ASSESSMENT OF ACOUSTICAL PERFORMANCE OF GREEN RATED OFFICE BUILDINGS IN DHAKA CITY

By

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ABSTRACT

According to recent investigations, indoor acoustical performance of green rated office buildings has been found to be unsatisfactory. This contradicts with green building rating criteria, where a good Indoor Environmental Quality (IEQ) is crucial for the well-being of occupants. Insufficient attempts have been taken to enrich the acoustical environment of these buildings. The situation in Bangladesh is unestablished, with no study undertaken to determine the existing acoustical performance of green rated office buildings. Specific acoustical considerations for performance should be met in green rated office buildings to conserve the environment and natural resources, and also provide a comfortable acoustical environment for its occupants. The aim of the thesis is to explore this issue in depth, by assessing the current quantitative and qualitative deviations in acoustical performance of green rated office buildings in Dhaka.

Primary data was collected through physical site survey to obtain quantitative data in selected office buildings, and through qualitative questionnaire survey of occupants. Secondary data was collected by analysing previous studies of similar topics through journals and other written records. Open, semi-private and private types of office spaces were studied in this research.

Results from both quantitative and qualitative surveys confirmed to similar sets of findings in background noise levels, reverberation time, speech intelligibility and speech privacy in all the office spaces. Overall acoustical performance in terms of these parameters was found below the level of required standard. Lack of awareness on appropriate acoustical measures for office buildings existed among design teams, contractors and clients. High levels of background noise and poor speech intelligibility conditions were dominant, with most participants expressing dissatisfaction with existing background noise control measures. This affected well-being and work productivity of most employees. Deviations from acoustical performance standards were the highest in semi-private office spaces, where participants were also affected by unsatisfactory speech privacy levels. Conversely, open and private office users were less affected by existing acoustical performance deviations, suggesting the need for revised standards of acoustical performance for these spaces. In general, deviations in acoustical performance were not affected by the office's vertical location in the building nor specific working hours, rather were dependent on proper acoustical design measures and planning guidelines.

It is expected that the study findings may increase awareness on acoustical issues of green rated office buildings among associated design and client groups, and encourage necessary design measures in future green rated office buildings.

Keywords: Green rated building, acoustical performance, office, Dhaka

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List of Abbreviations

AI Articulation Index

ANOVA Analysis of Variance

ANSI American National Standards Institute

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASTM American Society for Testing and Materials

BCA Building and Construction Authority

BD+C Building Design+Construction

BPDS Building Planning and Design Standard

BEAM Building Environmental Assessment Method

BMS Building Management System

BNBC Bangladesh National Building Code

BREEAM Building Research Establishment Environmental Assessment Method

CASBEE Comprehensive Assessment System for Built Environment Efficiency

CBE Centre for the Built Environment

CEO Chief Executive Officer

CI Confidence Interval

dBA Decibel

DEQ Department of Environmental Quality

DGNB German Sustainable Building Council

EEWH Ecology, Energy Saving, Waste Reduction and Health

EQ Environmental Quality

GBES Green Building Evaluation Standard

GBI Green Building Index

GBL Green Building Label

GRIHA Green Rating for Integrated Habitat Assessment

GSA General Services Administration

H_0 Null Hypothesis

H_1 Alternative Hypothesis

HQE High Quality Environmental standard

HVAC Heating, Ventilation and Air Conditioning

Hz Hertz

IAQ Indoor Air Quality

ID+C Interior Design+Construction

IEQ Indoor Environmental Quality

IES Illuminating Engineering Society

ISO International Organization for Standardization

ITACA Innovation and Transparency of the Contracts and Environmental Compatibility

LAeq A-weighted Equivalent continuous noise level

LEED Leadership in Energy and Environmental Design

NABERS-IE National Australian Built Environment Rating Scheme Indoor Environment

NC Noise Criteria

NIC Noise Isolation Class

NIOSH National Institute for Occupational Safety and Health

NCB Balanced Noise Criteria

NR Noise Rating

OSHA Occupational Safety and Health Administration

PA Public Address

PI Privacy Index

POE Post Occupancy Evaluation

PSA Percentage Syllable Articulation

PVC Polyvinyl Chloride

RAJUK Rajdhani Unnayan Kartripakkha

RASTI Rapid Speech Transmission Index

RMG Ready-Made Garments

RT Reverberation Time

SD Standard Deviation

SII Speech Intelligibility Index

SNR: Signal to Noise Ratio

SS Stainless Steel

STI Speech Transmission Index

USGBC U. S. Green Building Council

VOC Volatile Organic Compound

VRF Variable Refrigerant Flow

WGBC World Green Building Council

WHO World Health Organization

CHAPTER 01: INTRODUCTION

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1.1 Background

Buildings are one of the highest consumers of non-renewable energy in the world. More than 2/5th of all non-renewable energy reserves are being accounted for by buildings, including office and commercial structures (Centre for Science and Environment India 2014). Modern office buildings which have complete glass facades and greater surface to volume ratios tend to be exposed to greater levels of external temperature and direct sunlight, leading to significant dependency on energy sources for indoor cooling and lighting (Olbryk et al. 2019). For instance, in Europe, 40% of the continent's energy consumption goes behind the development and operation of commercial buildings. The scenario in Dhaka is not contradictory from the ongoing crisis worldwide. Dhaka city alone consumes 55% share from a total of 43% energy coverage countrywide (Haider et al. 2016); 7.63% of energy consumption from this 55% ration is used by commercial or office buildings in the city (Hassan 2015). As a result, there is a greater level of dependence on non-renewable energy sources for operational activities such as indoor lighting, indoor air cooling etc.

More designers and stakeholders are becoming conscious about the design and development of green buildings. They aim to lessen and/or abolish negative impacts and enhance positive impacts of the surrounding atmosphere through their design, construction and operation phases (U. S. Green Building Council 2014). Green buildings promote multiple benefits on an environmental, economic and global scale (World Green Building Council 2019). They aim to provide a 'healthy' environment for its occupants - one that does not cause diseases or illnesses, but promotes well-being and, in the case of workplaces, enhances productivity of all its users. Till date (21st October 2021), a total of 167 projects in Bangladesh have been recognized as being 'green' under various levels of LEED certification. 14 of them fall under the corporate/office typology.

Acoustical performance has been regarded as being an important part of Indoor Environment Quality (IEQ) of any building, including green rated office buildings. It can be assessed through various parameters, the most significant ones being background noise level, reverberation time, speech intelligibility and speech privacy. Noise is usually defined as unwanted sound (Everest 2001). When sound poses an undesirable physiological and/or psychological effect on people, it is regarded as being noise (Stansfeld et al. 2003). It is viewed as an environmental stressor and nuisance. Reverberation time is the time taken for sound persisting in a space to decay by 60 dBA, when the source is suddenly disrupted (Ermann 2015). Speech intelligibility is defined as the percentage of speech that a listener can stand (Jaramillo et al. 2014). Speech privacy is defined as the lack of ability to unintentionally understand the conversation of another person (Cavanaugh et al. 1999). These four parameters are correlated, and they significantly affect the acoustical environment and performance of a space.

Worldwide, there have been reports of extremely poor ratings in acoustical performance in POE surveys conducted in green rated office buildings. It has been seen that most acoustical performance issues were faced in open office spaces, where there are no separate enclosed office space or walled cubicles available for individual employees. However, satisfactory acoustical performance is an important part of IEQ of green rated office buildings, as it directly impacts productivity and healthy environment for occupants. A poor acoustical environment can result in numerous negative effects, including poor work performance and behaviour, communication hindrance, limited attention span, vocal strain and high stress levels. After receiving poor results in acoustical performance from multiple post occupancy surveys worldwide, various green building rating systems have finally started to implement credit points for acoustical performance in their schemes.

1.2 Statement of the Problem

An extremely important aspect of the built environment often overlooked or undervalued in design is the acoustical environment (Muehleisen 2011). Latest research indicates that green rated office buildings had higher post occupancy ratings for daylighting and air quality performance, but they were often less than satisfactory in terms of acoustical performance. According to these studies, green rated buildings had higher ratings in occupant environmental satisfaction, but had extremely lower ratings for acoustical environment satisfaction (Hayne et al. 2016). In a survey carried out on 400 green rated buildings in Berkeley in 2005, it was seen that over 85% of the surveyed buildings displayed a less than satisfactory acoustical environment (rated less than 0) according to Post Occupancy Evaluation (POE) surveys carried out on their longest occupied users (Abbaszadeh et al. 2006). In this particular POE survey, acoustics was the only category where performance was worse in newly rated green buildings compared to non-green buildings, and it was the category with lowest ratings for all buildings. In another study carried out on six green rated office buildings in British Columbia, Canada, it was seen that occupants were displeased with recurring excessive noise levels and poor speech privacy, and stated that acoustical performance of these green rated buildings did not enhance their ability to work in any way (Hodgson 2008). Commonly faced problem by users in most green rated buildings around the globe was lack of sound privacy, followed by noise isolation and lack of speech intelligibility (Red Thread 2016, Saengsawang et al. 2018). LEED regulations only account for a very meagre 0.91% rating to acoustics – despite being one of the largest and most popular green rating schemes (Hayne et al. 2016). This has led to an imperative question – whether a building that cannot provide a satisfactory acoustical environment to its users can in fact be recognized as being a green building (Field 2008).

Acoustics is considered to be an important part of employee comfort and well-being – its significance is cited in the Indoor Environmental Quality (IEQ) section of the Leadership in Energy and Environmental Design (LEED) regulations (Asdrubali et al. 2013). Poor acoustical performance design in any built environment can lead to inhibitions in communication, vocal stress, and may limit attention span of occupants (U. S. Department of Labor n.d.). In case of office buildings, more detrimental issues may arise such as increased stress levels, higher levels of absentee records for employees, and decreased rate of productivity and efficiency in the overall workplace (Muehleisen 2011). This contributes to some common acoustical performance issues. High levels of background noise and poor speech privacy has been reported to be the most common acoustical problem faced by occupants of office spaces (Rossing 2007, Rindel 2018). Poor speech intelligibility is another common occurrence in office spaces having unsatisfactory acoustical environment (Jaramillo et al. 2014). These effects are more pronounced in office spaces having open or semi-private types of design layout and planning (Ermann 2015).

Though most designers prioritize energy performance in green rated office buildings, they fail to acknowledge occupant environmental satisfaction in aspects such as acoustical performance (Esfandiari et al. 2017, Elzeyadi et al. 2017). After receiving poor results in acoustical performance from multiple post occupancy surveys worldwide, various green building rating systems such as LEED have started to implement credit points for acoustical performance in their schemes. Conversely, at the time of this research, all green rated offices in Dhaka had received LEED certification when no rating points were allocated for acoustical performance under the LEED 2009 standards. LEED users who had registered their buildings after 2009 were permitted to enrol their projects under the old LEED 2009 scheme till October 2016.

Most of the current green rating tools and schemes have added rating points for evaluation of acoustical performance in their latest adaptation. LEED has allocated an insignificant total of 2 points for rating acoustical performance under the IEQ category in its recent version (U.S. Green Building Council 2019). Other popular rating schemes such as Green Star, NABERS-IE, WELL, Green Globes and BEAM have newly introduced points for assessing the acoustical performance of green rated buildings in their latest editions (Hayne et al. 2016).

For existing green rated office buildings in Dhaka city, no study has been undertaken till date to assess the acoustical performance. Considering the significance, it has become imperative to undertake this study with an aim to accomplish the need for judging the acoustical condition and its overall performance of green rated office buildings in Dhaka city. Specific acoustical design considerations should be met in green rated buildings so that the structure not only conserves, protects and enhances the surrounding environment and natural resources, but also provides a comfortable IEQ in terms of acoustical environment to its occupants.

1.3 Aims and Objectives of the Research with Specific Outcome

Green rated office buildings should not only be environmentally responsive, but also comprise satisfactory acoustical design and environment to deliver a comfortable and healthy environment for its occupants. The broad goal of this research was to evaluate the current level of acoustical performance of green rated office buildings in the context of Dhaka city, and assessing the reasons behind this problem. The research primarily focused on observing and recording existing background noise levels, speech intelligibility and speech privacy in green rated office spaces in Dhaka city. A descriptive exploratory research disclosing the existing conditions would further contribute to broad-based and specific studies. It might assist policy makers and stakeholders to formulate specific laws and regulations for green rated office buildings. The specific objectives of this study were as follows.

i. To identify whether the current state of acoustical performance in green rated office buildings in Dhaka City was satisfactory or not.

ii. To assess the existing quantitative and qualitative levels of deviations from standards in acoustical performance of green rated office buildings in Dhaka city.

iii. To investigate the reasons behind levels of deviation in acoustical performance of green rated office buildings in Dhaka city.

The practical and possible outcomes of this study were as follows.

i. An assessment on the prevalence of acoustical performance problems in green rated office buildings in Dhaka city.
ii. An account of quantitative and qualitative levels of deviation from standards in acoustical performance of green rated office buildings in Dhaka city.
iii. An inventory of reasons behind probable causes owing to these deviations.

The probable research impacts of this thesis would be as follows.

i. Increased awareness among architects, planners and related consultants while planning and designing any green rated building with regards to acoustical performance.
ii. Increased awareness among clients while making key decisions in design and outlook with regards to acoustical performance.

The research aimed to explore the current acoustical performance scenario of green rated office buildings in Dhaka city. At the beginning of this research, it was hypothesized that levels of deviation in these four parameters of acoustical performance was not satisfactory. The null hypothesis (H_0) of this research was that no levels of deviation in background noise level, reverberation time, speech intelligibility and speech privacy from standards and recommendations existed in acoustical performance of green-rated office buildings in Dhaka city.

1.4 Overview of Research Methodology

A detailed description of the research methodology used for this particular study has been discussed in chapter 03 of this thesis. This chapter provides a brief overview of the research methodology for the thesis.

The research started with a literature survey to gather knowledge and information on the importance of satisfactory acoustical performance in office spaces, current acoustical performance of green rated office buildings worldwide, prevailing acoustical performance issues of green rated office buildings, as well as national and international noise level standards recommended for these structures.

Next, selected green rated office spaces in Dhaka city were studied for this research, over a specified period of time. The study employed two types of survey – objective measurement and subjective qualitative survey. Objective measurement procedures involved recording existing background noise levels in the green rated office spaces during work hours, and the deviation from recommended standards were assessed. Three other acoustical parameters were also calculated and evaluated: reverberation time, speech intelligibility and speech privacy. In order to recognize which common activities contributed to the overall background noise levels in the office spaces, observations of noise sources inside the work space as well as in adjacent spaces were made while collecting data. A checklist was prepared to conduct physical survey to aid in observing and recording design aspects and characteristics of the materials of walls, floor, ceiling, windows and doors of the office building.

A subjective qualitative survey in the form of an occupant perception survey was also carried out, using an acoustical comfort questionnaire form specifically designed for green rated office environment. Each question in the form involved participants to rate their overall satisfaction with the acoustical environment of the building as well as their workspace, office layout and furniture arrangement. Three aspects of the acoustical environment were rated: background noise levels, level of speech intelligibility and speech privacy. The employees and office personnel were also asked further questions to decide when they felt the office space was noisiest, how they thought the existing acoustical performance affected their job performance, and what they typically did to alleviate the existing issues. Meetings were also held with the building designers to gain an insight on their design principles, tactics and limitations.

The experiences of the findings of literature review, field investigation and survey were compiled and analysed to assess the impact and perception of noise levels, speech privacy and speech intelligibility of occupants.

1.5 Scope and Limitations of the Work

The research work mainly focused on the assessment of acoustical performance of existing green rated office buildings in the context of Dhaka region. Due to time and resource constraints, the research study was carried out only in selected LEED certified office and commercial buildings inside Dhaka city. Only three floors from each of the case studies were selected for objective measurement and subjective qualitative survey, due to limited amount of available time and resources, access and confidentiality issues, and small sample size. Further analysis into factors affecting rating of green buildings such as ISO ratings, IEQ, IAQ etc. were not taken into account during the study and thus was beyond the scope of this research. This study solely focused on the acoustical environment assessment of these office buildings.

Typically, integrated impulse response method is used to calculate reverberation time of an enclosed room, where the room is excited with a sine sweep sound signal (Passero et al. 2010). This signal is captured mechanically, converted into an impulse, and the reverberation time calculated digitally from the decay of this impulse. This method requires the impulse to have an intensity greater than the existing background noise level of the room. However, exposing external impulses having noise levels far greater than the existing background noise level would have disrupted the regular activities of the occupants, and thus this method was not used for calculating reverberation time in this research .

Strategies and recommendations based on this research could be carried out with a greater number of green rated office buildings. Other aspects like VOC content of materials, ISO ratings, IEQ, IAQ etc. and their probable effects on acoustical comfort could be investigated. Simulation study could also be carried out along with field investigation. Incorporating different technical solutions like altering the properties of acoustical materials, modifying the space and furniture layout, impact of schemes such as Building Energy Management System (BEMS), etc. could form basis for further research. Additional research could be conducted on other green rated building typologies such as educational buildings, healthcare, industries, residences etc. Assessment could be carried out on the standards needed for acoustical design of spaces specifically for these structures.

1.6 Structure of the Thesis

The thesis has been organized into six chapters. This chapter delivers an outline for each of the following chapters.

Chapter 01 is an introduction to the study. It provides a short background of the study, problem statement with the aim, objectives, scope and limitations of the work.

Chapter 02 is the outcome of literature synthesis. It is based on published sources and established prior researches. This helped in forming an initial knowledge base for the study and narrowing down to the main criteria on which the quantitative and qualitative studies were carried out.

Chapter 03 defines in detail the steps forming the methodology for qualitative case study exploratory mode of research in this thesis. It includes the selection criteria for choosing the case studies for data collection, as well as the considerations taken for subjective and objective survey methods.

Chapter 04 outlines the findings of the subjective and objective data collection surveys, and discusses the analysis of consequent data collected after completing field investigations.

Chapter 05 summarizes the findings of the whole investigation. This was done by fulfilment of aim and objectives described in this chapter, and by outlining deviations in acoustical performance from recommendations and standards in green rated office spaces in Dhaka. At the end of the chapter, research areas that required additional exploration were identified succeeding to this study.

1.7 Conclusion

This chapter aided in developing the basis for the foundation of the entire research. This chapter describes the background of the research, problem statement, aims and objectives of the research, outcomes, research methodology, and scopes and limitations of the research. The discussions in this chapter show that green rated office buildings are rated extremely low for acoustical performance by their users. No study has been carried out till date to determine the performance of acoustical environment of any green rated buildings in Dhaka City, even though POE surveys carried out worldwide has justified its significance in the overall performance of green rated buildings. This was among the main constraint mentioned in this chapter which the research aimed to overcome.

The research explores the existing conditions of acoustical performance in green rated office buildings of Bangladesh in terms of background noise levels, reverberation time, speech intelligibility and speech privacy. Through integrating a descriptive exploratory research approach, this research also investigates the current state of acoustical performance, existing quantitative and qualitative levels of deviations from standards and recommendations, and probable causes behind any recognised levels of deviation.

CHAPTER 02: LITERATURE REVIEW

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2.1 Introduction

This chapter aims to provide a strong framework on acoustical performance of green rated office buildings for this thesis. It provides knowledge, information and detailed evidence on components of acoustical performance in the context of green rated office buildings, focusing on three commonly faced issues– background noise level, speech privacy and speech intelligibility.

2.2 Acoustical Performance Components in Office Spaces

2.2.1 Sound

In research involving acoustical performance and design considerations, sound, noise and their related components are significant factors. In physics, sound can be described as a wave motion passing in air or in any other elastic medium, resulting in disturbance which causes an auditory sensation in the ears of living beings (Ermann 2015). It can also be referred to as an excitation of hearing mechanism of the human body, or any other living organisms. Sound wave motions are caused by an object which vibrates and passes on energy to its adjacent solid, liquid or gas molecules. Sound waves usually travel in the form of longitudinal waves. Sound level is measured in decibels (dBA).

Speed of sound in any medium is determined by its frequency and wavelength. Frequency is the number of wave cycles that occur in 1 second (Howard et al. 2012). It is measured in Hertz (Hz). On the other hand, wavelength is the distance between two successive regions of compressions or rarefactions of a sound wave (Howard et al. 2012). It can also be defined as the distance travelled by a sound wave in one complete cycle. The speed of sound in air can be determined by the following formula (Howard et al. 2012).

$$v = f\lambda \quad \text{(Eq. 2.2.1.a)}$$

where,

v = speed of the sound in air (in m/s)

f = frequency of the sound (in Hz, 1 Hz = 1 cycle per second)

λ = wavelength of the sound in air (in m)

The speed of sound in air at standard conditions is set to be approximately 343 m/s (Rossing 2007).

Fig. 2.2.1.a. illustrates the threshold of hearing and pain with regards to sound intensity among human beings, as well as the range of frequencies typically encountered in daily routine. Human hearing spans an audible range from 20 Hz to 20000 Hz. The range of frequencies below 20 Hz is referred to as infrasonic, where the frequency ranges above 20000 Hz are denoted as ultrasonic. Both infrasonic and ultrasonic frequency waves are beyond the audible capacity of a typical human being. Human beings can withstand a certain range of sound pressure levels. The threshold of hearing and pain varies with frequency as well. For instance, the threshold of hearing is 0 dBA at 1000 Hz, but is 60 dBA at 32 Hz. Vowels and consonants used during speech lie in frequency ranges of 125 to 8000 Hz, where human hearing is the most sensitive. Typical human hearing tends to be more sensitive in middle high ranges of frequencies compared to lower frequencies. The threshold of pain in human beings starts at sound pressure levels of 100 dBA and above, varying with frequency.

2.2.2 Noise

Noise can be described as sound which is undesirable and unwanted by inhabitants of the surrounding space (Everest 2009). It is often perceived as an audible energy source which can negatively effect and harm the physiological and psychological well-being of living creatures (Stansfeld et al. 2003). It is viewed as an environmental stressor and nuisance, causing hindrance to the convenience and peace of any individual (Stansfeld et al. 2003). Sound can become noise if it disrupts speech and communication, hinders the thinking process of individuals, impedes concentration during tasks, interrupts activities or presents a health risk due to hearing damage. Sources of noise can be from internal or external media.

2.2.3 Various parameters related to sound and noise

To further express the various parameters affecting sound and noise, a number of general terms are used in the field of acoustics. Some of the terms which are specifically involved in this thesis are given below.

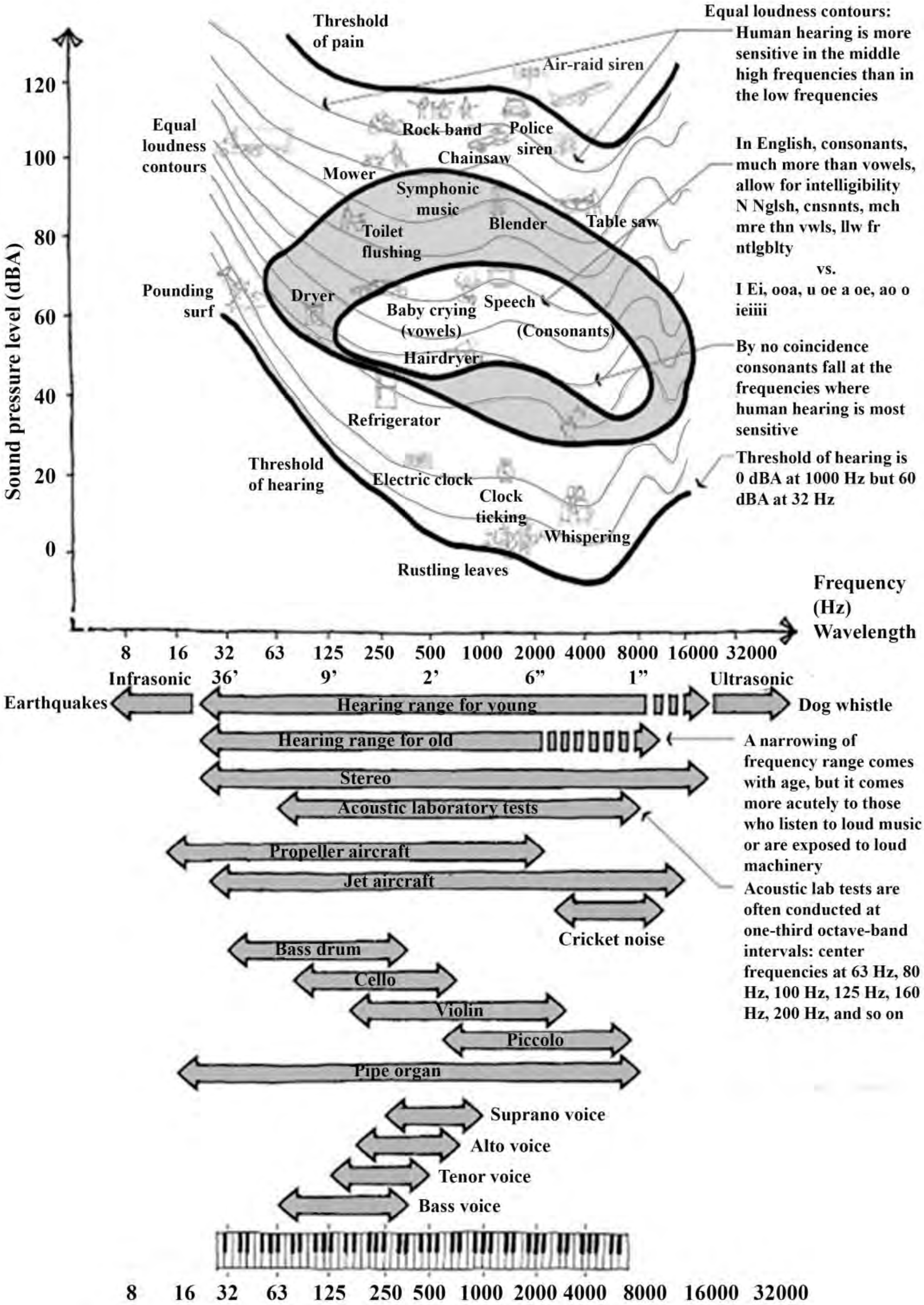


Fig. 2.2.1.a. Sound level perception and frequency (Source: Ermann 2015)

- **Decibel:** It is the unit of measurement used for denoting the logarithmic ratio of two sound pressures or powers. It can also be defined as the magnitude of sound with respect to a reference value proportionate to the threshold of human hearing. It is expressed as dBA.
- **Background noise level:** It is regarded as the background sound pressure level at a given location. Background noise levels of a specific area can be measured indoors as well as outdoors. Background noise level is occasionally referred to as ambient noise level, reference sound level or room noise level. It can be categorized in four types (Ermann 2015).

  - Very loud noise: Over time, this type of noise can cause hearing loss. E.g., Machine shops and loud rock concerts.
  - Loud noise: This type of noise interferes with speech intelligibility. E.g., Noisy restaurant or in a banquet hall with a loud air conditioner.
  - Relatively quiet noise: This type of noise can interrupt very quiet activities. E.g., Distant train travelling during night-time sleeping period or a distant cough during recording session in a quiet studio.
  - Annoying noise: This type of noise annoys building occupants more so by its content rather than its level. E.g., Football pattering impact, noise of an upstairs neighbour's dog or a dripping water faucet when one is trying to concentrate in a task.

  Background noise level is usually measured in "A-weighted" decibels. It is rated in dBA. The allowable upper limit of background noise level for a particular space depends on its speech intelligibility requirement. The background noise level in an office space should not be so high as to hinder concentration and communication, nor should it be so low that it provides no masking for other undesirable office noises.

- **Noise Criteria (NC):** Noise criteria refers to the single numerical index which is commonly practiced in order to designate design goals for the maximum allowable background noise level in a particular space (Ruys 1990). The NC comprises of a group of curves which outline the maximum allowable octave-band sound pressure level that correlates to a specific NC design goal. It was developed in the U.S. for rating indoor noise generating from HVAC and other systems. Alternatively, Noise Rating (NR) curve is used in European provinces. It ensures that background noise levels remain within acceptable limits in order to provide efficient speech intelligibility inside buildings (Table 2.2.3.a.).

  The NC rating can be established by outlining the measured sound pressure levels at each octave band. The noise spectrum is indicated as having an NC rating same as the lowest NC curve which is not exceeded by the spectrum.

Table 2.2.3.a. Recommended values for noise criteria ratings for steady background noise levels in various indoor spaces (Source: Barron 2002)

Activity and type of space	Balanced Noise Criteria (NCB) rating (in DBA)
Broadcast and recording studio:	
Distant microphone pickup used	10
Close microphone pickup used only	Not to exceed 25
Sleeping, resting, relaxing:	
Suburban and rural homes, apartments, hospitals	25-35
Urban homes, hotels, hospitals	30-40
Excellent listening conditions required:	
Concert halls, opera houses, recital halls	10-15
Very good listening conditions required:	
Large auditoriums, drama theatres, large churches	15-20
Small auditoriums, music rehearsal rooms, large conference rooms, libraries	30-40
Moderately good listening conditions required:	
Large office, reception areas, retail stores, restaurants	35-45
Fair listening conditions required:	
Living rooms in dwellings (conversation and listening to television)	30-40
Lobbies, laboratory work spaces, general secretarial areas	40-50
Moderately fair listening conditions required:	
Light maintenance shops, industrial plant control rooms, kitchens, and laundries	45-55
Acceptable speech and telephone communication areas:	
Shops, garages	50-60
Speech communication not required:	
Factory and shop areas	55-70

- **Signal to Noise Ratio (SNR):** Signal to Noise ratio is defined as the measure of signal strength compared to background noise levels in a specific space. It compares the level of the desired signal of source to the level of background noise. It is expressed in dBA.
- **Speech intensity level:** Speech intensity level is perceived as the loudness of the sound by an individual (Hacki 1996). Intensity is directly proportional to the perception of loudness.

Speech intensity level varies with context (e.g., presence of high background noise levels, surrounding activities), the subjective nature of the speaker's mind and the message content. It is measured in dBA.

- **LA_{eq}:** LA_{eq} is referred to as the A-weighted equivalent continuous sound level in decibels measured over a stated period of time $LA_{eq,T}$. As most measurements of noise from community and industrial sources are conducted in A-weighted scale, the LA_{eq} descriptor is thus extensively followed. It is the most preferred method to define sound levels which tend to fluctuate overtime, resulting in a single decibel value which takes into consideration the total sound energy over the period of time of interest.

- **Echo:** Echo is defined as the phenomenon when sound reflects off a surface towards a listener's ears (Cheshire 2010). The sound waves reflect from and across the incident surfaces in the space, losing some energy on impact and the phenomenon continues until it has lost all its energy. In spaces with very large areas such as caves and auditoriums, sound waves tend to take several seconds to return, resulting in a clearly distinguishable echo with no overlapping. Echoes are produced effectively against reflective, smooth and hard surfaces, such as glass or brick walls, as because less amount of energy is absorbed by the incident material and most of the sound waves are reflected in a single direction (Fig. 2.2.3.a.). Conversely, rough or porous surfaces tend to absorb higher amount of sound wave energy, resulting in weaker sound reflecting back at different angles from the incident plane.

