapter gives the requirements for speech intelligibility in open-plan offices. Firstly, spatial requirements, which are properties of divider panels or screens, ceilings, luminaries, floor materials and layout, are discussed in detail. Reasons of deciding major construction details of main elements are explained by giving the connections with objective room acoustic properties. Secondly, those objective room acoustic parameters are explained. Definitions of the parameters and requirements for open-plan offices are stated.

In the third chapter, phases of the experiment are explained. Firstly, aim of the experiment, research questions and hypothesis are given. Secondly, methods used in three phases of the experiment are given in detail. Thirdly, the site of case study and sample group are identified. Evaluations of three phases of the experiment are conducted. Lastly, analysis of the results derived from the experiment is done according to requirements of ideal open-plan office environment. Effects of speech and speech intelligibility on computer based task performance of STM Bilkent occupants are analyzed and acoustical characteristics of the site are discussed.

In the forth chapter, recommendations to improve occupant satisfaction and acoustical conditions in the site are given. Connections between room acoustics parameters and architectural solutions are explained. To be more reliable, results of the acoustical simulation of the renovated site are stated.

In the fifth chapter, the experiment is summarized, and conclusions are given. Also, suggestions on further studies are given.

2. SPEECH PRIVACY REQUIREMENTS IN OPEN-PLAN OFFICES

Speech itself is a part of sound in open-plan office environments with other sounds like footsteps, traffic noise, telephone rings, etc. The difference between other sound sources and speech is the meaning it carries. Distraction of work performance derives from its form of information, which is automatically processed by human cognitive system (Loewen, 1992). The attention of workers on their tasks hardly, if another source of information reach to their cognitive system. According to environmental load approach theory, "… individuals experiencing environmental stimulus bombardment may focus their attention exclusively on one stimulus or task, to the detriment of others" (Loewen, 1992, p. 382).

As Hongisto (2005) stated, both in open-plan offices and in conventional ones designer should aim at lower speech intelligibility for improved work performance. Also, design of the layout gain great importance because of psychological reasons like 'privacy'. Workers of open-plan office have a potential to make private conversations and chat between workstations. Salter, Powell, Begault and Alvarado (2003) support that issue about cubicle layouts, which streets' in between these cubicles become a natural conversation area. Therefore, to protect workers of open-plan offices from short-term task performance effects and long-term health issues, both spatial and acoustical requirements have to be considered in the design process. The spatial requirements also provide room acoustics parameters to match the ideal levels of speech privacy.

2.1 Spatial Requirements

Besides economical reasons, the major aim of using open-plan office design is improved communication and social interaction between office workers. Therefore, design of the layout and partitioning has a great importance to achieve an adequate level of communication. However, poor acoustical conditions are not taken seriously because of organizational benefits (Hongisto, 2005). Croon, Sluiter, Kuijer and Frings (2005) also point out that not only work performance, but also occupant health is affected by the new open-plan office concept. Open plan offices may increase distraction and irritability, and may affect the health office worker in the longer term. Also, personal one-on-one conversations may be distracting, where they would be preferred not to be overheard. Therefore, the aim of the design should be increasing speech privacy (Newsham, 2005).

To construct an open-plan office with improved acoustical conditions, a great attention should be given to specific details. Divider panels between workstations, floor and ceiling materials should be selected carefully to fulfill the speech privacy requirements of an open-plan office. Requirements of speech privacy are given by Mohammad, Hassanain and Harkness (2000) as: Protection from both intelligible and non-intelligible speech, protection from other noises such as office equipment, and a level of background noise, which masks private conversations. The suggestions of partitioning properties and material selections of surfaces to achieve ideal acoustical conditions in open-plan office environments will be discussed under this chapter.

2.1.1. Partitions

The main element that defines acoustical satisfaction in an open-plan office area is partitions, which can be either drywalls that separate open-plan office area with other volumes, or divider panels between adjacent workstations. Partitions should provide an appropriate level of visual and acoustical privacy for improved working conditions.

First requirement for partitions is the noise reduction coefficient (NRC). The aim should be blocking direct sound energy of speech and reducing the background noise level generated by outer sound sources. Extraneous sounds can distract a listener. All kinds of natural background masking noise should be controlled in the area. Using sound-absorbent material as finishing will be more effective for achieving speech privacy (Mohammed, Hassanain and Harkness, 2000). Also, sound blocking performance and NRC of doors is crucial for decreasing natural background noise and to minimize transmission of airborne sound.

Divider panels are mostly used for achieving an ideal level of speech privacy in open-plan offices by blocking the direct path of sound between workstations. They are usually open-weave, fabric-covered panels consisting of sound-absorbing material installed on opposite sides of an airtight hardboard or aluminum foil core. The sound transmission loss of the panel construction normally should not exceed 25 dB because its overall performance is limited by diffraction of sound energy over the top and around the sides. Larger divider panels and close distance between occupants and panels increase the overall sound transmission performance (Egan, 1988).

To block direct sound energy before reaching to the adjacent workspace, divider panels should be higher than heads of seated workers. Panels with enough height will also block visual communication between workstations; therefore will increase visual privacy (Newsham, 2005). Chusid states that partitions lower than 150 cm in height cannot block the sound energy efficiently, because the height is not enough to reach an average standing adult. However, the height of the divider panels should not exceed the psychological limit of closeness, especially if the workstations are small. Occupational stress that is caused by working in narrow cells may affect occupants' health in a long-term.

Last point to consider is the layout of divider panels and location of workstations in the area. The high-traffic areas of circulation may distract occupants' concentration because of one-on-one conversations and chat on those areas. Also, footsteps are one of the most distracting noise sources in an open-plan office. According to Newsham (2005) to prevent those factors, especially entrances of workstations should be away from circulation areas. Circulation areas between workstations should be as minimum as possible, and the distribution of workstations has to be distributed evenly around those areas. Also, size of every workstation should be as big as possible; therefore distance between adjacent workstations will increase to achieve speech privacy.

2.1.2. Materials

Material selections for floor, wall and divider panels are the key element for most of the room acoustics parameters. To achieve speech privacy all of the surface areas should be treated accordingly. Larger areas like ceilings and floors have a great impact on reverberation time and direct sound energy, which is closely related with speech intelligibility.

Absorption coefficients of ceiling surfaces should be highest at speech frequencies that are 1000 Hz., 2000 Hz, and 4000 Hz, because, sound energy can be reflected by ceiling surfaces over divider panels toward adjacent workspaces (Egan, 1988). Ceiling surfaces should be absorbent, for instance has an absorption coefficient of 0.9 or higher (Mohammed *et al,* 2000). This will have an effect on the level of reflected speech sounds. As a floor material, carpet may be an obvious choice for absorbing sound. Another issue is the impact noise that is generated by circulation traffic, therefore low impact noise floor covering materials should be considered to decrease the noise of footsteps, moving chairs, etc. The percentage of sound reflecting and sound absorbing materials should be decided according to desired level of reverberation time (Newsham, 2005). Lighting fixtures are also closely related with the absorption properties of ceiling surfaces. Ceiling-mounted fixtures with large flat lenses should not be used to prevent bouncing noise from one workstation to another (Chusid, 2001).

Wall surfaces should also be partially sound absorbent to ensure that the only speech sound perceived is direct sound from speaker to listener. Reflections of the speech sound reinforce the sound energy to move between adjacent workstations. This decision is again depends on desired acoustical condition, for instance, using artificial background noise generators require lower reverberation times, but to achieve speech privacy without using masking noise, reverberation time should be higher.

Partitions that are dividing open-plan office area from outer space should have an appropriate level of STL. Most applications of multiple layers of plasterboards with steel framing achieve ideal STL characteristics for office environments. Masonry walls may also be used to divide interior volumes, however, detailed attention must be given to floor and ceiling connections. As stated before, internal doors and windows should match the STL values of walls to prevent natural background noise.

Except those suggestions, the major importance should be given to administrative solutions in the organization. The social behavior of occupants directly affects speech privacy in open-plan office environments. Newsham (2005) claims that speech should be carried on at a level that provides just perceivable intelligibility and this is related with the occupant behavior in the office. However, open planning may not be suitable in cultures where visual and speech privacy are at high levels of importance.

2.2. Acoustical Requirements

The requirements of speech intelligibility are based on four room acoustics parameters; reverberation time, clarity, definition and speech transmission index. Those objective requirements define characteristics of speech in the space. Objective measures are the connection between design and subjective effect. Objective acoustic terms describe created sound field at the listener’s position according to the behavior of sound in rooms. With the help of objective measures, it can be established how design determines the sound field and how ear will then interpret it (Barron, 1993).

Contrary to other halls of music and speech, in open-plan offices, the aim should be low speech intelligibility or in other words, better speech privacy. The measurements of objective criteria could be found by equations, measurements or computer simulations, in order to evaluate acoustical characteristics of the volume.

2.2.1. Reverberation Time

General scientific description of reverberation time is the time is required for sound energy to decay 60 dB after the sound source stopped. Today, reverberation time is the major acoustical parameter that defines acoustical characteristics of a room, and it is usually constant throughout the space (Barron, 1993).

There are three formulas for calculating the reverberation time. Those are Sabine formula, Eyring formula, and Millington-Sette formula. The Sabine formula is mostly used for live fields that have an average sound absorption coefficient of 0.3 or below. If the field is considered dead, which has an average absorption coefficient greater than 0.3, either Eyring, or Millington-Sette formula can be used. Eyring formula should be used if surfaces of the volume have similar sound absorption coefficients. Millington-Sette formula can even be used for fields that have variable surface materials, with different sound absorption coefficients (Caliskan, 39). Those formulas are;

Sabine Formula:

RT = (0.163 V) / ($\alpha_i S_i$ + nA_p +4mV) (Caliskan, 39)

Millington-Sette Formula:

RT = (0.163 V) / $\sum -S_i \ln(1 - \alpha_i) + nA_p + 4mV$ (Caliskan, 39)

Where,

- V is volume of the room,
- S_i is the surface area,
- -ln (1 - α_i) is the sound absorption coefficient of the material i
- n is the number of people in the volume
- Ap is the sound absorption of every person
- m is the energy reduction coefficient caused by humidity, temperature and frequency

Reverberation time requirement for offices is generally known as below 0.5 seconds, but in open-plan offices, there need to be a sufficient level of reverberation time to decrease intelligibility of speech. This ideal RT is based on the level of background noise and masking system in the open-plan office area. Offices with natural or electro-acoustical background noise need lower reverberation time in order to achieve speech privacy, however offices with lower background noise levels needs more reverberation time.

2.2.2. Clarity (C80)

Second room acoustics parameter that is connected with speech intelligibility is clarity of the sound in the field. Clarity can be defined as the ratio of early sound energy to late or reverberant sound energy. Early-arriving reflected sound energy is the main parameter that defines clarity of sound. Early sound is usually defined as the direct and reflected sound arriving within 80 ms (Egan, 1988). The objective clarity is defined with the formula as;

$$C_{80} = 10 \log \left\{ \frac{\int_0^{80ms} g^2(t)dt}{\int_{80ms}^{\infty} g^2(t)dt} \right\} \text{dB}$$

(Kuttruff, 2000, p.208)

The early arriving sound energy contributes to clarity and definition, while the late reverberant part provides an acoustic context against which the early sound is heard. For evaluating the clarity of music, the relevant time interval is 80 ms, while it is taken as 50 ms for speech (Makrinenko, 38). To decrease intelligibility of speech, C80 should be as low as possible for achieving a more blurred speech. However, the C80 parameter is mostly used for musical clarity, definition (D50) becomes more crucial for speech.

2.2.3. Definition (D50)

Definition is the ratio of the effective energy to the total energy in an impulse response. The effective energy contains both the direct sound energy and the reflected sound energy with respect to the direct sound by up to 50 ms (Su, 35). The definition formula is given as;

$$D_{50} = \frac{\int_0^{0.050s} p^2(t)dt}{\int_0^{\infty} p^2(t)dt}$$ (Kuttruff, 2000, p.208)

To evaluate speech intelligibility by using definition parameter, early arriving sound energy should be high enough to achieve good acoustical conditions for speech. The ideal value of definition at halls for speech is higher than 0.15, however, in open-office environments the aim should be unintelligible speech. Therefore lower values of definition is required to create a better speech privacy in open-plan office environments.

2.2.4. Speech Transmission Index (STI)

Developed in the early 1970's, the Speech Transmission Index (STI) is a machine measure of intelligibility whose value varies from 0 (completely unintelligible) to 1 (perfect intelligibility). The speech transmission index (STI) has been developed for the evaluation of speech intelligibility in both direct communication situations and electro-acoustical situations.

The calculation of STI combines various distortions, for instance echoes, peak clipping, and other nonlinear distortion and interfering noise. The STI parameter has been improved and it takes into account other effects like non-contiguous frequency transfer and severe band pass limitation. While calculating STI male and female speakers are treated separately and a diffuse sound field is assumed (Larm & Hongisto, 2005). The reverberation time and the background noise have a direct effect on speech transmission index and speech intelligibility. STI also can be calculated by impulse responses of enclosed spaces (Caliskan, 56). The explanation of STI values can be conducted as,

0.8 – 1.0 = Excellent

0.6 – 0.8 = Good

0.4 – 0.6 = Fair

0.0 – 0.4 = Bad

Overall STI values in an open-office should not exceed to excellent values, however, too low STI is caused by either very high value of reverberation time or background noise levels. Therefore, long-term effects of high background noise on occupant health have to be considered in order to achieve a better work environment, and proper acoustical design. Importance should be given balance the ratio between reverberation time and background noise, especially if the background noise source is natural and uncontrolled.

2.2.5. Background Noise

Background noise levels in the open-plan offices should be high enough to provide satisfactory speech privacy conditions by interfering with speech communication (Egan, 1988). Bradley and Gover state that acoustic comfort in an open-plan office is related to ambient noise and an adequate level of speech privacy. However, high levels of ambient noise will increase speech privacy; too much noise will not lead to optimum acoustic comfort (2004). The acoustical situation should not be described by sound pressure levels in dB which is a logarithmic measure. In the workplace even very low levels of sound may be high enough to interfere with communication and to be stressful. Noise is not only an interruption but also a disruption of thought. Even if the permissible noise level is

70dB (A) for simple office work and as low as only 55dB (A) for mentally challenging work, these thresholds cannot guarantee the safety of employees (Strasser, Gruen and Koch, 2000). The background noise should be under control and homogeneous, and should not exceed the maximum level of 55 dB in order to prevent negative effects on occupants health.

If needed, additional background noise can be provided by an electronic sound masking system. A single random noise generator is connected to an equalizer to create a shaped spectrum tuned to the room's acoustical environment. A uniform level of background noise should be produced, so no one notices the masking noise. The loudspeakers should be located carefully throughout the space to produce the masking noise. They should be either placed on the ceiling or above the ceiling, so the masking noise can be distributed inside the plenum and produce a more uniform sound field throughout an office (Chusid, 2001).

3. EXPERIMENTAL STUDY

3.1. Aim of the Study

The aim of the study is to understand the effects of speech and speech intelligibility on computer based task performance in open-plan offices and examining if the performance of open-office workers differs in variable sound environments such as speech, masked speech, and continuous noise to understand ideal acoustical conditions of an open-plan office in terms of speech and speech intelligibility. Additionally, current acoustical situation of the site STM Bilkent Headquarters is analyzed and solutions are discussed under the guidance of task performance test results.

3.1.1. Research Questions

1. Is there any significant difference between computer-based task performances of open-plan office workers in variable sound environments?
2. What is the appropriate speech/noise ratio for computer based task performance in open-plan offices.
3. What are the acoustical properties of the case STM Savunma Teknolojileri Mühendislik A.Ş.?
4. Should the acoustical properties of the case STM Savunma Teknolojileri Mühendislik A.Ş. needs to be re-designed under the light of the results?

3.1.2. Hypotheses

There is a significant effect of intelligible speech on computer-based task performance.

3.2. Methodology

The case study consists of three main phases; Real-size measurements of the site, computer simulation of the site, and the computer-based task performance test. First two phases were done to analyze room acoustics parameters of the selected open-plan office area in terms of reverberation time (T30), clarity (C80), definition (D50) and Speech Transmission Index (STI). Computer simulation of the site mainly done for achieving distribution graphs of room acoustics parameters, and the real-size measurements were done to analyze the effects of divider panels used in the open-plan office area. Again, the comparison between real-size measurements and computer simulation give a wider scope to analyze various parameters.

The computer-based task performance test is evaluating the open-plan office personnel under three different sound environments by using both subjective and objective methods, to understand the effects of speech and speech intelligibility on computer based task performance. Statistical analysis of gathered data will guide the study to create solutions for a better work environment.