- **Reverberation:** Reverberation is the persistence of sound in an enclosed space after it has been produced and reflected continuously from objects and surfaces such as furniture, walls, floor, ceiling, windows, people etc. This results in a build-up of numerous overlapping reflections which decay gradually after being absorbed by the surfaces and objects present in the enclosed space. The main difference between echoes and reverberations is that the distance between the sound source and reflecting surface is significantly larger in the case of echoes when compared to reverberation. Reverberation can reduce speech intelligibility of a space, especially if background noise is already present there.

- **Reverberation time:** Reverberation time of a given enclosed room or space is defined as the time taken for the sound to decay or "fade away" by 60 dBA after an abrupt termination. It is measured in seconds.

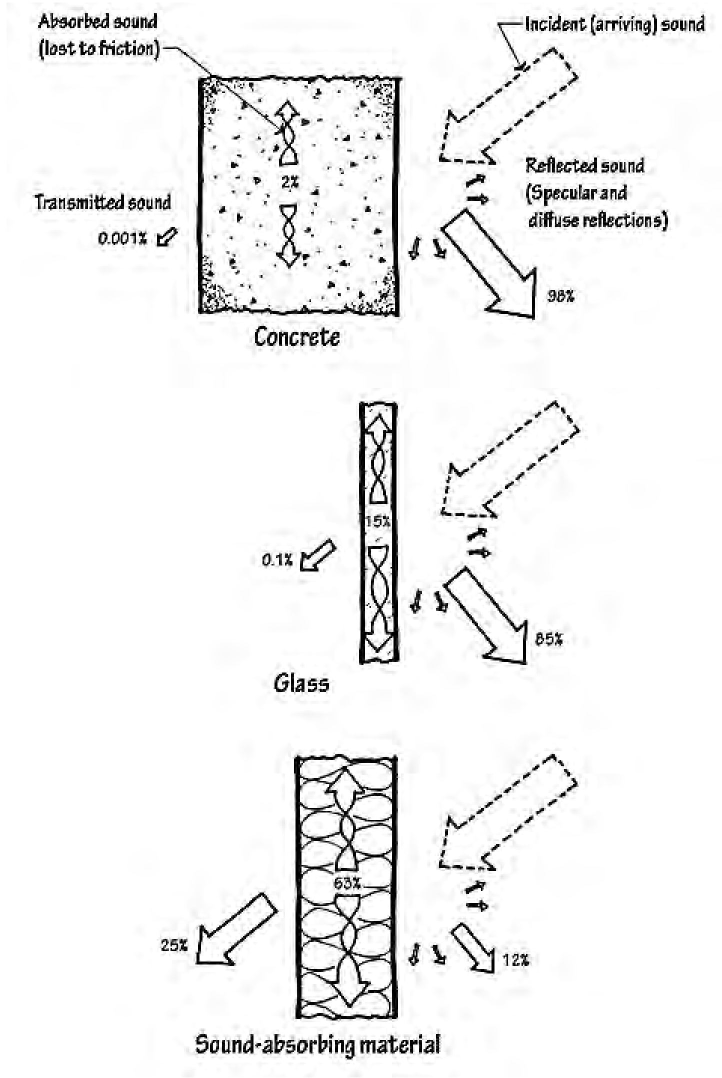


Fig. 2.2.3.a. Reflecting properties of various materials with regards to sound (Source: Ermann 2015)

- **Absorption coefficient (α):** Absorption coefficient is defined as the fraction of the incident sound power absorbed by a material (Ermann 2015). It refers to the property of sound absorption by a surface material, and to compute the amount of incident sound energy absorbed by the material and transformed into heat energy. It is measured on a scale ranging from 0 to 1. Higher values of absorption coefficient indicate higher levels of absorption and lower amount of reflection of the sound by the material and vice versa. For an open window, the absorption coefficient value is 1 as no sound energy is reflected back into the space. Conversely, an ideal reflector would have an absorption coefficient of 0 as all incident sound would be reflected off. Materials with high absorption coefficient tend to be more porous, less smooth, have less weight, have more thickness, mounted over an airspace and/or have less mass. The absorption coefficient of a material also varies according to frequencies (Fig. 2.2.3.b.).

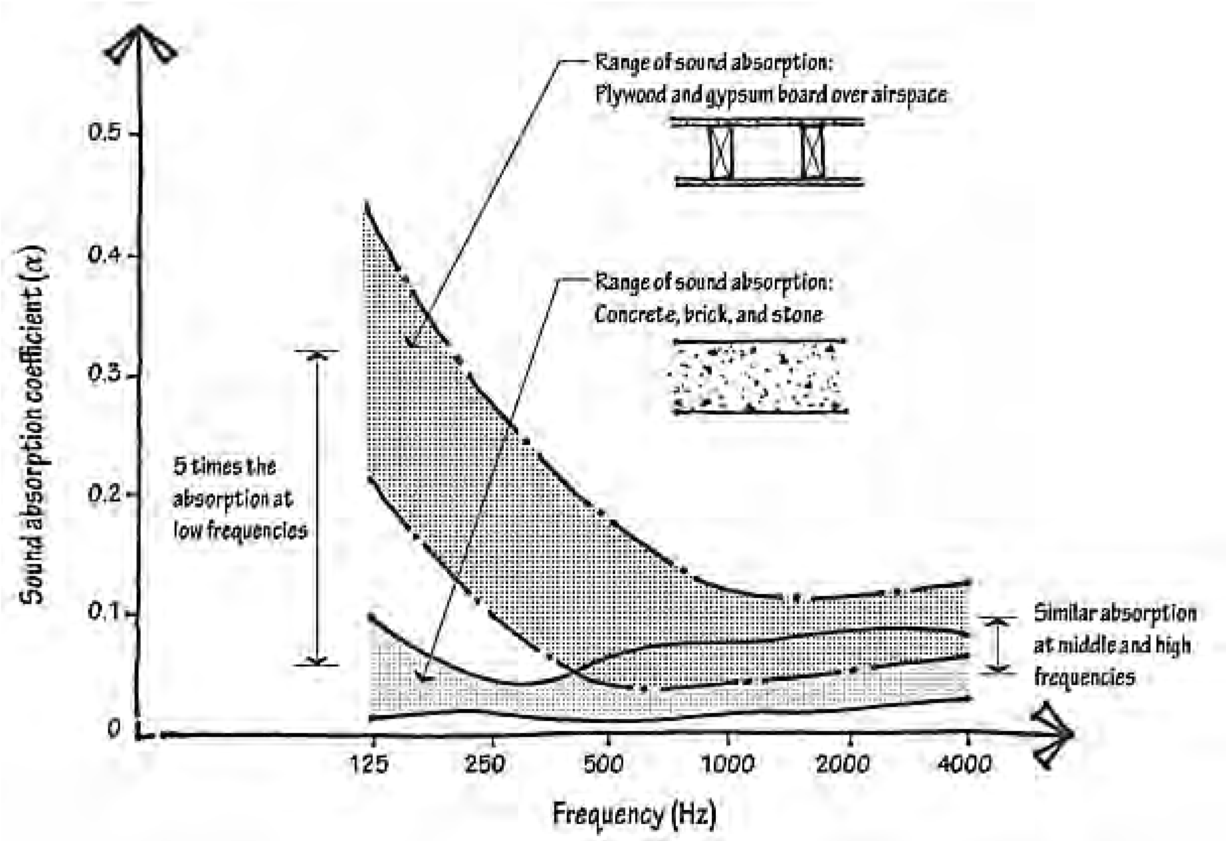


Fig. 2.2.3.b. Relationship between sound absorption coefficient of a material and frequency (Source: Ermann 2015)

- **Noise map:** Noise map is defined as "the presentation of data on an existing or predicted noise situation in terms of a noise indicator, where the trespassing of any relevant regulation limit value will be indicated, also the number of people affected in a specific area or the number of households exposed to certain values of a selected noise indicator in a specific area" (Siano 2012). It illustrates the physical distribution of noise exposure in a given space, either in terms of measured or calculated data. It is developed through significant amounts of comprehensive field work, and is often used by designers and building management as a tool to communicate information about noise levels.

- **Sound masking/masking sound:** Sound masking refers to the effect in which two sounds are present simultaneously, but one sound masks the other one in order to make the latter inaudible (Pang 2018). The sound responsible for masking other sounds in the space is referred to as masking sound, while the sound which is being masked is termed as masked sound. Sound masking effect depends on frequency and sound pressure level of the masking sound and masked sounds.

2.2.4 Speech privacy

Along with background noise level, two commonly faced acoustical performance issues in office spaces are speech privacy and speech intelligibility. Speech privacy is regarded as the lack of ability to unintentionally understand the conversation of another person (Cavanaugh et al. 1999). Studies of acoustical privacy conducted in office spaces show that occupants are irritated and sense a loss of privacy when sound broadcasted from activities in adjacent areas convey related minor comprehensible details. Privacy and distraction have been reported to be the most common issues in acoustical performance of office spaces (Rossing 2007). Speech privacy has been regarded as an issue with signal to noise ratio, and it is inversely proportional to the signal to noise rating. Speech privacy between enclosed rooms is affected by six factors (Cavanaugh et al. 1999).

- **Level of background noise in the receiving space (listener's space):** In the listener's area, background noise masks unwanted noises from adjacent area (source) and makes them more incomprehensible to listeners in receiving space. Thus, higher background noise level in the listener's space would result in higher amount of speech privacy between the two areas.

- **Strength of sound or noise source in the given space (vocal effort):** The higher the loudness of the speech signal in adjacent room (source), the higher the chances of the speech to be comprehensible to listeners in receiving room. Thus, speech privacy between the areas would decrease.

- **Amount of noise absorption present in receiving space:** The lower the amount of reverberant accumulation of speech sound from an adjacent area (source) into the receiving room, the lower would be the speech signal level. This would result in higher level of speech privacy and consequently lower level of speech intelligibility between the two spaces.

- **Relative sizes of adjacent and receiving rooms:** If the size of the receiving room is larger than the adjacent room, the speech signal level in the receiving room would be lower. Thus, speech privacy between the two spaces would increase.

- **Sound transmission characteristics of barrier materials between the adjacent and receiving rooms:** An increase in loss of sound transmission of the wall or barrier between the adjacent and receiving room would cause a decrease in the speech signal level in the receiving room. Thus, speech privacy between the two spaces would increase.

- **Required speech privacy standards for the spaces:** Different areas inside office spaces require different speech privacy ratings (in context to circumstances). The higher the rating, the lower would be the speech signal level relative to the background noise level, to confirm sufficient masking of the speech signals. This would result in higher speech privacy levels between the two spaces.

Speech privacy objectives can be classified into three categories – minimal distraction, normal speech privacy and confidential speech privacy (Rossing 2007).

- Normal speech privacy refers to the condition when work can be carried out without any distractions or interruptions, and discussions from adjacent spaces can only be heard occasionally.

- Confidential speech privacy occurs when discussions can be carried out without any worries of it being intelligible to listeners in adjacent spaces. Speech may be perceived by others but is not comprehended. Inadequate levels of speech privacy can cause distractions in the workspace, which can decrease productivity and efficiency among workers. For confidential privacy in office spaces, rooms with fully enclosed walls and doors extending to structural ceiling are required. If doors extend to only suspended ceiling, sound will still be able to travel through suspended ceiling panels and walls, decreasing the acoustical privacy of these office spaces.

Speech privacy of a space can be determined by various metrics. The most commonly practiced are given below (Rossing 2007).

- **Articulation Index (AI):** AI refers to the ratio between a voice level and steady background noise level. It was initially developed to assess communication systems, and has been widely practiced to evaluate conditions of speech intelligibility of a particular space. The values of AI range from near 0 (denoting low speech level and high background noise level, resulting in poor speech intelligibility and good speech privacy) to 1.0 (no speech privacy).

Fig. 2.2.4.a. illustrates the relationship between AI and speech privacy. Minimal distraction parallels to an AI of 0.35 or less. Normal speech privacy corresponds to an AI of 0.20 or less. Confidential speech privacy, where no parts of discussions can be overheard in adjacent rooms, corresponds to an AI of 0.05 or less. No speech privacy occurs for AI values above 0.40.

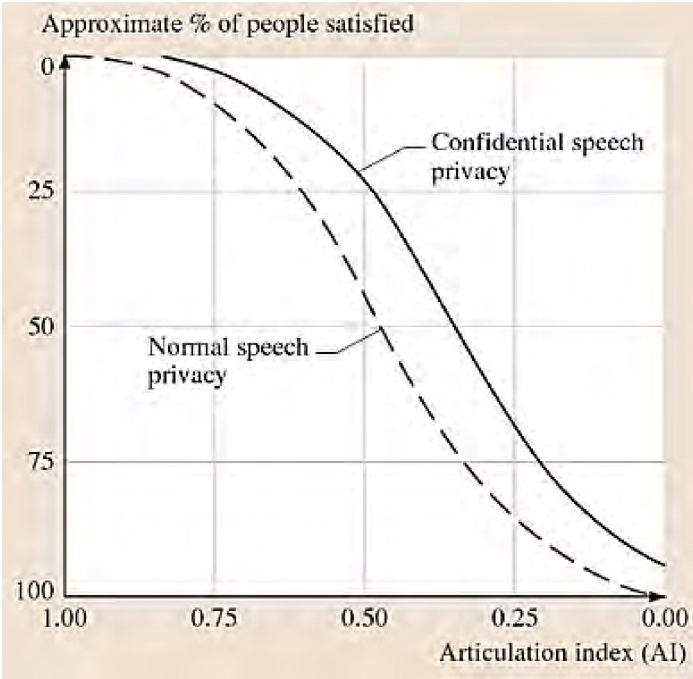


Fig. 2.2.4.a. Correlation between AI and speech privacy (Source: Rossing 2007)

- **Speech Intelligibility Index (SII):** AI is now commonly replaced by SII, which is a measure of signal to noise ratio with revised frequency weighting and the masking effect of one frequency band on nearby frequency bands. SII values range from 0 to 1.0, similar to conditions of AI but corresponding to much larger values.

- **Privacy index (PI):** PI is related to AI. It can be calculated by:

PI = (1-AI) x 100 …………………………………. (Eq. 2.2.4.a)

It is denoted as a percentage. The value of PI ranges from 0 (poor speech privacy) to 1.0 (high speech privacy). An AI of 0.10 corresponds to a PI of 90%.

Table 2.2.4.a. shows the relationship between corresponding values of AI, SII and PI for office spaces.

Table 2.2.4.a. AI, SII and PI values for open office spaces (Source: Rossing 2007)

AI	SII	PI	Privacy condition	Office environment
> 0.65	> 0.75	< 35%	Good communication	Necessary when communication is desirable (conference rooms, classrooms, auditoriums, etc.)
> 0.40	> 0.45	< 60%	No privacy	Clear intelligibility of conversations and distraction
0.35	0.45	65%	Freedom from distraction	Reasonable work conditions not requiring heavy concentration or speech privacy; can hear and understand neighbouring conversations
0.20	0.27	80%	Normal speech privacy	Only occasional intelligibility from a neighbour's conversation; work patterns not interrupted
< 0.05	< 0.10	> 95%	Confidential speech privacy	Aware of neighbour's conversation but it is not intelligible

2.2.5 Speech intelligibility

Speech intelligibility is the percentage of speech a listener can comprehend (Jaramillo et al. 2014). The term intelligibility can also be referred to as 'speech clarity'. It is a degree of how well someone can be understood when they are speaking in the same space, in the presence of given conditions such as existing background noise levels. It indicates how well speech is correctly understood in a room – either directly between a speaker and a number of listeners, or by means of a sound system with a microphone, amplifier and speakers. Speech is deliberated to be the chief process of communication between human beings. Humans alter the way they speak and hear according to many biological and socioecological factors. Age, gender, native language and social relationship between talker and listener affects the way a person speaks, and the extent to which they can hear and understand others properly. Speech intelligibility may also be affected by pathologies such as speech and hearing disorders. It is related to occupants having a conversation with each other, whereas speech privacy relates to individuals not being in a conversation with each other (Chigot et al. 2004). Speech intelligibility is an important acoustical quality factor, not only for spaces designed for communication such as classrooms and office spaces, but also for other seemingly less apparent areas such as theatres, auditoriums and railway stations.

Speech intelligibility is also affected by signal to noise ratio, and it is directly proportional to the signal to noise rating. Speech intelligibility of a particular area and between two enclosed spaces (source and receiver) is affected by several factors which includes the following.

- **Reverberation time:** Longer reverberation times result in lower levels of speech intelligibility between the source and receiving spaces.
- **Distance between sound or noise source and receiver between the two spaces:** The longer the distance between source and receiving space, the lower would be the speech intelligibility between the two spaces.
- **Level of background noise in the receiving space:** The higher the background noise level in the receiving space, the lower would be the speech intelligibility between the source and receiving areas (Fig. 2.2.5.a.).

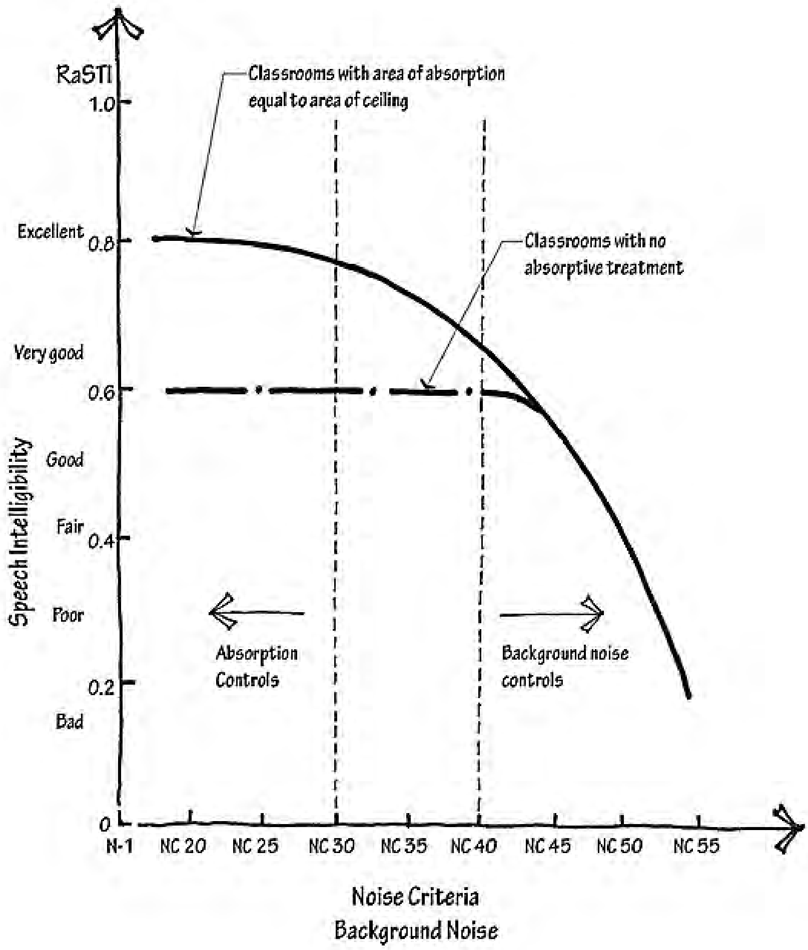


Fig. 2.2.5.a. Relationship between speech intelligibility and background noise level (Source: Ermann 2015)

- **Signal to Noise Ratio (SNR) of the given space:** Lower levels of SNR with relation to background noise level would cause a decrease in the speech intelligibility between the source and receiving spaces (Table 2.2.5.a.).

Table 2.2.5.a. Speech intelligibility ratings based on SNR values (Source: Rossing 2007)

Signal-to-noise ratio at listener's position (dBA-SIL)	Speech intelligibility rating
< -6	Insufficient
-6 to -3	Unsatisfactory
-3 to 0	Sufficient
0 to 6	Satisfactory
6 to 12	Good
12 to 18	Very good
> 18	Excellent

For a satisfactory speech intelligibility, speech intensity level of the speaker should be at minimum 15 to 20 dBA higher than background noise level of the receiving room so that the voice is not masked or compromised (Cavanaugh et al. 2009).

Speech intelligibility of a given space can be predicted by a number of computing systems.

- **Articulation Index (AI):** An AI value of 0 denotes poor or no speech intelligibility, whereas 1.0 denotes high speech intelligibility. Hearing condition is very good at AI values of 0.85 and above (Knudsen 1932). A value of 0.75 indicates satisfactory hearing condition but in which attentive hearing is needed. 0.65 AI value denotes barely acceptable speech intelligibility. AI values less than 0.65 indicates unsatisfactory speech intelligibility. However, AI is rarely used in current researches because it fails to effectively account for reverberation time in its calculation (Ermann 2015).

- **Speech Intelligibility Index (SII):** This method is based on the AI principle. The value of SII ranges from 0 (poor speech intelligibility) to 1 (high speech intelligibility) (Rossing 2007).

- **Speech Transmission Index (STI):** STI is commonly used to evaluate speech intelligibility in performance and lecture spaces. STI can be measured using commercially available measuring instruments, often in terms of the metric known as the Rapid Speech Transmission Index (RASTI) to simplify the monitoring effect. When background noise levels exceed NC-40, RASTI values for speech intelligibility decreases significantly.

- **Percentage Syllable Articulation (PSA):** A commonly used system to determine speech intelligibility is to use Percentage Syllable Articulation method. In this process, a speaker reads nonsensical syllables of the consonant-vowel-consonant form, while listeners note down what they can hear (Barron 2009). A PSA is calculated from the derived results. PSA values above 75% indicate good speech intelligibility for Bangla language (Imam et al. 2017).

Table 2.2.5.b. shows values for STI, RASTI and SII for different speech intelligibility conditions.

Table 2.2.5.b. Values of STI, RASTI and SII for various speech intelligibilities (Source: Ermann 2015)

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

2.2.6 Relationship between speech privacy and speech intelligibility

Speech privacy of a given space is inversely proportional to speech intelligibility (Ermann 2015). A higher value for speech intelligibility would indicate a lower value for speech privacy in the given area. Conversely, low speech intelligibility in a given space implies higher values for speech privacy. Both speech privacy and speech intelligibility are related to signal to noise ratio (Cavanaugh et al. 1999). The lower the signal to noise rating, the lower will be the speech intelligibility and higher will be the speech privacy.

2.3 Overview of Green Buildings

Green buildings are referred to as buildings which, in their design, construction and operation phases, decrease or eradicate undesirable effects and enhance positive effects on the surrounding climate and natural environment (World Green Building Council n.d.). It is widely regarded as an all-inclusive idea that even though all buildings and infrastructure can pose both positive and negative effects on the surrounding atmosphere and occupants, but the positive effects should be intensified (Kriss 2014). Green buildings and infrastructure must ensure that they minimize environmental interference, promote the use of environmentally friendly and non-hazardous materials, decrease non-renewable energy usage and promote low energy use, employ high quality and long-lasting construction materials, and promote economic operation (Bauer et al. 2009). Buildings and infrastructure termed as green tend to have the following features.

- Conservation and efficient use of all energy sources throughout design, construction and operation phases
- Implementing renewable energy sources such as solar energy
- Enabling reduction, reuse and recycling of materials
- Enhancing Indoor Environmental Quality (IEQ) and Indoor Air Quality (IAQ) of occupants
- Promoting sustainable, ethical and non-toxic materials in design and construction phases
- Enhancing users' quality of life in design, construction and operation phases
- Promoting a design which effortlessly adapts to the changing surrounding environment

The features which make a building green also depends on the distinctive climatic conditions, diverse cultures, traditions, various types and ages of infrastructure, and a wide range of environmental, social and economic significances.

Green buildings also enhance the well-being of occupants and ensure healthy indoor climate through sustainable design based on internal surface temperatures, air temperature, relative humidity, air movement, pressure and quality; clothing and activity level, electromagnetic compatibility, visual influences and acoustical influences (Table 2.3.a.) (Bauer et al. 2009).

Table 2.3.a. Influence factors for comfort level sensation indoors (Source: Bauer et al. 2009)

Factors affecting comfort level sensation in indoor spaces	Conditions which affect the factors determining the comfort level sensation in indoor spaces
• Internal surface temperature • Air temperature • Relative humidity • Air movement • Air pressure • Air quality • Electromagnetic compatibility • Acoustic influences • Visual influences	• Clothing • Nutrition • Degree of activity • Ethnic influences • Individual control possibility • Age • Adaptation and acclimatization • Sex • Day and annual rhythm • Bodily condition • Room occupancy • Building design • Psycho-social factors

2.3.1 Acoustical influences in green buildings

One of the main objectives of green buildings is to reduce negative impacts on their inhabitants by producing a healthy, comfortable and productive indoor environment. The performance of indoor environment is regarded as its indoor environmental quality (IEQ). IEQ involves the existing conditions inside a building such as acoustical performance, air quality, lighting, thermal conditions, ergonomics, and it also considers their effects on building users. A high-quality indoor environment can result in increased occupant indoor satisfaction, improved performance and productivity among users, decreased liability, marketing advantage and lower operations and maintenance costs. Significant evidences have established the relationship between chronic health conditions and reduced indoor environmental quality. This awareness has led designers and clients to inspect project materials, design developments and policies related to ongoing sustainability (Cavanaugh et al. 2009).

IEQ also considers acoustical performance and design of green buildings. Even though acoustical influences are sensed subconsciously by human beings, but the amount and type of noise can significantly affect the physical and mental health of an individual. Acoustical performance of a building depends on all its features, and it influences every type of system present in the building (7group and Reed 2009). It must be taken into account in all design, construction and operation phases. The relationship between acoustical performance and green building design can be determined by the following factors.

- The scale and form of a room: Most green buildings support an open plan layout for interior spaces in order reduce construction of indoor walls and elements, thereby decreasing cost and materials. However, noise related factors such as reverberation time and speech intelligibility of a room are greatly influenced by the size, scale and form of the space, and also the type of layout of interior spaces.
- Building construction and interior materials: Materials used in the building construction and final interior layout can significantly influence the behaviour of sound within a space and the transmission of noise between spaces. Materials appropriate for usage in green buildings are often not appropriate for producing satisfactory acoustical environment and performance.
- Noise from external and internal sources: Noise can generate from outdoor sources such as vehicular movement on streets. As most green buildings encourage passive cooling systems for ventilations indoors, they rely on the outer envelope and openings of buildings being exposed at all times. Noise may also generate from internal sources such as electrical and mechanical systems (e.g., HVAC systems). Budget and building configurations play a huge factor in designing for low noise criteria.

2.3.2 Green building assessment tools

A wide range of green building standards, certifications and rating systems have been developed worldwide to assess in the guidance, demonstration and documentation of activities that deliver high performance, sustainable buildings and infrastructure. Standards refer to the set of guidelines and criteria against which a product can be evaluated. Product certification refers to the confirmation that a product has met a particular standard and offers an environmental advantage. Building rating and certification programs, commonly known as Green Building Labels (GBL), aim to reward relative levels of compliance or performance with distinctive environmental goals and criteria (Vierra 2019). They require an integrated design process and consider the project holistically. There are around 600 green standards, certification and rating schemes worldwide, with over 100 systems in USA (Vierra 2019).

LEED v4, which was introduced in 2013, included 2 credit points for evaluating acoustical performance of green buildings in its IEQ category scorecard (Table 2.3.2.a.). These points were applicable only for school and healthcare buildings. LEED v4.1, the current version of LEED launched in January 2019, did not have any change in credit points or prerequisites for acoustical performance. In the previous LEED v3 version, no rating points were allocated under the IEQ category in order to evaluate acoustical performance of any projects.

Table 2.3.2.a. Project checklist and scorecard for IEQ of healthcare buildings in LEED v4.1 (Source: USGBC 2019)

Indoor Environmental Quality		**16**
Prerequisite	Minimum Indoor Air Quality Performance	Required
Prerequisite	Environmental Tobacco Smoke Control	Required
Credit	Enhanced Indoor Air Quality Strategies	2
Credit	Low-Emitting Materials	3
Credit	Construction Indoor Air Quality Management Plan	1
Credit	Indoor Air Quality Assessment	2
Credit	Thermal Comfort	1
Credit	Interior Lighting	1
Credit	Daylight	2
Credit	Quality Views	2
Credit	**Acoustic Performance**	**2**

2.3.3 Green rated buildings in Bangladesh

In Bangladesh, LEED is the most popular rating scheme of designers and related teams for evaluating buildings following green design principles. LEED scheme in Bangladesh is overseen by Bangladesh Green Building Academy, whereas worldwide its activities are overseen by the U.S. Green Building Council (USGBC). Till date (21st October 2021), 724 projects in Bangladesh have been registered and 167 projects have received LEED accreditation, ranging from ‘certified’ to ‘platinum’ level of certification (Fig. 2.3.3.a.). These projects include ready-made garments (RMG) industries, factories, offices and commercial buildings, private residences and religious establishments.

At the time of this research, there were 13 office spaces in Bangladesh which had attained LEED certification. 10 were located in Dhaka city, 2 were located in Bhaluka Upazila and 1 was located in Chittagong. These office spaces were certified under the LEED 2009 (also referred to as LEED v2009 or LEED v3) version rating scheme, and they had received certifications under the following categories.

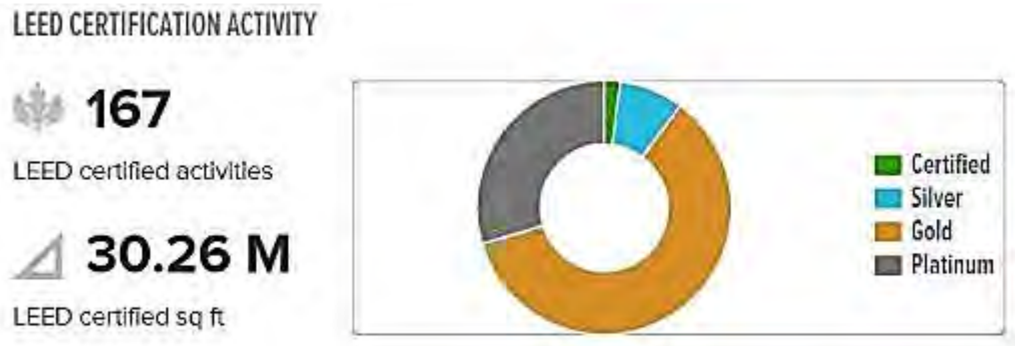


Fig. 2.3.3.a. Number of LEED certified projects in Bangladesh (Source: Green Building Information Gateway 2021)

- **LEED BD+C: Core and Shell 2009 -** This scheme was developed for projects where the design and engineering team controlled the design and operation of the whole mechanical, electrical, plumbing and fire protection system, which is referred to as the 'core and shell'. They were not responsible for the design and construction of the tenant fit-out. The final interior design, partitioning, flooring, walls, paintings, woodwork, decorations and fittings were installed by contractors of clients who rented out each floor of the building.
- **LEED ID+C: Commercial Interiors 2009 –** This scheme recognizes project teams who did not have control over the entire building operations of office, retail and institutional buildings, but were responsible for developing indoor spaces suitable for the enhanced well-being of occupants. This certification could be obtained by leaseholders who lease their space or do not occupy the entire building.
- **LEED BD+C: New Construction 2009 –** LEED for New Construction and Major Renovations was aimed to guide and distinguish high performance buildings that enhanced positive effects and reduced negative impacts on the surrounding environment. It can be awarded to commercial, institutional and high-rise residential projects, with a focus on office buildings.

The buildings have received accreditation under four levels of certification (Samarasekera 2017) - Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points). The buildings were given points in LEED certification under nine categories - Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality (IEQ), Innovation, Regional Priority and Integrative Process.

In the LEED 2009 version under which all these office spaces in Bangladesh were certified, no points were allocated for evaluating acoustical performance under the IEQ category.

2.4 Post Occupancy Evaluation Survey

Post Occupancy Evaluation (POE) surveys are carried out on occupants after the building has initiated its operation, to address issues such as air quality, lighting, thermal comfort, work environment, cleanliness and acoustics (Cavanaugh et al. 2009). These surveys provide an insight on the building performance and the assessment of users after it has been occupied. Feedback from these surveys aids engineers, architects, clients and educators to gain insights on the building's interior environment, and how it affects users during operation. The subjective results correspond to the objective measurements. The U.S. General Services Administration and the Centre for the Built Environment (CBE) of the University of California, Berkeley are two of the largest organizations which have conducted thousands of POE surveys over a long period of time on both green and non-green building occupants. POE surveys may include surveys of building inhabitants, observations and/or interviews, energy and/or water usage performance, and physical measurements of temperature, humidity, acoustical performance and lighting (Lehrer 2006, p. 4). POE surveys may be conducted during commissioning plan (6 months) or post commissioning (at least 12 months).

Research indicates that most green rated office buildings performed unsatisfactorily in acoustical performance in their POE surveys. While these buildings had significantly higher ratings in occupant environmental satisfaction in the fields of air quality and daylighting, they had extremely low ratings for acoustical performance (Cavanaugh et al. 2009). Poor acoustical performance was one of the largest criticisms issued by occupants of LEED certified office buildings (Curtland 2012). Many concerned groups have deliberated whether a building is actually sustainable if it does not provide a satisfactory acoustical performance and comfort for its occupants.

2.5 Review on Acoustical Performance of Green Rated Office Buildings Worldwide

2.5.1 Case study 1: Berkeley, California, USA

This research is an ongoing survey since 1996, conducted by CBE at the University of California, Berkeley. It follows the principle of a web-based survey tool developed by CBE, that evaluates the performance of their designed projects through the response of the occupants of those buildings (Fig. 2.5.1.a.). The main goal of this CBE post-occupancy evaluation survey was to evaluate Indoor Environmental Quality (IEQ) in all types of buildings, located in USA, Canada and some European countries. The seven areas of evaluation included thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout and office furnishings. As of March 2017, over 1000 buildings has been surveyed in this research using this survey tool, with over 100,000 occupants responding to the given questionnaires (Centre for the Built Environment 2019).

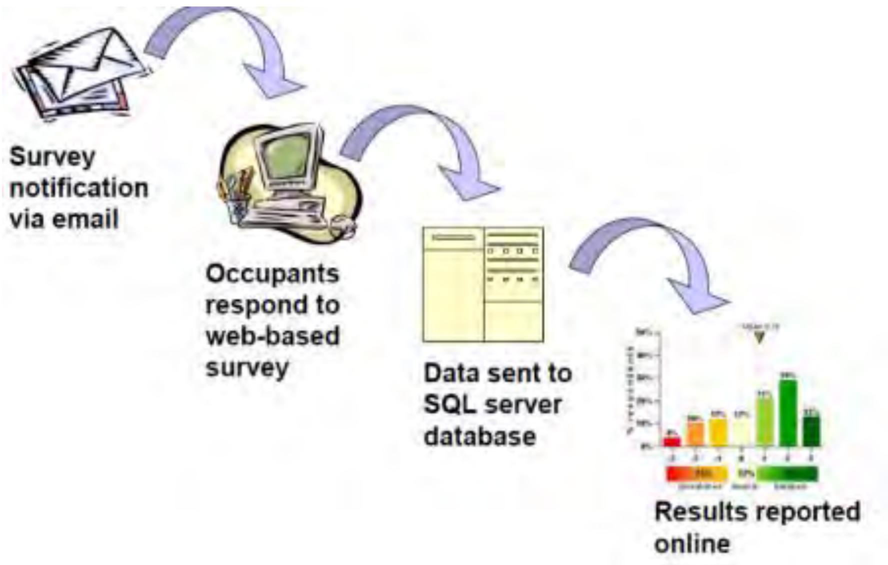


Fig. 2.5.1.a. Steps involved in post-occupancy evaluation survey conducted by CBE (Source: Lehrer 2006)

Till 2006, 215 buildings had been studied by CBE. 15 office buildings were certified green by LEED rating system (Abbaszadeh et al. 2006). A total of 4096 occupants responded to the post-occupancy questionnaire survey. Survey results show that although occupants of green office buildings gave satisfactory remarks in air quality, lighting and other categories, but they displayed dissatisfaction with thermal comfort and acoustical performance. Most occupants faced problems with conversations of their neighbouring colleagues, conversations of others over phones and ringing noise of phones (Fig. 2.5.1.b.). These three objections were associated with lack of speech privacy, and disruptions due to being able to hear and understand others' conversations, rather than increased background noise levels (Abbaszadeh et al. 2006). This was due to open office layout and cubicle arrangement of workspaces in the offices (Fig. 2.5.1.c.). LEED/green rated office buildings tend to have lower percentage of occupants working in enclosed office spaces (Abbaszadeh et al. 2006). Over 50% of the participants working in dedicated office cubicles perceived their surrounding acoustical environment to be poor, and that it significantly deteriorated their work efficiency (Lehrer 2006).

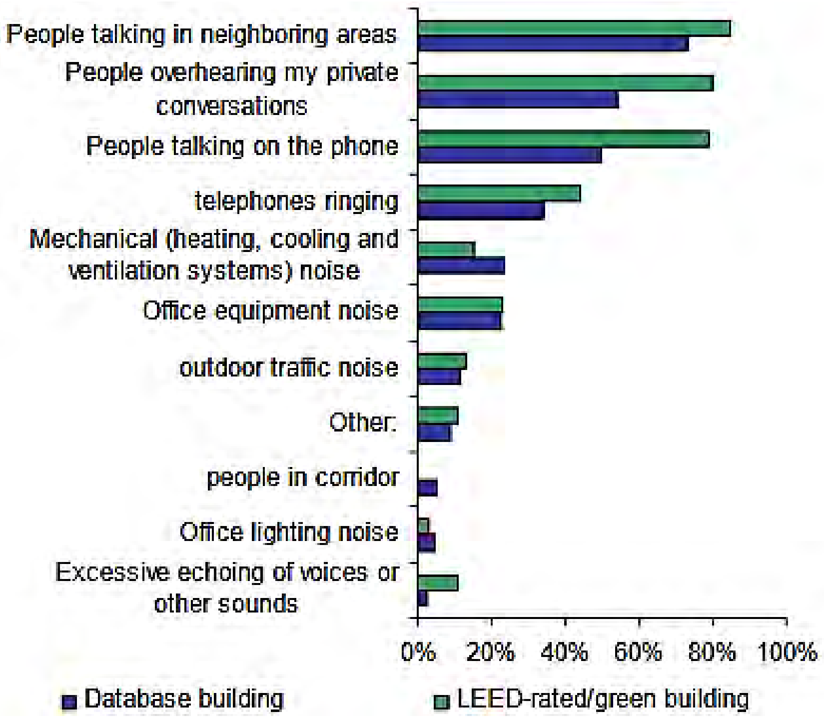


Fig. 2.5.1.b. Mean percentage of acoustical performance complaints from the investigation conducted by CBE (Source: Abbaszadeh et al. 2006)

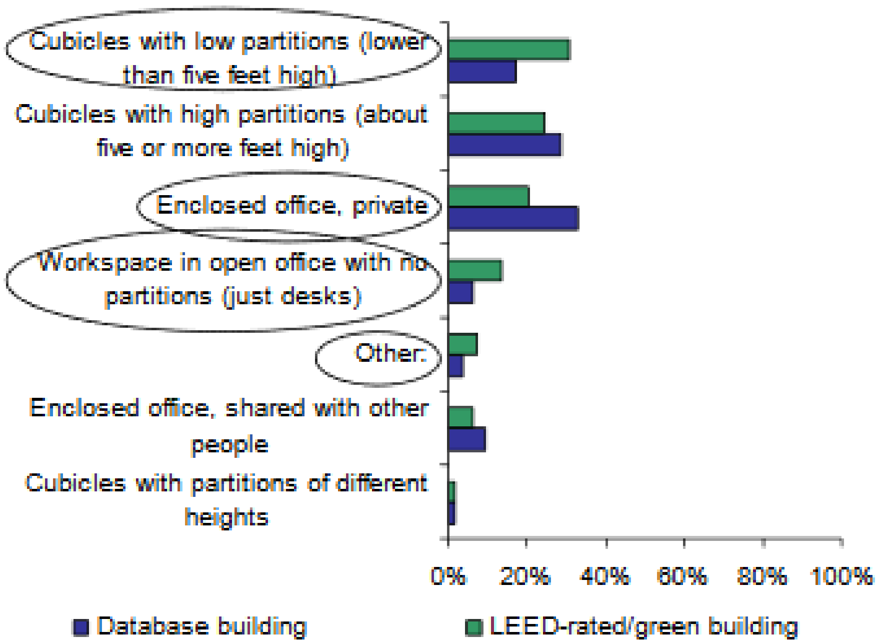


Fig. 2.5.1.c. Mean percentage of office types found from the investigation conducted by CBE (Source: Abbaszadeh et al. 2006)

2.5.2 Case study 2: British Columbia, Canada

The survey was conducted on six green rated office buildings located in British Columbia, Canada during 2008. The buildings had LEED certification, ranging from gold to silver rating. The survey aimed to establish the influence of design decisions on acoustical performance of green office spaces, and how performance can be improved. The survey methodology included meetings with the design team of each building, walk-through surveys, and objective measurements on background noise levels, reverberation times, Speech Intelligibility Index (SII) and noise isolation (Hodgson 2008). Survey results concluded that occupants were mostly dissatisfied with thermal comfort and acoustical performance of the buildings. The occupants reported that excessive background noise levels and poor speech privacy were the prime issues faced during working hours, and that existing acoustical environment significantly hampered their work productivity (Fig. 2.5.2.a.).

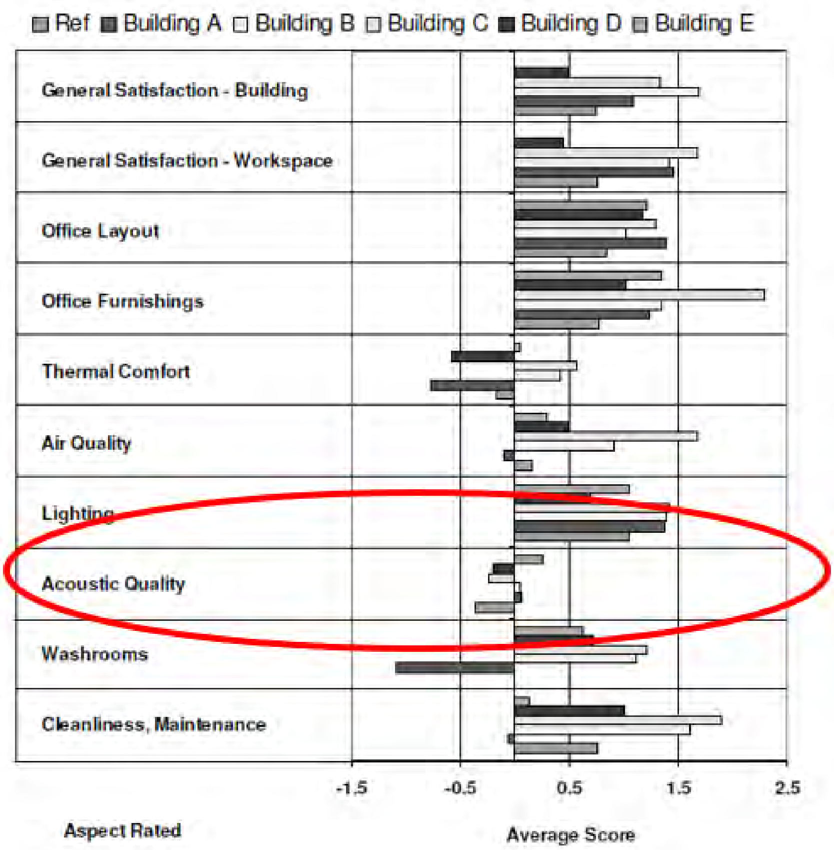


Fig. 2.5.2.a. Post-occupancy evaluation survey results from the investigation conducted in British Columbia (Source: Hodgson 2008)

Speech privacy was perceived to be the largest acoustical issue faced by the occupants (Table 2.5.2.a.). From the pre-established acceptable criteria used to assess each objective measurement metrics in the office buildings (Table 2.5.2.b.), it was observed that background noise levels were higher in areas near external walls or noisy zones (Table 2.5.2.c.).

Reverberation times were excessive in spaces having huge volumes and inadequate noise absorption measures. Even though speech intelligibility was satisfactory, speech privacy was found to be insufficient in open office spaces, and in private office spaces where the doors remained open for ventilation (Hodgson 2008).

Table 2.5.2.a. Ranges and averages of occupant ratings of three aspects of the acoustical environment (Source: Hodgson 2008)

Aspect	Range (min, max)	Average
Noise level	-0.03, 0.7	0.44
Speech privacy	-1.0, -0.17	-0.47
Productivity	0.08, 0.33	0.19

Table 2.5.2.b. Acoustical measurement parameters and acceptability criteria used in the study (Source: Hodgson 2008)

Measurement parameter	Acceptable criteria
Background-noise level, NC in dBA	NC 30-35 in meeting and conference rooms NC 35-40 in workspaces
Reverberation time (mid-frequency), RT_{mid} in s	< 0.75 s for comfort, easy verbal communication
Speech Intelligibility Index (SII)	> 0.5 (0.75) for acceptable (high) speech intelligibility < 0.2 (0.1) for acceptable (high) speech privacy
Noise Isolation, NIC in dBA	NIC 35-40 for executive offices, conference rooms NIC 30-35 for general offices, meeting rooms

Table 2.5.2.c. Summary of main results of acoustical measurements in six green office building (Source: Hodgson 2008)

Quantity	Location	Test conditions	Value
Background-noise level (NC)	Work areas	Unoccupied building, natural ventilation	NC 26 – 34
		Unoccupied building, forced-air ventilation	NC 35 – 42
		Occupied building	NC 40 – 60
		External noise, windows open	NC 45 - 60
Reverberation Time (RT_{mid}, s)	Open-office areas	Low sound absorption	0.6 – 1.0 s
		High sound absorption	0.2 – 0.4 s
	Closed-office areas	Low sound absorption	0.4 – 0.7 s

Quantity	Location	Test conditions	Value
		High sound absorption	0.2 – 0.4 s
	Hallways, atriums	Low sound absorption	0.9 – 2.4 s
Speech Intelligibility (SII)	Private office, across desk (casual voice)	Forced-air ventilation, low absorption	0.3 to 0.6
		Natural ventilation, high absorption	0.7 to 0.8
Speech Privacy (SII)	Between open-office cubicles (casual voice)	Forced-air ventilation, low absorption	0.3 to 0.6
		Natural ventilation, high absorption	0.7 to 0.8
	Outside to inside private office (door open, casual voice)		0.7

2.5.3 Case study 3: Kuala Lumpur, Malaysia

The study was carried out on a 7 storied government owned green rated office building located in Kuala Lumpur, Malaysia in October 2012. The building had a platinum Green Building Index (GBI) rating. The POE survey included both objective measurements and subjective qualitative survey of occupants (Kwong et al. 2015). Objective survey results showed that although the mean background noise level range of 45 to 50 dBA was lower than recommended comfort level, it was higher than the maximum permissible level recommended by GBI standards (Fig. 2.5.3.a.).

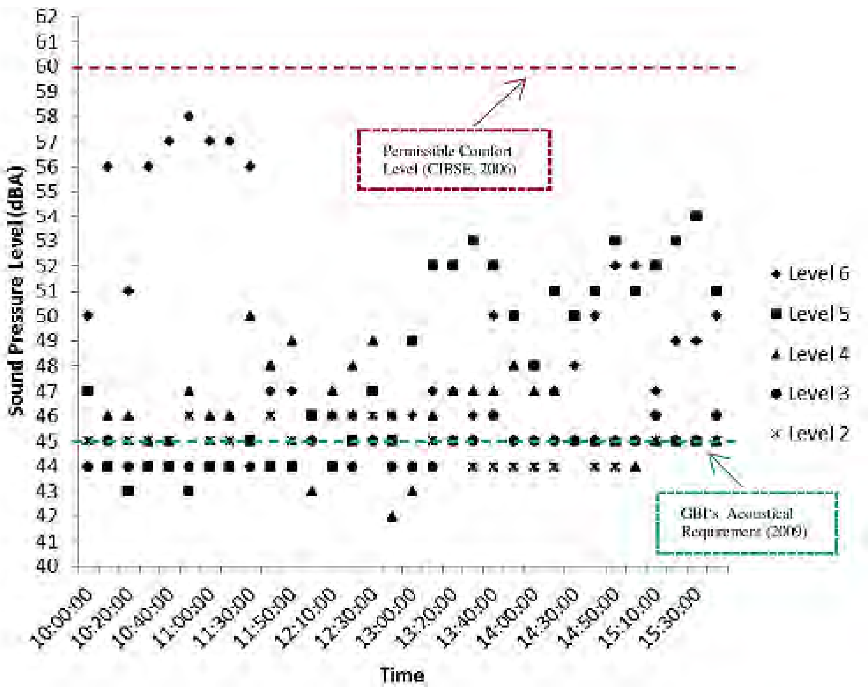


Fig. 2.5.3.a. Summary of main results of acoustical measurements in the survey (Source: Kwong et al. 2015)

Subjective qualitative survey results indicated that most occupants found the noise from HVAC sources disruptive during their work routine (Fig. 2.5.3.b.). More than 502 occupants perceived noise from other sources such as office equipment, human conversation and radio music to be annoying and intrusive. Employees in private and semi-private office spaces were more affected by background noise issues than open office users, because open office employees reportedly were more adapted to surrounding noises. More than 50% of the participants reported that problems faced in acoustical performance of their office spaces were negatively affecting their daily work productivity.

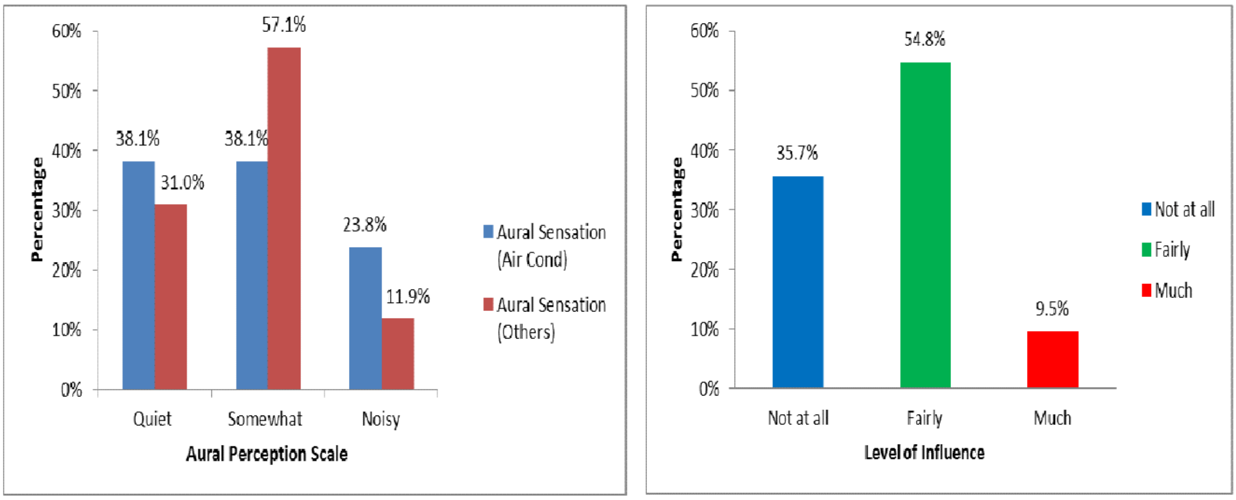


Fig. 2.5.3.b. Main findings from occupant satisfaction survey conducted in the case study (Source: Kwong et al. 2015)

2.5.4 Acoustical criteria in existing green building rating schemes

Existing green building rating schemes do not consider all potential acoustical performance requirements related with green buildings. Acoustics is one of the primary factors by which building users assess the indoor quality of a building. It is vital in confirming occupant comfort and productivity perception. Due to lack of minimum acoustical performance requirement in many green building rating structures, a lower rating is commonly attained for acoustical performance in green buildings (Hayne et al. 2016). LEED, one of the biggest and popular green rating schemes followed by designers, clients and educators worldwide, only accounts for an insignificant 0.91% of its total rating points to acoustical performance of the building (Table 2.5.4.a.). Majority of the rating systems show a lack of minimum requirement for assessing the acoustical performance of green buildings.

Table 2.5.4.a. Acoustical performance consideration in various green building rating schemes (Source: Hayne et al. 2016)

Rating Scheme	Is there a min. requirement?	Number of Points for Acoustics	Total Number of Points Possible	Weighted Value in System (%)
Green Star	No	3	110	2.72
NABERS-IE	Yes	1	5	20.00
EnviroDevelopment	No	1	123	0.81
EarthCheck BDPS	No	1	80	1.25
LEED	No	1	110	0.91
WELL	Yes	6	102	5.88
ASHRAE – 189.1	There are no points			
Green Globes	No	29	1000	2.90
BREEAM	No	4	110	3.63
CASBEE	Yes	0.086	2	4.30
Estidama - Pearl	No	2	177	1.13
BEAM	No	5	128	3.91
DGNB-Seal	No	1	111	0.90
HQE France	Yes	6	442	1.35
Protocollo ITACA	No	1	33	3.00
GBES	No	3.3	110	3.00
Green Mark	No	2	140	1.42
Green Building Index	No	1	100	1.00
GRIHA	No	2	104	1.92
EEWH	No	3	100	3.00
Greenship	No	1	101	0.99

2.5.5 Current development in Bangladesh

No study has been carried out till date to determine the performance of acoustical environment of any green rated buildings in Bangladesh. All LEED certified office buildings in Bangladesh till date at the time of this research had received LEED certification under the LEED 2009 (LEED v3) version. In this version, no rating points were allocated under the IEQ category in order to evaluate acoustical performance of the specified project. Even though LEED introduced rating points for acoustical performance in 2013 in the LEED v4 version, USGBC still allowed previously registered LEED users to enlist their projects under the criteria of LEED 2009 scheme; and this privilege was allowed to them up till October 2016. The buildings surveyed for this research had their projects enlisted, registered and certified before October 2016.

2.6 General Issues and Challenges Faced in Acoustical Performance of Green Rated Buildings

Green buildings have been credited for enhancing natural ventilation, daylighting and the use of exposed mass for thermal efficiency, in order to decrease energy use and promote sustainability. Results of POE surveys of green buildings worldwide have indicated that in most instances, these physical features of green buildings are accountable for aggravating their acoustical performance (Cavanaugh et al. 2009).

- Operable windows are popularly installed in green buildings to facilitate natural ventilation indoors. Even though they provide high levels of user satisfaction, they increase the occurrence of vehicular traffic noise inside the building. Natural ventilation systems may reduce HVAC noise, resulting in too quiet space, and also cause poor noise isolation between indoor and outdoor spaces and between spaces inside the building itself.
- Light shelves, increased surface area of facades and interior glazing, and specifying interior sun shades aid in reducing glare and decrease the requirement of artificial lighting sources. These features also increase environmental noise intrusion inside buildings. They can result in decreased indoor-outdoor noise isolation, decreased interior noise isolation, increased reflection of noise due to presence of acoustically reflective surfaces, and decreased area for installing noise absorptive materials.
- Installation of exposed thermal mass requires direct heat exchange system with the interior spaces. This may cause reduction in areas for installing noise absorptive materials.
- Sustainable materials are commonly used in the design, construction and operation of green buildings. As most acoustical ceiling tiles, absorptive panels and carpet are composed of non-sustainable materials, most acoustical treatments cannot be installed in buildings termed as being green.
- Low height partitions commonly used in open office spaces enhance natural daylighting and help designers receive more LEED credit points. Conversely, lower partitions provide little to no noise isolation between occupants in the workspace.

- Scarcity of consultants with acoustical expertise cause an overall decrease in awareness of acoustical performance issues during design, construction and operation phases.
- Most architects and design teams focus on the project's functional and aesthetical components. There is no prior planning or budgeting developed for acoustical design and retrofitting because these issues struggle for limited project funds with other project targets such as sustainable design, physical security or anti-terrorism, information technology and building automation.
- In most projects, contractors and clients are responsible for the design and construction of tenant fit-out, including the final interior design, partitioning, flooring, walls, paintings, woodwork, decorations and fittings. These demands from clients for material and furniture affect the final interior layout and planning of the space, which in turn affects acoustical performance.

2.6.1 Acoustical performance problems faced in office spaces

Some of the issues faced by occupants of office spaces due to poor acoustical environment and performance are as follows.

- Poor speech privacy, which results in disturbances, frustration and decreased acoustic comfort (Chigot et al. 2004)
- Reduced speech intelligibility
- Emotional problems, e.g., irritation to noise levels due to: Phone conversations, chattering, equipment ringing, HVAC noises, outdoor traffic noise
- Health problems, e.g., headache, stress

Occupants of open office spaces incline to be more dissatisfied with acoustical performance than private (enclosed) office space occupants (Ermann 2015). Most of the noise producing sources such as printers, photocopiers and telephones tend to be situated centrally in open office plans. Sound energy can easily diffract over and around partitions, resulting in reflection of noise from ceiling and other nearby surfaces in the office space.

Height of cubicle walls in open office spaces have no effect on the acoustical performance satisfaction among occupants. In a survey carried out on 24,000 occupants by the CBE, it was seen that no significant difference in acoustical satisfaction existed between employees of high partitions and low partitions (GSA Public Buildings Service 2011). This is because privacy has both an acoustical and visual component (Moellar 2003). Increase in visual privacy due to high partitions often results in employees conversing more loudly because they assume they have more privacy (GSA Public Buildings Service 2011). Occupants in open office cubicles often have no regards for the privacy and respect of neighbouring employees, and they tend to converse loudly without keeping other employees' comfort and tolerance in mind. Along with the design and acoustical treatment measures, behaviour of occupants (work patterns, behavioural change, behavioural protocols) play a huge role in determining the acoustical performance of any office space (GSA Public Buildings Service 2011).

Overhearing others' conversations unintentionally can decrease performance of cognitively demanding tasks. Fig. 2.6.1.a. shows that in private office spaces, where the space is fully enclosed on all sides, level of speech privacy is significantly higher compared to open office spaces. There is no change in the performance and productivity of private office employees in their routine tasks. Open office spaces in general have lower levels of speech privacy between adjacent spaces. This decreases the quality of work performance among most employees.

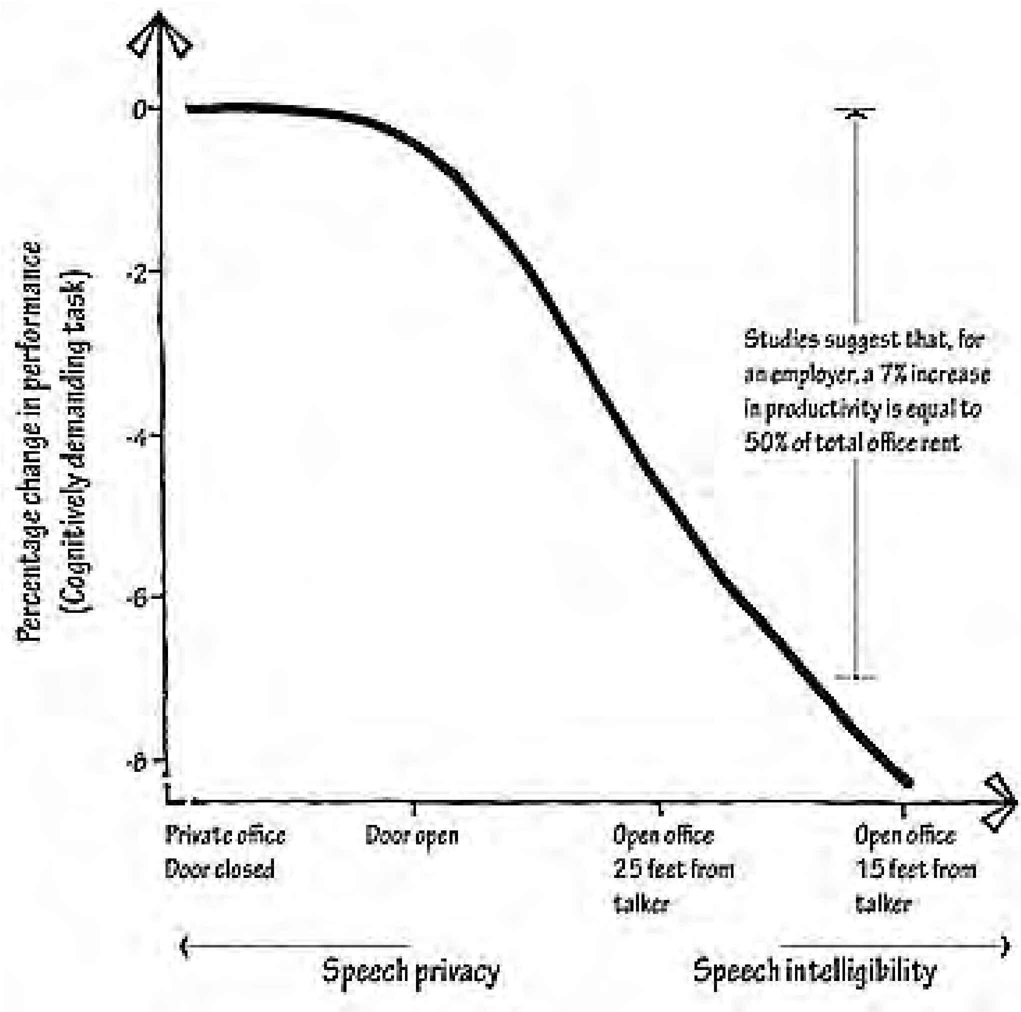


Fig. 2.6.1.a. Relationship between speech privacy, speech intelligibility and work performance in office spaces (Source: Ermann 2015)

Open office employees who had no partitions between their workstations reported less dissatisfaction with background noise levels compared to those working in cubicles. This may be due to the following factors (Ermann 2015).