Results of three phases will be used to propose a better acoustical design for the STM Bilkent Office to improve the performance of the workers, and to improve the quality of the work environment.

3.2.1. Real-size Measurements of the Site

Real-size measurements of STM were analyzed by using Dirac 3.0 room acoustics software, which is a product of Bruel & Kjaer. It measures various room acoustics parameters by using impulse response files such as MLS (Maximum Length Sequence) or Sweep signals. The Dirac delta function is infinitely short and has unit energy. A system's response to an impulse contains all the information on the system and is enough for analysis. Dirac uses the same method, measures and saves acoustical impulse responses to calculate acoustical parameters. It can also calculate the impulse response using other signals to achieve better directivity, frequency spectrum and reproducibility than impulsive sound sources (Bruel & Kjaer, 2007, p.2). Examples of suitable non-impulsive excitation signals are the MLS signal, the sweep or swept sine (sine with frequency increasing linearly or exponentially with time), white noise and pink noise. To achieve more reliable results, an external omni-directional sound source and an omni-directional sound receiver should be used.

For the measurement of STM office, Bruel & Kjaer OmniPower Sound Source Type 4292 (Figure 3.1) was used as an omni-directional sound source. To distribute the sound evenly to all directions, it uses 12 loudspeakers in a dodecahedral configuration. Another important equipment of the setup is the power amplifier that drives the omni-directional sound source. To acquire maximum compatibility, Bruel & Kjaer 2716 Power Amplifier was used (Figure 3.2). Total output of the amplifier is 300 W, which fully match the requirements of the sound source with a guarantee of safety.

As a sound receiver, Bruel & Kjaer Type 2230 Sound Level Meter (Figure 3.3) was connected to the personal computer (PC) via AC output of the device. Calibration of the device held by an external pure tone calibrator at 94 dB. Also, before on-site measurements, Dirac room acoustics software performed calibration on the sound device to achieve maximum reliability.

Figure 3.1. Bruel & Kjaer OmniPower Sound Source Type 4292

Figure 3.2. Bruel & Kjaer 2716 Power Amplifier

Figure 3.3. Bruel & Kjaer 2230 Sound Level Meter

For evaluating speech intelligibility criteria, measurements were focused on three basic objective parameters of room acoustics; Reverberation Time (T30), Clarity (C80) and Speech Transmission Index (STI). To obtain responses, internal MLS and internal E-Sweep signals, which are included in Dirac software, were used. For measuring Reverberation Time and Clarity parameters, internal E-Sweep samples play backed and recorded simultaneously. For speech parameters, internal MLS signal processed by speech filters ‘male’ and ‘female’, which cuts out frequencies below 500 Hz and above 2000 Hz. It is not enough to gather only MLS response file, it has to be mixed with the background noise recordings of the site. To achieve this, another measurement was held by using external impulse selection, which record background noise level of the site.

Measurements was performed in one sound source and two sound receiver positions, which are one in front of the divider panel (MP1) and one is at the back of the same panel (MP2), because it is important to observe the effects of divider panels in the open-plan office area. Those positions are highlighted in the perspective view of the open-plan office (Figure 3.4).

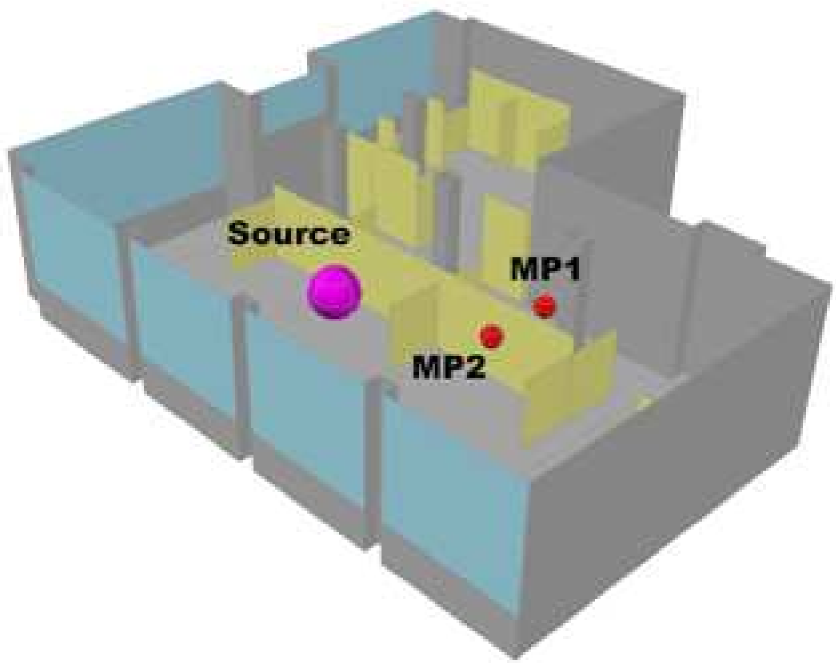

Figure 3.4. Source and Receiver Positions for Real-Size Measurements

3.2.2. Acoustical Simulation of the Site

After deriving results of real-time calculations from Dirac software, it is important to check those results by comparing with a computer based acoustical simulation software, because most effective way of evaluating solution proposals is again modeling and simulating them in the same software. Nowadays, architects prefer evaluating their decisions about the shape of the interior space and the surface materials by using simulation programs rather than scale models (Sendra, 1999). A computer model is more flexible than a scale model and it is easy to modify the geometry and the surface materials of the computer model (Rindel, 2000).

In this study, Odeon 8.5 Room Acoustics Software was used for the acoustical simulation of the site. To give brief information, it uses prediction algorithms (image-source method combined with ray tracing) to simulate the interior acoustics of buildings. Odeon is both used for analyzing acoustics and for evaluating and recommending solutions of large rooms such as concert halls, opera halls, auditoria, foyers, underground stations, airport terminals, and industrial workrooms (Bruel&Kjaer, 2007).

The very first step of the computer simulation is modeling the geometry of the space in AutoCAD 2007 by using face modeling technique (Figure 3.5.). After modeling the space and saving it in exporting format DXF, the model was opened in Odeon 8.5 Room Acoustics Software. The next step was defining source types and positions. Point sources can be defined by directivity pattern, gain, equalization and delay, allowing the definition of natural sound sources or loudspeaker systems (Bruel&Kjaer, 2007). Also, receiver type and position was defined as a surface receiver, which is divided into grids of 0.50 m. to perceive detailed distribution graphs of variable room acoustics parameters.

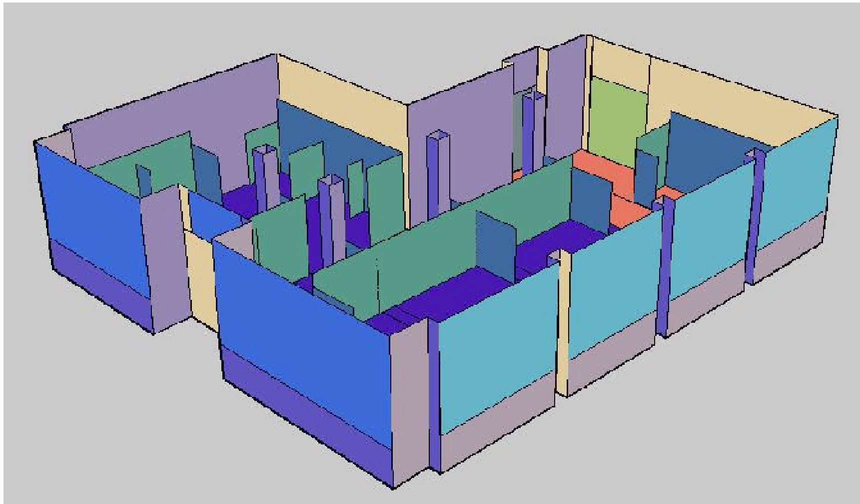

Figure 3.5. 3D Model of the office in AutoCAD 2007

Materials were selected and assigned from Odeon's own material library. The materials were assigned to surfaces that are already layered accordingly in the AutoCAD software. The sound absorption coefficients used in the model are shown in the Figure 3.6. It can also be defined by manually entering the absorption coefficients of desired materials from 63 to 8000Hz and a scattering coefficient and a transparency coefficient can also be used.

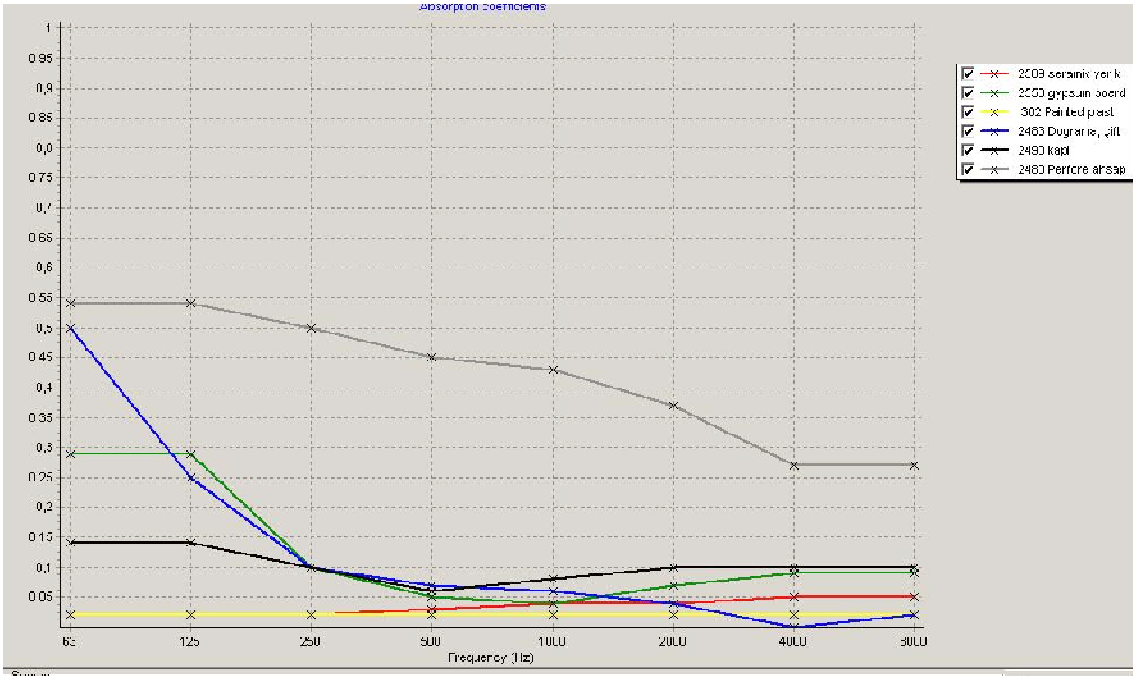

Figure 3.6. Absorption coefficients of materials assigned to the computer model in Odeon 8.5

To be sure that calculation results are reliable, it is important to check the consistency of geometries. Odeon includes a number of tools for geometry verification that check for duplicate, overlapping or warped surfaces. The ray-tracing display was used to verify the room geometry (Bruel&Kjaer, 2007).

Last step was the calculation of the results. Two methods are available in Odeon software. The Global Estimate based on ray tracing, which is taking room shape, source position, and the position of absorbing materials into account. It uses an infinite number of points to simulate reverberation decay in the model. The other method, Quick Estimate is based on statistical formulae (Bruel&Kjaer, 2007). For evaluation of STM open-plan office, the results of quick estimation and global estimation are compaired to obtain the results of different acoustical parameters and their distribution throughout the office.

3.2.3. Computer-Based Task Performance Test

The aim of the computer-based task performance test is to analyze the basic information processing abilities of engineers under three different sound environments; ‘speech’, ‘masked speech’ and ‘continuous noise’. The difference between those results will explain if the intelligible speech is affecting the overall performance of workers in open-plan offices or not.

The experiment was composed of two questionnaires and a computer based task performance test. Each subject was given two questionnaires, one before and one after the visual short-term memory test. The test is applied three times to the same subject, each for one sound environment. Before starting the experiment, subjects were given an introduction that clearly explains the procedure and each subject had some time for practicing the test.

First questionnaire is for evaluating subjects’ physical situations by three questions i.e. if they could sleep preceding night; if they have physical problems and if they are hungry. Subjects were asked to mark a number from the five-point scale given. Second questionnaire is about their subjective self-evaluation about the test, for comparing with objective measured computer based performance test results.

3.2.3.1. Sound Environments

Three sound environments were used for the experiment. Every subject was exposed to three of the environments in the sequence of ‘continuous noise’ environment, ‘masked speech’ environment and ‘speech’ environment. For achieving more realistic results, both real office noise and white noise was mixed with the speech sample. Equivalent sound level is 60 dBA.

The first sound environment is the ‘continuous noise’ environment. This sample is composed by mixing recorded office sounds i.e. computer typing sounds, chair sounds, footsteps, and white noise. Speech cannot be heard at this sound environment because speech to noise ratio is -23dB, which means STI=0.00 (Venetjoki *et al*, 2006).

The second sound environment is the ‘masked speech’ environment. It is composed by mixing ‘continuous noise’ sound sample and a ten-minute speech sample derived from a Turkish TV program. Speech sample is used at 40 dB, and mixed with ‘continuous noise’ sound sample. Difference between the samples is -8 dBA, which means STI=0.30, simulating adjacent workstations in an open-plan office. However, speech can be heard, meaning of the speech cannot be understood clearly (Venetjoki *et al*, 2006).

The third and last sound environment is the ‘speech’ sound environment. The same ‘continuous noise’ sample is mixed with same ‘speech’ sample, however, this time difference between those two samples are +13 dBA (STI=0.80), which corresponds to open-plan offices with no acoustic design (Venetjoki *et al*, 2006).

Audacity 1.2.6 free software was used for mixing audio samples (Figure 3.7). Samples used for ‘continues noise’ composition was derived from both live recordings via Shure Beta 58A microphone connected to Apple iMac G5 personal computer by M-Audio Audiophile soundcard, and free sound samples found on internet. Final compositions are ten minutes long, which is enough for even very long test sessions. An average person completes the test between forty seconds and one and a half minute. Normalization process was not applied to final recording, because high and low frequencies may be distracted. Sound sample used for ‘speech’ is from a TV Show and the subject is about health issues. The male sound is calm and stable that there are no distracting changes in the sample. Subjects listened to the final sound environment mixes through headphones in the real open-plan office environment to use other environmental parameters such as thermal conditions and lighting as it is in STM Bilkent Headquarters open-plan office environment.

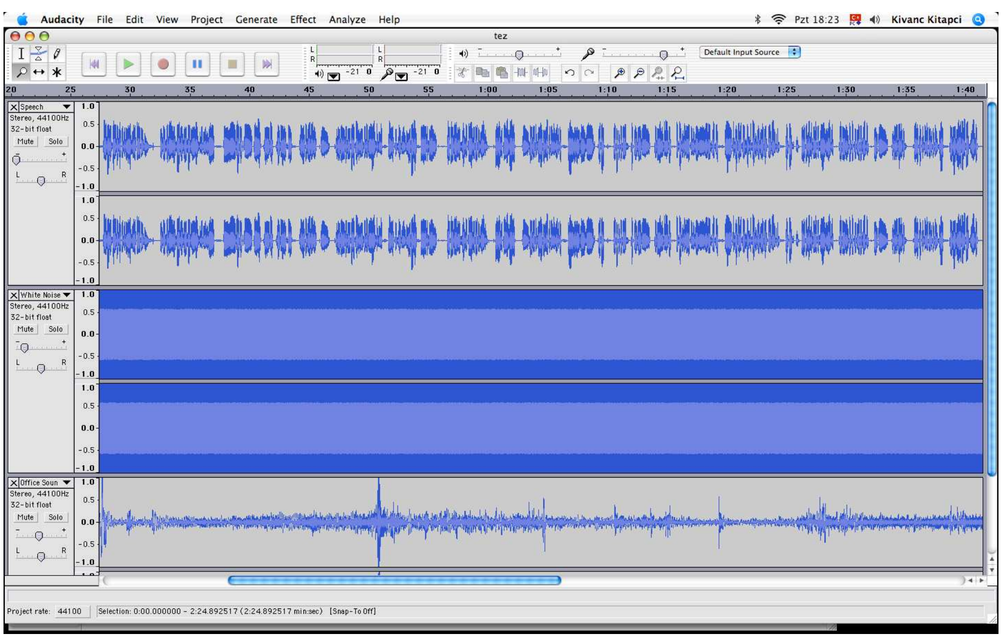

Figure 3.7. Screenshot from Audacity 1.2.6 Software

3.2.3.2. Software

Computer based task performance test was a very simple arithmetic test, which determines both accuracy and reaction time of the subjects. They were presented with an arithmetic problem in the middle of the screen and a target number in the upper right hand corner of the screen (Figure 3.8). The problem was always be comprised of two single-digit numbers bound by an arithmetic symbol (+ or –). Subjects were asked to;

- Press the right arrow key on their keyboard as quickly as possible, if the answer to the arithmetic problem is greater than the target,
- Press the left arrow key on their keyboard as quickly as possible, if the answer to the arithmetic problem is less than the target,
- Press the left and right arrow keys on their keyboard simultaneously as quickly as possible, if the answer to the arithmetic problem equals the target,
- Press the left arrow key if the answer is greater than the target and press the left arrow key if the answer is less than the target, when the word 'Reversal' appears.

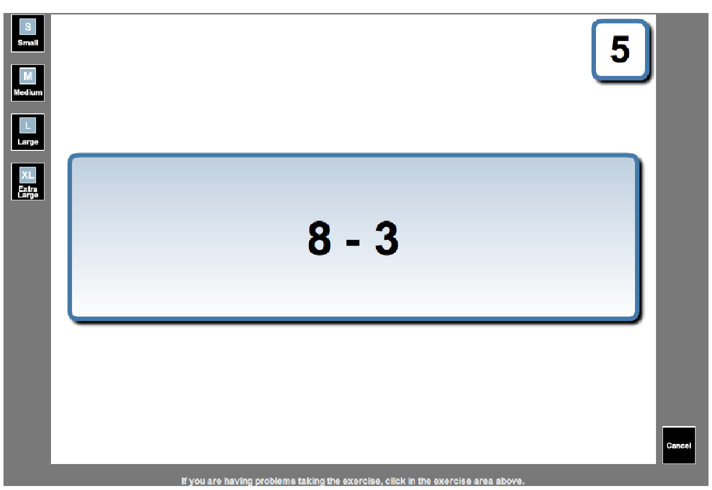

Figure 3.8. Screenshot from Audacity 1.2.6 Software

To evaluate in the statistical analysis, two parameters were recorded after every test. First parameter is ‘accuracy’, and the second parameter is ‘reaction time’. In second questionnaire subjects were asked that if they pay more attention to speed, or accuracy, for evaluating objective measurements. After the session was completed, every subject’s gender and age information were noted.

3.3. Case Study

3.3.1. Site Description

The experiment was conducted at STM Software Development Laboratory located within Bilkent University Cyberpark, which is for the software development activities and the promotion of research and development in the field of software tools, methods and practices with the incorporation of new technologies.

3.3.1.1. Layout

STM Bilkent University Cyberpark building consists of three floors; ground floor, first floor and second floor. Entrance and lobby area, security, meeting room, human relations office, dining area and one large open-office area is located on the ground floor, which has a L-Shaped plan. The long arm of the L-Shape leads to technical offices and the dining area. Also an unsecured entrance is located on the ground floor, which is used for service purposes. First and second floors are identical, consisting of three small and one large open-plan office areas and administrative offices. Circulation areas are located around the atrium defined by the central staircase in a rectangular form, leading to office entrances. First and second floors differ from ground floor by their rectangular floor plan.

The building has a total of nine open-plan offices, which has varying capacities of four to forty office personnel. Software development department use the largest two offices, which are located on the ground floor and first floor. The one on the ground floor level has a capacity of forty-five software developers. It also has a separate closed office that is located at near of the entrance of the open-office area for administrative personnel. The dividers used in the open-plan office area are 167cm in height and allow visual and acoustical contact while standing at any point of the office. Other open-plan office that is located on first floor has a limited capacity compared to the first one that is thirty-two personnel. The space dividers used in that open-plan office has a height of 190cm that does not allow any visual contact while standing in the area.

The open-plan office on the ground floor was selected for the experimental study (Figure 3.9). First reason for selecting this office is the personnel capacity. However the experiment was not applied to only residents of that office, capacity has a major effect on background noise levels. Second reason is the type of dividers used. *Openness* is the key element of an open-plan office area, and ground floor open-plan office has a better visual contact compared to first floor open-plan office.

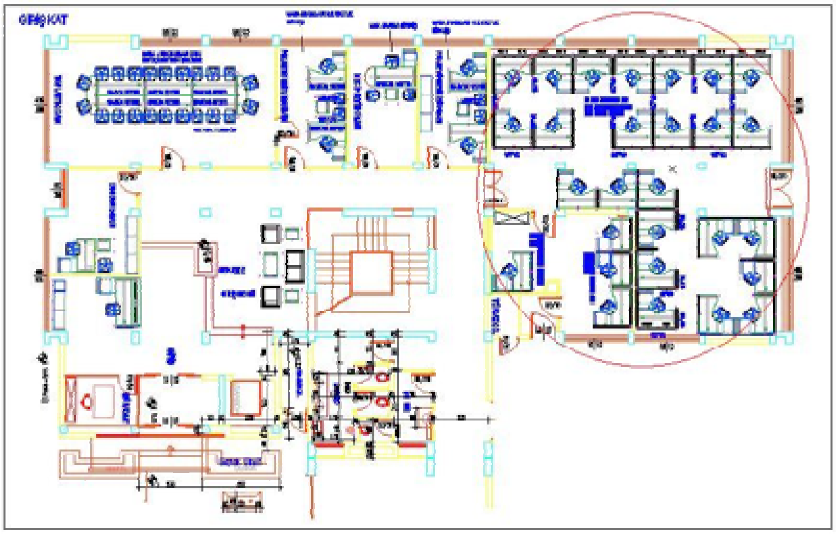

Figure 3.9. Location of the selected open-plan office at the ground floor

3.3.1.2. Sample Group

The sample group consisted of a total of 40 full-time workers of STM Bilkent Cyberpark. The building accommodates administrative, technical and software departments. However, total number of personnel working in that building is 110, circulation between STM headquarters, SSM (Civil Defense Undersecretaries) and STM Bilkent University Cyberpark decrease the number of available software developer personnel. For the experiment, 40 available software developers participated to the computer-based task performance test. All of the participants work in open-plan offices, so they are all familiar to the work environment selected for the experiment.

3.3.2. Results of the Real-size Measurements

Reverberation time, clarity, definition and speech transmission index values were gathered from real-size measurements of the site. Those results were analysed for three frequencies, 500 Hz, 1000 Hz and 2000 Hz, which are in speech frequency spectrum.

3.3.2.1. Reverberation Time (T30)

The first parameter is Reverberation Time (T30). RT requirements for general-purpose offices are below 0.5 seconds. The average value for the back of the divider panels that is Measurement Point 1 (MP1) is 0.76 seconds at 1000 Hz and 0.67 at 500 Hz. To evaluate according to speech intelligibility, RT values at 2000 Hz should also be considered, which is 0.69 for MP1. Frequencies below 500 Hz and above 2000 Hz are not considered in the evaluation. A measurement result from front of the divider panels, which is Measurement Position 2 (MP2), is close to the results from MP1. Average T30 values for MP2 is 0.52 s. at 500 Hz, 0.66 s. at 1000 Hz and 0.62 s. at 2000 Hz. It is observed that measurement results at MP1 are slightly higher than the results gained from MP2. The difference between two measurement points derives from ceiling and wall reflections affecting the receiver at the back of divider panels. Because receiver location of MP2 is closer to the sound source, it is not affected from surface reflections as much as receiver of MP1. Both measurement points have a higher reverberation time than it should be. Results show that the office volume has an average reverberation time ranging from 0.52 s. to 0.76 s, however it still cannot be stated that the RT values are not appropriate for the open-office area. The results should be evaluated according to speech intelligibility requirements, so slightly higher RT values may not distract the office personnel, because it may help to reduce the intelligibility of speech.

By analyzing Early Decay Time (EDT) values from Table 3.1 and Table 3.2, it is found that EDT values are lower than 10% of T30 values in all frequencies. This percentage is lower at MP2 than MP1, however it still means that there are some reflective surfaces directing early reflections to receivers. For good acoustical conditions EDT values should not exceed 10% of RT. For MP1 at high frequencies it is observed that RT and EDT are the same, however at mid frequencies, the difference is again exceeding 10% of RT. This means, there are some surfaces reflecting mid frequencies on to the receiver. At MP2 the problem persists in all frequencies ranging from 250 Hz to 8000 Hz, so surfaces that reflect all frequencies cause early reflections on to the receiver of MP2. The overall range of EDT from 0.30 s. to 0.69 s. at speech frequency range and difference between back and front of divider panels in open-plan office shows that, reflective surfaces such as divider panels cause early reflections on working areas, so distribution of RT become uneven throughout the office volume. Reflective and absorptive surfaces should be designed accordingly to achieve an even distribution of RT throughout both circulation paths and at working areas.

Table 3.1. Reverberation Times for Measurement Position 1

	31.5	63	125	250	500	1000	2000	4000	8000	16000
EDT [s]	0,155	0,076	0,038	0,019	0,554	0,664	0,696	0,610	0,481	--
cc	-0,950	-0,951	-0,955	-0,959	-0,584	-0,986	-0,994	-0,995	-0,988	--
T10 [s]	0,068	0,052	0,016	0,012	0,655	0,653	0,662	0,609	0,494	--
cc	-0,954	-0,961	-0,958	-0,957	-0,994	-0,998	-0,998	-0,998	-0,996	--
T20 [s]	0,061	40,322	0,015	0,758	0,677	0,723	0,696	0,617	0,547	--
cc	-0,962	-0,948	-0,967	-0,962	-0,998	-0,999	-0,999	-0,999	-0,999	--
T30 [s]	0,049	31,884	0,011	0,673	0,607	0,766	0,692	0,635	0,541	--
cc	-0,928	-0,906	-0,903	-0,993	-0,999	-0,999	-0,999	-1,000	-1,000	--

Table 3.2. Reverberation Times for Measurement Position 2

	31.5	63	125	250	500	1000	2000	4000	8000	16000
EDT [s]	0,153	56,884	0,040	0,019	0,300	0,417	0,432	0,352	0,262	--
cc	-0,976	-0,952	-0,955	-0,951	-0,918	-0,987	-0,962	-0,966	-0,986	--
T10 [s]	0,042	40,339	0,010	0,014	0,385	0,532	0,558	0,541	0,410	--
cc	-0,992	-0,964	-0,993	-0,970	-0,990	-0,997	-0,998	-0,997	-0,998	--
T20 [s]	0,058	27,982	0,013	0,330	0,471	0,635	0,612	0,556	0,464	--
cc	-0,973	-0,907	-0,971	-0,934	-0,995	-0,995	-0,999	-0,999	-0,998	--
T30 [s]	0,049	26,966	0,182	0,485	0,521	0,667	0,626	0,584	0,491	--
cc	-0,982	-0,896	-0,959	-0,975	-0,997	-0,998	-1,000	-0,999	-0,998	--

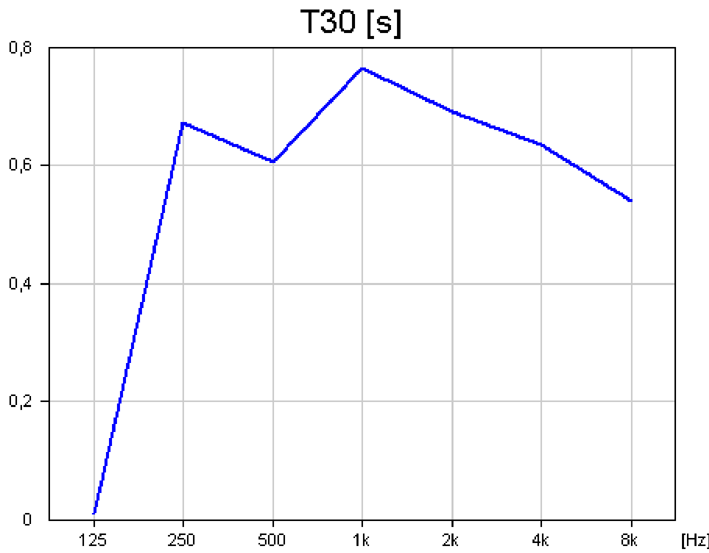

Figure 3.10. T30 Values for Measurement Position 1

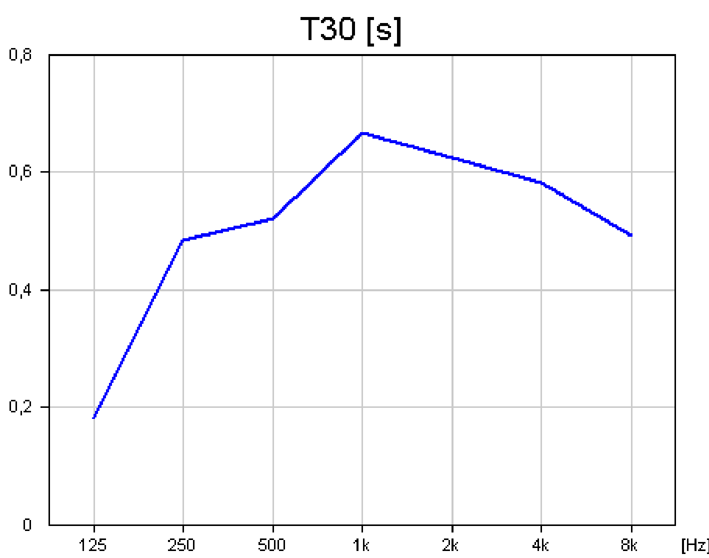

Figure 3.11. T30 Values for Measurement Position 2

3.3.2.2. Clarity (C80) and Definition (D50)

Relatively small size of the office volume and closeness of the sound source to the receiver cause a high level of early reflections arriving to the receivers. However the C80 values are very high than it should be, the difference between two receiver positions should be considered to evaluate the results. The clarity results for MP1, which is back of the divider panels are 14.96 dB at 500 Hz, 10.05 dB at 1000 Hz and 6.67 dB at 2000 Hz. Low frequencies ranging from 125 Hz to 250 Hz and high frequencies over 2000 Hz again are not considered while evaluating clarity parameters. Result for the MP2, which is in front of the divider panels are 12.41 dB at 500 Hz, 9.46 dB at 1000 Hz and 11.52 dB at 2000 Hz. The main difference between clarity values of MP1 and MP2 is at 1000 Hz and 2000 Hz. However, both measurement points have higher clarity values at low frequencies; early reflections (<80ms) are lower at higher frequencies. Especially clarity values of MP1 at 2000 Hz is lower than MP2, because of higher RT caused by ceiling and wall reflections directed to the MP1 receiver. Further analysis according to optimum C80 standards are done according to distribution graphs derived from Odeon Room Acoustics Software.

Definition (D50) is analyzed by looking at Table 3.3 and Table 3.4. D50 should be higher than 0.15 for speech purposes, however, higher values means better intelligibility of speech is the volume. Results for MP1 are 0.94 at 500 Hz, 0.85 at 1000 Hz, and 0.68 at 2000 Hz. For MP2 results show that D50 is 0.93 at 500 Hz, 0.85 at 1000 Hz and 0.87 at 2000 Hz. While comparing two measurement positions, there exists only slight difference at 2000 Hz values resulting in relatively lower speech intelligibility in MP1, which is at the back of the divider panels. Divider panels block the sound energy received in first 50 ms at 2000 Hz, so the ratio of early arriving sound energy to total sound energy becomes lower at MP1. MP2 receives more early sound energy because there are no interruptions between the sound source and the sound receiver of MP2. More detailed evaluation of D50 values are discussed by looking at distribution graphs derived from Odeon in Chapter 3.3.3.3.