- Increased level in comfort of being able to see other speakers who are conversing in the office space
- Decreased expectations of privacy in workstations without partitions
- Increased sensitivity of employees while talking with other occupants who might overhear
- Increased satisfaction with access to unobstructed views of surrounding environment and daylight
- Types, ages and tasks related to employees who work in conditions where partitions are absent.

Comparatively, occupants of private office spaces are generally satisfied with the overall acoustical performance of their environment (Fig. 2.6.1.b.).

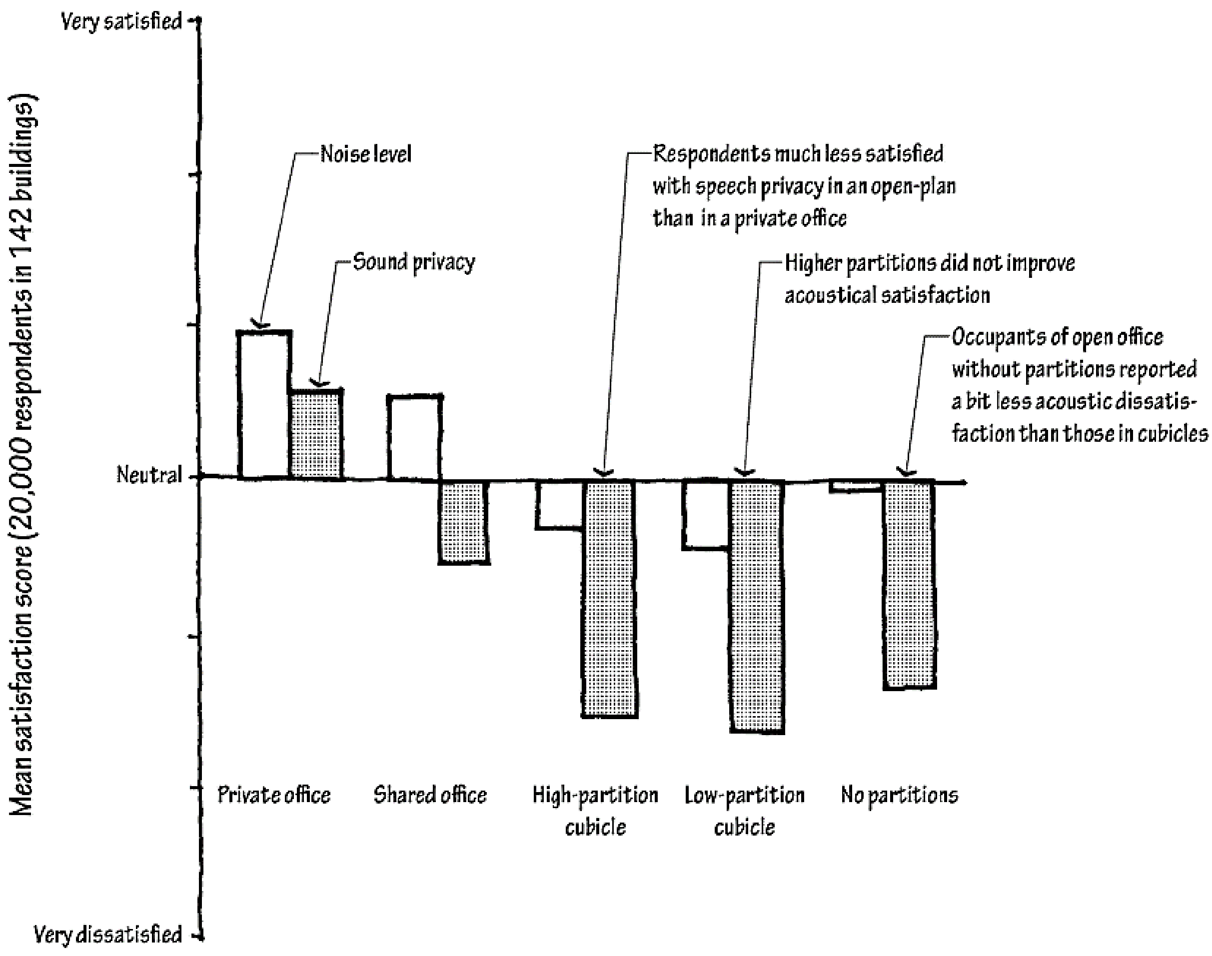


Fig. 2.6.1.b. Satisfaction of office employees with regards to background noise level and speech privacy (Source: Ermann 2015)

2.7 Importance of Acoustical Performance in Office Space

Acoustical performance is a significant part of Indoor Environmental Quality (IEQ) of any building, including green rated office buildings. One important aspect of IEQ is to ensure a healthy environment for occupants, that also enhances productivity. Poor acoustical performance of a space may adversely affect the IEQ of occupants in a number of auditory and non-auditory approaches (Fig. 2.7.a.). Poor acoustical performance of an office space can adversely affect both the psychological and physiological well-being of users (Table 2.7.a.). There has been an increase in awareness on the lack of satisfactory acoustical performance in green rated office buildings, and the unfavourable effects it can pose on building occupants. Exposure to high background noise levels above recommended standards can irreversibly damage the hearing organ, leading to permanent deafness (Yuen 2014). Exposure to background noise levels above 80 dBA for more than 24 hours ($L_{Aeq,24h}$) can lead to an increased risk of noise induced hearing impairment (World Health Organization 1999). The Australian Occupational Health and Safety regulations indicate that the maximum daily workplace noise exposure level ($L_{Aeq,8h}$) should never exceed 85 dBA (Beach et al. 2010). Increased exposure to high levels of background noise can result in poor quality of sleep, increasing the risk of cardiovascular diseases such as heart attacks, high blood pressure, strokes, arrhythmia and arterial hypertension. Continual exposure to high background noise levels can cause higher respiratory rates, headaches, stomach ulcer and vertigo (Alam et al. 2006).

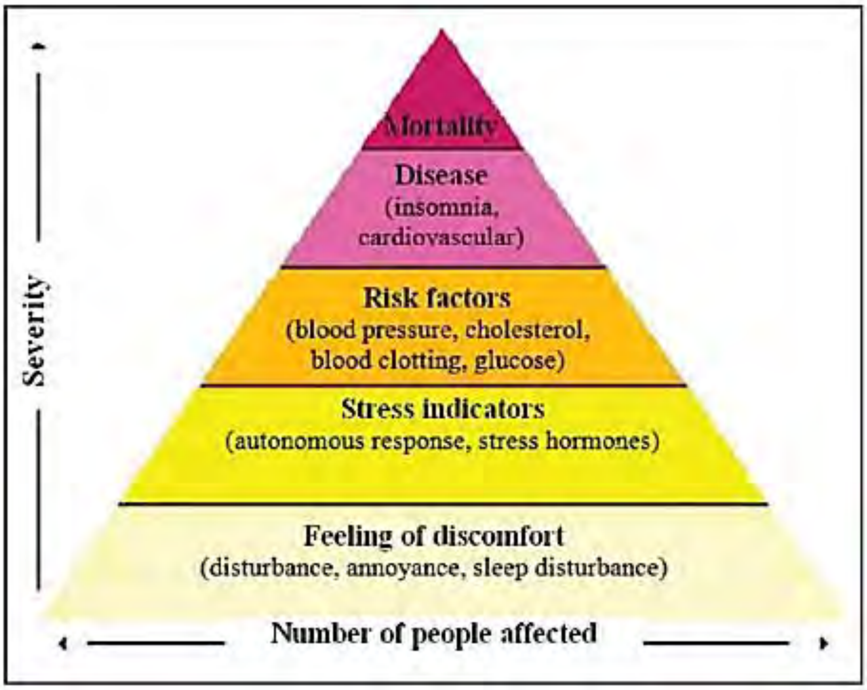


Fig. 2.7.a. WHO pyramid for health effects on noise (Source: Yuen 2014)

Table 2.7.a. Noise levels and their impacts on health (Source: American Academy of Paediatrics 1997)

Quality	Peak Intensity, dBA	Example	Inside Incubator	Effect
Just audible	10	Heartbeat		
Very quiet	20 - 30	Whisper		<35 dBA desired for sleep
Quiet	40	Average home		
	50	Light traffic	Background	<50 dBA desired for work
Moderately loud	60	Normal conversation	Motor on and off	
	70	Vacuum cleaner	Bubbling in ventilator tubing	Annoyance
Loud	80	Heavy traffic	Tapping incubator with fingers	
		Telephone ringing		
	90	Pneumatic drill	Closing the metal cabinet doors under the incubator	Hearing loss with persistent exposure
Very loud	100	Power mower	Closing solid plastic porthole	
Uncomfortably loud	120	Boom box in car	Dropping the head of the mattress	Pain and distress
	140	Jet plane 30 m overhead		

Poor acoustical performance can also affect psychological health of an individual (Hammersen et al. 2016). Prevailing poor acoustical performance may cause anxiety and exhaustion connected with unsuccessful efforts to cope with high background noise levels. It can cause poor speech intelligibility and speech privacy among occupants of the office space. It can negatively affect mental health of employees.

Exposure to high background noise levels can result in unfavourable effects such as annoyance and displeasure, subjected to environmental factors and the personal opinion of the listener. Annoyance may occur even when background noise levels are far below the range required for damage to ears (Beutel et al. 2016). Even though individuals get acclimatized to certain background noise levels, this degree of adaptation varies from person to person. Noise annoyance can sometimes be accompanied with other undesirable responses such as stress, aggressive behaviour, depression, exhaustion etc. (Beutel et al. 2016). A survey carried out in

Mainz, Germany showed that persons who suffered from annoyance due to background noise were more likely to suffer from mental and physical diseases, and used more psychotropic medicines, general practice and outpatient services. Prolonged exposure to high background noise levels can lead to memory problems and impaired pain tolerance (Clarke 2011). Poor acoustical performance can cause further detrimental consequences for office occupants, including the following.

- Shift in attention, resulting in decrease of focus in tasks
- Increased efforts to concentrate, causing high levels of stress and fatigue
- Losing flow of thought and the need to re-orient to the task, which can take up to 15 minutes
- Deserting a current task to deal with demands triggered by a disruption
- Vocal strain due to the need for raising voice in order to be clearly heard amidst others' loud conversations
- Hinder in communication due to disruption caused by others' loud conversations
- Poor work performance and behaviour

2.7.1 Changes in current green building rating schemes and standards

After receiving unsatisfactory results in acoustical performance of green buildings from numerous POE surveys conducted worldwide, various green building rating schemes have started to implement credit points for acoustical performance.

- **LEED v4:** The first version of LEED to include credit points for assessing acoustical performance of green buildings was LEED v4, which was introduced in 2013. LEED v4 introduced 2 credit points for evaluating acoustical performance of green buildings in its IEQ category scorecard. This was only applicable for schools and healthcare buildings.
  - LEED v4.1 is the current version of LEED followed by designers, clients and educators, which was launched in January 2019. There has been no increase in allocation of credit points or prerequisites for acoustical performance in this latest scheme compared to the previous LEED v4 (2013).
- **ASHRAE Standard 189.1-2011:** ASHRAE is an American organization committed to advances in the fields of heating, ventilation, air-conditioning and refrigeration systems,

design and construction., in order to promote sustainability. They have introduced standards for enhancing acoustical performance in green buildings in the year 2011.

- ASHRAE Standard 189.1-2017, Standard for the Design of High-Performance Green Buildings: This is the latest version of ASHRAE standards for green buildings, launched in the year 2017.

- **POE survey:** Acoustical performance is one of the most important aspects examined during POE surveys of green buildings conducted worldwide.
  - Both LEED, ASHRAE and Bangladesh National Building Code (BNBC) standards consider POE surveys to be an important part of their schemes.

2.8 Standards for Acoustical Performance in Green Rated Office Buildings

2.8.1 International standards

A number of internationally renowned organizing bodies have formulated standards and codes for a satisfactory acoustical environment that would also promote and enhance quality of life.

- **WHO Environmental Noise Guidelines for the European Region (2018):**
  - Background noise levels in any space should be within the range of 35 to 45 dBA in order for speech with normal vocal effort to be 100% intelligible. If speech has more vocal effort, then maximum background noise level in the space should be lower than 65 dBA. Yearly average exposure from all leisure noise sources (i.e., activities during non-working hours such as attending entertainment venues, sports programs, arts and cultural activities, travel, domestic activities etc.) should not exceed 70 dBA, $L_{Aeq,24h}$ in order to prevent adverse health effects.
  - When listening to important conversations, the signal to noise ratio should not exceed 15 dBA. For a speech level of 50 dBA, the background noise level should not exceed 35 dBA.
  - In order to prevent annoyance of occupants, background noise levels should not exceed 50 to 55 dBA L_{Aeq}.
  - For adequate speech intelligibility, reverberation time of a space should be below 0.6 s, and should never exceed 1 s.

- **The Occupational Safety and Health Act of 1970 (revised on 1998), developed by the National Institute for Occupational Safety and Health (NIOSH) and communicated to the Occupational Safety and Health Administration (OSHA):**
  - Occupants in a workspace should not be exposed to background noise levels beyond an average of 85 dBA for more than 8 hours.
- **LEED v4.1 (2019) Indoor Environmental Quality (EQ) prerequisite – Minimum Acoustic Performance required:**
  - This prerequisite was introduced in 2019 and applies for BD+C schools.
  - Background noise levels from HVAC sources should not exceed 35 to 40 dBA.
  - For projects located near high noise sites (peak-hour L_{eq} above 60 dBA during school hours), acoustical treatment is obligatory.
  - In terms of rating acoustical performance, 1-2 points are allocated for BD+C of New construction (1 point), schools (1 point), data centres (1 point), warehouses and distribution centres (1 point), hospitality (1 point) and healthcare facilities (1-2 points).
  - Reverberation time for open office spaces (with/without sound masking facilities) should not exceed 0.8 s, and it should be below 0.6 s for semi-private offices, private offices and conference/meeting rooms.
  - For conference/meeting rooms accommodating more than 50 persons, sound reinforcement systems should have minimum sound level of 70 dBA and should be able to maintain sound-level coverage within +/–3 dBA at the 2000 Hz octave band throughout the space. The masking sound system should have maximum design levels of 48 dBA and have loudspeaker coverage with uniformity of +/- 2 dBA.
- **ANSI/ASHRAE/USGBC/IES Standard 189.1-2017 Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings, Indoor Environmental Quality (IEQ) section 801.3.3 (8.3.3):**
  - Maximum interior background noise level should be within 35 to 45 dBA for meeting rooms, conference rooms and enclosed private office spaces, and within 45 to 55 dBA for open office spaces.

- Reverberation time should not exceed 0.6 s for open office spaces, enclosed private office spaces and conference rooms.

2.8.2 National standards

- **Bangladesh National Building Code (2020 final draft) – Chapter 3.13 Building Acoustics for Occupancy F – Business and Mercantile Buildings:**
  - Outdoor noise resulting from traffic, playgrounds, market places, shopping areas and crowds should be taken into account in the planning and design of buildings.
  - Indoor noise sources such as HVAC systems, office equipment, human conversations, machinery and plumbing systems should be taken into account for noise attenuation measures.
  - Rooms susceptible to noises should be located far away from potential sources.
  - In open office spaces, thick carpets should be installed on top of resilient flooring. Ceilings should be highly noise absorptive, having an absorption coefficient value of at least 0.7. Relatively noisy office equipment should be distributed uniformly all across the office space. If noisy equipment is concentrated in one particular area, they should be treated with highly noise absorptive material and have visual separation from the rest of the space. Sound masking system should be provided to mask undesirable office noises and enhance speech privacy.
  - For all other office and meeting spaces, noise absorptive materials should be installed in ceiling. Noise from HVAC may be employed to provide sound masking if it falls under the desired frequency spectrum.
  - Automatic quiet-action type door closer should be installed on all doors. Continuous soft, resilient strip on door frames and quiet-action door latches should be installed.
  - All apertures, gaps and joints at walls, floor and ceiling junction should be properly sealed.
  - Resilient pads should be installed on all noisy office equipment such as printers, typewriters etc.
  - Floor carpeting should be installed and be highly noise absorptive. Fibre type carpet should be avoided. Hair, hair jute and foam rubber pads are more preferable than the

less permeable rubber coated hair jute and sponge rubber. Loop pile fabrics with increased pile height should be installed. A more permeable backing should be chosen for increased noise absorption.

- **Bangladesh National Building Code (2020 final draft) – Chapter 3 Building Acoustics:**
  - Noise exceeding recommended limit should be controlled. The space should provide satisfactory speech intelligibility and speech privacy. Undesirable acoustical performance issues such as flutter echoes and echoes should be prevented.
  - Noise survey, POE survey and noise mapping should be conducted to identify acoustical performance problems in the building.
  - Background noise levels should be limited to 48 to 58 dBA for general open office spaces, 43 to 53 dBA for large semi-private office spaces, 38 to 48 dBA for small private office spaces, 38 to 48 dBA for conference rooms, and 63 to 78 dBA for work spaces where speech is not required.
  - The recommended background noise criteria for executive office are 20 to 30 NC and for business office is 35 to 45 NC.
  - The acceptable intrusive noise levels for privately owned office spaces are 40 dBA and 30 NR, and for publicly owned office spaces is 50 dBA and 40 NR.
  - The recommended optimum reverberation time for Bangla language is within 0.5 to 0.8s.
  - For satisfactory speech intelligibility of Bangla language, the minimum permissible value for PSA should be 75%.
  - For satisfactory speech privacy between two spaces, sufficient degree of noise isolation by the barriers between the two rooms as well as adequate level of background noise level in the receiving room should be provided.

None of the international and national standards available till date offer standards for acoustical performance specifically tailored for green rated office buildings.

2.9 Conclusion

This chapter has identified the important factors needed for consideration while assessing the acoustical performance and environment of green rated office buildings. This would aid in achieving the first objective of the research by identifying whether satisfactory acoustical performance in green rated office buildings of Dhaka city exists, in relation to these factors. The most significant factors affecting the acoustical performance of green rated office buildings are background noise levels, reverberation time, speech intelligibility and speech privacy. Worldwide, acoustical performance has been rated the lowest in POE surveys among users of green rated office buildings, and awareness on the relationship between good acoustical environment and its positive impact on employees' work productivity has increased. However, no POE survey has been carried out on any green rated office buildings in Bangladesh to assess acoustical performance. In addition, no specific planning, design and construction standards or recommendations for ensuring satisfactory acoustical performance in green rated office buildings of Bangladesh are available. Based on previous research and published sources, importance of acoustical performance, review of green rated office buildings, acoustical issues and acoustical performance standards have been discussed in this chapter. The findings of this chapter helped to select the criteria for the quantitative and qualitative assessment study in succeeding chapter (Chapter 03).

CHAPTER 03: METHODOLOGY

Introduction

Literature Review

Reconnaissance Survey

Selection Criteria of Green Rated Office Buildings

Research Strategy

Quantitative Research Method

Qualitative Research Method

Data analysis

Research Quality Consideration

Limitations

Conclusion

CHAPTER 03: METHODOLOGY

3.1 Introduction

This chapter focuses on the methodology followed to determine the acoustical performance of green rated office buildings in Dhaka city. It discusses on the research methods undertaken to evaluate the current level of acoustical performance in terms of level of existing background noise, reverberation time, speech privacy and speech intelligibility in selected office buildings. Both existing quantitative and qualitative levels of deviation from national and international standards were assessed during physical survey.

The methodology steps followed in this research are illustrated in Fig. 3.1.a.

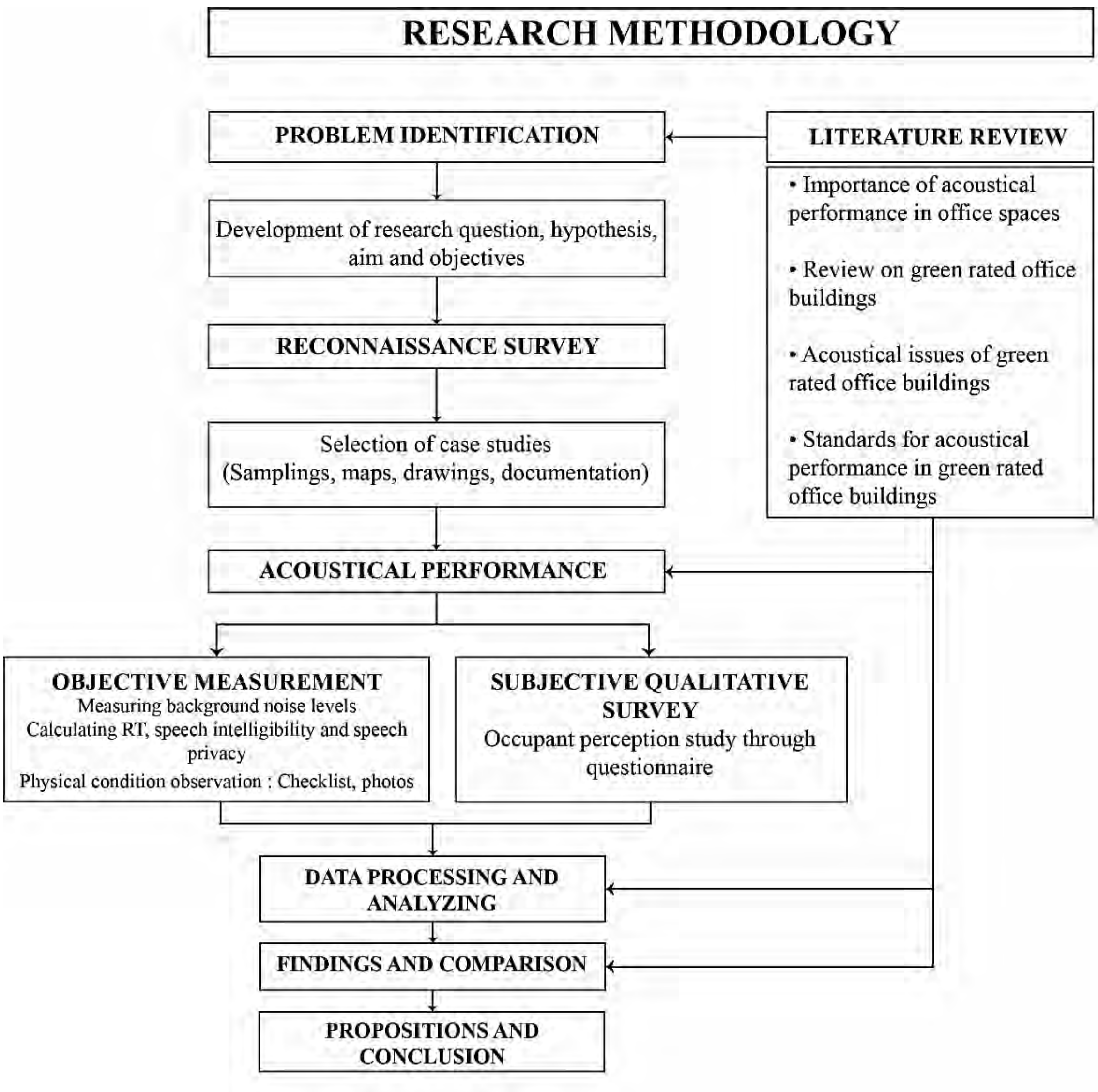


Fig. 3.1.a. Flowchart depicting the methodology followed in this research (Source: Author)

3.2 Literature Review

Literature survey was conducted at the beginning of this thesis in order to gather knowledge and information on theories and practices of acoustical design considerations of green rated office buildings (Chapter 2.2), current national and international standards of allowable background noise levels, reverberation time and acoustical performance guidelines (Chapter 2.8). Literature review also provided detailed evidence on the reasons behind, and long-term effects of poor acoustical performance of office spaces, as well as the importance of proper acoustical performance in green rated office buildings (Chapters 2.6 and 2.7). Chapters 2.2.3, 2.2.4, 2.2.5 and 2.2.6 of this thesis presented a framework for methods to calculate reverberation time, speech intelligibility and speech privacy. Previous researches conducted overseas and related topics were reviewed to assess acoustical performance of green rated office buildings, as stated in chapters 2.5.1, 2.5.2 and 2.5.3.

3.3 Reconnaissance Survey

An extensive reconnaissance survey was undertaken prior to conducting the main acoustical performance field investigation. This helped identify the green rated office buildings currently located in Dhaka city and their features, which were used to select the final cases for detailed field investigation. It also facilitated in determining the types of workstation layout in each office building as well as typical working hours, occupancy rate, traffic peak times and background noise conditions. This provided a primary framework that would develop the latter detailed steps in the final field investigation.

3.4 Selection Criteria of Green Rated Office Buildings

The target population for this study was green rated office buildings located in Dhaka city. Currently, all buildings and infrastructure in Bangladesh are given green certification under LEED rating only. Thus, office buildings which had received LEED certification were selected for this study. In Bangladesh, 10 of the office buildings certified by LEED were situated in Dhaka city at the time of this research. Selected office buildings from this population were fully operating during the time of survey, and had at least 1 year of occupancy. Floors selected for physical survey from each office building had a layout combining open, semi-private and private type of workspaces.

20 to 25% of the floors from each building were studied. Since most of the green rated office buildings in Dhaka city were high rises comprising from 10 to 13 stories, 3 floors from each building were selected for survey. Each building was divided into 3 groups according to their floor levels. The floors to be surveyed were selected randomly according to these three strata - lower tier (ground to 3rd floor), middle tier (4th to 7th floor) and upper tier (8th floor and above). The quantitative and qualitative surveys for this research were carried out from 8th July

2019 to 31st October 2019. The measurements and surveys were carried out in each building during typical working hours, when the office was in full capacity and represented typical working conditions. Measurements and surveys were not carried out during Ramadhan, weekly office holidays and national public holidays.

3.4.1 Selection of sample group from green rated office buildings

Stratified sampling method was used to determine the sample size of green rated office buildings for this research. Following stratified random sampling method, the total target population of green rated office buildings in Dhaka city was divided into specific number of strata, and a probability sample was drawn from each stratum (Singh and Mangat 2013, p. 102). The advantage of this sampling method was that all essential subgroups i.e., all different LEED certifications obtained by the existing green rated office target population were included – leading to a more representative final sample of green rated office buildings (Akanda 2009).

The existing LEED certified office buildings in Dhaka city were divided into three strata according to the typology of LEED certification they had earned. The strata were as follows.

- LEED BD+C: Core and Shell
- LEED ID+C: Commercial Interiors
- LEED BD+C: New Construction

From the 10 LEED certified office spaces, 5 had LEED BD+C: Core and Shell rating, 3 had LEED ID+C: Commercial Interiors rating and 2 were rated LEED BD+C: New Construction. The sample size in each stratum along with their relative proportions in the total green rated office population is listed in Table 3.4.1.a.

Table 3.4.1.a. Strata of the LEED certified office population in Dhaka city (Source: Author)

Statistics	Overall	Strata		
		LEED BD+C: Core and Shell	LEED ID+C: Commercial Interiors	LEED BD+C: New Construction
Population	10	5	3	2
		Proportion	Proportion	Proportion
		50%	30%	20%

For researches focusing on green rated office buildings with both quantitative and qualitative surveys involved in the research strategy, at least 3 office buildings are recommended for studying to confirm the research's validity (Allen et al. 2015). Alternatively, when the population consists of buildings and infrastructures, and the corresponding population size is extremely small, the minimum allowed sampling rate is considered to be 50% and minimum recommended overall sampling rate is 70% of the total population (Žmuk et al. 2016).

To determine the sample size of green office buildings from each stratum, proportional allocation method was used. In this method, the sample size is chosen such that it is proportional to the stratum size (Kish 1995, Singh et al. 2013). The sample size was determined using the following formulae.

$$n_i \propto N_i \quad \text{(Eq. 3.4.1.a)}$$

where, n_i = Sample size

N_i = Stratum size

Table 3.4.1.b. shows the sample sizes of green office buildings from each stratum according to the three standards. The lowest acceptable sample size of green office buildings derived was 3, and the highest sample size was 7.

Table 3.4.1.b. Sample sizes of green rated office buildings determined using 3 different standards (Source: Author)

Statistics	Overall	Strata		
		LEED BD+C: Core and Shell	LEED ID+C: Commercial Interiors	LEED BD+C: New Construction
Population	10	5	3	2
Sample = 50%	**5**	**2 or 3**	**1 or 2**	**1**
Sample = 70%	**7**	**4**	**2**	**1**
Allen et al., 2015, p. 253	**3**	**1**	**1**	**1**

In case of LEED BD+C: Core and Shell and LEED BD+C: New Construction, the certification is awarded to the whole building i.e., all floors of that building are considered to be LEED certified. For LEED ID+C: Commercial Interiors, only specific locations (or floors) of the building are awarded LEED certification. For buildings having LEED ID+C: Commercial Interiors rating, the entire building itself is not considered to have LEED certification. In the context of Dhaka, the 3 multi-storied projects having LEED ID+C: Commercial Interiors rating were given certification for only a single floor. They were not included in the final strata (Fig. 3.4.1.a.).

According to Table 3.4.1.c., the actual target population of green rated offices was 7. The lowest acceptable sample size of LEED office buildings was 3, and the highest was 5. For this research, a total of 4 LEED office buildings were selected randomly from the derived strata for conducting the acoustical performance survey.