Table 3.3. Clarity (C80) and Definition (D50) Values for Measurement Position 1

	63	125	250	500	1000	2000	4000
Ts [ms]	1524,6	44,4	17,5	32,9	73,9	58,6	60,2
C80 [dB]	-0,01	18,77	19,70	14,96	10,05	6,67	7,00
D50	0,50	0,99	0,98	0,94	0,85	0,68	0,68

Table 3.4. Clarity (C80) and Definition (D50) Values for Measurement Position 2

	63	125	250	500	1000	2000	4000
Ts [ms]	2578,8	221,8	79,6	131,4	183,8	37,4	29,3
C80 [dB]	-7,60	11,03	15,55	12,41	9,46	11,52	12,32
D50	0,14	0,93	0,97	0,93	0,85	0,87	0,89

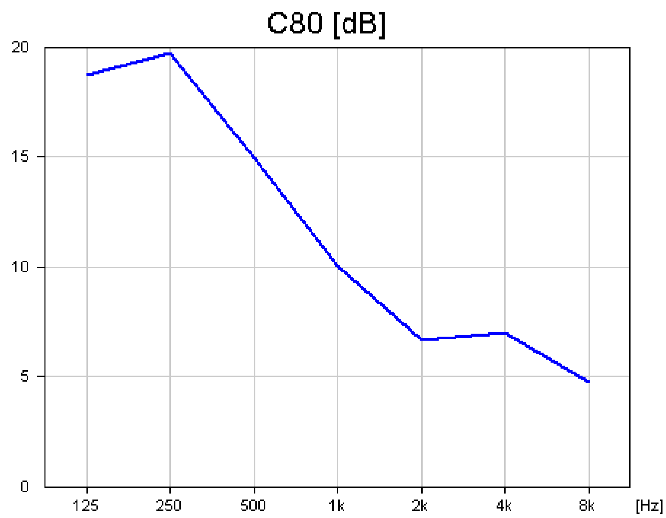

Figure 3.12. Clarity (C80) Values for Measurement Position 1

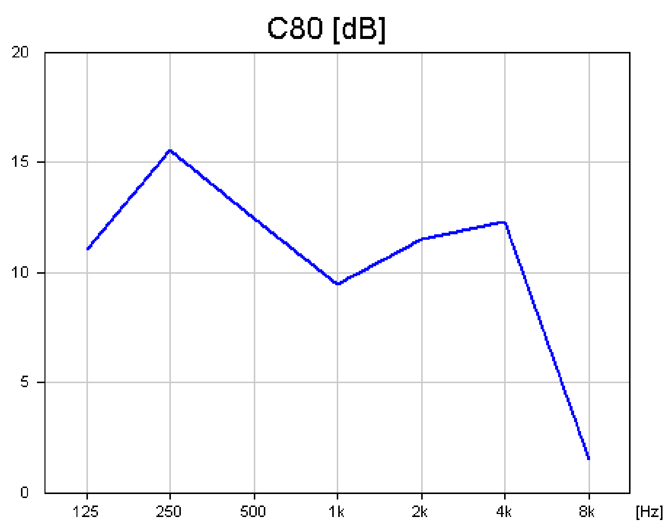

Figure 3.13. Clarity (C80) Values for Measurement Position 2

3.3.2.3. Speech Transmission Index (STI)

To gain the STI, impulse response samples and background noise sample was mixed in Dirac software. Analysis of the STI was made the final mixed sample. According to real-size measurement results, STI is 0.73 for female and 0.79 for male filter, which corresponds to good – perfect speech intelligibility (Figure 3.14.). RASTI filter did not used on MLS signal, so the RASTI result is not reliable for this measurement. More detailed analysis of speech intelligibility is conducted by looking to the STI distribution graphs of Odeon room acoustics software simulation.

Figure 3.14. STI Values

3.3.3. Results of the Acoustical Simulation

Acoustical simulation of the site was analyzed by investigating distribution graphs of reverberation time (T30), clarity (C80), definition (D50) and speech transmission index (STI). Frequencies in the range of speech spectrum, which are 500 Hz, 1000 Hz, and 2000 Hz were evaluated.

3.3.3.1. Reverberation Time

To figure out RT of the office volume, both quick estimate and global estimate results were analyzed. Differences between these results will show the affects of geometry and volume of the office area. Looking at quick estimate table (Figure 3.15), Eyring results are 0.61 s at 500 Hz, 0.63 s at 1000 Hz and 0.70 s at 2000 Hz, which are very close to real-size measurement results. The global estimate calculations with grid responses are 0.67 s at 500 Hz, 0.83 s at 1000 Hz and 1.03 s at 2000 Hz. When compared with the quick estimate and real-size measurement results, global estimate RT values are slightly higher at 500 Hz and 1000 Hz, and have a great different at 2000 Hz. For achieving good acoustical conditions, both the RT and its distribution through volume is important, which should be equal in general. In this situation, it can be seen from distribution graphs plotted from Odeon (Figure 3.16, Figure 3.17 and Figure 3.18) that especially at the corners of the office there are some focal points of higher reverberation times up to 2.40 s. The focal point, which is at the center of the office area, is the location of sound source, so it is not considered as a problem. Average T30 values are shown at Figure 3.19.

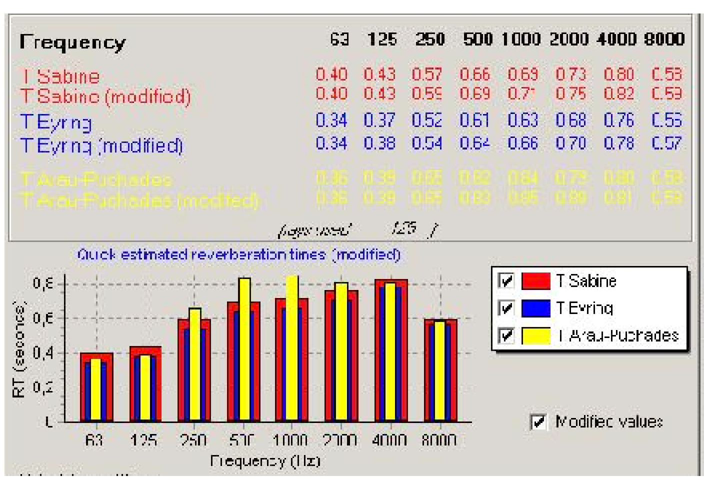

Figure 3.15. Quick Estimate Values for Reverberation Time

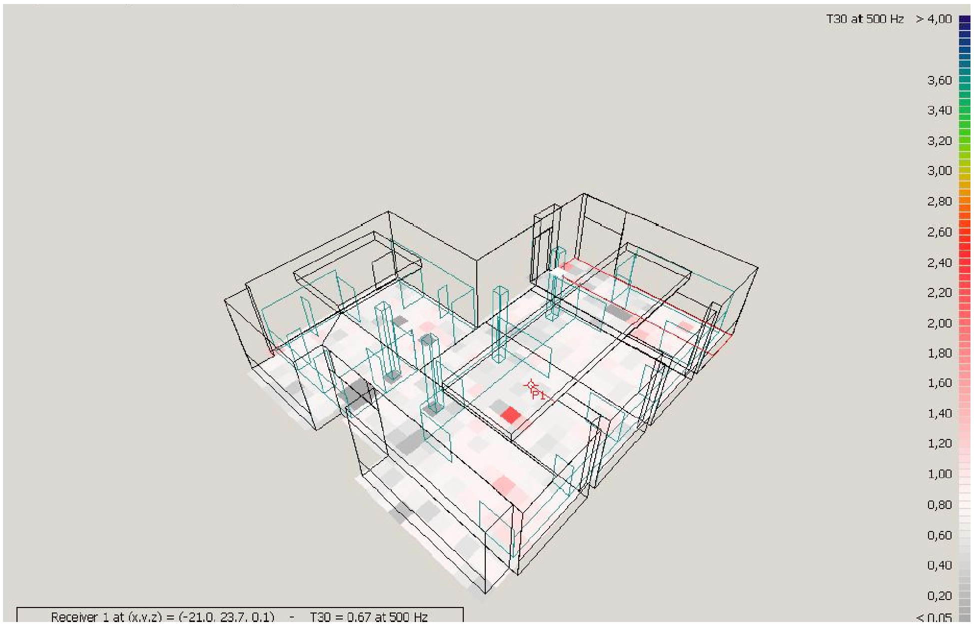

Figure 3.16. T30 values at 500 Hz

Figure 3.17. T30 values at 1000 Hz

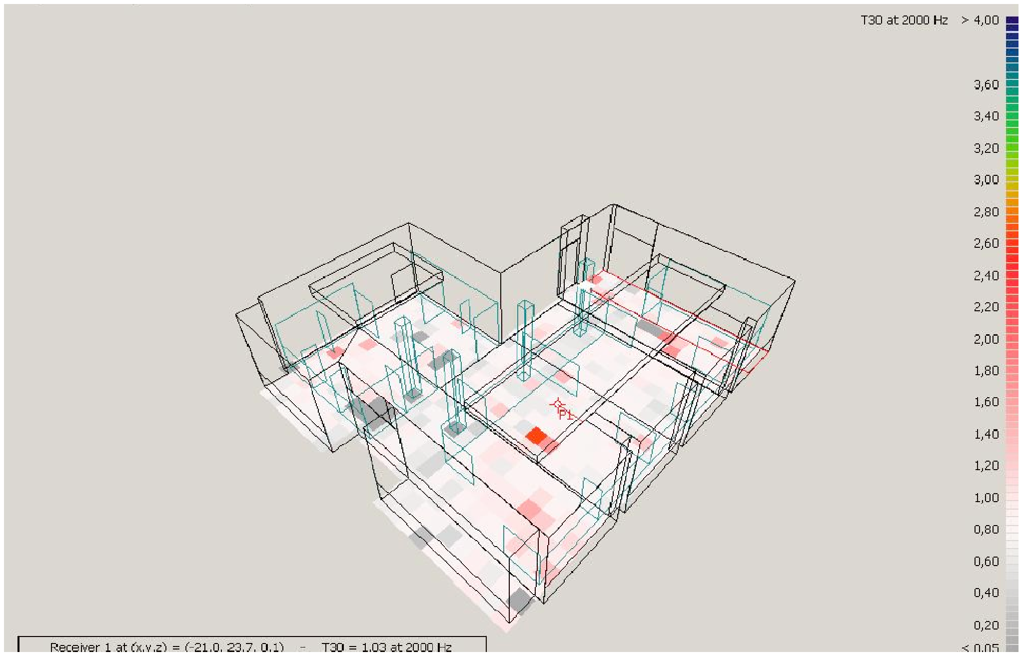

Figure 3.18. T30 values at 2000 Hz

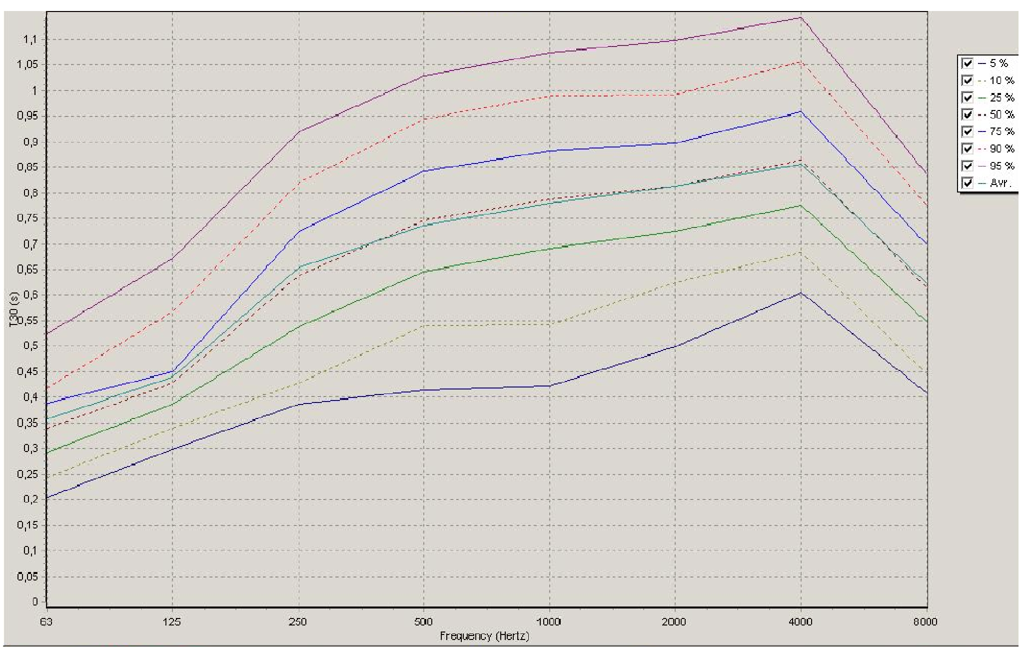

Figure 3.19. T30 average Values

3.3.3.2. Clarity (C80)

Evaluating the clarity distribution maps for low, mid (Figure 3.20, Figure 3.21, Figure 3.22) and high frequencies, it is seen that divider panels decrease the clarity of the sound significantly. The average clarity values are 0.7 dB at 500 Hz, 0.5 dB at 1000 Hz and 0.2 Hz at 2000 Hz. Because the ceiling and wall reflections are higher at 500 Hz and 1000 Hz the ratio between early reflections and late reflections increase at these frequencies. Affects of divider panels are seen clearly by looking at clarity distribution graphs that areas close to the sound source has higher clarity values between 8.5 dB and 12.5 dB, however, back of the divider panels clarity values decrease between -1.5 dB and 2.5 dB. There are three focal points shown on clarity distribution graphs at mid frequencies, which result at 16.5 dB. Average C80 values are displayed at Figure X.X.

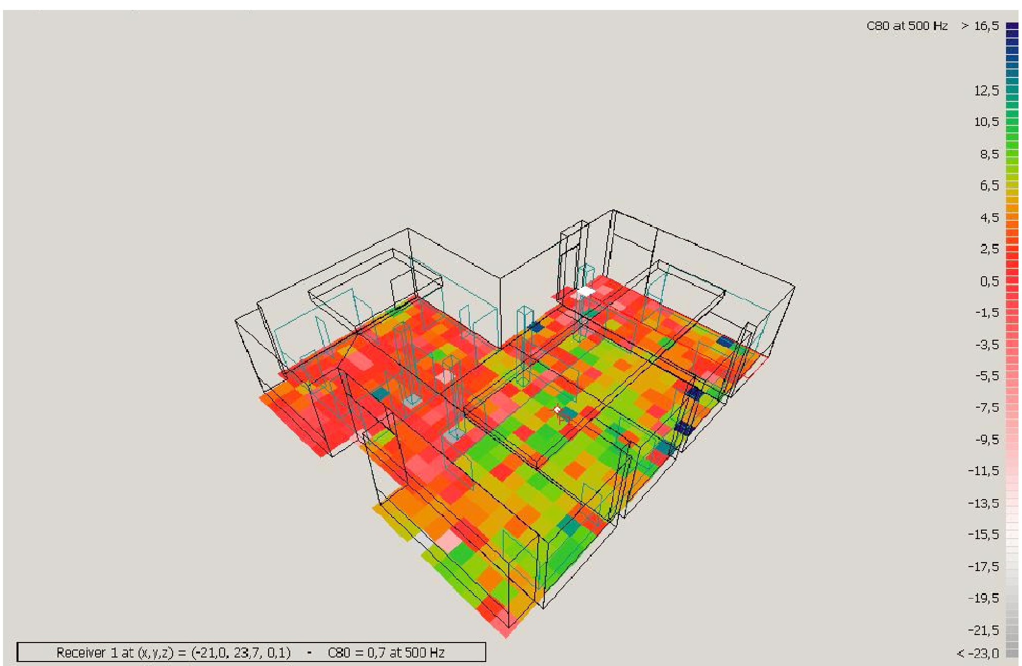

Figure 3.20. C80 values at 500 Hz

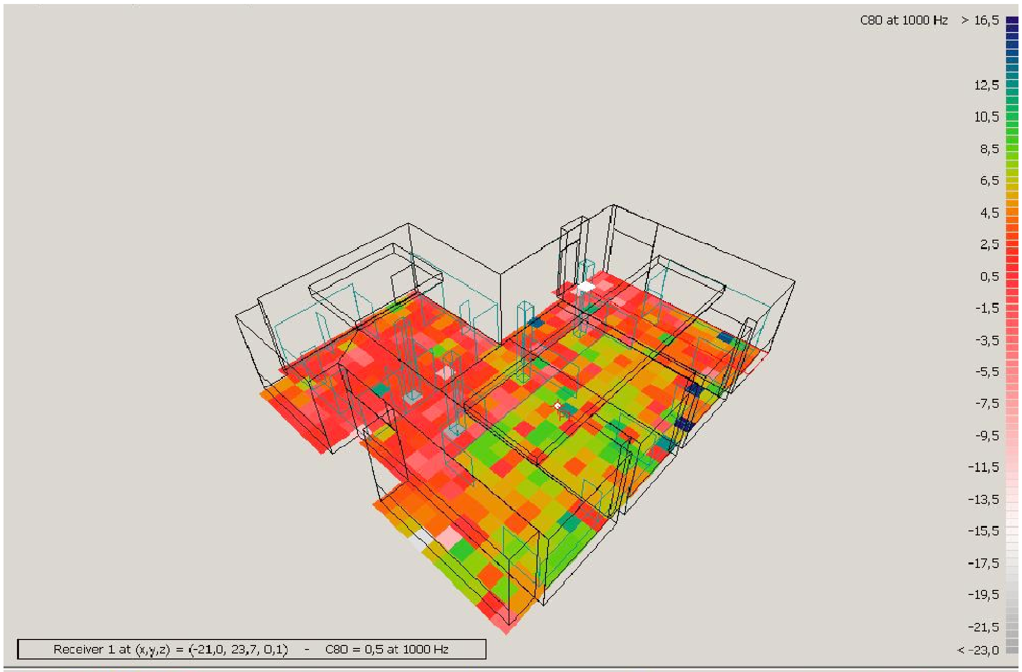

Figure 3.21. C80 values at 1000 Hz

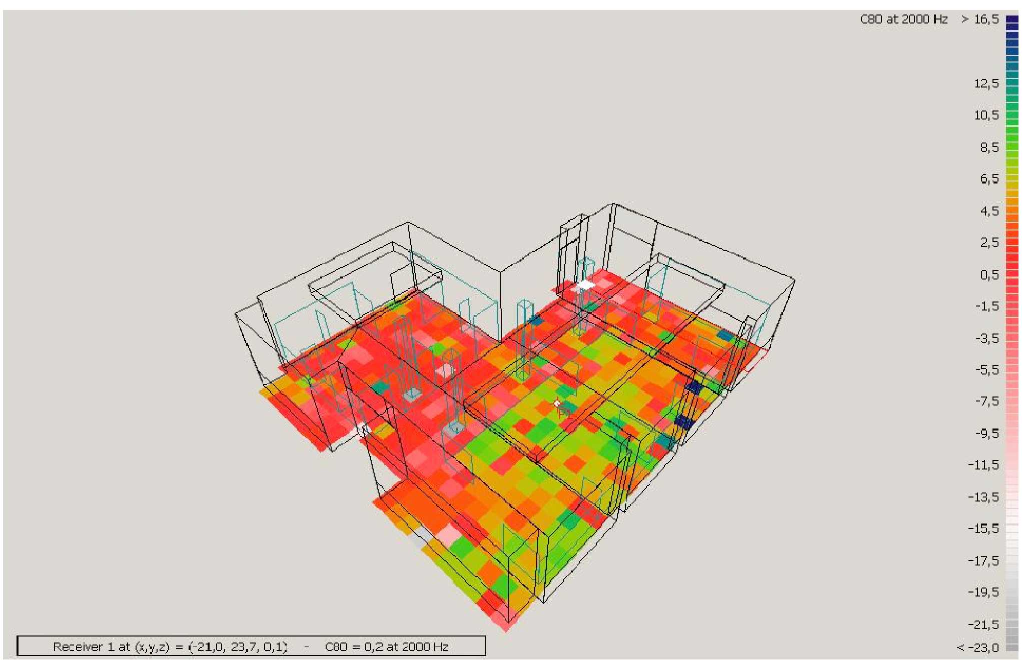

Figure 3.22. C80 values at 2000 Hz

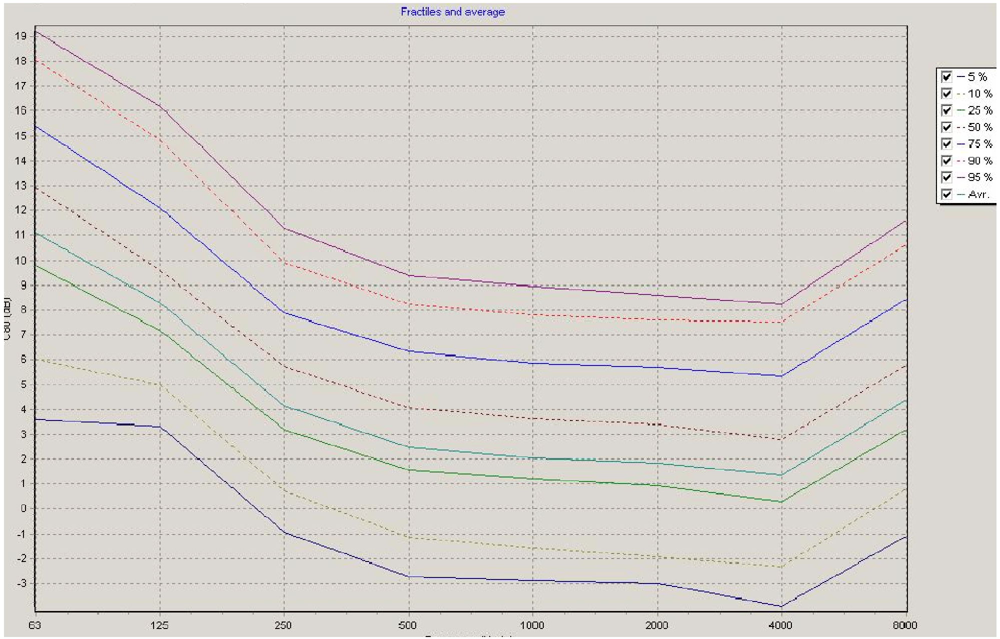

Figure 3.23. C80 Average Values

3.3.3.3. Definition (D50)

The definition distribution graphs (Figure 3.24, Figure 3.25, Figure 3.26 and Figure 3.27) show that average D50 values are 0.43 at 500 Hz, 0.40 at 1000 Hz and 0.38 at 2000 Hz. Distribution of the parameter is not homogeneous in the area because of varying sound energy levels across the volume. Areas closer to the sound source has higher D50 levels ranging from 0.75 to 0.80. Back of the divider panels that are away from the sound source has a larger spectrum of D50 ranging from 0.01 to 0.70. Lower D50 levels cause poor speech intelligibility, so the distribution graphs show that divider panels are working effectively at low frequency isolation. At high frequencies like 2000 Hz and 4000 Hz, D50 values also decrease at closer points to the sound source. As it is seen in the definition distribution graphs, far corners of the open-plan office area are lack of total sound energy, and showing very low sound definition properties.

Figure 3.24 D50 Values at 500 Hz

Figure 3.25. D50 Values at 1000 Hz

Figure 3.26. D50 Values at 2000 Hz

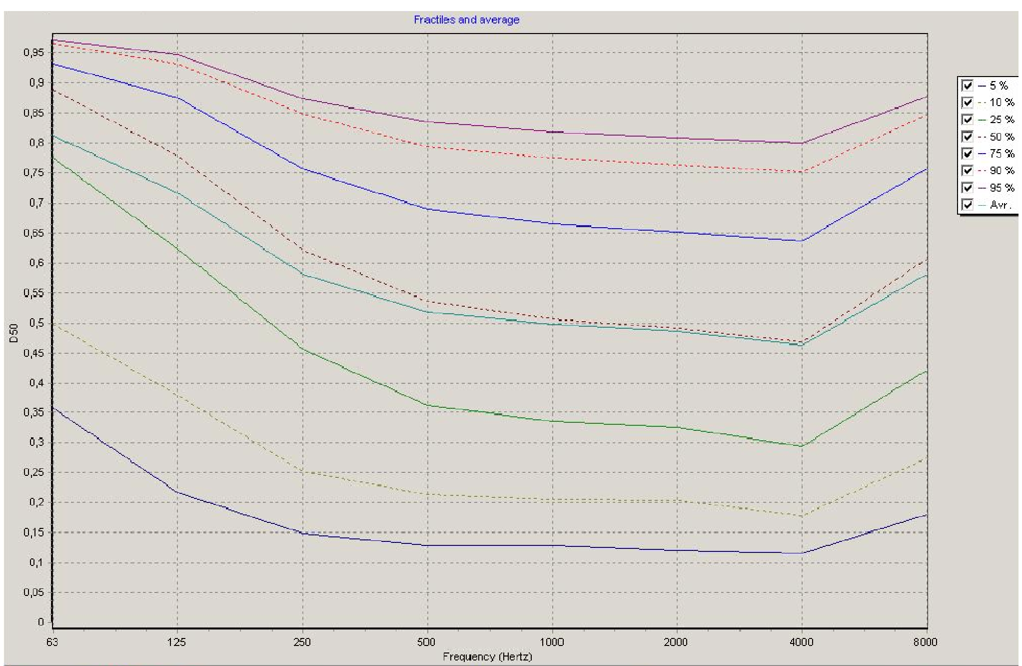

Figure 3.27. D50 Average Values

3.3.3.4. Speech Transmission Index (STI)

Average speech transmission index for the office area is 0.60 (Figure 3.28), which means good in terms of speech intelligibility. Areas closer to the sound source has a higher STI value in between 0.75 to 0.80 meaning excellent speech intelligibility. Even at close distances from the sound source, there are some death spots in terms of speech intelligibility. Those death points are mostly at the back of divider panels used in the open-office area. The lack of energy transmission from one side of the divider panel to the other cause the STI decrease to the levels of 0.55 – 0.60. Again, at the far corners of the office area, there are hot spots of speech transmission index that are caused because of surface reflections.

Figure 3.28. STI distribution map

3.3.4. Results of the Computer-Based Task Performance Test

For statistical analysis of findings from computer-based task performance test and subjective evaluation questionnaire, Statistical Package for the Social Sciences 15.0 (SPSS Inc., Chicago, IL, USA) was used. The one-way ANOVA test was used in the analysis of the data.

3.3.4.1. Results of the Objective Evaluation

Two different parameters were recorded after the test; first one is the *reaction time*, and the second one is the *accuracy.* According to the hypothesis, it is expected that the reaction time results will increase and the accuracy results will decrease at masked speech (MS) and speech (S) environments. By analyzing Table 3.5 it is clear that the opposite results occurred between three sound environments. It is significant that subjects' accuracy increased (Table 3.6, F=9.875, Sig.=0.000) and reaction time decreased (Table 3.6, F=16.369, Sig.=0.000) throughout three sound environments. This increase of overall performance can be explained by familiarity to the test and it was expected, however, all of the subjects had time to practice, and the test was simple enough for senior software developers to show the negative effects of intelligible speech between three sound environments.

Table 3.5. Comparison of means for the difference between performances

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Reaction Time	CN	40	**1,352.2500**	335.35605	53.02445	1,244.9979	1,459.5021
	MS	40	**1,223.6500**	350.24647	55.37883	1,111.6357	1,335.6643
	S	40	**1,178.6750**	305.20127	48.25656	1,081.0669	1,276.2831
	Total	160	1,355.2938	390.92813	30.90558	1,294.2553	1,416.3322
Accuracy	CN	40	**92.2250**	7.20928	1.13989	89.9194	94.5306
	MS	40	**93.6000**	6.06715	0.95930	91.6596	95.5404
	S	40	**94.1000**	5.62412	0.88925	92.3013	95.8987
	Total	160	91.7500	6.99326	0.55287	90.6581	92.8419

Table 3.6. ANOVA for the difference between performances

		Sum of Squares	df	Mean Square	F	Sig.
RTime	Between Groups	5,817,804.219	3	1,939,268.073	16.369	**0.000**
	Within Groups	18,481,338.975	156	118,470.122		
	Total	24,299,143.194	159			
Acc	Between Groups	1,241.050	3	413.683	9.875	**0.000**
	Within Groups	6,534.950	156	41.891		
	Total	7,776.000	159			

3.3.4.2. Results of the Subjective Evaluation

When the data from second questionnaires analyzed, it was seen that subjects feel distracted and under stress in masked speech (MS) and speech (S) sound environments. The mean values of results from five-point scale questionnaire for continuous noise (CN), masked speech and speech sound environments are 1.8, 2.37 and 3.27 sequentially (Table 3.7). The difference between three sound environments is statistically significant across all subjects (Table 3.8, F=24.006, Sig.=0.000). The internal validity of the questionnaire was tested by SPSS reliability module. Cronbach's Alpha result of the analysis is 0,989, where over 0,80 means reliable.

Table 3.7. Comparison of means for the subjective evaluation

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound
Subjective						
CN	40	**1.8000**	0.93918	0.14850	1.4996	2.1004
MS	40	**2.3750**	0.80662	0.12754	2.1170	2.6330
S	40	**3.2750**	1.10911	0.17537	2.9203	3.6297
Total	120	2.4833	1.13006	0.10316	2.2791	2.6876

Table 3.8. ANOVA for the subjective evaluation

		Sum of Squares	df	Mean Square	F	Sig.
Subjective	Between Groups	44.217	2	22.108	24.006	**0.000**
	Within Groups	107.750	117	0.921		
	Total	151.967	119			

3.4. Analysis of the Results

The data gathered from three steps of the study, real-size measurements and computer simulation and computer based task performance test, are analyzed according to effects of speech and speech intelligibility on office personnel. Reverberation time (T30), Clarity (C80), Definition (D50) and Speech Transmission Index (STI) values' affects on speech and speech intelligibility and the statistical analysis of the computer based task performance test are discussed.

Reverberation Time (T30): the ideal RT for offices is below 0.5 s. Comparing gathered data with optimum RT, it is found that calculated T30 values are slightly higher than it should be. Higher RT has a negative effect on speech and speech intelligibility, however, in an open-plan office environment; the aim should be achieving either less RT with an acceptable level of background noise, or lower levels of background noise with an acceptable RT to make the speech less intelligible. In the STM Bilkent case, positions and levels of background noise is not equally distributed through the space. Especially desks near to office entrance have higher levels of background noise caused by both circulation traffic and copiers used by all of the office personnel. That means, using natural background noise as a masker is not possible in the space, so slightly higher RT will help reducing speech intelligibility after reducing background noise in the office area.

By looking at the RT distribution graphs derived from Odeon, it is clearly seen that the distribution of RT is not homogenous in the office area, especially at mid frequencies. Working areas that are closer to exterior walls have RT below 0.4 s, while corners of the office area reach higher RT up to 2.0 s. Objectively dry areas that are close to the walls are away from noise sources, too, which leads to experiencing higher levels of speech intelligibility. Hotspots at the corners are receiving multiple reflections from adjacent walls, leading to lower speech intelligibility, but other sound sources like computer fans and footsteps become disturbing to the workers at the corner desks because of reverberation, too. Homogeneity of T30 value is crucial for improving the work performance of every STM Bilkent open-plan office personnel.

Clarity (C80): Evaluating clarity distribution graphs, it is clear that back of the divider panels do not receive early reflections as much as front sides. Areas closer to the sound source have higher C80 values, causing better speech intelligibility. The pink areas, which are seen on the clarity distribution graphs are mostly working surfaces behind the divider panels and has negative C80 values meaning low speech intelligibility that is desirable for open-plan offices. Besides, working areas in front of the divider panels receive too much early reflection and shown in shades of green color on the distribution graphs, which is equal to values between 6.5 dB and 12.5 dB, meaning high speech intelligibility.

Early reflections directed to wall-side work surfaces from interior walls and divider panels cause C80 to increase in those areas. Again, uneven distribution of late reflections causes focal and dead points of clarity, especially at mid and high frequencies. Those problematic areas should be controlled by diffusing the early reflections and directing late reflections evenly throughout the open-plan office area.

Definition (D50): the ratio between early arriving sound energy is mostly related with the early reflections, therefore, in a small volume like STM open-plan office, definition distribution graphs look so similar to clarity distribution graphs. It is again clearly seen that divider panels are effectively blocking early sound energy to reach to the working surfaces remaining at the backside. However, the overall D50 values seem acceptable, working surfaces that are closer to the sound source receive too much early energy that is leading to higher speech intelligibility. To decrease early sound energy arriving to front working surfaces, ceiling and floor materials should be selected carefully to absorb especially the speech frequencies between 500 Hz and 2000 Hz.

Excluding the front working surfaces, D50 values at the back of the divider panels are still unevenly distributed, causing hotspots and dead areas of definition, which is because of non-uniform wall and ceiling reflections. Flattening the ceiling surface should be considered to achieve a better sound energy distribution.

Sound Transmission Index (STI): the average STI value for the open-office area is 0.60, which corresponds to fair-good in terms of speech intelligibility, according to Odeon simulation results. However, real-size measurements result for female is at 0.73 that is good speech intelligibility and for male 0.79 that is excellent speech intelligibility. Real-size measurements show the results for a single working surface, so it is more realistic to trust those results, compared to average STI values of Odeon simulation. But, STI distribution graphs give much more detailed information of comparison between front sides and backsides of the divider panels. By analyzing STI distribution graphs, it is clearly been understood that clarity (C80) and definition (D50) values are in a strong relation with speech transmission index. Dead areas of speech intelligibility are the mostly the areas that are not receiving early sound energy and early reflection because of panel dividers. However, it is seen that the uneven distribution of sound energy and reflections cause STI not to be homogenous through the open-plan office area. Divider panels are less effective after 50 cm distance, because late reflections are directed over divider panels by ceiling surfaces. Even far corners of the office space show high STI values because of non-diffuse surface reflections.