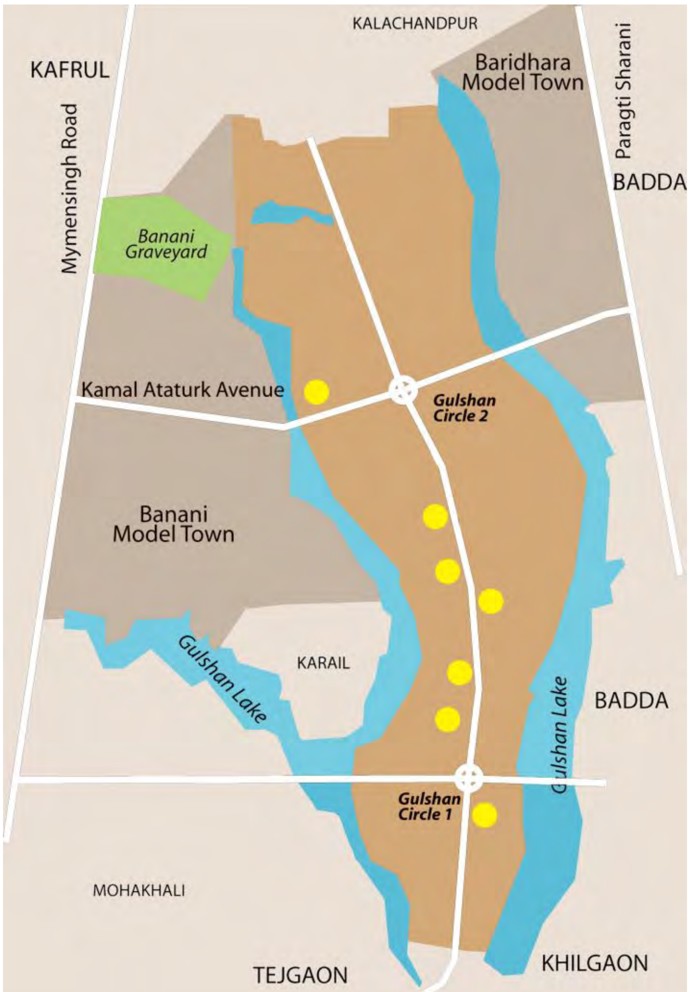


Fig. 3.4.1.a. Location of the seven LEED certified office buildings (marked in yellow) which were considered in the final strata (Source: www.wikipedia.org, edited by author)

Table 3.4.1.c. Sample sizes of green rated office buildings after excluding LEED ID+C: Commercial Interiors stratum (Source: Author)

Statistics	Overall	Strata	
		LEED BD+C: Core and Shell	LEED BD+C: New Construction
Population	7	5	2
Sample = 50%	**3 or 4**	**2 or 3**	**1**
Sample = 70%	**4 or 5**	**3 or 4**	**1**
Allen et al., 201, p. 253	**3**	**2**	**1**

3.5 Research Strategy

For this research, two main types of investigation were conducted to assess the acoustical performance of green rated office buildings – objective measurement (involving quantitative research methods) and subjective occupant survey (involving qualitative research methods). Subjective survey results recognized situations (workplaces and their locations, and building conditions) of high and low occupant satisfaction, whereas objective measurements helped to evaluate the subjective survey results (Hodgson 2008).

The research followed a convergent parallel mixed methods research approach. In this approach, both quantitative and qualitative data were collected simultaneously. The subsequent data were analysed separately, and the results compared to deduce if the two sets of findings confirm or disconfirm each other (Creswell 2014). The main assumption of this method was that both quantitative and qualitative data were equally important, so the two sets of data were collected approximately at the same time. Both quantitative and qualitative data would provide different types of detailed evidence that together would result in similar findings.

3.6 Quantitative Research Method

One of the main objectives of this thesis was to evaluate the levels of existing quantitative and qualitative deviations in different variables of acoustical performance of green rated office buildings in Dhaka city. Variables focusing on background noise, speech privacy and speech intelligibility were not altered or manipulated during the course of field survey. Thus, the numeric and quantifiable variables in each office space were not controlled and were studied as they existed in their environment. A non-experimental research approach was followed for collecting and studying the quantitative variables of each green rated office building (Belli 2009).

A descriptive and cross-sectional non-experimental research method was undertaken to collect quantitative data from each building. The primary focus of descriptive non-experimental research methodology was to study and analyse a given phenomenon or area of interest in a particular environment, and document its characteristics in terms of quantitative features (Belli 2009). The data collected would provide a clear understanding behind any quantitative levels of deviation from standards in acoustical performance. Cross sectional research states that the quantitative data were to be collected at any one point in time (Belli 2009). This was done to compare the results attained from different green rated office buildings in Dhaka. Combining these two methods, the main goal of descriptive cross-sectional non-experimental research was to provide a documentation of the levels of quantitative deviation in acoustical performance of each green rated office space (Belli 2009).

3.6.1 Objective measurement

Objective measurement involved the study of four key elements and other secondary aspects.

i. Measuring background noise levels (in dBA) during typical working hours in the office space
ii. Calculating Reverberation Time, RT_{60} (in seconds)
iii. Calculating Speech Intelligibility
iv. Calculating Speech Privacy
v. Determining population peak graph
vi. Observation and checklist

i. **Measuring background noise level (in dBA):** The background noise levels persisting in typical working hours in selected floors of each building were measured using a data logger type sound level meter (Lutron SL-4023SD model) (specifications are provided in Appendix 01), which could record noise levels at a rate of 60 readings per minute. A total of 301 readings per minute were recorded for each point or location, accurate to 1 decimal place. For researches involving assessment of acoustical performance, background noise levels should be measured in approximately 20 to 25 points or locations in each building (Hodgson 2008) and a minimum of 4 points in each selected floor (Yazhini et al. 2017). The noise levels were measured in a number of locations at three main spaces in each floor – open office, semi-private office and private office.

Through the pilot survey, three main time periods were established for recording background noise levels – 10.00 AM to 12.00 PM (off peak hours), 12.00 PM to 2.00 PM (peak hours - 01) and 4.00 PM to 6.00 PM (peak hours - 02). Off peak hours are referred to the time period when it is less busy in the office space, due to the presence of fewer number of people and hence background activity. There is also less demand from higher officials to get work done by other employees in this period. Conversely peak hours were defined as the time period which was the busiest i.e., number of occupants in the space and corresponding background activity were at the highest level.

At each location and at each time period, the background noise level was measured for an interval of 5 minutes. The recorded measurements were transferred and saved in Microsoft Excel Office 2019 format. Using Analysis ToolPak plug-in of this software, the maximum, minimum and mean values of background noise level at each location of open, semi-private and private office space were calculated, for the three specific time periods. Mean values for background noise level in each tier level and during each time period were also deduced as well as the overall mean background noise level of the 4 buildings. The standard deviation, standard error and 95% confidence interval for mean at each location for the three time periods were also evaluated.

Before taking each measurement, the sound level meter was held 1.3 m from the top of floor surface, and positioned at a 45° angle from the horizontal level with the help of tripod stand. The meter was also calibrated at 'A' weighting class, as measurements were being conducted on environment noise levels. The A-weighted sound level differentiates against low levels of frequencies, corresponding to the response of the ear. The meter principally measures in the 500 to 10,000 Hz range in this setting. It is the weighting scale most frequently followed by OSHA and DEQ governing measurements.

ii. **Calculating Reverberation Time, RT_{60} (in seconds):** For open, semi-private and private office spaces of each building, the reverberation time was calculated using Sabine's formula which is given below (Cavanaugh et al. 1999).

$$RT_{60} = \frac{0.161V}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 3.6.1.a)}$$

where,

RT_{60} = Reverberation time in seconds (s)
V = Volume of the office space in cubic meter (m^3)
A = Total absorption of the office space in square meter Sabin (m^2 Sabin)
$0.161 = k = \frac{24 \ln 10}{c20}$, where c_{20} = speed of sound i.e., 343 m/s

iii. **Calculating Speech Intelligibility:** Through the pilot survey, it was determined that employees in each office space mostly conversed in Bangla language during typical working hours. For open, semi-private and private office spaces in each building, speech intelligibility was determined by using Percentage Syllable Articulation method. For Bangla language, the PSA was calculated using the following formula (Imam et al. 2009) (Fig. 3.6.1.b.).

$$PSA = 93k_ik_rk_nk_s\ (\%) \ \ldots\ldots \ (Eq.\ 3.6.1.b)$$

where,

PSA = Percentage Syllable Articulation in percentage (%)

k_i = Reduction factor for average speech level

k_r = Reduction factor for RT (Reverberation Time)

k_n = Reduction factor for Noise to Speech level ratio

k_s = Reduction factor for room shape

Assuming speech intensity to be 70 dBA,

$$k_i = 1$$

Using the reverberation time (for each space) calculated earlier,

$$k_r = -0.3179\ \ln(2{*}RT+1) + 0.9825 \ \ldots\ldots \ (Eq.\ 3.6.1.c)\ (Fig.\ 3.6.1.a.)$$

where,

RT = Reverberation Time in seconds (s)

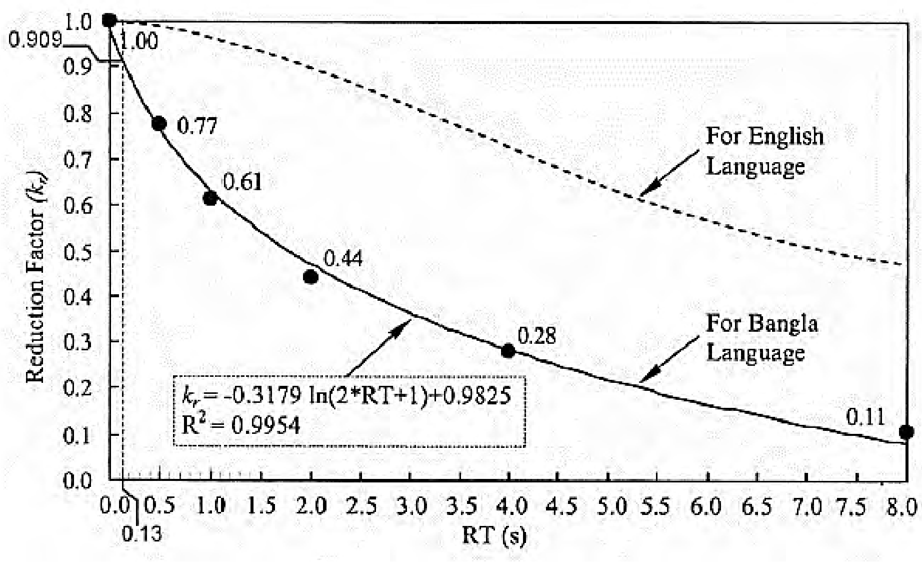


Fig. 3.6.1.a. Reduction factor for a range of RT for Bangla language as derived by Imam et al. (2009), compared to those for English language derived by Knudsen (1932) (Source: Islam 2017)

Signal to Noise Ratio (SNR) for each space was calculated by the following formula.

$$\text{SNR} = \frac{\text{Existing average background noise level (in dBA)}}{\text{Speech intensity (in DBA)}} \text{ .... (Eq. 3.6.1.d)}$$

where,

Speech intensity is assumed to be 70 dBA.

Using the value of SNR for each space, k_n for Bangla language was calculated by the following method.

$$k_n = -0.3243\ x^2 - 0.2124\ x + 1 \text{........ (Eq. 3.6.1.e) (Fig. 3.6.1.b.)}$$

where, x is the value of SNR found from the previously stated formula. The comparison of curves in Fig. 3.6.1.b. implies that the ordinates of k_n curve for Bangla language has a lower value than English language in most SNR conditions. The values of the ordinates of k_n curve decrease with increase in SNR values.

For rectangular shaped spaces,

$$k_s = 1$$

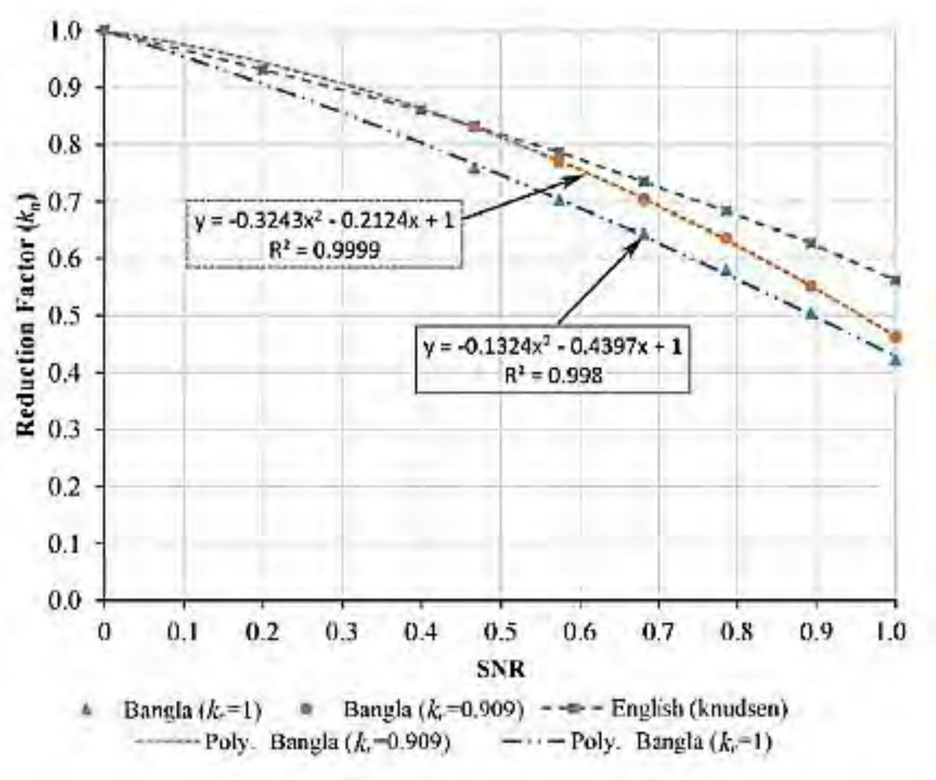


Fig. 3.6.1.b. Reduction factors (k_n) for a range of SNR values for Bangla language compared to those with English language (Knudsen 1929) (Source: Islam 2017)

iv. **Calculating Speech Privacy:** Since speech privacy is inversely proportional to speech intelligibility (Ermann 2015), PSA values calculated for open, semi-private and private office space in each building were also used to determine the speech privacy for those spaces.

v. **Determining population peak graph:** One of the factors which affect average background noise level of a given space is the total number of occupants present at any given time. Assessing the total number of occupants present during the three time periods would have provided framework for reasons behind variations in background noise level at a given time. The purpose of counting number of occupants present were as follows.

- To determine how many occupants are present in open, semi-private and private office space in a specific point of time
- To map the busy or lag times during office hours (Wolnik 2017)

The pilot survey results indicated that in typical floor plans of each LEED certified office building in Dhaka city, the number of entry and exit points ranged from two to three, which was deemed to be very less in number. For this research, walk through count method (Wolnik 2017) was used to determine the number of occupants present in each space at a given time. From the pilot survey, it was established that clients or outside visitors in each office space usually stayed for a period of at least 10 to 20 minutes. At every 15 minutes, a walk through was done by three volunteers in the three work spaces, and total number of occupants present at that particular time was counted. The choice to conduct the walkthrough every 15 minutes was relatively arbitrary, as no prior study was conducted to establish an average length of time per visitor in office spaces in any of the selected buildings.

After counting the total number of occupants present every 15 minutes in open, semi-private and private office spaces, the results were tabulated and Analysis ToolPak plug-in was used to present the findings graphically. From the graph, peak occupancy rate and the corresponding time interval was determined.

vi. **Observation and checklist:** A checklist was prepared prior to conducting the field investigations, and was used to observe and document various features and attributes of each building such as interior dimensions of studied spaces, layout of furniture, materials of exterior finishing, interior finishing and furniture, organogram of employee ranking, typical office hours with corresponding peak hours, and number of total employees occupying each studied floor.

The values for background noise level, reverberation time, speech intelligibility and speech privacy derived from quantitative survey in each building were compared to the recommended values obtained from BNBC 2020 standards as shown in table 3.6.1.a.

Table 3.6.1.a. Recommended values for the objective measurement variables for this research (Source: BNBC 2020)

Objective measurement variable	Recommended allowable maximum limit of the variable
RT_{60} for Bangla language	0.5s to 0.8s
Allowable upper limit of background noise level/ambient noise level	Meeting room: 38-48 dBA
	Open office space: 48-58 dBA
	Semi private office space: 43-53 dBA
	Private office: 38-48 dBA
Speech Intelligibility (in terms of PSA value)	At least 75%
Speech Privacy (in terms of PSA value)	Should not exceed 75%

3.7 Qualitative Research Method

For collecting and studying qualitative data focusing on noise, speech privacy and speech intelligibility, collective or multiple case study research method was followed (Creswell 2007). The qualitative deviations in acoustical performance were studied in multiple green-rated office buildings in order to validate and confirm the results obtained.

3.7.1 Subjective qualitative survey

The qualitative levels of deviation from acoustical performance standards in each building were determined through questionnaire survey (Haapakangas et al. 2008). Self-completion surveys based on paper questionnaire (Brace 2008) were distributed among random employees of open, semi-private and private office spaces in each building. A mixed or semi-structured questionnaire was prepared for the survey, containing a number of both open-ended and close-ended questions (Gillham 2008).

3.7.2 Selection of participants for questionnaire survey

Stratified random sampling method was undertaken to determine the sample size of participants from each studied floor. Following the observations of pilot survey, the total number of employees in each studied floor was divided according to three strata: occupants working in open, semi-private and private office space. Employees who had their workstations located in either of the three strata were selected to conduct the questionnaire survey. Sample size of participants in each stratum were based on the following.

- Confidence level 95% = Z-score 1.96. Confidence level refers to the degree of confidence or certainty of the data being representative of the entire population. Most researchers strive for a 95% confidence level i.e., 95% certainty that the research outcomes reflect the outlooks of the entire population.
- Confidence interval (margin of error) = 5%. Confidence intervals indicate the probable range of values of the population mean. Most researched follow a 5% confidence interval, indicating there is a 5% chance that the population mean lies outside of the upper and lower confidence interval.
- Standard of deviation = 0.5. Standard deviation is a mathematical tool for evaluating how far values are spread above and below the mean. High standard deviation indicated widely spread data (less reliable) and a low standard deviation shows that the data are densely grouped around the mean (more reliable). A standard deviation of 0.5 means that on average, the difference between mean and data points is 0.5.

Office employees in this survey belonged to a finite population i.e., a countable population. The employees occupied a certain area in open, semi-private or private office spaces, and thus their numbers could be counted. For a finite population, sample size of participants in each stratum was determined according to the following formula (Daniel 1999).

$$n = \frac{noN}{no+(N-1)} \quad \text{.................................... (Eq. 3.7.2.a)}$$

$$\{\text{where} \quad n_o = \frac{Z2p\ (1-p)}{e2}\} \quad \text{.......................... (Eq. 3.7.2.b)}$$

where,

n = Sample size taken from each stratum (open, semi private and private office spaces)

n_o = Sample size without considering finite population correlation factor

N = Total population of employees in each stratum

Z = Critical value of the normal distribution at 0.5

p = Sample proportion

e = Margin of error

For research involving green rated office buildings located in a city or state, with both quantitative and qualitative survey methods involved, at least total of 47 employees from each building should be selected for questionnaire survey (Allen et al. 2015). Based on this standard and the formula stated above, the sample size of participants from each studied floor were determined.

3.7.3 Occupant perception study

Through the questionnaire survey, the average employee's perception of the overall acoustical environment was studied. A set of questions were prepared at the beginning of the survey based on four key factors – noise perception, speech intelligibility, speech privacy and general comments on the acoustical environment of the workspace. 8 to 12 questions were set for each section. The questionnaires were distributed among employees during working hours and at the time of surveying. Most of the questions involved participants rating their perception based on a five-point scale. Questions involved participants providing answers by ticking boxes or writing down short paragraphs. The data obtained from the questionnaire survey were tabulated and the results graphically presented with the help of Analysis ToolPak plug-in.

At the beginning of the questionnaire survey, demographic information such as age, gender, years of work experience in specified office building and number of hours spent at work desk were collected. Personal information was kept confidential. Prior to the questionnaire survey, the purpose of the study was explained to the participants and their consent taken before proceeding further. Participants filled out the surveys voluntarily, and the surveys were anonymous.

3.8 Data Analysis

To check whether any statistically significant differences existed between mean background noise level and tier position or office hours, a one-way Analysis of Variance (ANOVA) was conducted using Analysis ToolPak plugin of Microsoft Excel 2019 software. It helped determine whether the survey results were significant or not. To conduct ANOVA test, the significance level (α) was set at 0.05, following previous studies performed in this theme (Islam 2017).

In one way ANOVA test, four variables are significant in determining whether the null hypothesis H_0 should be rejected or supported – F value, F critical value, P-value and significance level. The F value is a ratio of two different measure of variance for the given data in ANOVA test. The F critical value is a specific value used to compare the resulting F value to. F value is compared with F critical value in order to reject or support the null hypothesis. If

F value is found to be greater than F critical value in ANOVA test, the null hypothesis H_0 will be rejected and alternative hypothesis H_1 will be accepted. If F value is less than F critical value, it implies that there is not enough strong evidence to reject the null hypothesis.

The F statistic must be used in combination with a P-value in order to determine whether the overall results obtained from ANOVA test are significant enough to reject the null hypothesis. The P-value is determined by the F statistic. A P-value is a measure of the probability that an observed difference could have occurred just by random chance. It is compared to significance level (taken as 0.05 for this research) to assess the null hypothesis H_0. If P-value is found to be less than or equal to the significance level of 0.05, the null hypothesis H_0 will be rejected and alternative hypothesis H_1 will be accepted. If P-value is greater than the significance level of 0.05, the null hypothesis is supported.

From the derived quantitative data, a comparative analysis was done to determine the levels of deviation from international and national acoustical performance standards in open, semi-private and private office spaces in each green rated office building. The results of quantitative survey were then compared with qualitative data from questionnaire to investigate whether the two sets of data provided similar types of findings. Any deviations present in quantitative variables of acoustical performance were rationalized with the results of questionnaire survey.

3.9 Research Quality Consideration

This research focuses on the acoustical performance of green rated office buildings in Dhaka city. In view of quality of the research, the following issues were taken in consideration.

3.9.1 Internal validity

The sound level meter model used for recording background noise levels in this research was set to provide a recording rate of 60 readings per minute. It had an accuracy of 4 to 16% for recording up to 35 dBA, and 2.4 to 9.6% for recording up to 58 dBA.

Calculating reverberation time using Sabine’s formula is a widely established method which is accepted internationally by other researchers.

Speech intelligibility was determined using PSA method. The formula of PSA for Bangla language was established by Imam et al. (2009) and it has been widely accepted and used in other researches involving calculation of speech intelligibility and reverberation time.

The stratification allocation method used for determining sample size of office population is accepted universally by most researchers. Sample size formula for determining number of participants in questionnaire survey had a 95% confidence level and 5% margin of error, which is ideally followed by most researchers in various studies.

3.9.2 Reliability

Analysis ToolPak plug-in of Microsoft Excel Office 2019 software was used for determining mean, maximum and minimum values, standard deviation and other factors of background noise level. It was used for further analysis of quantitative and qualitative data. This software is renowned and has been accepted internationally by most researchers. The quantitative and qualitative results would attest to be reliable as well.

3.10 Limitations

Given the limited time frame and scope, this research concentrates on the acoustical performance evaluation of green rated office buildings only. Other typologies of buildings were not considered for investigation. Some of the office floors in each building, and some locations in each floor could not be surveyed due to access and confidentiality issues in site.

In similar researches conducted abroad, reverberation time was typically calculated using a Real Time analyser instrument. As this instrument was not available in Bangladesh during the time of research, reverberation time was calculated using Sabine's formula which is also widely accepted by researchers. Automated counting method involving the study of records from video cameras was generally used in researches abroad to determine the number of occupants in a space at a given time. Due to safety and security issues from higher office management committee, this method could not be employed in this study.

Due to confidentiality issues, the names and locations of the selected green rated office buildings were not disclosed in this research.

3.11 Conclusion

This chapter has justified the research area, research methodology, sample selection and sample size determination procedures. The main methodology is based on descriptive and cross-sectional non-experimental research method, and collective or multiple case study research method. Through integrating both quantitative and qualitative modes of research method, this thesis also investigates deviations of acoustical performance in these two parameters, and whether the two sets of findings confirm or disconfirm each other in actuality. The research methodology has been elaborated for both quantitative and qualitative analysis. These explanations aided in establishing the collection of required quantitative data and their processing, observation of the acoustical environment through pre-established checklist and development of qualitative questionnaires. It formed the basis for a comparative analysis between derived quantitative and qualitative data from questionnaire to determine the levels of deviation from international and national acoustical performance standards, and whether the two sets of data provided similar types of findings. Both these research methods involved field observation, discussion with designer team, photographic documentation and sketches, measuring variables for quantitative parameters and Analysis ToolPak investigation, and questionnaire survey with occupants. These techniques have been used consistently throughout the following chapter (Chapter 04), in order to accomplish the research objectives.

CHAPTER 04: FINDINGS AND ANALYSIS

CHAPTER 04: FINDINGS AND ANALYSIS

This chapter focuses on data processing, findings and analysis of the study through data obtained from field investigations of selected green rated office buildings in Dhaka city. Data for open, semi-private and private office spaces were obtained through three methods: observation and checklist, objective measurements and subjective qualitative surveys. The results of each category were analysed and compared with each other to determine whether the three sets of data concluded with similar findings.

4.1 Initial Observations of Green Rated Office Buildings According to the Context of Dhaka City

The four green rated office buildings chosen for this research were situated along primary roads and fell under the F (Business) building category according to RAJUK regulations (Table 4.1.a.). They had LEED ratings ranging from gold to platinum level of certification (Table 4.1.b.). The survey was carried out from 8th July 2019 to 31st October 2019.

Table 4.1.a. Details of surrounding features of the selected buildings (Source: Author)

Building	Building category	Plot area	Total built area	Access road direction	Land configuration
Building A	F (Business)	1291.94 sq m	8387.12 sq m	South	• North: Empty plot (Width: 15.24 m) • South: Road (Width: 18.29 m) • West: Lake (Width: 71.63 m) • East: Road (Width: 12.19 m)
Building B	F (Business)	1780.14 sq m	16537 sq m	East	• North: 6-storey residential and commercial building (Setback: 4.57 m) • South: 3-storey commercial and 4-storey residential building (Setback: 4.57 m) • West: Road (Width: 9.14 m) • East: Road (Width: 21.34 m)
Building C	F (Business)	1044.97 sq m	9957.81 sq m	West	• North: 14-storey commercial building (Setback: 9.25 m) • South: 3-storey commercial building (Setback: 9.25 m) • West: Road (Width: 21.34 m) • East: 7-storey residential building (Setback: 4.57 m)

Building	Building category	Plot area	Total built area	Access road direction	Land configuration
Building D	F (Business)	1487.98 sq m	12867 sq m	East	• North: 6-storey commercial building (Setback: 4.57 m) • South: 6-storey commercial building (setback: 4.57 m) • West: Road (Width: 9.14 m) • East: Road (Width: 21.34 m)

Table 4.1.b. Information on LEED certification of the four green rated office buildings (Source: U.S. Green Building Council)

Building	LEED certification	Level of certification	Year of award	LEED scorecard
Building A	LEED BD+C: Core and Shell (v2009)	Gold	2017	60/110
Building B	LEED BD+C: Core and Shell (v2009)	Gold	2016	71/110
Building C	LEED BD+C: Core and Shell (v2009)	Platinum	2017	81/110
Building D	LEED BD+C: New construction (v2009)	Gold	2019	68/110

Building A: Building A was a 14-storey high-rise commercial building, with 3 basement levels. It consisted of rental office spaces for two privately-owned companies. Its construction was completed in 2015, and it formally opened for operation in 2016. The goal of reduced energy consumption was pursued by using strategies of rain water harvesting system, hands-free automatic sensor plumbing fixtures, solar panel installation on rooftop, charging pods for electric cars, automated lighting control system on rooftop, daylighting and occupancy sensors, and controlled ventilation using carbon dioxide monitoring. The exterior façade incorporated louvers and specially designed 'jali' screening on the west, east and south sides. On the south western corner of the building where louver was absent, a special '3M' coated film was installed above the glazing units for additional heat protection. Low VOC paint was used in interior finishing. Building A obtained LEED BD+C: Core and Shell (v2009) Gold rating in 2017.

Building B: Building B was a 13-storey high-rise commercial building with 3 basement levels, consisting of rental office spaces for multiple privately-owned companies. Its construction was completed in 2016. The lighting design involved maximum daylighting, with 90% of the spaces intended to be day-lit. The design incorporated recycled water system, energy efficient elevator technology, photovoltaic solar panels on rooftop, and daylighting and occupancy sensors for reduced lighting energy consumption. It claimed to have achieved 13% reduction in energy usage, 41% less water usage, harvesting 90% of precipitation as well as treating 116% of wastewater and sewage. It received LEED BD+C: Core and Shell (v2009) Gold rating in 2016.

Building C: Building C had 17 stories with a 3-storey basement. It housed rental office spaces for multiple privately-owned companies. Its construction was completed in 2014. It claimed to have 44% reduction in energy consumption, 60% increase in water savings and 30% increase in natural air ventilation. The goal of reduction in energy usage was achieved by a remote Building Management System (BMS) for controlled energy analysis and management. Additional energy-conservation measures included installation of energy efficient elevator technology and photovoltaic solar panels in rooftop. The goal of optimized indoor air-quality was pursued using a high efficiency air-cooled Variable Refrigerant Flow (VRF) air conditioning system. Intelligent lighting system involving motion sensors, and ambient light sensors were installed for reducing lighting energy consumption. The goal of water consumption was pursued using a water treatment plant, sewage treatment plant, low-flow fixtures, waterless urinals and dual flush toilets, and by making use of captured storm water for flushing. The exterior façade was designed using specially designed and imported low-E glazing units for reducing indoor outdoor heat transfer. Building C was awarded LEED BD+C: Core and Shell (v2009) Platinum rating in the year 2017.

Building D: Building D was a 14-storey privately-owned commercial building, with 3 basement levels. It was formally permitted for occupancy in the year 2017. The goal of energy and load reduction was pursued using a high-performance envelope and solar shading. The exterior facades comprised of an elevation following layers of glass. The first layer of glazing had horizontal ceramic fretting bands for added heat resistance, while the second layer was a shading measure made of glass fins with low-emissivity thermal properties. The southern side was composed of horizontal aluminium louvers for shading. The central core of the building was optimally positioned in the west in order to maximize usable floor space on each floor, while acting as a buffer zone from the heat of west side. The goal of reduced water consumption was pursued using low-flow fixtures, dual-flush toilets, waterless urinals and hands-free automatic sensor plumbing fixtures. Building D gained LEED BD+C: New construction (v2009) Gold rating in the year 2019.

All four buildings were awarded LEED certification under LEED 2009 scheme, where no points were allocated for evaluating acoustical performance. Thus, their overall acoustical performance was not evaluated during the time of green rating assessment following LEED benchmarks (Table A4.1.1).

4.1.1 Typical structure and attributes of selected buildings

The four buildings were located right along extremely busy main streets, in thriving commercial zones of Dhaka Metropolitan area. They were high rises, ranging from 13 to 17 stories. They each housed 3-storied basements for vehicular parking. They consisted of typical floor plans throughout all the floors. Their operating hours usually were from around 8.00 AM to 7.00 PM, and for some floors till 11.30 PM. They each housed on average around 650 to 700 occupants at any given time. At the time of conception, they were designed following sustainable-development principles, i.e., to have extremely high energy and water efficiencies. The longest face of all the buildings were positioned facing north-south orientation. The buildings were comprised of glass facades on the exterior for maximum daylighting, with some of them incorporating louvers or screening materials for shading and sun protection. None of the buildings had operable windows in the exterior façade of main working spaces. They solely relied on active cooling system for ventilation and cooling indoors. It was primarily assumed that any discrepancies in acoustical performances of the selected buildings would not be due to noise coming from outside, for example roads, vehicles etc. At the time of this research, they were being evaluated 2 to 5 years after occupancy.

4.1.2 Typical layout of working spaces in selected floors

The 3 floors selected from each of the four buildings housed office spaces for various privately-owned establishments. They all encompassed a mixture of open, semi-private and private office spaces, along with additional functions such as meeting room, pantry, other office spaces which were inaccessible by the author, and gender specific washrooms. For these additional functions, spaces were usually divided by floor to ceiling length configurable glass or gypsum board partition walls. Plans of the three floors selected from each building are given in Appendix 05.

In all buildings, open office spaces were located centrally in each floor, where employees worked in a common open space. Most of them were not situated alongside external glass facades of the buildings. Surrounding the open office spaces were semi-private office spaces, most of them being positioned next to the building perimeter. Finally, private office spaces were located furthest away from the former two office spaces, placed next to the building perimeter (Fig. 4.1.2.a.).

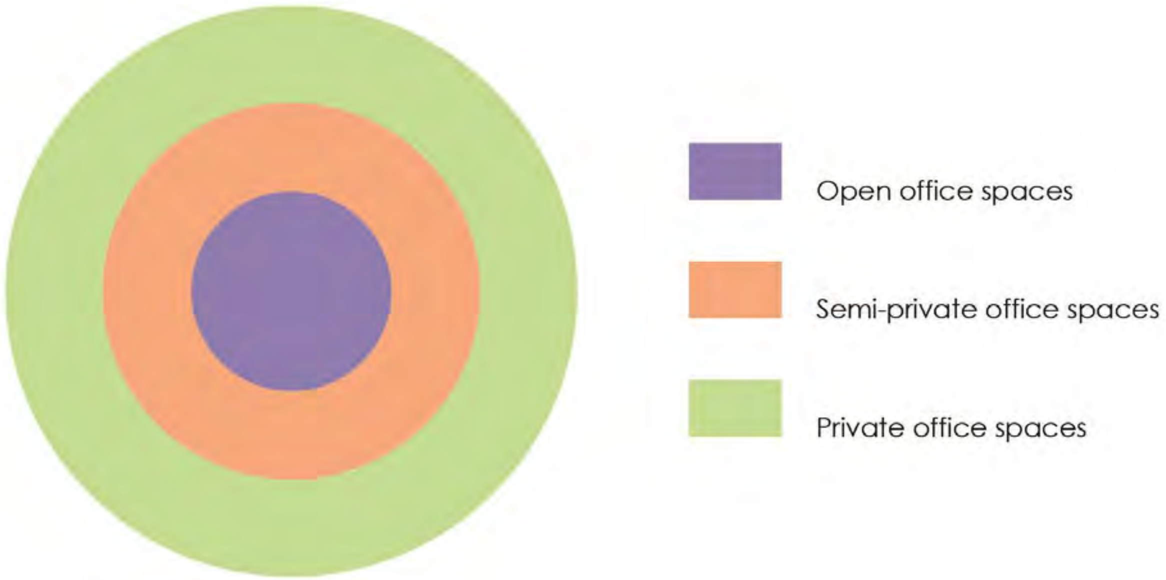


Fig. 4.1.2.a. Concentric zoning model of open, semi-private and private office spaces in the buildings (Source: Author)

Open office spaces in all the buildings consisted of single occupancy desks and chairs. In some cases, each workstation consisted of configurable modular low height cubicles with desks. In other instances, separators were present to separate desks from each other, and to provide privacy (Table 4.1.2.a.). Desks which were separated by configurable modular low height cubicles (Building A and C) on average measured 1.37 m by 0.76 m by 0.76 m each, and they were constructed of 25 mm thick veneered particle board. Desks which were separated by a single desk separator (Building B and D) measured 1.22 m by 0.61 m by 0.76 m each. Each workstation was usually placed side by side and/or facing opposite to each other, grouped together in 2, 4, 6 or 8 units. The desks did not have any other additional furniture. The spaces were not enclosed by floor to ceiling height walls or partitions (Fig. 4.1.2.b.).

Table 4.1.2.a. Details on low height cubicles or desk separators present in open office spaces in the selected buildings (Source: Author)

Building	Type of partition present in workstations
Building A	Low height cubicles consisting of free-standing partition of 1.07 m height. 56.25 mm thick steel and aluminium frame post, with panel consisting of colourful fiberglass layer over 56.25 mm thick solid particle board backing. The panels were lifted 25 mm above floor surface by PVC 'feet'.
Building B	Desk separator of 0.36 m height from desk surface. It consisted of colourful fiberglass layer over 56.25 mm thick particle board, held by 56.25 mm thick steel and aluminium frame post.
Building C	Low height cubicles consisting of free-standing partition of 1.07 m height. 56.25 mm thick steel and aluminium frame post, with panel consisting of colourful fiberglass layer over 56.25 mm thick solid particle board backing. The panels were lifted 25 mm above floor surface by PVC 'feet'.
Building D	Desk separator of 0.36 m height from desk surface. It consisted of colourful fiberglass layer over 56.25 mm thick particle board, held by 56.25 mm thick steel and aluminium frame post.

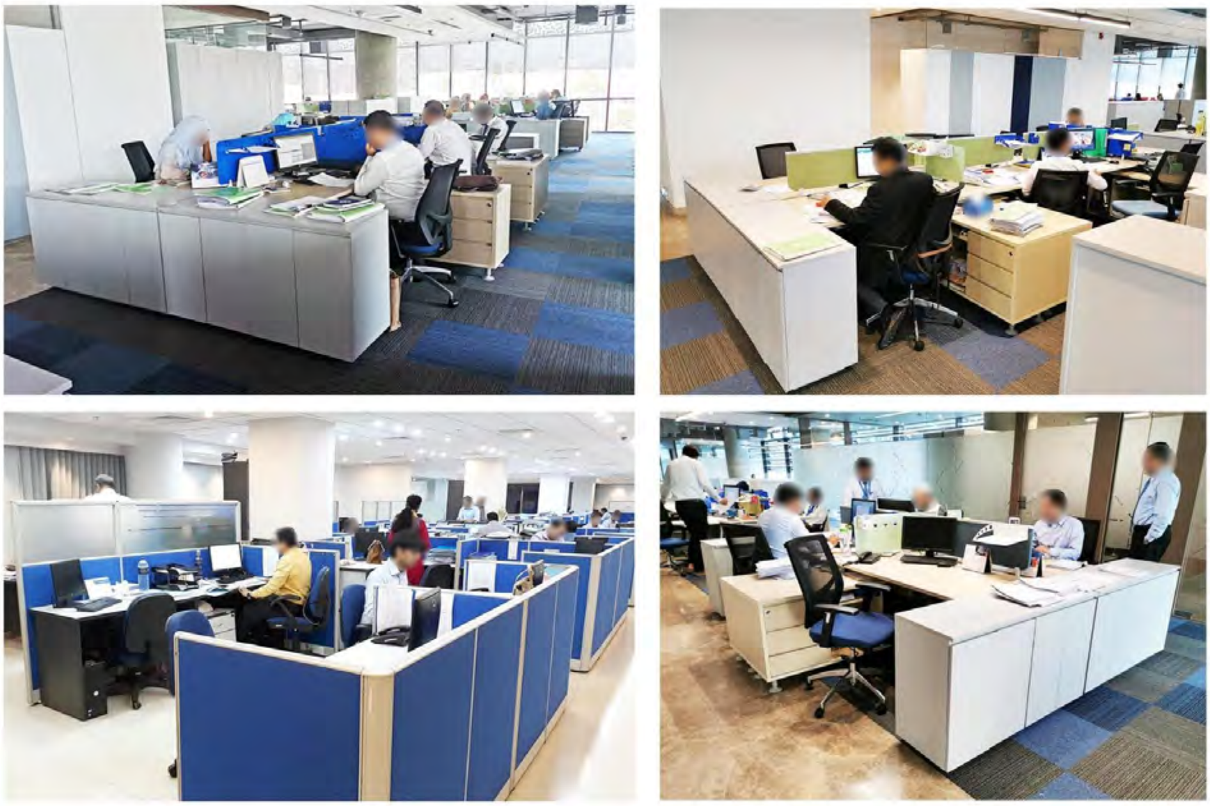


Fig. 4.1.2.b. Open office workstation layouts inside selected buildings (Source: Author)

Semi-private office spaces also consisted of single occupancy desks and chairs. Most semi-private workstations consisted of configurable modular higher-height cubicles with desks. In other cases, vertical cable supported glass façade systems were present to separate workstations from each other (Table 4.1.2.b.). Desks which were separated by configurable modular higher height cubicles (Building A, C and D) on average measured 1.37 m by 0.76 m by 0.76 m each, and they were constructed of 25 mm thick veneered particle board. Desks which were separated by suspended frameless glass partition (Building B) measured 1.35 m by 0.76 m by 0.76 m each. Each desk usually consisted of additional two chairs for visitors. Some of the workstations had dedicated furniture such as file cabinets. The spaces were not enclosed by floor to ceiling height walls or partitions (Fig. 4.1.2.c.).

Table 4.1.2.b. Details on higher height cubicles or glass partitions present in semi-private office spaces in the selected buildings (Source: Author)

Building	Type of partition present in workstations
Building A	Higher-height cubicles consisting of free-standing partition of 1.35 m height. 56.25 mm thick steel and aluminium frame post, with panel consisting of 1.07 m high fiberglass layer over 56.25 mm thick solid particle board backing. 12 mm thick polycarbonate glass window panel above it. The panels were lifted 25 mm above floor surface by PVC 'feet'.
Building B	Suspended frameless glass partitions consisting of 12 mm thick tempered frosted glass with colourful motifs, held by 12.5 mm SS gripper on the upper and lower edges and fixed to the ceiling channel by 3 mm steel cable.
Building C	Higher-height cubicles consisting of free-standing partition of 1.35 m height. 56.25 mm thick steel and aluminium frame post, with panel consisting of 1.07 m high fiberglass layer over 56.25 mm thick solid particle board backing. 12 mm thick polycarbonate glass window panel above it. The panels were lifted 25 mm above floor surface by PVC 'feet'.
Building D	Higher-height cubicles consisting of free-standing partition of 1.35 m height. 56.25 mm thick steel and aluminium frame post, with panel consisting of 1.07 m high fiberglass layer over 56.25 mm thick solid particle board backing. 12 mm thick polycarbonate glass window panel above it. The panels were lifted 25 mm above floor surface by PVC 'feet'.

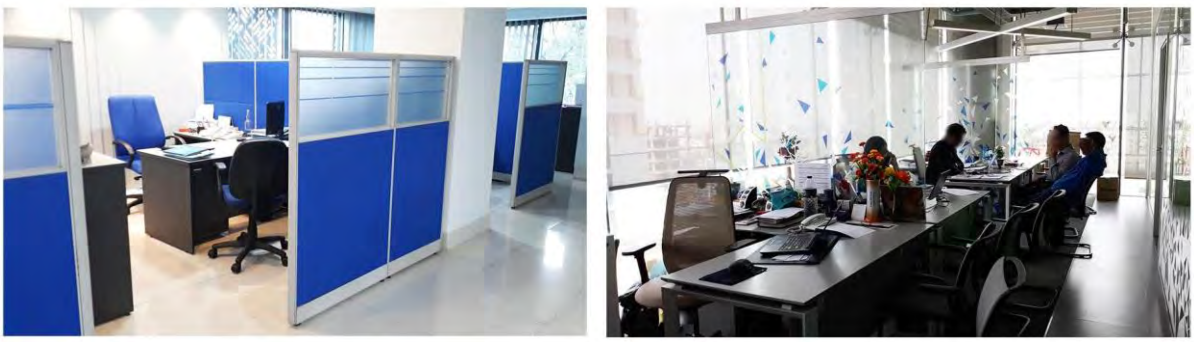


Fig. 4.1.2.c. Semi-private workstation layouts inside selected buildings (Source: Author)

Private office spaces had single occupancy desks and chairs. Each private office space was enclosed by floor to ceiling height tempered glass partition walls and external walls (Table 4.1.2.c.). Each of them was completely secluded from all open and semi-private office spaces, and other areas present in that floor. Desks on average measured 1.37 m by 0.76 m by 0.76 m each, and they were constructed of 25 mm thick veneered particle board. Each desk consisted of additional two chairs for visitors. Some of the workstations had dedicated furniture such as file cabinets. Several spaces consisted of additional seating arrangement to accommodate large number of visitors (Fig. 4.1.2.d.).

Table 4.1.2.c. Details on tempered glass partition walls present in private office spaces in the selected buildings (Source: Author)

Building	Type of partition present in workstations
Building A	Frameless tempered glass partition consisting of 2.13 m high by 12 mm thick toughened glass, held by SS U-shaped channel, and 100 mm thick gypsum partition. These were held together by 75 mm thick wooden member.
Building B	Frameless tempered glass partition consisting of 2.13 m high by 12 mm thick toughened glass, held by SS U-shaped channel, and 100 mm thick gypsum partition. These were held together by 75 mm thick wooden member.
Building C	Frameless tempered glass partition consisting of 2.13 m high by 12 mm thick toughened glass, held by SS U-shaped channel, and 100 mm thick gypsum partition. These were held together by 75 mm thick wooden member.
Building D	Frameless tempered glass partition consisting of 2.13 m high by 12 mm thick toughened glass, held by SS U-shaped channel, and 100 mm thick gypsum partition. These were held together by 75 mm thick wooden member.

Fig. 4.1.2.d. Private workstation layouts inside selected buildings (Source: Author)

4.1.3 Typical organizational structure and demographic data of employees in selected floors

Open office spaces in each selected building comprised of employees working under the same or different divisions of the company. Designations of the employees included that of executive officers, junior officers, assistant officers, trainee assistant officers, cashiers, store keepers and other staff members. Their roles in the company fell in the lower tier of the company organograms (Fig. 4.1.3.a.). Staff members such as store keepers, clerks, cooks etc. did not have any allocated desks or cubicles in the office space. They were not regarded as open office participants in this research, and were not included in the subjective qualitative survey. Employees of semi-private office spaces comprised of senior executive officers, assistant general managers and deputy general managers of each division of the company. Their roles fell in the middle tier of company organograms. Private office space employees stood in the upper tier of company organograms. Their designations included general managers, deputy managing directors, managing directors, executive directors and CEOs.

Fig. 4.1.3.a. Typical organogram followed in offices spaces of selected buildings (Source: Author)

A total of 411 open office employees, 70 semi-private office employees and 39 private office employees worked in the selected floors of the 4 buildings. Open office employees accounted for more than 70% of all the occupants at any given time, followed by semi-private office employees (13%). Private office employees accounted for the least proportion of occupants (8%) (Fig. 4.1.3.b.). On average, there were 34 employees in open office, 6 in semi-private and 3 in private office spaces.

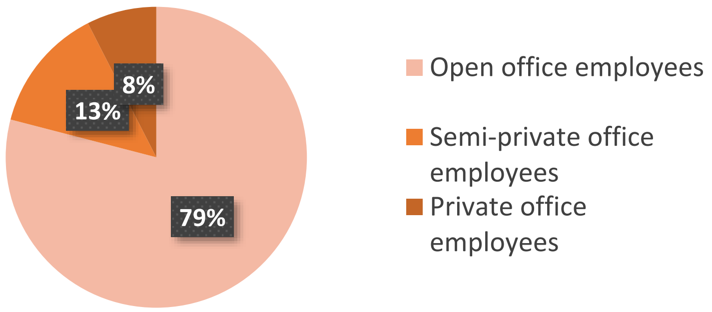


Fig. 4.1.3.b. Percentage of open, semi-private and private office employees in the 4 buildings (Source: Author)

A total of 483 employees participated in the subjective qualitative survey (Table 4.1.3.a.). This sample size conformed with the sample size selection criteria of 95% confidence interval, 5% margin of error and 0.5 standard of deviation. 355 male employees and 128 female employees took part in the survey.

Table 4.1.3.a. Total number of employees surveyed in open, semi-private and private office spaces in the selected floors of studied buildings (Source: Author)

Building	Number of employees surveyed		
	Open office	Semi-private office	Private office
Building A	94	19	3
Building B	115	30	17
Building C	50	19	3
Building D	111	10	12
TOTAL = 483	**370**	**78**	**35**

Around 52% of all survey participants were aged 25 to 34 years, followed by 35 to 44 years age range (34%), 45 to 54 years age range (9%), 18 to 24 years age range (5%) and 55 to 64 years age range (0.2%). In open office spaces, most of the participants fell under the 25 to 34 years age range (64%), followed by 35 to 44 years age range, 18 to 24 years age range and 45 to 54 years age range. In semi-private office spaces, 64% of the participants fell under 35 to 44 years age range, followed by both 25 to 34 and 45 to 54 years age range. Most of the participants from private office spaces were aged 45 to 54 years (71%), followed by 35 to 44 years age range and 55 to 64 years age range (Fig. 4.1.3.c.).

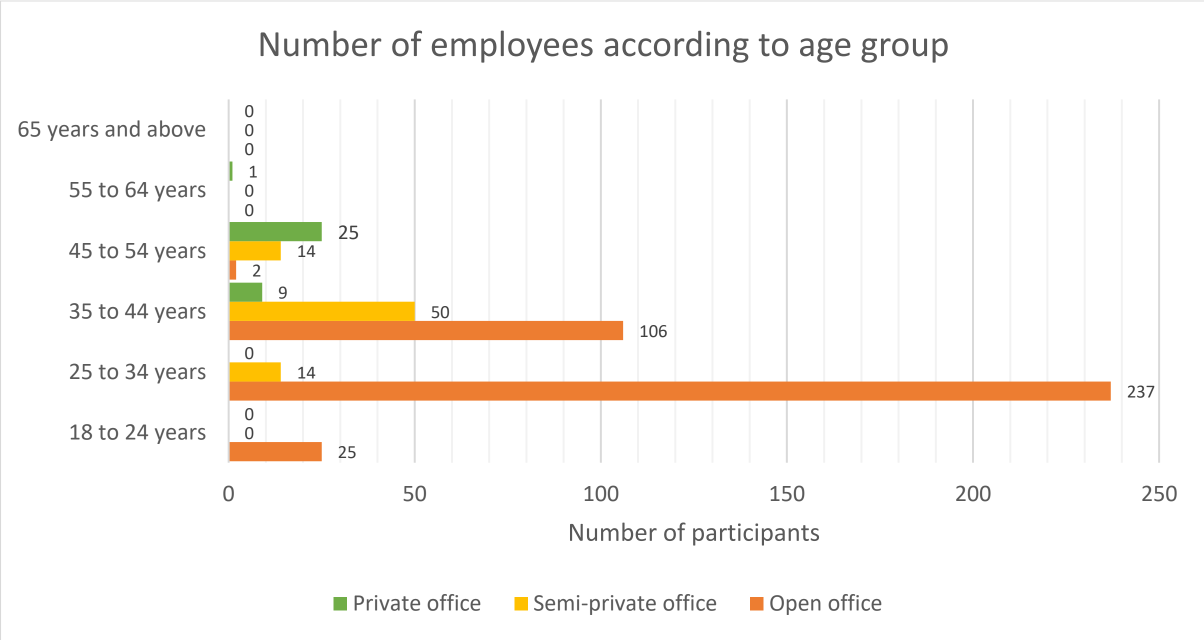


Fig. 4.1.3.c. Number of open, semi-private and private office participants according to age group (Source: Author)

Most of the participants (91%) responded to hearing perfectly well in terms of their assessment of hearing. In open office spaces, around 94% participants responded that they had perfect hearing abilities, followed by little difficulty, some difficulty and needing hearing aids. Most of the semi-private office participants also claimed to have perfect hearing (87%), followed by little difficulty and some difficulty. Private office participants also responded to have perfect hearing (66%), followed by little difficulty, some difficulty and lots of difficulty (Fig. 4.1.3.d.).

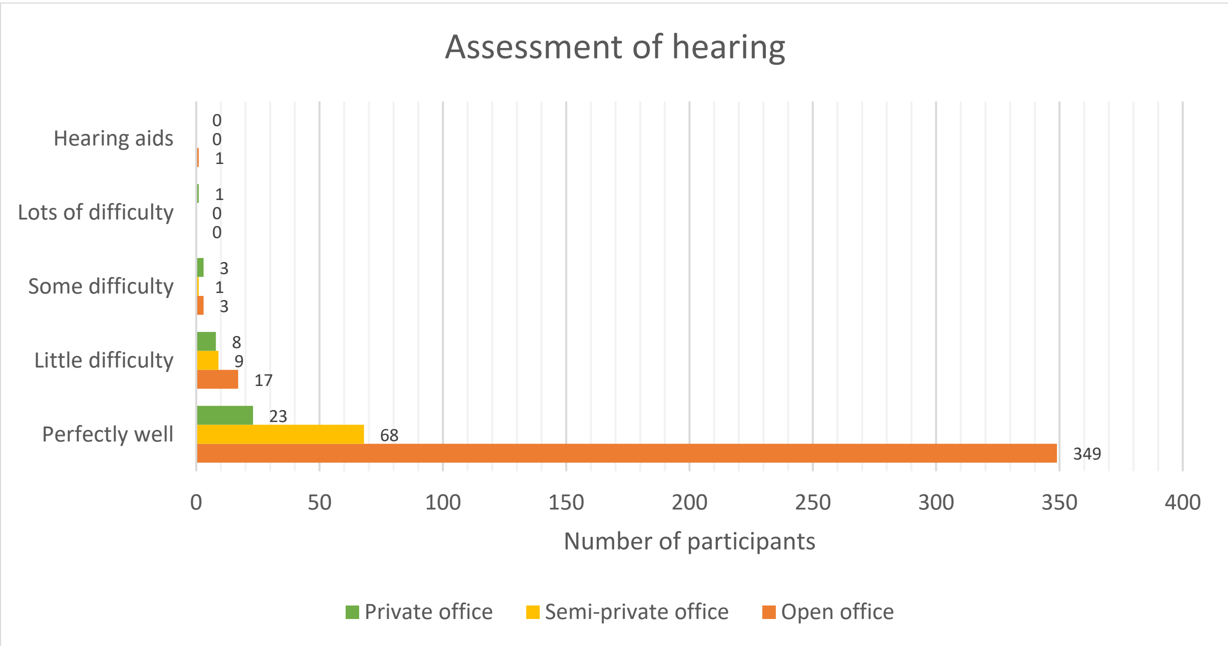


Fig. 4.1.3.d. Hearing assessment of open, semi-private and private office participants (Source: Author)

Majority of the participants (63%) had 1 to 2 years of experience in their respective office floors. Most open office participants had 1 to 2 years' experience (64%), followed by less than 1 year, 3 to 5 years and more than 5 years. Most semi-private office users also had 1 to 2 years' experience (49%), followed by 3 to 5 years, more than 5 years and less than 1 year. 83% of private office users also spent 1 to 2 years in their respective office floors, followed by more than 5 years, and less than 1 year and 3 to 5 years (Fig. 4.1.3.e.).

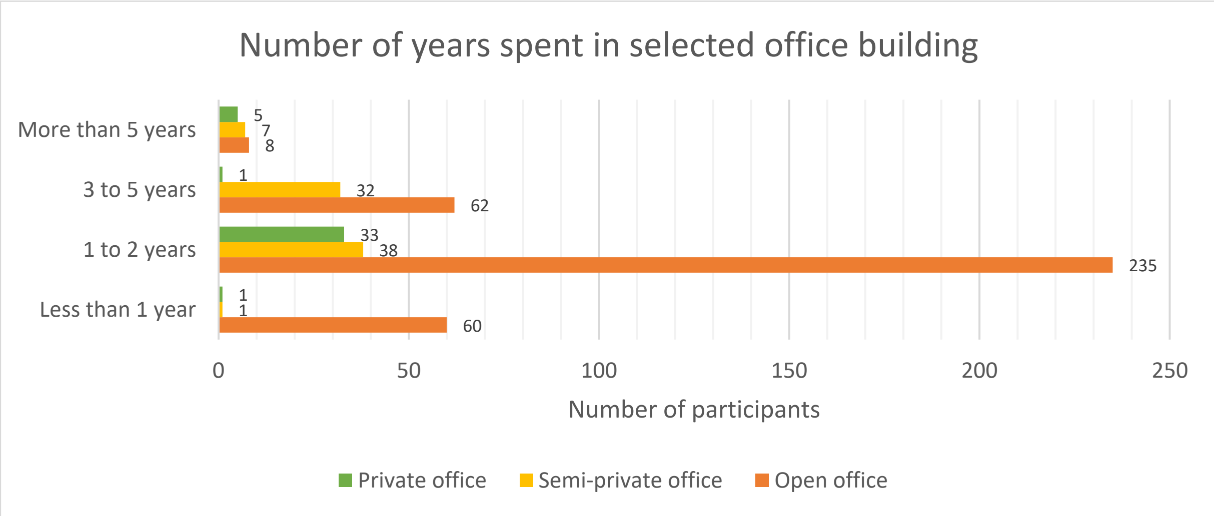


Fig. 4.1.3.e. Years of occupancy in office space of open, semi-private and private office participants (Source: Author)

Typical working hours in the office spaces were from 10.00 AM to 6.00 PM. Most participants (74%) spent more than 8 hours in their desk. Most open office users spent more than 8 hours at their desk (77%), followed by 6 to 8 hours. 85% of semi-private office participants spent more than 8 hours at their desk, and only 15% spent 6 to 8 hours. 77% of private office users spent 6 to 8 hours at their desk, followed by more than 8 hours and 3 to 5 hours (Fig. 4.1.3.f.).

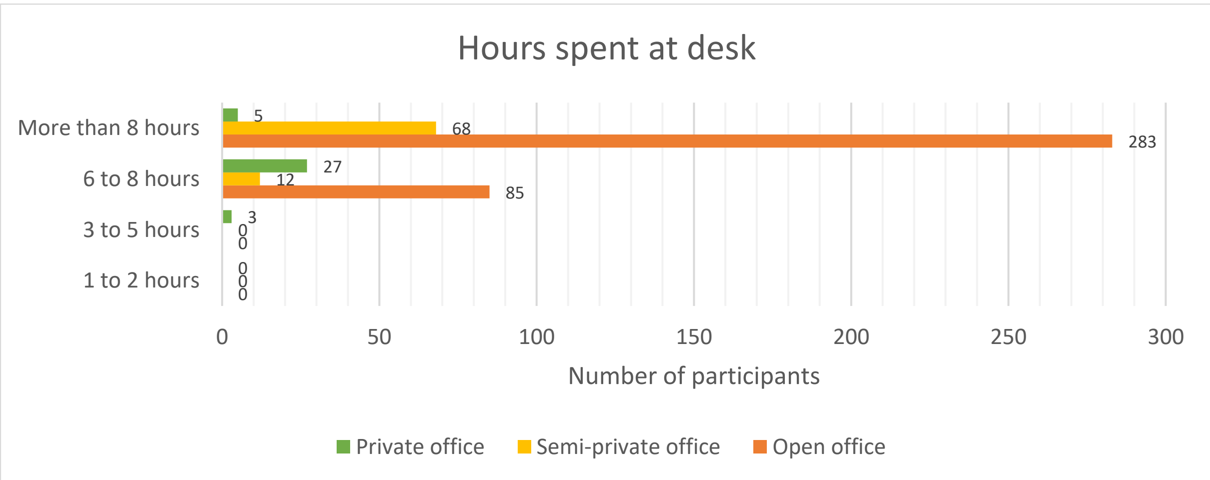


Fig. 4.1.3.f. Hours spent at desk by survey participants in the (Source: Author)

4.2 Initial Acoustical Performance Observations from Field Survey with Context to Checklist

A checklist was developed at the beginning of the research to aid in initial acoustical performance observations of selected floors in the office buildings. At first, consultations were held with the designer team (architects, interior designers and related engineers) of each selected building in order to gain an insight on their design goals, approaches and limitations. Table 4.2.a. shows the main summary of observations from consultations held with building designer team at the beginning of field survey.

Table 4.2.a. Summary of meetings held with respective design team of each building (Source: Author)

Building	Acoustical design consultant appointed	Acoustical design targets set	Awareness of acoustical performance issues	Acoustical performance POE survey	Noise map prepared
Building A	No	No	No	No	No
Building B			Yes		
Building C			Yes		
Building D			No		

From Table 4.2.a., it was seen that in all buildings, the main design team did not appoint any specialized acoustical expertise during design and construction phases. Contractors were hired later on to design the interior spaces (including any necessary acoustical design and retrofitting), often on limited financial resources. Limitation of available expenses at the end of overall project phase often affected the quality and efficiency of chosen acoustical treatment. Clients' wishes for particular design materials and furniture often affected the final design, interior layout and planning.

No quantitative or qualitative acoustical design targets were set by any of the buildings' design teams, even if designers were aware of any prevailing or imminent acoustical performance issues during design phases. After occupancy, designers of building B and C received reports of unsatisfactory acoustical performance by the building occupants, as determined from initial discussions with the designer team of each building. Issues included outside noise, reverberation and HVAC noise, decreased speech intelligibility and high levels of background noise. No initiatives were taken to resolve the concerns. Most designers were prejudiced in favour of their design concept, and believed their buildings were well designed and positively received by all occupants. No post occupancy evaluation survey based on acoustical performance was carried out in any of the buildings after operation commenced. No noise map was prepared in any phase of the building timeline.

Table 4.2.b. displays the main summary of observations from planning and design of the selected buildings with respect to outdoor noise, noise attenuation measures with respect to indoor noise, site planning, and activities and space layout.

Table 4.2.b. Summary of observations on planning and design of selected buildings with respect to surrounding indoor and outdoor environment (Source: Author)

Building	Satisfactory location of building with respect to outdoor noise	Presence of indoor noise	Locating susceptible spaces away from noise sources	Measures taken to separate noise source from vulnerable spaces
Building A	No	Yes	No	No
Building B				
Building C				
Building D				

According to national and international guidelines, sources of outdoor noise such as traffic, playground, markets, shopping places, huge group of crowds around buildings etc. should be taken into consideration in the initial planning and design phases of buildings falling under business and commercial use category. From Table 4.2.b., it was seen that all 4 buildings had their front facing sides positioned to face main primary roads in the surrounding area, which always remained active and encountered heavy traffic flow throughout the typical office working hours. No buffer measures such as trees were present between the front face of buildings and main streets.

In all buildings, there was presence of indoor noise during typical office hours. Sources of indoor noise included mechanical noise (e.g., HVAC systems), noise from office equipment (e.g., printers, photocopy machine), noise from employees' conversations, door closing noise and general network public address (PA) solution (e.g., to meet the needs of public broadcasting such as prayer calls). Insufficient measures were taken to attenuate indoor noise from these sources.