Speech intelligibility is directly related with RT and background noise levels. In the case of STM, background noise level is 32 dB in an empty condition. Because the building is located in a green area, where is away from traffic and other background noise sources, RT of the office volume and interior noise sources such as telephone rings, copiers, speech and even footsteps become so important in terms of speech intelligibility. Adequate levels and even distribution of early reflections and RT, and controlled background noise should be considered to create a better work environment.

Computer-Based Task Performance Test: the significant results of computer-based task performance test shows that the effects of speech and speech intelligibility on work performance are only subjective, if the task is relevant with workers background and working habits. Objective test results did not show any negative effect on workers task performance in the arithmetic test, neither in accuracy nor in reaction time parameter. However, it is significant that workers feel under stress in speech sound environment according to subjective questionnaire results.

According to the results of the test, it should be stated that the effects of speech and speech intelligibility in open-plan office environments has negative effects on workers in a long term because of stress factor. So, intelligible speech should be under control in open-plan office environments to avoid long-term negative effects. Short-term effects of intelligible speech should be investigated by using other tasks that are not relevant with the subjects' background and working habits.

4. PROPOSAL FOR RENOVATION

Speech and speech intelligibility problem in STM Bilkent Headquarters open-plan office case can be solved by two methods. First method is decreasing the reverberation time by using absorbent materials more and creating a sufficient background noise that serves as a masking system, and the second method is keeping the reverberation time same, but decreasing the background noise to a safe level. Noise sources inside of the office area are commonly copiers, fax machines and telephone rings, however the level of sound is adequate, distribution of the noise sources are not equal in the area. Also, the noise from office equipment is not continuous to mask every speech in the office area. Using artificial background noise generators may be a proposal for the solution, however electro-acoustical masking systems are out of context of this study. Therefore, first method proposed is not logical at this stage. To achieve an adequate level of masking, location of background noise sources should be revised, by keeping reverberation time the same. Divider panels will also be revised to isolate direct sound energy before reaching to working surfaces closer to the circulation area.

4.1. Suggestions

Renovation design for the case has three phases; renovation of ceiling and floor, renovation of divider panels, and isolation of noise sources. Decreasing background noise level, keeping reverberation time the same, distributing late reflections homogeneously and blocking direct sound to reach to the working surfaces are major aims of the renovation. Plan, section and perspective views of the site are given according to the renovations.

Renovation of ceiling and floor: the major aim of renovating floor and ceiling materials is absorbing direct sound energy of speech. Decreasing direct sound energy will have a primary affect on D50, causing speech to be unintelligible. However, changing all of the floor area with a material that has a higher absorbing coefficient will cause reverberation time to decrease. Therefore, higher reverberation times are needed in the volume to prevent intelligible speech. In this case, it is proposed that changing floor material only at circulation areas is enough to both absorb direct sound energy of speech, and keep reverberation time at higher values.

Heavy carpet flooring on circulation areas is suggested for the case (Figure 4.1). Average sound absorbing coefficients of heavy carpet finish on concrete surface at speech frequencies are 0.14 for 500 Hz, 0.37 for 1000 Hz and 0.60 for 2000 Hz. The carpet floor will also prevent the noise of footsteps in the office area. Suggested areas of carpet finish are shown in Figure 4.1. The ceiling material on the same route of circulation should be revised in order to absorb ceiling reflections of early sound energy of speech. Suggested ceiling material is acoustical gypsum board with 50mm glass wool on top, which corresponds to sound absorption coefficients of 0.80 at 500 Hz, 0.99 at 1000 Hz and 0.99 2000 Hz. This ceiling will also prevent early reflections reach to the working surfaces that decrease clarity of sound (C80) in speech frequencies.

The two level differences on the ceiling cause uneven distribution of reflections in the space. To achieve a homogenous reflection map, those level differences should be flattened by using gypsum boards that are reflective surfaces, as the same with rest of the ceiling area.

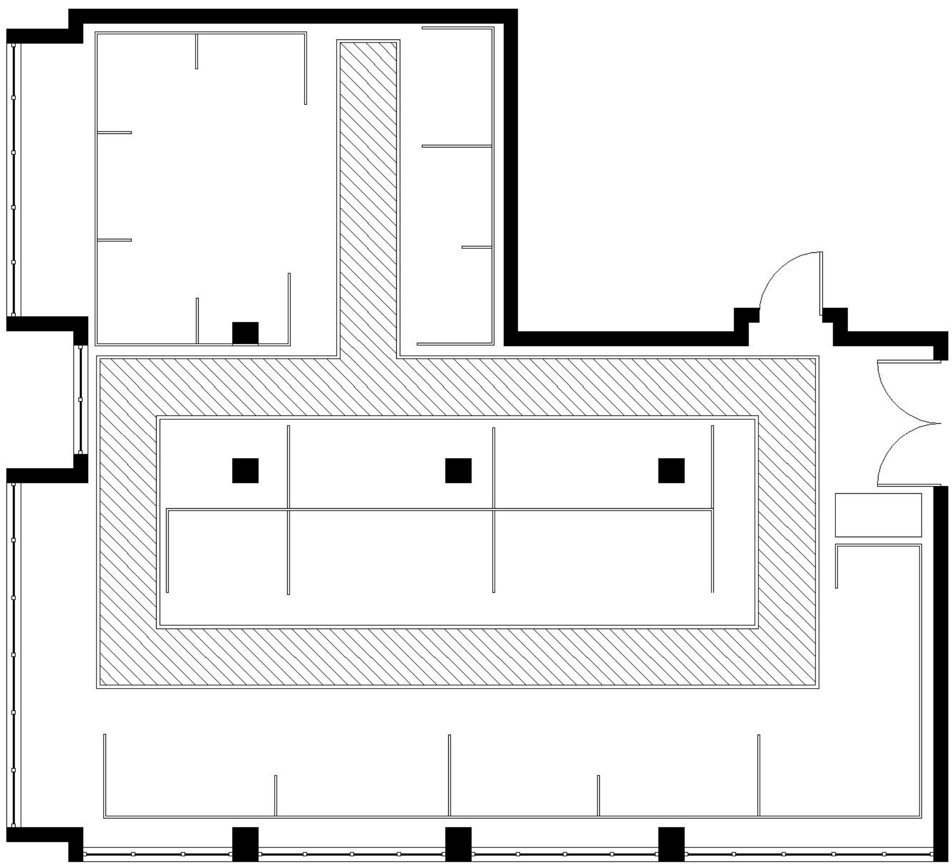

Figure 4.1. Circulation axis of material change on floor and ceiling

Renovation of divider panels: the efficiency of divider panels used in the open-plan office area can be seen by analyzing clarity (C80) and definition (D50) distribution graphs plotted by Odeon software. However, the effective area behind the divider panels is too short to block the sound energy at listener positions behind work surfaces. To improve the condition, height of the divider panels should be raised to 160 cm, which is sufficient to block the direct sound energy in a larger range including workers position behind the working surface. Also, panels between two adjacent desks should be extended in order to block especially telephone conversations. Those suggestions target to decrease definition of speech, so perceivable improve of intelligibility of speech is predicted in the office area. Materials of divider panels should not be changed, because the results show that noise reduction performance of the panels are sufficient for the volume. The difference of direct sound energy path is illustrated on Figure 4.2.

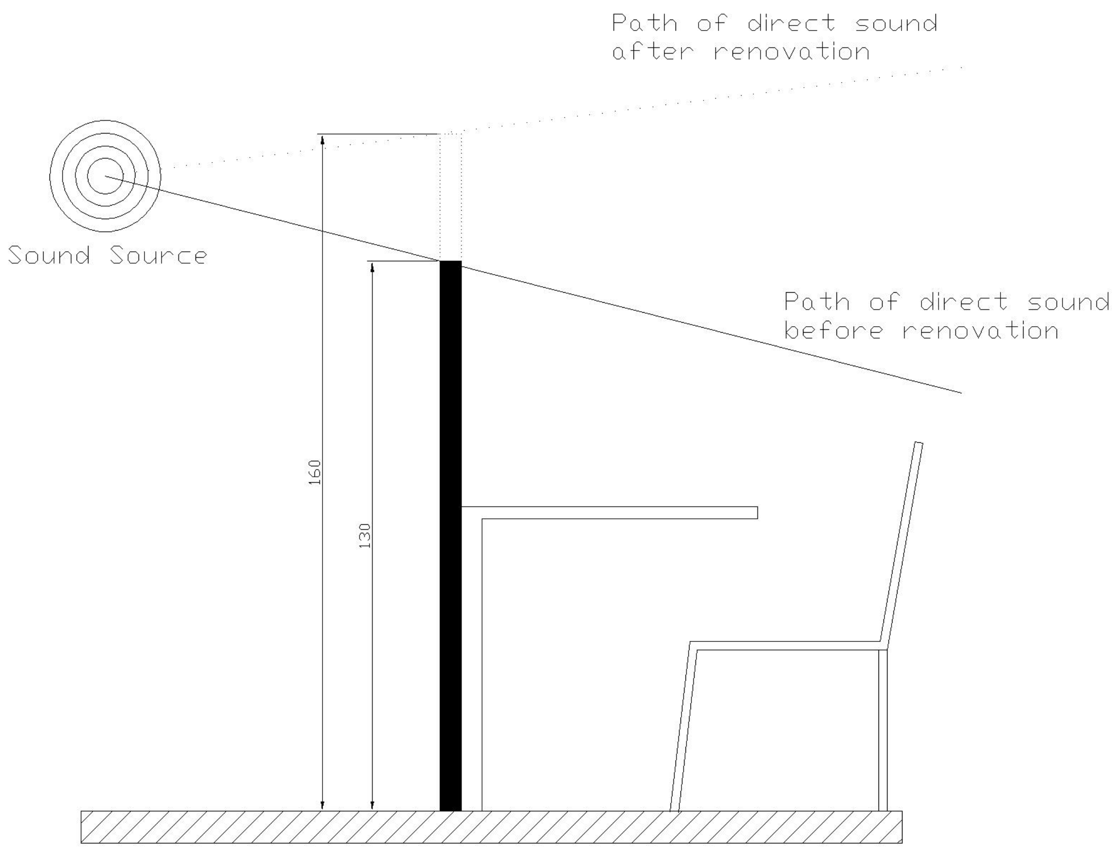

Figure 4.2. Renovation of divider panels

Isolation of noise sources: after achieving desired reverberation time, distributing reflections evenly through the office volume and blocking the direct sound energy, last and the crucial suggestion is isolating the common used area of photocopy and fax machines, to decrease the background noise. Ideal location of the enclosed space is at the outside of the open-plan office area, a space used by a small group of office personnel and secretary, which is shown on Figure 4.3. The separated area should be easy to access and ventilated, and may have another interior module for private phone calls, which will decrease the number of conversations in the area. Further administrational precautions should be applied to decrease the conversations in the open-plan office area.

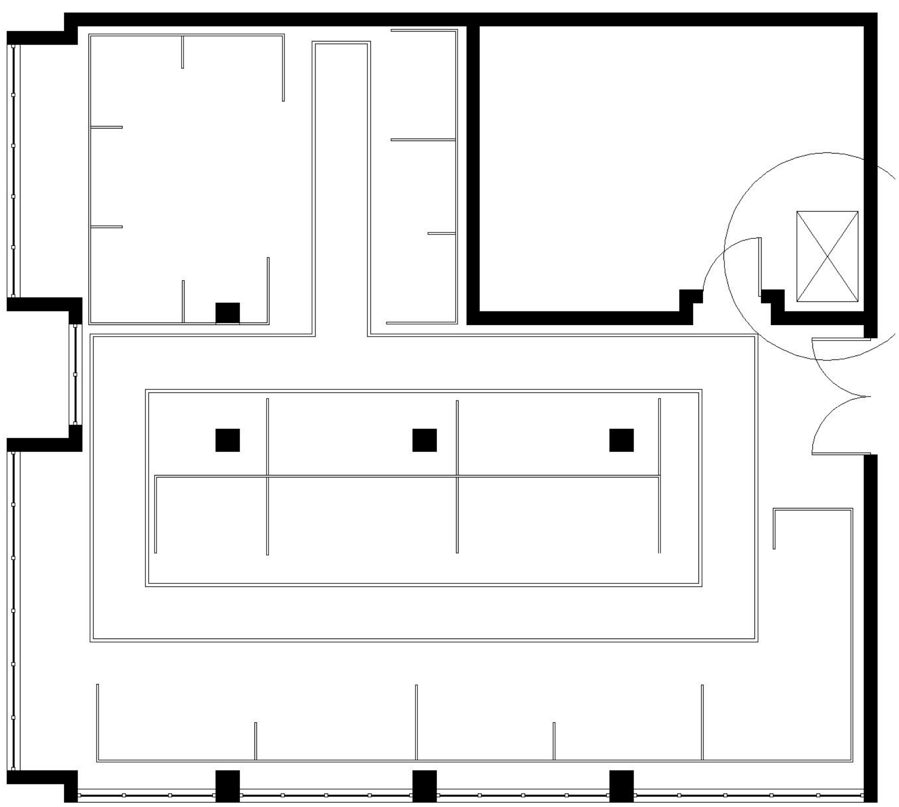

Figure 4.3. New location of photocopy and fax unit.

4.2. Simulation of the Renovated Office

The three major suggestions for renovation was modified on the 3D model of STM Bilkent open-office area; partial change of floor material, partial change of ceiling material, and height change of divider panels. Modified 3D model was imported to ODEON Room Acoustics Software Version 8.5 for acoustical simulation. None of the other parameters were changed from the older model. Position and gain of the sound source, and position of the grid surface was kept the same. Density of the grid surface was again 0.5 meters. Material assignments were also kept the same with the previous simulation, except partial floor and ceiling materials. Partial ceiling material was selected as perforated gypsum board with 50mm glass wool backing, and the partial floor material was selected as heavy carpet flooring. Divider panels were raised to 160 cm of height to decrease D50 values at the backside of the panels.

Results were evaluated by analyzing grid response calculations of ODEON. Distribution graphs of reverberation time (T30), clarity (C80), definition (D50) and speech transmission index (STI) were plotted at speech frequencies that are 500 Hz, 1000 Hz and 2000 Hz. The even distribution of sound energy and extended area of low speech intelligibility was expected. Homogeneity of the reflections was also expected in the open-plan office volume.

The first parameter to be analyzed is the reverberation time. T30 values are evaluated by looking to Figure 4.4, Figure 4.5 and Figure 4.6 Comparing the results of previous simulation and renovation, reverberation times were decreased from 0.67 s to 0.42 s at

500 Hz, 0.83 s to 0.65 s at 1000 Hz, and 1.03 s to 0.72 s at 2000 Hz. The parameter does not drop below 0.5 s, so in a small office like STM, the range between 0.42 s to 0.72 at speech frequencies is appropriate according to speech and speech intelligibility. Three major hotspots are shown on distribution graphs, one at the entrance, one at far corner and the last one at between two workstations, however, those hotspots are out of range of working surfaces. Other areas have a more homogeneous distribution as expected.

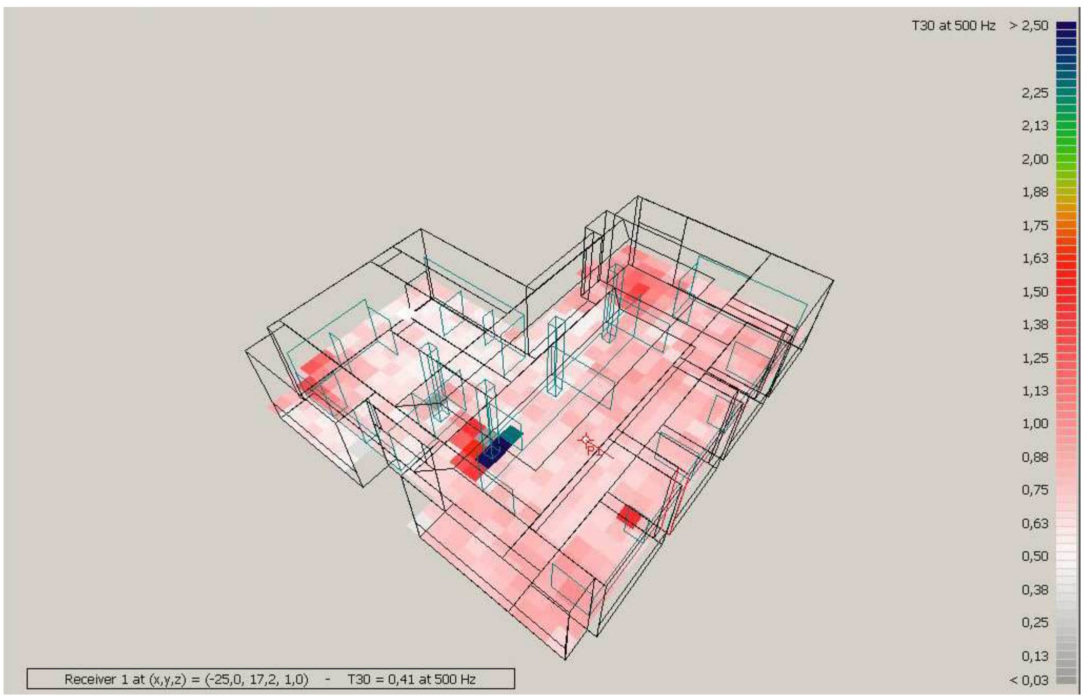

Figure 4.4. T30 distribution graph of renovated office at 500 Hz.