General observation was that spaces susceptible to noise were not located away from noise sources. Open office spaces were located centrally in the floor plans of all buildings, and due to absence of solid walls or enclosures, they were more vulnerable to surrounding noises. Typical noise sources such as office equipment, PA solution and mechanical equipment were concentrated in those spaces as well. Semi-private office spaces were also susceptible to surrounding noises due to lack of fully enclosed vertical walls. Their position in the floor plans tended to be right beside open office spaces and/or external building facades. They were always exposed to noise from open office employees, other indoor noise sources and outdoor noise. Most private office spaces were not vulnerable to increased indoor noise, as they were fully enclosed with solid walls and/or partitions.

Table 4.2.c. summarizes the observations made in the interior design, furnishings and retrofitting done in the office spaces with regards to acoustical performance.

Table 4.2.c. Summary of observations on interior design, furnishings and retrofitting done with regards to acoustical performance (Source: Author)

<table>
<tr><th colspan="2">Building</th><th>Carpeted flooring</th><th>Treated ceiling</th><th>Treated walls or screens</th><th>Noisy equipment distribution</th><th>Door closers</th><th>Resilient pads</th><th>Artificial Masking noise</th></tr>
<tr><th rowspan="3">Building A</th><th>Open</th><td rowspan="3">No</td><td rowspan="3">Yes</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td></tr>
<tr><th>Semi-private</th></tr>
<tr><th>Private</th></tr>
<tr><th rowspan="3">Building B</th><th>Open</th><td rowspan="2">Yes</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td></tr>
<tr><th>Semi-private</th></tr>
<tr><th>Private</th><td>No</td></tr>
<tr><th rowspan="3">Building C</th><th>Open</th><td rowspan="3">No</td><td rowspan="3">Yes</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td></tr>
<tr><th>Semi-private</th></tr>
<tr><th>Private</th></tr>
<tr><th rowspan="3">Building D</th><th>Open</th><td rowspan="3">Yes</td><td rowspan="3">Yes</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td><td rowspan="3">No</td></tr>
<tr><th>Semi-private</th></tr>
<tr><th>Private</th></tr>
</table>

From Table 4.2.c., it was seen that in all buildings, the finishing material of floor surface consisted of polished ceramic tiles laid down over 150 mm reinforced concrete slab. These tiles do not have high values of absorption coefficient, and resulted in increased surface area for reflecting noise in the surrounding space. Carpets were only installed in open and some semi-private spaces in Building B, and in all office spaces in Building D. Fibre type carpeting was used in these cases, which did not provide any practical effect on noise absorption.

The ceiling segment of all selected floors of Building B was not treated with any noise absorptive materials. In this building, the HVAC ducts on the ceiling were left exposed and lined with 12 mm thick polyester material, which had an absorption coefficient less than the recommended 0.7 value. In other buildings, gypsum or mineral board made up the reflected ceiling in office spaces. They were not highly noise absorptive, and had an absorption coefficient less than the recommended 0.7 value.

The interior and exterior walls in the office spaces were not treated with any sort of acoustical performance enhancing material. They tended to be highly reflective instead of highly absorptive with regards to surrounding noise.

Noisy office equipment such as printers, photocopy machines and PA system were not distributed uniformly over the office floor layout, as recommended by national and international guidelines. In all buildings, they were concentrated in the centrally located open office spaces. These spaces were not treated with maximum noise absorptive material, and the spaces were not visually separated from adjacent workspaces. Office equipment was not fitted or installed with resilient pads for noise absorption.

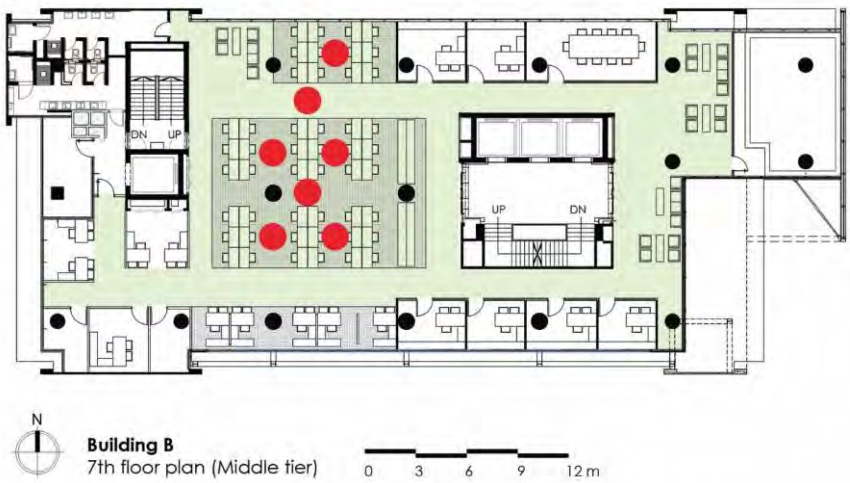
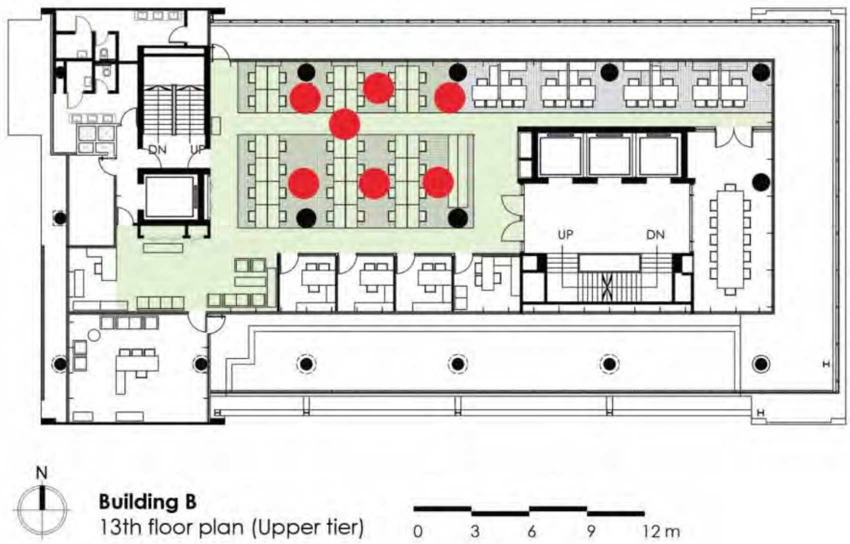
In all office spaces, no automatic quiet-action type door closers were fitted with any of the doors. Quiet-action door latches on doors and continuous resilient strip on door frames were absent. No artificial masking sound system was present. Mechanical noise sources such as HVAC systems in these office spaces did not generate an acceptable degree of masking sound to mask the undesirable indoor office noise generated from other sources.

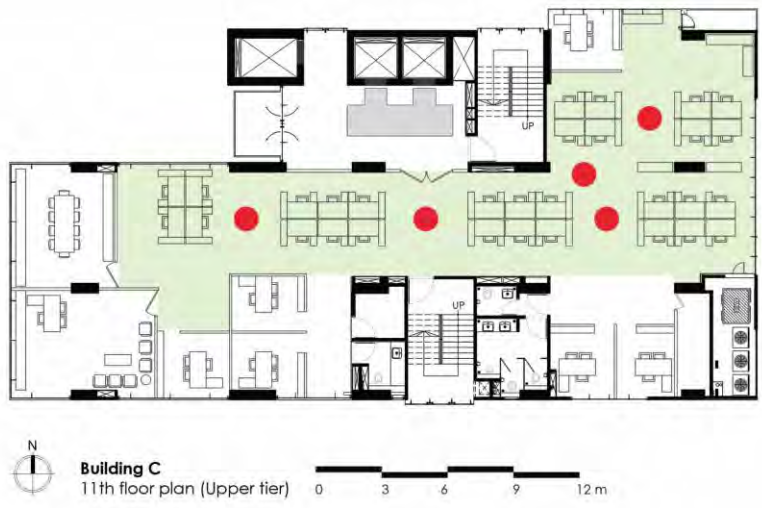
4.3 Data Obtained from Objective Measurements in Open Office Spaces

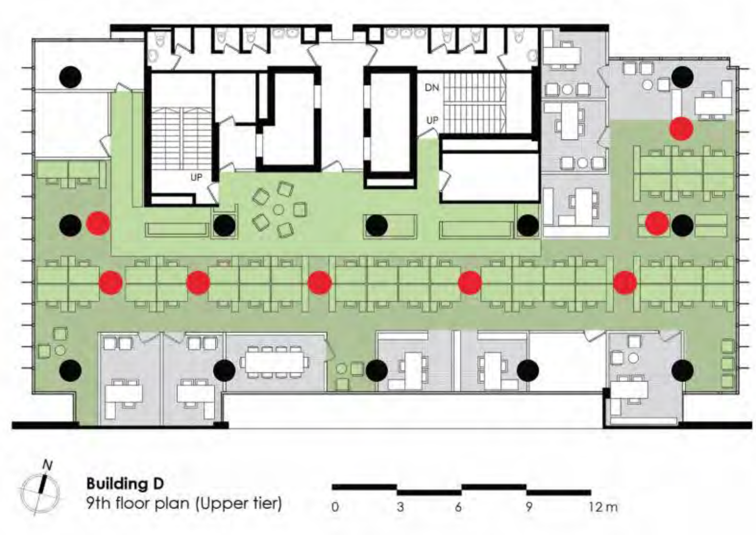
In the three selected floors from each building, 5 to 9 points or locations were set to measure background noise level in open office spaces using sound level meter, and consequently where reverberation time, speech intelligibility and speech privacy were later on determined. The points where background noise level was measured in open office spaces are illustrated by red coloured dots in Table 4.3.1.a.

Table 4.3.a. Points/locations in open office spaces where background noise level was measured (Source: Author)

Building A	
Lower tier	
Middle tier	
Upper tier	

Building B	
Lower tier	
Middle tier	
Upper tier	

Building C	
Lower tier	
Middle tier	
Upper tier	

Building D	
Lower tier	
Middle tier	
Upper tier	

4.3.1 Background noise levels

Table 4.3.1.a. shows the mean background noise level in each selected floor, mean background noise level in each building and overall average background noise level in all 4 buildings during off-peak hours (10.00 AM to 12.00 PM) in open office spaces. The values for background noise level, reverberation time, speech intelligibility and speech privacy derived from quantitative survey in each building were compared to the recommended values obtained from BNBC 2020 standards as shown in Table 3.6.1.a. The allowable upper limit of background noise level/ambient noise level for open office spaces was taken to be 48 to 58 dBA.

Table 4.3.1.a. Mean background noise level during off-peak hours in various floors of open office spaces (Source: Author)

Mean background noise levels during off-peak hours (10.00 AM to 12.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	53.63 dBA	53.13 dBA	53.81 dBA	53.52 dBA
Building B	60.99 dBA	56.94 dBA	61.31 dBA	***59.75 dBA***
Building C	56.75 dBA	55.78 dBA	58.77 dBA	57.10 dBA
Building D	62.04 dBA	58.04 dBA	***62.19 dBA***	***60.76 dBA***
Mean of each tier	***58.35 dBA***	55.97 dBA	***59.02 dBA***	**Overall mean = 57.78 dBA**

The overall mean background noise level in open office space of all buildings during off-peak hours was found to be 57.78 dBA, which is slightly less than the highest recommended limit of 58 dBA. Building B and Building D had mean background noise levels greater than 58 dBA. The lower and upper tiers of all buildings had a mean background noise level greater than 58 dBA. Highest recorded mean background noise level during off-peak hours was in the upper tier of Building D.

Table 4.3.1.b. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all 4 buildings during peak hours - 01 (12.00 PM to 2.00 PM) in open office spaces.

Table 4.3.1.b. Mean background noise level during peak hours – 01 in various floors of open office spaces (Source: Author)

Mean background noise levels during peak hours - 01 (1.00 PM to 2.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	56.12 dBA	56.21 dBA	60.32 dBA	57.55 dBA
Building B	62.03 dBA	61.03 dBA	59.84 dBA	***60.97 dBA***
Building C	58.75 dBA	60.89 dBA	59.88 dBA	***59.84 dBA***
Building D	***62.54 dBA***	56.44 dBA	60.30 dBA	***59.76 dBA***
Mean of each tier	***59.86 dBA***	***58.64 dBA***	***60.09 dBA***	**Overall mean = 59.53 dBA**

The overall mean background noise level in open office space of all buildings during peak hours - 01 was found to be 59.53 dBA, which is greater than the highest recommended limit of 58 dBA. Building B, C and D had mean background noise levels greater than 58 dBA. All the tiers had a mean background noise level greater than 58 dBA. Highest recorded mean background noise level in open office space during peak hours - 01 was in the lower tier of Building D.

Table 4.3.1.c. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during peak hours - 02 (4.00 PM to 6.00 PM) in open office spaces.

Table 4.3.1.c. Mean background noise level during peak hours – 02 in various floors of open office spaces (Source: Author)

Mean background noise levels during peak hours - 02 (4.00 PM to 6.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	56.98 dBA	57.43 dBA	60.35 dBA	***58.25 dBA***
Building B	62.01 dBA	61.18 dBA	60.79 dBA	***61.33 dBA***
Building C	61.20 dBA	***64.64 dBA***	61.98 dBA	***62.61 dBA***
Building D	60.39 dBA	62.21 dBA	61.62 dBA	***61.41 dBA***
Mean of each tier	***60.15 dBA***	***61.37 dBA***	***61.19 dBA***	**Overall mean = 60.90 dBA**

The overall mean background noise level in open office space of all the buildings during peak hours - 02 was found to be 60.90 dBA, which is greater than the highest recommended limit of 58 dBA. All 4 buildings had mean background noise levels greater than 58 dBA. All the tiers had a mean background noise level greater than 58 dBA. Highest recorded mean background noise level in open office space during peak hours -02 was in the middle tier of Building C.

The overall mean background noise level in open office space of all the buildings during typical working hours (10.00 AM to 6.00 PM) was found to be 59.40 dBA, which is greater than the highest recommended background noise limit of 58 dBA for open office spaces. The highest mean background noise level was found during peak hours – 02 (60.90 dBA). Mean background noise level during typical working hours in upper tiers was found to be the highest. Mean background noise level in open office space during typical working hours was the highest in Building B (Table 4.3.1.d.).

Table 4.3.1.d. Mean background noise levels during typical working hours in open office spaces (Source: Author)

Mean background noise levels during working hours (10.00 AM to 6.00 PM)			
Building A	**Building B**	**Building C**	**Building D**
56.44 dBA	***60.68 dBA***	59.85 dBA	60.64 dBA
Lower tiers	**Middle tiers**	**Upper tiers**	
59.45 dBA	58.66 dBA	***60.10 dBA***	
Overall mean = 59.40 dBA			

4.3.2 Reverberation time

In all the buildings, semi-private office spaces were not enclosed by floor to ceiling height walls or partitions. They shared the same enclosed space as that of open office. Reverberation time of open and semi-private spaces were calculated together and was equal for both spaces. The total absorption A for open and semi-private office spaces in selected floors of each office building was found multiplying the area of each type of material by its own absorption coefficient, and summing the result to obtain total absorption. In particular,

$$A = \Sigma S_i \alpha_i \quad \text{......} \quad \text{(Eq. 4.3.2.a.)}$$

where, S_i = Area of each material inside the space

α_i = Absorption coefficient of each material inside the space

The absorption coefficients of all materials vary with frequency. Appendix 03 shows the value of absorption coefficient of the same material type for different frequencies. The voiced speech of a typical adult male has a fundamental frequency from 85 to 1800 Hz, and from 165 to 2550 Hz for a typical adult female (Baken et al. 1987, Titze 1994). This thesis considered the average value of speech frequency to be 1000 Hz or 1 kHz to calculate total absorption for all materials. Tables A7.1.1 to A7.4.3 of Appendix 07 shows the detailed calculation of total absorption in 1 kHz frequency (A) for open and semi-private office spaces of selected floors. Reverberation time of the office spaces was calculated using Sabine's formula (Eq. 3.6.1.a) which is given below (Cavanaugh and Wilkes 1999).

$$RT_{60} = \frac{0.161V}{A} \quad \text{......} \quad \text{(Eq. 3.6.1.a)}$$

where, RT_{60} = Reverberation time in seconds (s)

V = Volume of the office space in cubic meter (m^3)

A = Total absorption (α) of the office space in square meter sabin (m^2 sabin)

$0.161 = k = \frac{24 \ln 10}{c20}$, where c_{20} = speed of sound i.e., 343 m/s

Table 4.3.2.a. Mean reverberation time of open office spaces in selected floors of each office building calculated during survey (Source: Author)

Building A								
Lower tier			Middle tier			Upper tier		
Volume (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)
1004.40	214.35	0.75	976.71	192.00	***0.82***	982.15	214.91	0.74
Mean RT of Building A in seconds (s) = 0.77								
Building B								
Lower tier			**Middle tier**			**Upper tier**		
Volume (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)
1442.18	322.43	0.72	1290.37	274.16	0.76	687.56	210.04	0.53
Mean RT of Building B in seconds (s) = 0.67								
Building C								
Lower tier			**Middle tier**			**Upper tier**		
Volume (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)
536.33	101.23	***0.85***	667.55	124.19	***0.87***	848.80	174.54	0.78
Mean RT of Building C in seconds (s) = *0.83*								
Building D								
Lower tier			**Middle tier**			**Upper tier**		
Volume (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)	**Volume** (m^3)	**Total absorption, α_{1kHz}** (sqm sabin)	**RT_{60}** (s)
779.05	193.63	0.65	849.51	252.94	0.54	827.97	268.66	0.50
Mean RT of Building D in seconds (s) = 0.56								
Mean of lower tier (s) = 0.74			**Mean of middle tier (s) = 0.75**			**Mean of upper tier (s) = 0.63**		

Data in Table 4.3.2.a. shows that reverberation time in open office spaces of all floors lies between the range 0.56 s to 0.83 s. This range of values lies between the recommended reverberation time limit range of 0.5 to 0.8 s (Table 3.6.1.a.). The mean reverberation time of all buildings was found to be 0.70 s, which also lies between the recommended limit range. Reverberation time of open office spaces in this research was found to be satisfactory. Mean RT_{60} values for Building A, Building B, Building C and Building D were 0.77 s, 0.67 s, 0.83 s and 0.56 s respectively. It was observed that the average values for RT_{60} in lower, middle and upper tiers were 0.74 s, 0.75 s and 0.63 s respectively. These values are almost similar with extremely low deviations from each other, which indicates that the reverberation time for open office spaces did not significantly change with their position in the observation floor of any specific tier.

4.3.3 Speech Intelligibility

Speech intelligibility of the office spaces was determined using Percentage Syllable Articulation method, as shown in Eq. 3.6.1.b. For Bangla language, the Percentage Syllable Articulation was calculated using the following formula (Imam, Ahmed and Takahashi, 2009, p. 45).

$$PSA = 93k_ik_rk_nk_s\ (\%) \quad \text{.......................... (Eq. 3.6.1.b.)}$$

where, PSA = Percentage Syllable Articulation in percentage (%)

k_i = Reduction factor for average speech level

= 1, assuming speech intensity to be 70 dBA

k_r = Reduction factor for RT (Reverberation Time)

= -0.3179 ln(2*RT+1) + 0.9825, where RT = Reverberation Time calculated for that particular space

k_n = Reduction factor for Noise to Speech level ratio

= $-0.3243\ x^2 - 0.2124\ x + 1$, where x = SNR calculated for that particular space

k_s = Reduction factor for room shape

= 1

Table 4.3.3.a. shows the PSA values calculated for open office spaces located in the selected floors of each building. The numerical values derived for k_i, k_r, k_n and k_s which were required for calculating PSA values for open office spaces have been shown in Appendix 08.

Table 4.3.3.a. Mean PSA value of open office spaces in selected floors of each office building calculated during survey (Source: Author)

Building A		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
PSA value (%)	**PSA value** (%)	**PSA value** (%)
41.52	***40.60***	***40.03***
Mean PSA value of Building A (%) = ***40.80***		
Building B		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
PSA value (%)	**PSA value** (%)	**PSA value** (%)
36.13	***37.89***	***39.71***
Mean PSA value of Building B (%) = ***37.99***		
Building C		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
PSA value (%)	**PSA value (%)**	**PSA value** (%)
36.50	***35.52***	***36.66***
Mean PSA value of Building C (%) = ***36.23***		
Building D		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
PSA value (%)	**PSA value (%)**	**PSA value (%)**
38.61	***42.34***	***41.46***
Mean PSA value of Building D (%) = ***40.80***		
Mean of lower tier (%) = 38.19	**Mean of middle tier (%) = 39.09**	**Mean of upper tier (%) = 39.47**

The mean PSA value of open office spaces was found to be 39.04%, which is lower than the minimum acceptable PSA value of 75%. Mean speech intelligibility of open office spaces in this research was not satisfactory. Mean PSA values of open office spaces of each building ranged from 36.41 to 40.96%, which is lower than the minimum recommended value of 75%.

Mean PSA values for Building A, Building B, Building C and Building D were 40.80%, 37.99%, 36.23% and 40.80% respectively. It was observed that the average values for PSA in lower, middle and upper tiers were 38.19%, 39.09% and 39.47% respectively. These values are almost similar with extremely low deviations from each other, which indicates that the PSA values for open office spaces did not significantly change with their position in the observation floor of any specific tier.

4.3.4 Speech Privacy

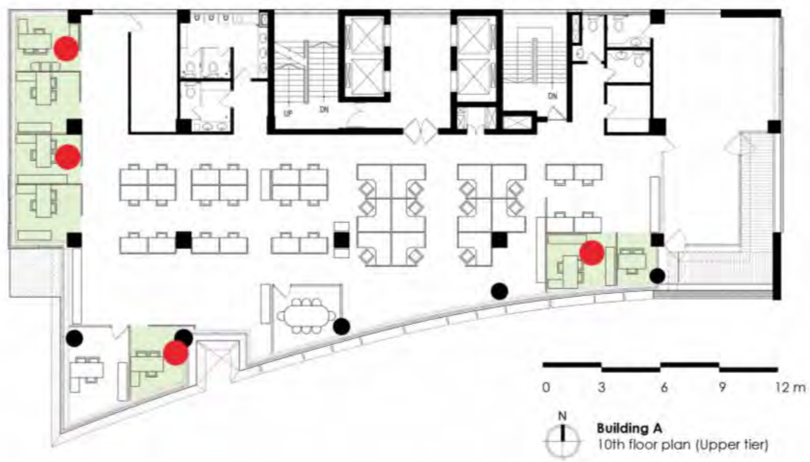
PSA values of each office space was used to determine the corresponding speech privacy of those spaces. Speech privacy is inversely proportional to speech intelligibility. A low value of PSA would suggest a high rating for speech privacy and low rating for speech intelligibility, and vice versa. For Bangla language, the PSA value must be 75% or higher in order for speech intelligibility of a particular space to be considered as satisfactory. On the other hand, PSA values lower than 75% would result in a satisfactory or higher rating for speech privacy.

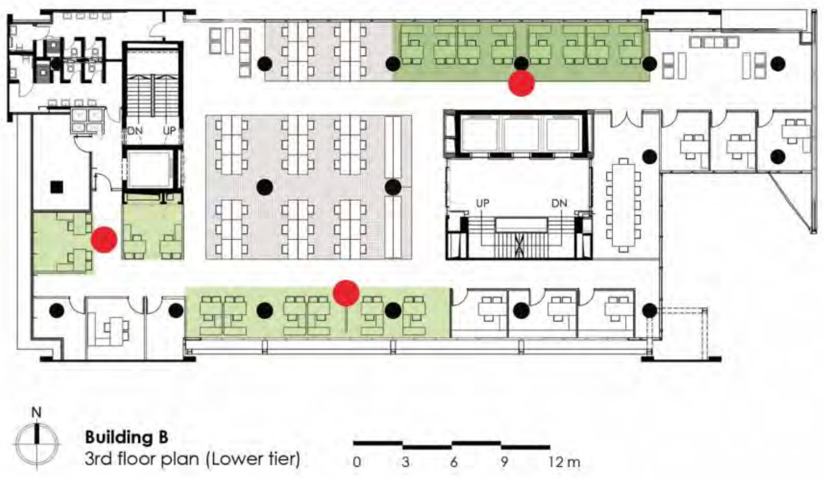
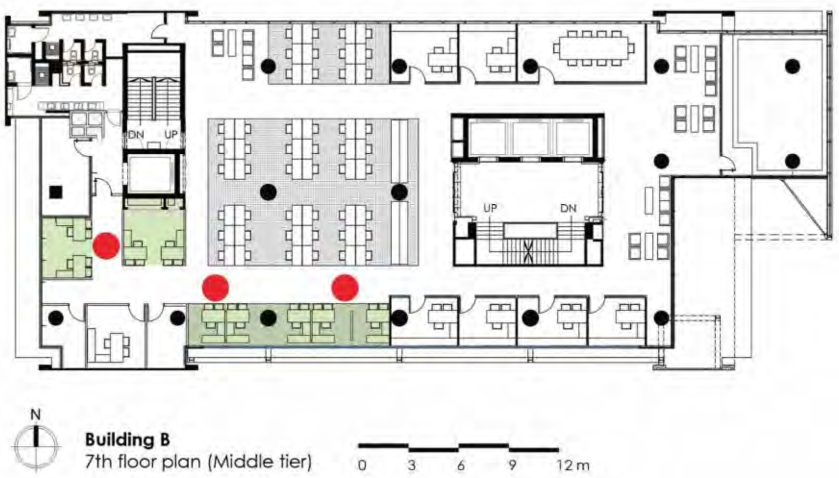
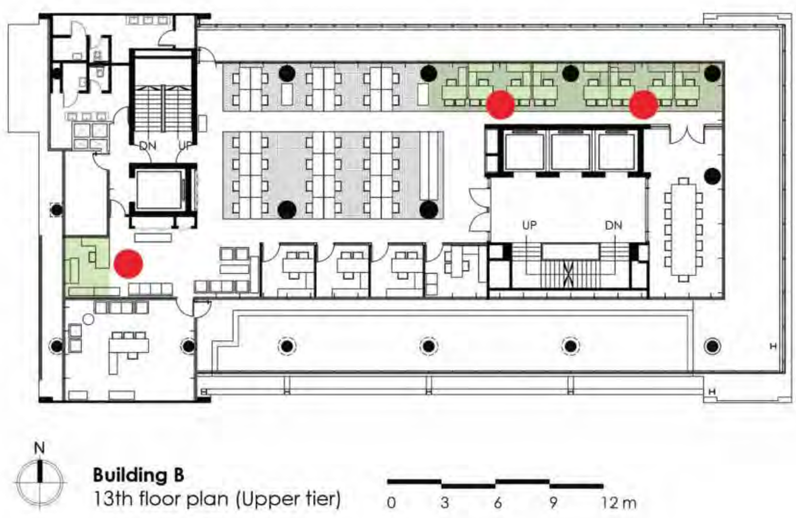
From Table 4.3.3.a, it can be seen that the mean PSA value of all the open office spaces was 39.04%, which is lower than 75%. This is lower than the minimum required value of 75% required for a satisfactory speech intelligibility. However, PSA values lower than 75% are required for a satisfactory speech privacy of a particular space. Therefore, the mean PSA value of 39.04% calculate to determine the average speech privacy rating in the open office spaces was acceptable and satisfactory. It was observed that the average values for PSA in lower, middle and upper tiers are almost similar with extremely low deviations from each other. Position of the open office spaces in lower, middle and upper tiers did not significantly affect speech privacy conditions.

4.4 Data Obtained from Objective Measurements in Semi-Private Office Spaces

The points where background noise level was measured in semi-private office spaces in the three selected floors from Building A, B, C and D are illustrated by red coloured dots in Table 4.4.a.

Table 4.4.a. Points/locations in semi-private office spaces where background noise level was measured (Source: Author)

Building A	
Lower tier	
Middle tier	
Upper tier	

Building B	
Lower tier	
Middle tier	
Upper tier	

Building C	
Lower tier	
Middle tier	
Upper tier	

Building D	
Lower tier	
Middle tier	
Upper tier	

4.4.1 Background noise levels

Table 4.4.1.a. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during off-peak hours (10.00 AM to 12.00 PM) in semi-private office spaces.

Table 4.4.1.a. Mean background noise level during off-peak hours in various floors of semi-private office spaces (Source: Author)

Mean background noise levels during off-peak hours (10.00 AM to 12.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	50.70 dBA	52.50 dBA	53.29 dBA	52.16 dBA
Building B	60.86 dBA	59.32 dBA	***61.99 dBA***	***60.72 dBA***
Building C	57.36 dBA	56.71 dBA	58.89 dBA	***57.65 dBA***
Building D	58.26 dBA	54.20 dBA	59.54 dBA	***57.33 dBA***
Mean of each tier	***56.80 dBA***	***55.68 dBA***	***58.43 dBA***	**Overall mean = 56.97 dBA**

The overall mean background noise level in semi-private office space of all the buildings during off-peak hours was found to be 56.97 dBA, which is greater than the allowable upper limit range of background noise level/ambient noise level of 43 dBA to 53 dBA (Table 3.6.1.a.). Building B, C and D had mean background noise levels greater than 53 dBA. All the tiers of the 4 buildings had a mean background noise level greater than 53 dBA. Highest recorded mean background noise level in semi-private office space during off-peak hours was in the upper tier of Building B.

Table 4.4.1.b. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during peak hours - 01 (12.00 PM to 2.00 PM) in semi-private office spaces.

Table 4.4.1.b. Mean background noise level during peak hours – 01 in various floors of semi-private office spaces (Source: Author)

Mean background noise levels during peak hours - 01 (12.00 PM to 2.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	52.04 dBA	52.42 dBA	55.56 dBA	***53.34 dBA***
Building B	60.06 dBA	57.06 dBA	57.44 dBA	***58.19 dBA***
Building C	60.56 dBA	61.78 dBA	61.41 dBA	***61.25 dBA***
Building D	***62.40 dBA***	52.42 dBA	55.32 dBA	***56.71 dBA***
Mean of each tier	***58.77 dBA***	***55.92 dBA***	***57.43 dBA***	**Overall mean = 57.37 dBA**

The overall mean background noise level in semi-private office space of all the buildings during peak hours - 01 was found to be 57.37 dBA, which is greater than the highest recommended upper limit range of 43 to 53 dBA. All the buildings had mean background noise levels greater than 53 dBA. All the tiers had a mean background noise level greater than 53 dBA. Highest recorded mean background noise level in semi-private office space during peak hours - 01 was in the lower tier of Building D.

Table 4.4.1.c. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during peak hours - 02 (4.00 PM to 6.00 PM) in semi-private office spaces.