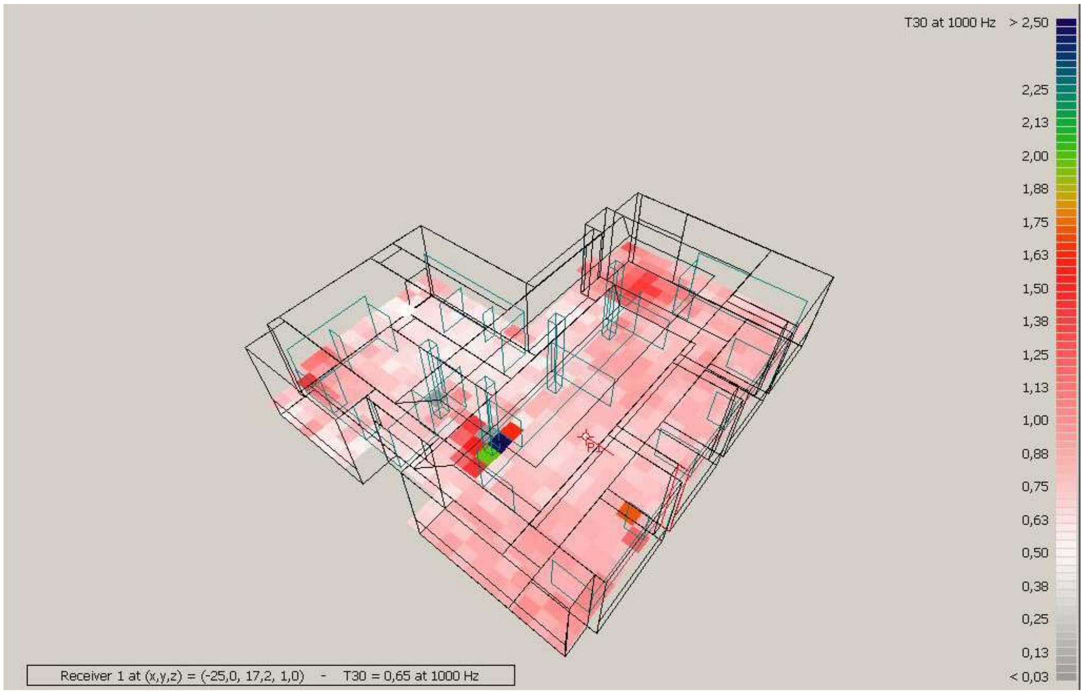

Figure 4.5. T30 distribution graph of renovated office at 1000 Hz.

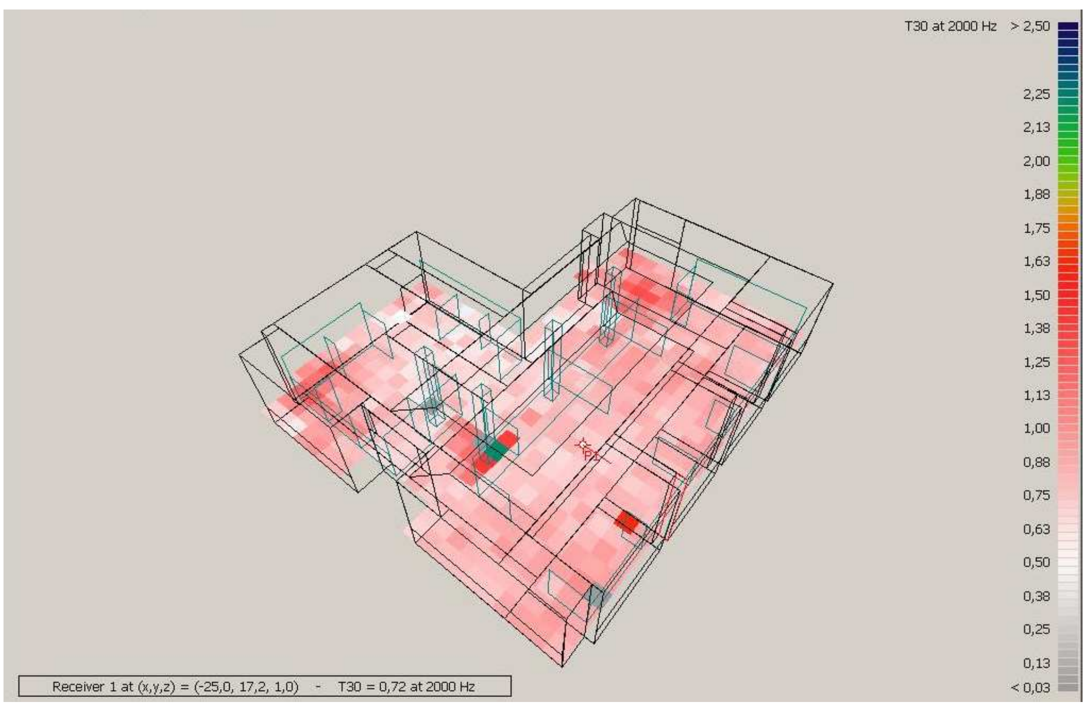

Figure 4.6. T30 distribution graph of renovated office at 2000 Hz.

Clarity parameter was evaluated by analyzing distribution graphs given at Figure 4.7, Figure 4.8, and Figure 4.9 It is observed that C80 values are changed from 0.7 dB to 3.1 dB at 500 Hz, 0.5 dB to 3.0 dB at 1000 Hz. and 0.2 dB to 2.0 dB at 2000 Hz. It is clearly seen that however the clarity value increase, efficiency of divider panels is also increased significantly. The increase of clarity is caused by improved early reflections by flattened the ceiling, but the even distribution of the parameter decrease the hotspot areas at the backside of divider panels. Also, the efficiency of new divider panels can be seen on the distribution graphs.

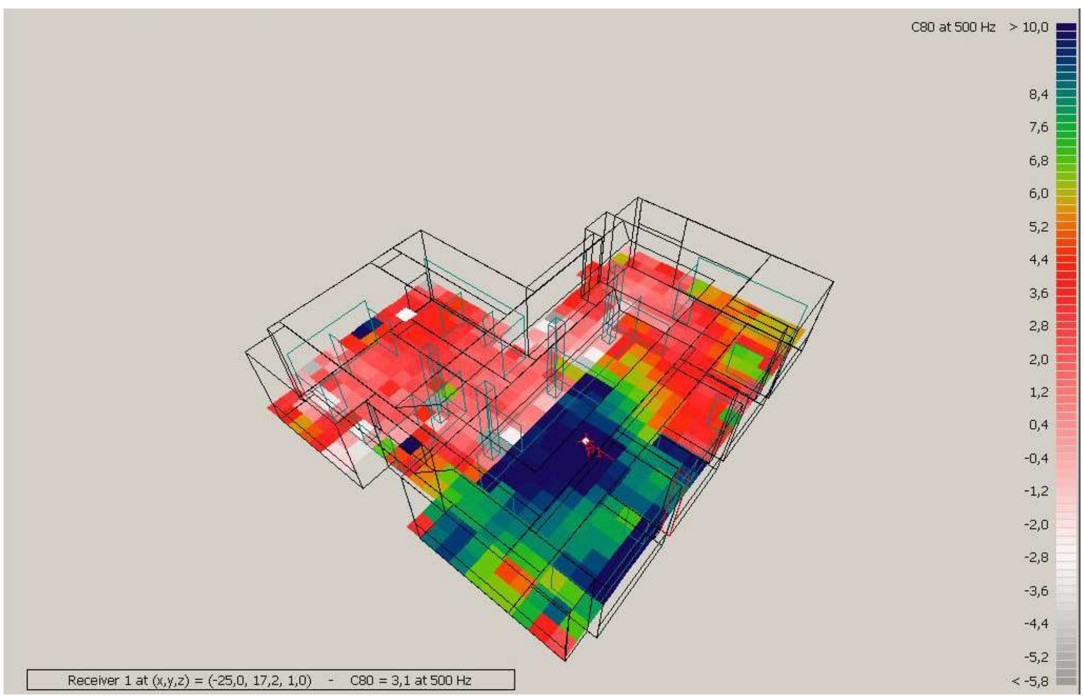

Figure 4.7. C80 distribution graph of renovated office at 500 Hz.

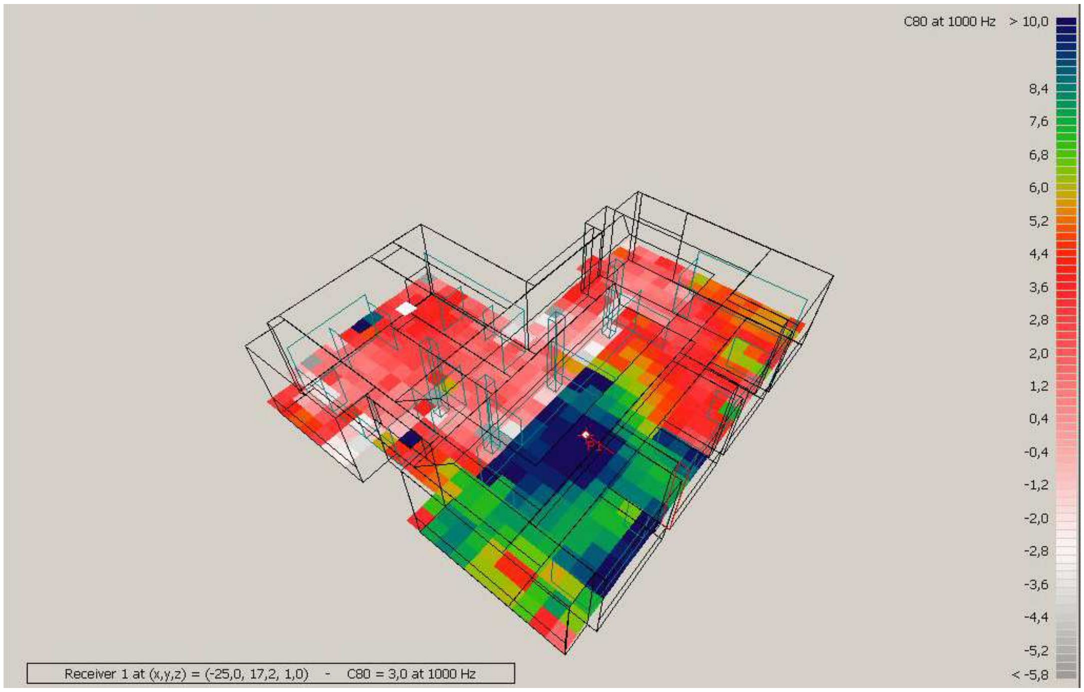

Figure 4.8. C80 distribution graph of renovated office at 1000 Hz.

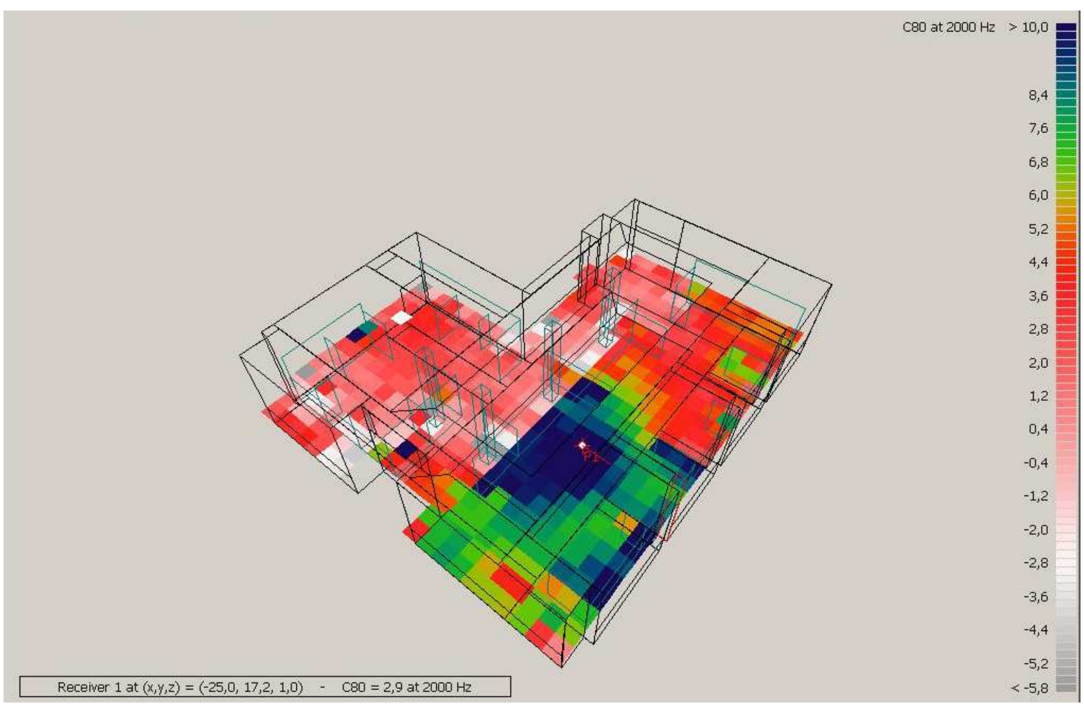

Figure 4.9. C80 distribution graph of renovated office at 2000 Hz.

The definition is also increased in renovated office, from 0.46 to 0.61 at 500 Hz, 0.4 to 0.54 at 1000 Hz, and 0.38 to 0.56 at 2000 Hz (Figure 4.10, Figure 4.11, Figure 4.12). Because the early sound energy is distributed to the volume evenly, the areas that are affected by speech increase in front of divider panels, but the major importance is given to the backside of divider panels, and the effective range of divider panels are extended to include seating positions of the office personnel. High gain value of the sound source used in the simulation cause increased D50 values. In real office environments, speech sound pressure level is around 70 dB, but the gain of sound source used in the simulation was 90 dB. Both the even distribution of early sound energy and the effective area of divider panels can also be seen on D50 distribution graphs.

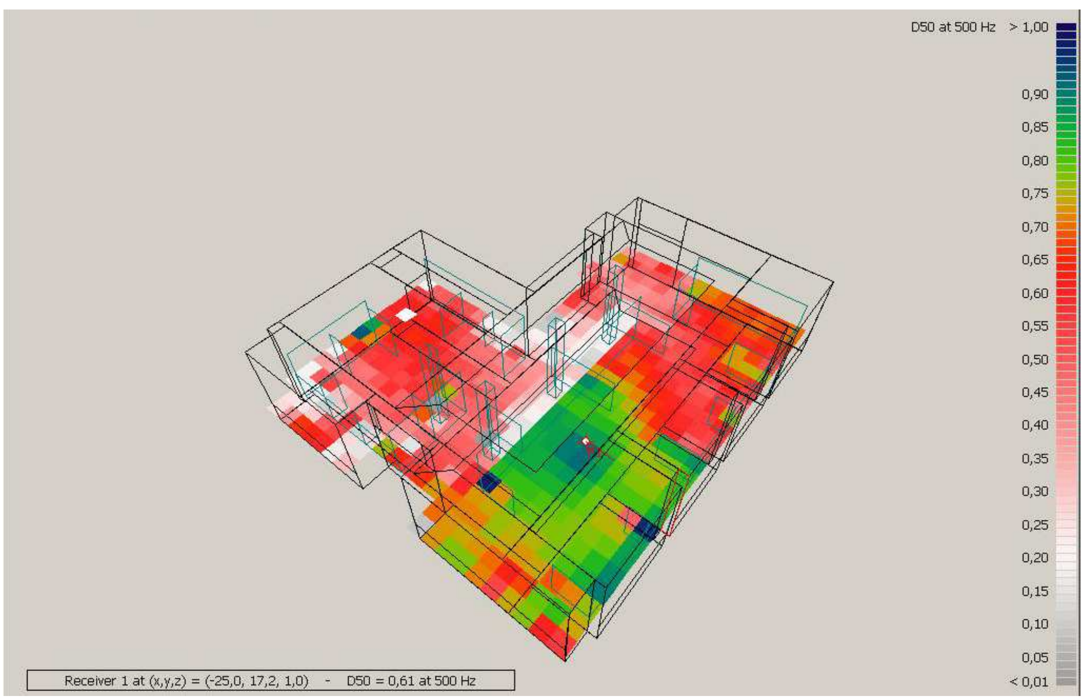

Figure 4.10. D50 distribution graph of renovated office at 500 Hz.

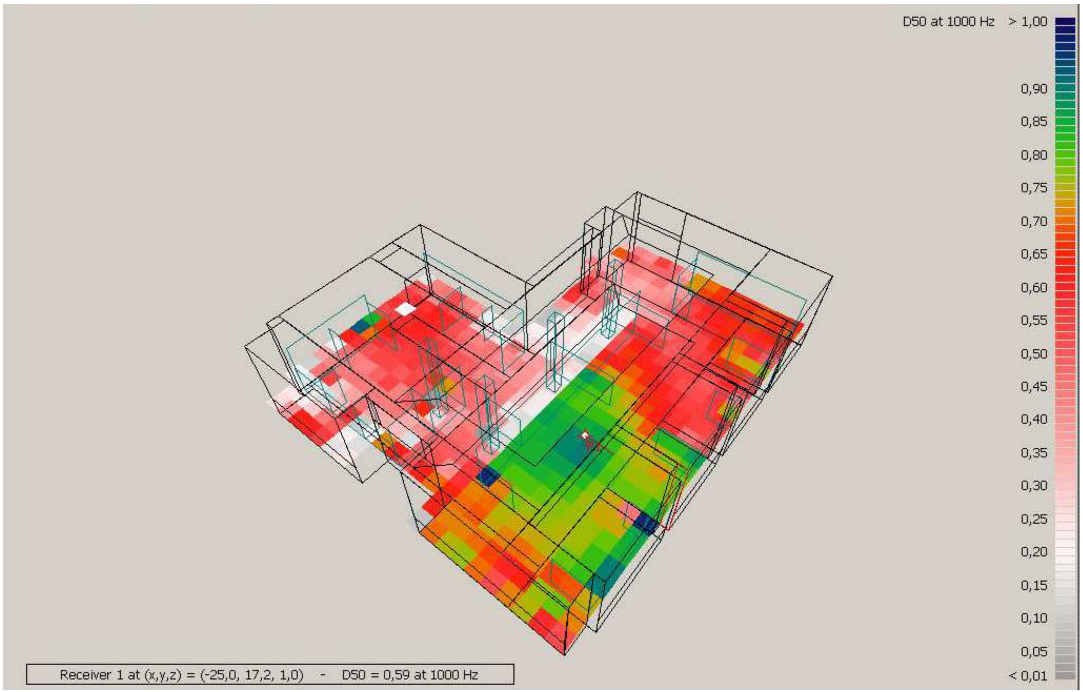

Figure 4.11. D50 distribution graph of renovated office at 1000 Hz.

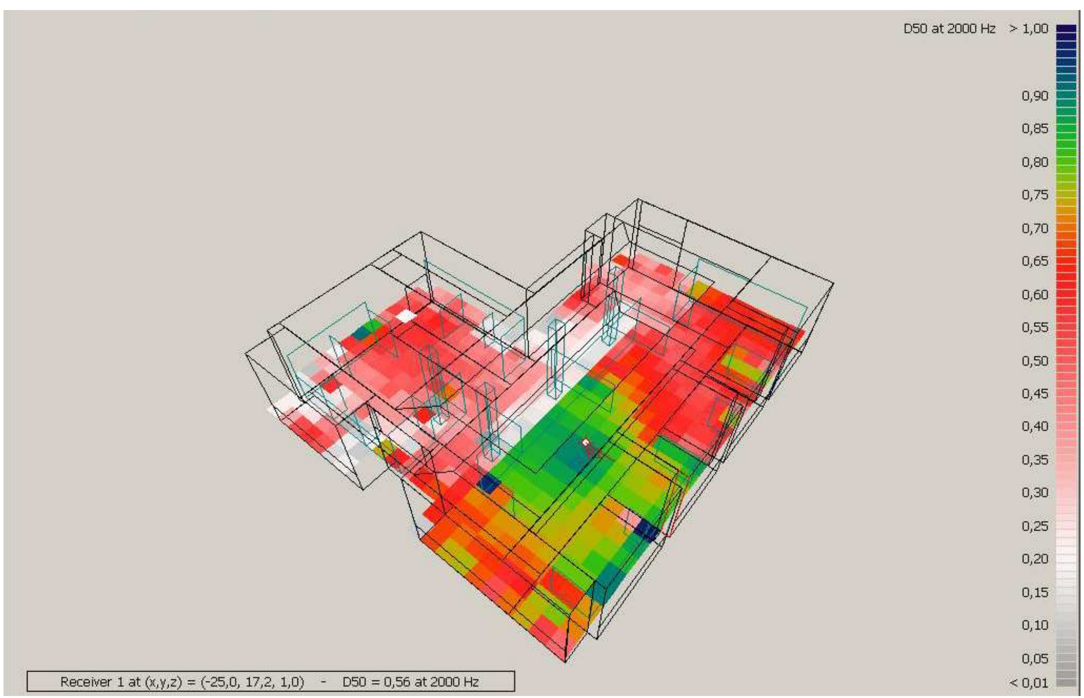

Figure 4.12. D50 distribution graph of renovated office at 2000 Hz.

Speech transmission index is the final parameter to be analyzed. As a cause of decreased reverberation time, STI value is also increased from 0.60 to 0.66 in the renovated office simulation (Figure 4.13). The STI value can also be evaluated according to distribution of the parameter in the area, and the problematic areas seen on present office area are clearly improved, especially by the means of two sides of divider panels. Hotspots also appear on renovated area's distribution graphs, but only at two workstation corners and can be ignored.

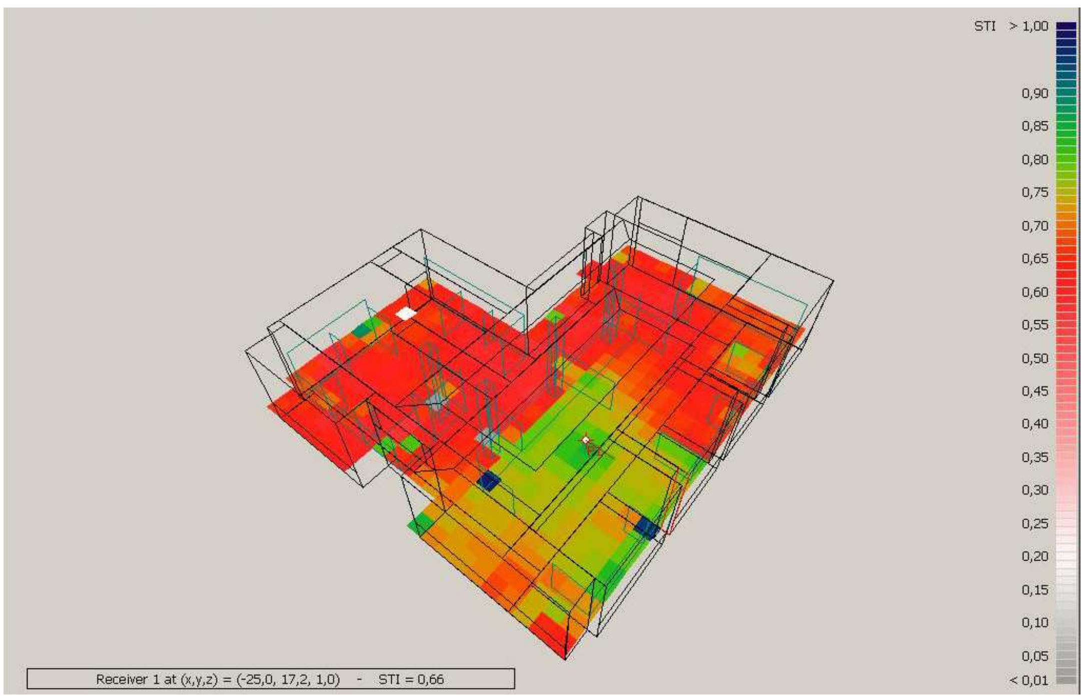

Figure 4.13. STI distribution graph of renovated office.

5. CONCLUSION

According to literature survey, there is a significant effect of speech and speech intelligibility on various task performances. For instance, Hongisto listed various tasks of work performance such as proofreading, short-term memory, reading comprehension, etc. In most of those cases, subjects are affected by intelligible speech (2005). Banbury et al's experiment analyzed memory and arithmetic tasks, which are called 'office-related' tasks. Results show that the irrelevant speech reduces memory for prose and mental arithmetic task performance impressively (1998). However, those studies were carried out under laboratory conditions. This study, analyze the effects of speech and speech intelligibility in a real open-plan office environment, which all of the subjects participated to the test is familiar to the working environment, and the task.

The structure of the thesis is based on three major methods, to completely analyze effects of speech and speech intelligibility on computer-based task performance in a real open-plan office environment. Results derived from the computer-based task performance test guided proposal for renovation of the site STM Bilkent Headquarters. Real-size measurements and computer simulation of the site was used to achieve detailed acoustical information, and to create solutions for a better work environment.

The first method is the real-size measurements of the site, which is carried with one source and two different receiver positions, by using Dirac software. Four different room acoustics parameters were analyzed after the measurement; reverberation time (T30), clarity (C80), definition (D50) and the speech transmission index (STI). Comparison of results from two different receiver locations shows the effectiveness of divider panels between work surfaces. The results of real-size measurement and computer simulation are nearly the same for similar receiver locations according to distribution graphs in frequencies of speech that are 500 Hz, 1000 Hz and 2000 Hz. Therefore, the distribution graphs reliability on different locations was proven to use for analysis of the open-plan office area.

The second method is the computer simulation of the site using Odeon room acoustics software. Results were analyzed for evaluating speech intelligibility requirements of an open-plan office, so the same four parameters related with speech were analyzed. The results show that, reverberation time is slightly higher than office requirements, but in open-plan offices, to achieve a less intelligible speech, reverberation time can be higher in case of lower background noise situations. By looking at clarity and definition distribution graphs, it can be said that divider panels are effective to block direct sound energy, however, the range of the effective areas behind screens are not enough to prevent the office personnel from speech. STI distribution graph is like a brief of all other distribution graphs, showing the uneven distribution of reflections, and the affects of divider panels to the intelligible speech.

The third method is the computer-based task performance test, and the results show that if the worker is experienced with the task and familiar to the open-plan office environment, effect of intelligible speech is only psychological. Stress factor may cause various health or psychological problems in a long-term, rather than instant performance drops. According to those results, the site should be renovated to achieve an open-plan office environment with less intelligible speech.

It is claimed that effect of unwanted speech is independent from sound pressure level of the sound; it is more related with the meaning of speech (Banbury and Berry, 1998). Speech becomes disturbing only when it is clear. Increasing speech-noise ratio and decreasing reverberation time provides more intelligible speech in rooms. As Hongisto stated, the designer should aim at low speech privacy in both conventional and open-plan offices (2005). By evaluating real-size measurements and computer simulation of the site, three main renovations were suggested to improve work performance by decreasing speech intelligibility in STM case. First suggestion is the renovation of ceiling and floor materials on the circulation axis to absorb direct sound energy of sound instantly, by using heavy weighted carpet on the floor and acoustical gypsum board with glass wool on the ceiling. This renovation also prevents footstep noises that may distract the open-office personnel. Second suggestion is raising divider panels in between work surfaces to 160 cm, to enlarge the effective area of blocking the sound energy and early reflections. The final suggestion is isolating major noise sources like photocopy and fax machines, because of relatively high level of reverberation time.

Open-plan office environments are very popular today, because of organizational benefits and better flow of communication. However, it is hard to achieve an ideal condition for a better work environment. Intelligible speech and speech privacy is one of the most distracting affect on both work performance and occupants health. Solutions were suggested for the case STM Bilkent, but the office workers participated to the test is software engineer and they are working on nearly same tasks during the day. A further study could be designed by using various task performance tests different than subjects' background and experience, again in a real open-plan office environment, rather than laboratory conditions.

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APPENDIX A

INTERIOR VIEW OF THE SITE

Figure A1.1. Two adjacent workstations in the open-plan office area

Figure A1.2. General view from the open-plan office area

Figure A1.4. View from circulation area

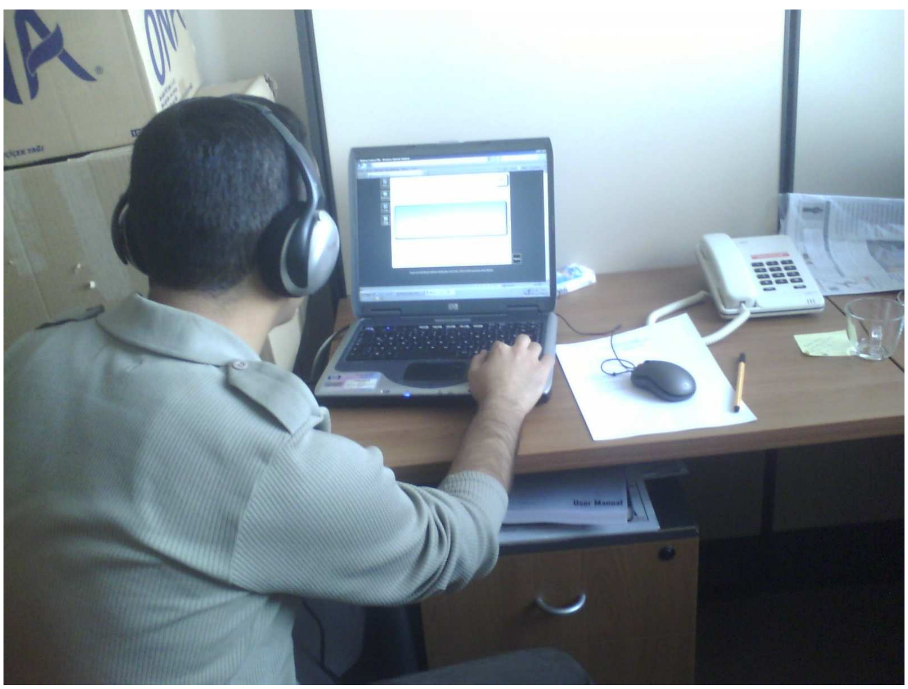

Figure A1.3. An occupant in the task performance test

APPENDIX B

QUESTIONNAIRES

Bilkent Üniversitesi
İç Mimarlık ve Çevre Tasarımı

Orta Seviye Bilgi İşlem Testi
Anket No.1

1. Gece iyi uyudunuz mu?

1	2	3	4	5

(En az için 1, en çok için 5)

2. Açlık hissediyor musunuz?

1	2	3	4	5

(En az için 1, en çok için 5)

3. Şu anda fiziksel bir rahatsızlığınız (baş ağrısı, boyun ağrısı, vb.) var mı?

1	2	3	4	5

(En az için 1, en çok için 5)

Bilkent Üniversitesi
İç Mimarlık ve Çevre Tasarımı

Orta Seviye Bilgi İşlem Testi
Anket No.2

1. İlk ses ortamı sizi ne kadar rahatsız etti?

1	2	3	4	5

(En az için 1, en çok için 5)

2. İkinci ses ortamı sizi ne kadar rahatsız etti?

1	2	3	4	5

(En az için 1, en çok için 5)

3. Üçüncü ses ortamı sizi ne kadar rahatsız etti?

1	2	3	4	5

(En az için 1, en çok için 5)

4. Ses ortamları dışında performansınızı etkilediğini düşündüğünüz dış etkenler var mıydı? Var ise nelerdi?

5. Ne kadar başarılı olduğunuzu düşünüyorsunuz?

1	2	3	4	5

(En az için 1, en çok için 5)

6. Hıza ne kadar önem verdiniz?

1	2	3	4	5

(En az için 1, en çok için 5)

7. Doğruluğa ne kadar önem verdiniz?

1	2	3	4	5

(En az için 1, en çok için 5)