Table 4.4.1.c. Mean background noise level during peak hours – 02 in various floors of semi-private office spaces (Source: Author)

Mean background noise levels during peak hours - 02 (4.00 PM to 6.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	52.34 dBA	51.31 dBA	54.40 dBA	52.68 dBA
Building B	***66.89 dBA***	58.18 dBA	65.78 dBA	***63.62 dBA***
Building C	60.08 dBA	62.27 dBA	60.40 dBA	***60.92 dBA***
Building D	55.33 dBA	61.27 dBA	58.63 dBA	***58.41 dBA***
Mean of each tier	***58.66 dBA***	***58.26 dBA***	***59.80 dBA***	**Overall mean = 58.91 dBA**

The overall mean background noise level in semi-private office space of all the buildings during peak hours - 02 was found to be 58.91 dBA, which is greater than the highest recommended limit range of 43 to 53 dBA. Building B, C and D had mean background noise levels greater than 53 dBA. All the tiers had a mean background noise level greater than 53 dBA. Highest recorded mean background noise level in semi-private office space during peak hours -02 was in the lower tier of Building B.

The overall mean background noise level in semi-private office space of all the buildings during typical working hours (10.00 AM to 6.00 PM) was 57.75 dBA, which is greater than the highest recommended background noise range limit of 43 to 53 dBA for semi-private office spaces. The highest mean background noise level was found during peak hours – 02 (58.91 dBA). Mean background noise level during typical working hours in upper tiers was found to be the highest. Mean background noise level in semi-private office space during typical working hours was the highest in Building B (Table 4.4.1.d.).

Table 4.4.1.d. Mean background noise levels during typical working hours in semi-private spaces (Source: Author)

Mean background noise levels during working hours (10.00 AM to 6.00 PM)			
Building A	**Building B**	**Building C**	**Building D**
52.73 dBA	***60.84 dBA***	59.94 dBA	57.48 dBA
Lower tiers	**Middle tiers**	**Upper tiers**	
58.08 dBA	56.62 dBA	***58.55 dBA***	
Overall mean = 57.75 dBA			

4.4.2 Reverberation time

In all buildings, semi-private office spaces were not enclosed by floor to ceiling height walls or partitions. They shared the same enclosed space as that of open office. Reverberation time of open and semi-private spaces were calculated together and was equal for both spaces. The mean reverberation time of semi-private offices spaces in all buildings was found to be 0.70 s (Table 4.3.2.a.). This value lies between the recommended maximum limit range of 0.5 to 0.8 s (Table 3.6.1.a.). Position of the semi-private office spaces in lower, middle and upper tiers did not significantly affect reverberation time.

4.4.3 Speech Intelligibility

PSA values determined for open office spaces would be the same for semi-private office spaces, because these spaces share the same reverberation time, as mentioned in chapter 4.4.2. From Table 4.3.3.a, the mean PSA value for semi-private office spaces in all the buildings was 39.04%, which is lower than the minimum recommended value of 75% (Table 3.6.1.a.). Hence, speech intelligibility in semi-private office spaces was found to be unsatisfactory. Position of the semi-private office spaces in lower, middle and upper tiers did not significantly affect values for PSA, hence speech intelligibility conditions.

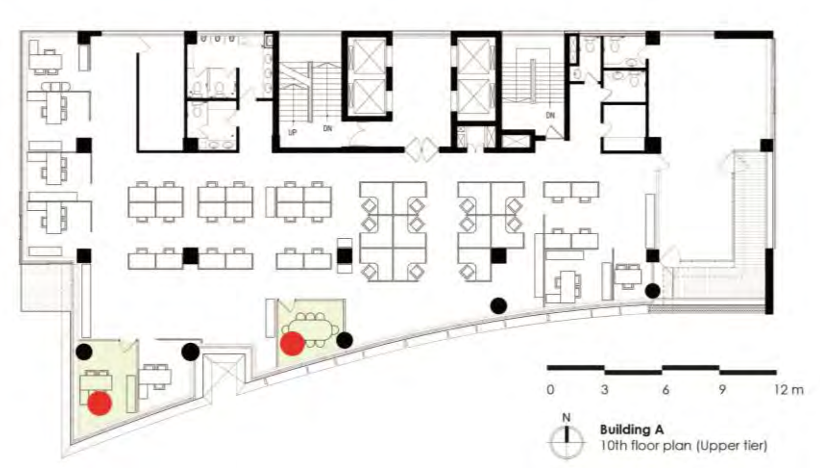
4.4.4 Speech Privacy

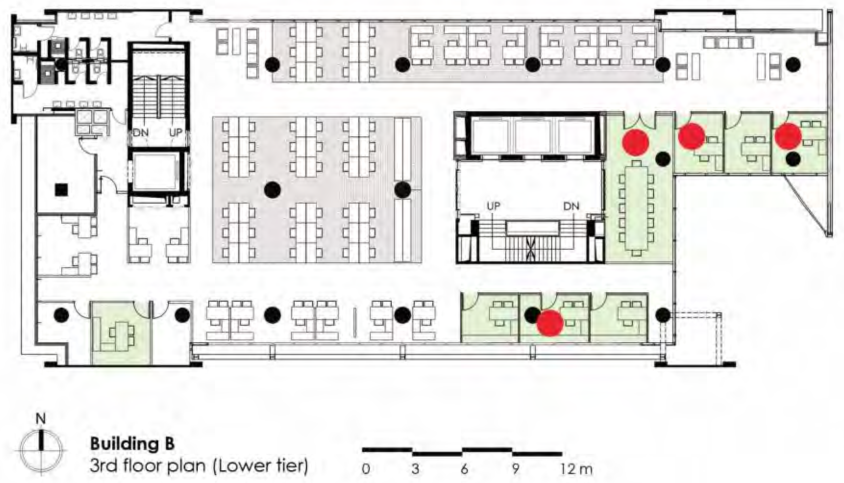
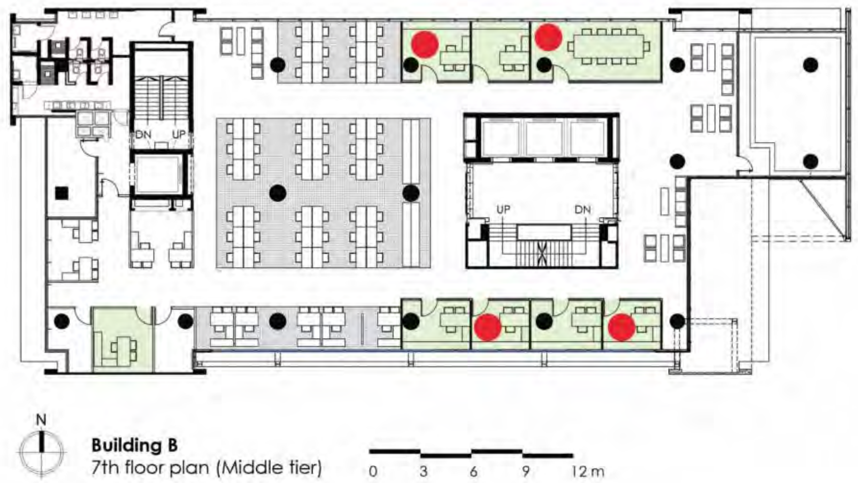
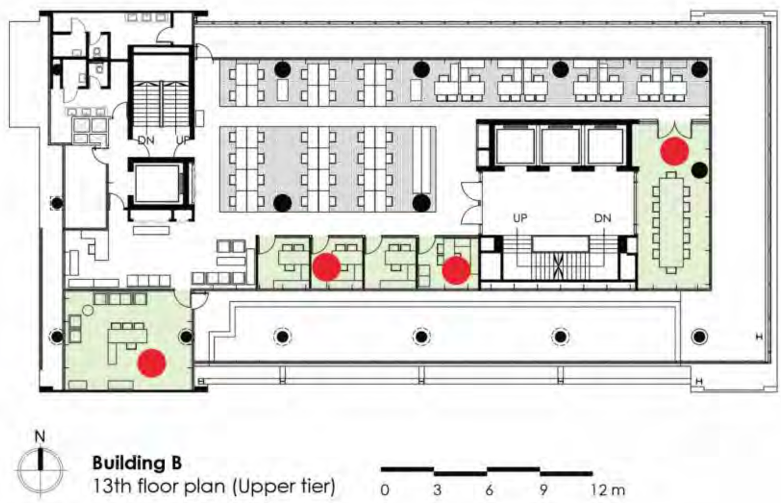
Mean PSA value for semi-private office spaces in all the buildings was 39.04%, which is lower than the maximum recommended value of 75% in the case of speech privacy (Table 3.6.1.a.). Mean speech privacy in the semi-private office spaces was found to be satisfactory. Position of the semi-private office spaces in lower, middle and upper tiers did not significantly affect speech privacy conditions.

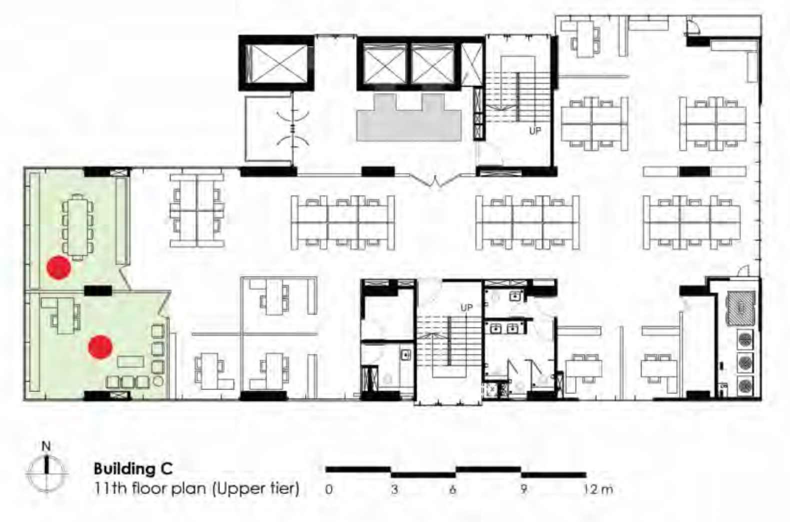
4.5 Data Obtained from Objective Measurements in Private Office Spaces

The points where background noise level was measured in private office spaces and meeting rooms in each of the three selected floors are illustrated by red coloured dots in Table 4.5.a.

Table 4.5.a. Points/locations in private office spaces where background noise level was measured (Source: Author)

Building A	
Lower tier	
Middle tier	
Upper tier	

Building B	
Lower tier	
Middle tier	
Upper tier	

Building C	
Lower tier	
Middle tier	
Upper tier	

Building D	
Lower tier	
Middle tier	
Upper tier	

4.5.1 Background noise levels

Table 4.5.1.a. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during off peak hours (10.00 AM to 12.00 PM) in private office spaces (including meeting rooms).

Table 4.5.1.a. Mean background noise level during off peak hours in various floors of private office spaces (Source: Author)

Mean background noise levels during off peak hours (10.00 AM to 12.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	47.97 dBA	48.00 dBA	48.69 dBA	***48.22 dBA***
Building B	48.53 dBA	48.61 dBA	***57.90 dBA***	***51.68 dBA***
Building C	51.98 dBA	50.41 dBA	49.28 dBA	***50.56 dBA***
Building D	50.03 dBA	53.04 dBA	52.36 dBA	***51.81 dBA***
Mean of each tier	***49.63 dBA***	***50.02 dBA***	***52.06 dBA***	**Overall mean = 50.57 dBA**

The overall mean background noise level in private office space of all the buildings during off peak hours was found to be 50.57 dBA, which is which is greater than the allowable upper limit range of background noise level/ambient noise level of 38 dBA to 48 dBA (Table 3.6.1.a.). All buildings had mean background noise levels greater than 48 dBA. All the tiers of the 4 buildings had a mean background noise level greater than 48 dBA. Highest recorded mean background noise level in private office space during off peak hours was in the upper tier of Building B.

Table 4.5.1.b. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during peak hours - 01 (12.00 PM to 2.00 PM) in private office spaces.

Table 4.5.1.b. Mean background noise level during peak hours – 01 in various floors of private office spaces (Source: Author)

Mean background noise levels during peak hours - 01 (12.00 PM to 2.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	45.05 dBA	45.65 dBA	47.91 dBA	46.20 dBA
Building B	50.27 dBA	47.11 dBA	***63.83 dBA***	***53.74 dBA***
Building C	46.72 dBA	46.42 dBA	46.21 dBA	46.45 dBA
Building D	53.21 dBA	45.77 dBA	48.39 dBA	***49.12 dBA***
Mean of each tier	***48.81 dBA***	46.24 dBA	***51.59 dBA***	**Overall mean = 48.88 dBA**

The overall mean background noise level in private office space of all the buildings during peak hours - 01 was found to be 48.88 dBA, which is slightly greater than the highest recommended limit range of 38 to 48 dBA. Building B and D had mean background noise levels greater than 48 dBA. Lower and upper tiers had a mean background noise level greater than 48 dBA. Highest recorded mean background noise level in private office space during peak hours - 01 was in the upper tier of Building B.

Table 4.5.1.c. shows the mean background noise level in each selected floor, mean background noise level in each building and overall mean background noise level in all the 4 buildings during peak hours - 02 (4.00 PM to 6.00 PM) in private office spaces.

Table 4.5.1.c. Mean background noise level during peak hours – 02 in various floors of private office spaces (Source: Author)

Mean background noise levels during peak hours - 02 (4.00 PM to 6.00 PM)				
Building	**Lower tier**	**Middle tier**	**Upper tier**	**Mean of each building**
Building A	45.63 dBA	46.19 dBA	50.20 dBA	47.34 dBA
Building B	***63.07 dBA***	50.29 dBA	58.66 dBA	***57.34 dBA***
Building C	47.09 dBA	46.18 dBA	46.30 dBA	46.52 dBA
Building D	49.61 dBA	53.81 dBA	53.76 dBA	***52.39 dBA***
Mean of each tier	***51.35 dBA***	***49.12 dBA***	***52.23 dBA***	**Overall mean = 50.90 dBA**

The overall mean background noise level in private office space of all the buildings during peak hours - 02 was found to be 50.90 dBA, which is greater than the highest recommended limit range of 38 to 48 dBA. Building B and D had mean background noise levels greater than 48 dBA. All the tiers had a mean background noise level greater than 48 dBA. Highest recorded mean background noise level in private office space during peak hours - 02 was in the lower tier of Building B.

The overall mean background noise level in private office space of all the buildings during typical working hours (10.00 AM to 6.00 PM) was 50.12 dBA, which is greater than the highest recommended background noise limit range of 38 to 48 dBA for private office spaces. The highest mean background noise level was found during peak hours – 02 (50.90 dBA). Mean background noise level during typical working hours in upper tiers was found to be the highest. Mean background noise level in private office space during typical working hours was the highest in Building B (Table 4.5.1.d.).

Table 4.5.1.d. Mean background noise levels during typical working hours in private office spaces (Source: Author)

Mean background noise levels during working hours (10.00 am to 6.00 pm)			
Building A	**Building B**	**Building C**	**Building D**
47.25 dBA	***54.25 dBA***	47.84 dBA	51.12 dBA

Lower tiers	**Middle tiers**	**Upper tiers**
49.93 dBA	48.46 dBA	***51.96 dBA***
Overall mean = 50.12 dBA		

4.5.2 Reverberation time

Tables A7.5.1 to A7.8.3 of Appendix 07 shows the detailed calculation of total absorption for private office spaces and meeting rooms. Table 4.5.2.a. shows the mean reverberation time calculated in private office spaces and meeting rooms in selected floors of the buildings.

Table 4.5.2.a. Mean reverberation time of private office spaces in selected floors of each office building calculated during survey (Source: Author)

Building A		
Lower tier	**Middle tier**	**Upper tier**
Mean RT_{60} (s)	**Mean RT_{60}** (s)	**Mean RT_{60}** (s)
1.13	***0.98***	***1.10***
Mean RT of Building A in seconds (s) **=** ***1.06***		
Building B		
Lower tier	**Middle tier**	**Upper tier**
Mean RT_{60} (s)	**Mean RT_{60}** (s)	**Mean RT_{60}** (s)
1.16	***1.03***	***1.20***
Mean RT of Building B in seconds (s) **=** ***1.13***		
Building C		
Lower tier	**Middle tier**	**Upper tier**
Mean RT_{60} (s)	**Mean RT_{60}** (s)	**Mean RT_{60}** (s)
0.82	0.79	***1.32***
Mean RT of Building C in seconds (s) **=** ***0.98***		
Building D		
Lower tier	**Middle tier**	**Upper tier**
Mean RT_{60} (s)	**Mean RT_{60}** (s)	**Mean RT_{60}** (s)
0.62	0.62	0.60
Mean RT of Building D in seconds (s) = 0.61		
Mean of lower tier (s) = ***0.93***	**Mean of middle tier (s) =** ***0.86***	**Mean of upper tier (s) =** ***1.06***

From the data in Table 4.5.2.a., it can be seen that reverberation time in private office spaces and meeting rooms of all floors lie between the range 0.61 s to 1.13 s. Building A and Building B had reverberation time of 1.06 s and 1.13 s respectively, which is greater than the maximum recommended reverberation time limit range of 0.5 to 0.8 s (Table 3.6.1.a.). The mean reverberation time of all buildings was found to be 0.95 s, which is slightly greater the maximum recommended limit range. Reverberation time of private office spaces in this research was found to be unsatisfactory. Mean RT_{60} values for Building A, Building B, Building C and Building D were 1.06 s, 1.13 s, 0.98 s and 0.61 s respectively. It was observed that the average values for RT_{60} in lower, middle and upper tiers were 0.93 s, 0.86 s and 1.06 s respectively. These values are almost similar with extremely low deviations from each other, which indicates that the reverberation time for private office spaces did not significantly change with their position in the observation floor of any specific tier. High value for reverberation time calculated in private office spaces may have been due to lack of noise absorptive materials and objects present in the workstations, as shown in the calculation tables of Appendix 07.

4.5.3 Speech Intelligibility

Table 4.5.3.a. shows the mean PSA values calculated for private office spaces and meeting rooms located in the selected floors of each building. The detailed calculations have been shown in Appendix 08. The numerical values derived for k_i, k_r, k_n and k_s which were required for calculating PSA values have been shown in Appendix 08.

Table 4.5.3.a. Mean PSA value of private office spaces in selected floors of each office building calculated during survey (Source: Author)

Building A		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
Mean PSA value (%)	**Mean PSA value (%)**	**Mean PSA value (%)**
40.54	***42.45***	***39.51***
Mean PSA value of Building A (%) = *40.83*		
Building B		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
Mean PSA value (%)	**Mean PSA value (%)**	**Mean PSA value (%)**
36.04	***40.66***	***32.23***
Mean PSA value of Building B (%) = *36.31*		

Building C		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
Mean PSA value (%)	**Mean PSA value (%)**	**Mean PSA value (%)**
43.69	***44.59***	***37.71***
Mean PSA value of Building C (%) = *42.00*		
Building D		
Lower tier floor	**Middle tier floor**	**Upper tier floor**
Mean PSA value (%)	**Mean PSA value (%)**	**Mean PSA value (%)**
45.43	***45.60***	***45.47***
Mean PSA value of Building D (%) = *45.50*		
Mean of lower tier (%) = 41.43	**Mean of middle tier (%) = 43.33**	**Mean of upper tier (%) = 38.73**

The mean PSA value of private office spaces in the office buildings was found to be 41.16%, which is lower than the minimum acceptable PSA value of 75% (Table 3.6.1.a.). Mean speech intelligibility in the private office spaces in this research was not satisfactory. Mean PSA values in each building ranged from 36.31 to 45.50 %, which is lower than the minimum recommended value of 75%. Mean PSA values for Building A, Building B, Building C and Building D were 40.83%, 36.31%, 42.00% and 45.50% respectively. It was observed that the average values for PSA in lower, middle and upper tiers were 41.43%, 43.33% and 38.73% respectively. These values are almost similar with extremely low deviations from each other, which indicates that the PSA values for private office spaces did not significantly change with their position in the observation floor of any specific tier.

4.5.4 Speech Privacy

Mean PSA value for private office spaces in all the buildings was 41.16%, which is lower than the maximum recommended value of 75% in the case of speech privacy (Table 3.6.1.a.). Mean speech privacy was found to be satisfactory. Position of private office spaces in lower, middle and upper tiers did not significantly affect speech privacy conditions.

Low PSA values which were calculated for open, semi-private and private office spaces may have resulted due to higher ratio of office space volume to total absorption of the office space, as shown in the calculations of Appendix 07 of this research. In addition, these spaces had high values for k_r coefficient, as shown in Appendix 08.

4.6 Human Flow Estimation

Fig. 4.6.a. and 4.6.b. illustrates the average occupancy in open, semi-private and private office spaces in the 4 buildings during typical office hours of 10.00 AM to 6.00 PM. A walk-through count method was performed to determine the number of occupants present in each space at a given time.

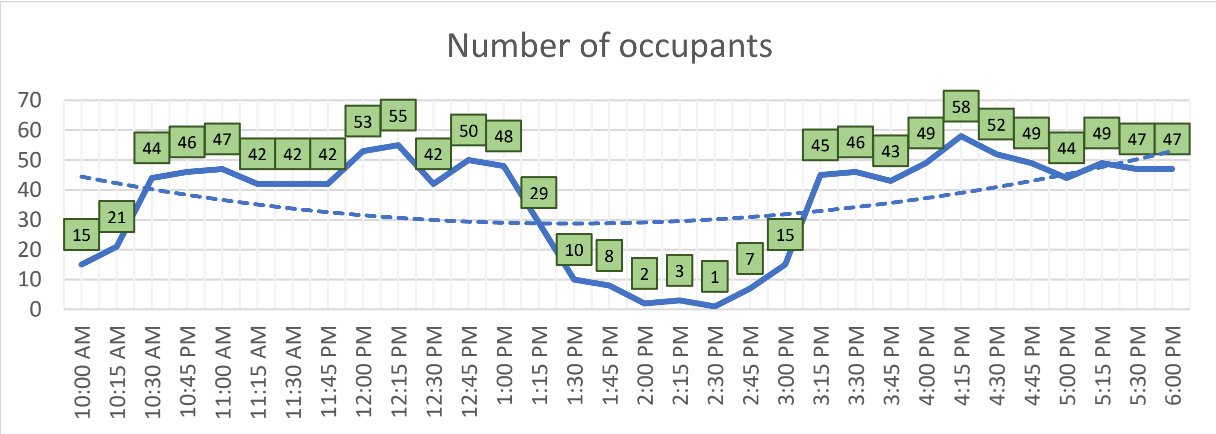


Fig. 4.6.a. Average number of occupants in the whole office floor during working hours (Source: Author)

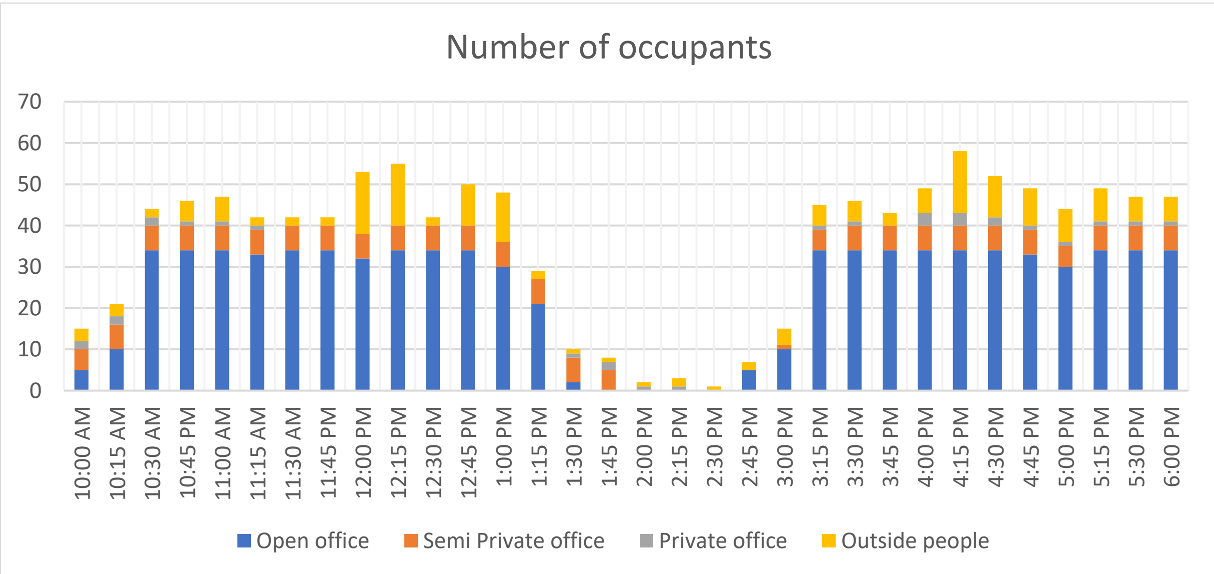


Fig. 4.6.b. Average number of occupants in open, semi-private and private office spaces during working hours (Source: Author)

From the two figures above, it is seen that on average, 34 employees occupied the open office spaces, 6 were in semi-private and 3 were in private office spaces. Open office spaces had full occupancy by 10.30 AM, semi-private had full occupancy by 10.15 AM and private office space had full occupancy during 4.00 PM. In open and semi-private office spaces, full occupancy was observed throughout office hours (i.e., till 6.00 PM). Between 10.00 PM and 6.00 PM, full occupancy was not maintained at certain times due to miscellaneous activities such as washroom breaks, tea breaks, visiting office spaces of other colleagues etc. Typical lunch break hours were during 2.00 PM to 3.00 PM. During 2.00 PM to 2.45 PM, no employees were usually present in open and semi-private office spaces. During 1.00 PM to 1.45 PM and 2.45 PM to 3.00 PM, employees generally took turns going to their lunch or prayer breaks, so full occupancy in these office spaces were not maintained during that time period. Private office spaces had on average 67% occupancy during 10.00 AM to 10.30 AM. Occupancy rate varied significantly at all instances during 10.00 AM to 6.00 PM in private office spaces. Most private office employees were involved in field work and meetings taking place outside the office. Their work category was flexible, and did not require adhering to strict working hours at their desks.

Apart from open, semi-private and private office employees, other individuals also were included in the human flow estimation, who did not have any personal desk or cubicle. In each selected floor, 2 to 3 ‘peons’ took on the role of store keeper, clerk or cook. They were present throughout the whole working period, and at least one of them was always present at any given time period. Work in all office spaces involved communication with clients and outside vendors in person as well as over phones. These individuals usually visited the office spaces from 10.45 AM to 1.00 PM and 3.00 PM to 6.00 PM, with the highest number of clients or vendors visiting during 12.00 PM to 1.00 PM and 4.00 PM to 5.15 PM (Fig. 4.6.b.).

During typical working hours in the surveyed buildings, highest number of occupants was observed during 12.00 PM to 1.00 PM and from 4.00 PM to 6.00 PM. This implies that excessive background noise levels may have been affected by increase in number of occupants, and consequently background activities, during certain time periods.

4.7 Statistical Analysis

Table 4.7.a. shows the summary of main results obtained from objective measurements in open, semi-private and private office spaces in selected floors of the 4 green rated office buildings.

Table 4.7.a. Summary of main results of objective measurements in the selected green rated office buildings (Source: Author)

Quantity	Location	Mean value measured	Recommended value	Percent deviation from upper limit (in %)
Background Noise level (dBA)	Open office spaces	59.40	Should not exceed 48 – 58 dBA	+ 2.41
	Semi-private office spaces	57.75	Should not exceed 43 – 53 dBA	+ 8.96
	Private office spaces (including meeting rooms)	50.12	Should not exceed 38 – 48 dBA	+ 4.42
Reverberation Time, RT_{60} (s)	Open office spaces	0.70	Should not exceed 0.5 – 0.8 s	-
	Semi-private office spaces	0.70	Should not exceed 0.5 – 0.8 s	-
	Private office spaces (including meeting rooms)	0.95	Should not exceed 0.5 – 0.8 s	+18.00
Speech Intelligibility, determined by PSA (%)	Open office spaces	39.04	Should be more than 75%	- 47.95
	Semi-private office spaces	39.04	Should be more than 75%	- 47.95
	Private office spaces (including meeting rooms)	41.16	Should be more than 75%	- 45.12
Speech Privacy, determined by PSA (%)	Open office spaces	39.04	Should be less than 75%	- 47.95
	Semi-private office spaces	39.04	Should be less than 75%	- 47.95
	Private office spaces (including meeting rooms)	41.16	Should be less than 75%	- 45.12

In all office spaces, existing mean background noise level was higher than the recommended values. Deviation from recommended value was greatest in the case of semi-private spaces, with the existing mean background noise level being 8.96% greater than the recommended upper limit range. The deviations were slightly less in open offices (2.41%) and private office spaces (4.42%). Mean reverberation time was found to be satisfactory in all office spaces except for private office spaces.

Speech intelligibility was unsatisfactory in the office spaces. The deviation from recommended value was lowest in private office spaces, with the existing mean PSA value being 45.12% less than the minimum recommended value. Speech privacy in all office spaces was satisfactory. The deviation from recommended value was highest in open and semi-private office spaces, with the existing mean PSA value being 47.95% less than the maximum recommended value. Open office spaces and semi-private office spaces had greater mean speech privacy and lower mean speech intelligibility compared to private office spaces.

4.7.1 Justification of sample sizes of locations of background noise levels

For researches following a 95% confidence interval, ± 5 of confidence interval may be assumed for acceptable accuracy. To justify the sample sizes of locations or points where background noise levels were measured in this research, the derived mean, Standard Deviation (SD), Standard Error and 95% Confidence Interval (CI) was calculated as shown in Appendix 06. The 95% CI ranges for mean values of background noise level in selected floors of all buildings were less than ± 5. In that context, the sample size for locations or points where background noise levels were measured in this research conforms to the acceptable precision. The corresponding values of PSA calculated for each respective office space also conforms to the acceptable precision.

4.7.2 Analysis of variance

For this research, it was initially considered that levels of deviation in the four parameters of acoustical performance in the four green rated office buildings was not satisfactory (alternative hypothesis H_1). The null hypothesis (H_0) of this research was that no levels of deviation in background noise level, reverberation time, speech intelligibility and speech privacy from standards and recommendations existed in acoustical performance of the green-rated office buildings surveyed in this thesis. From the initial findings of chapter 4.2, 4.3, 4.4 and 4.5, It was established that levels of deviation from standards and recommendations existed in the acoustical performance of the four selected green-rated office buildings. To check whether any statistically significant differences existed between mean background noise level and tier position or office hours, a one-way Analysis of Variance (ANOVA) was conducted. Fig. 4.7.2.a., 4.7.2.b. and 4.7.2.c. illustrate the mean background noise level measured in the various office spaces of each selected building according to lower, middle and upper tiers.

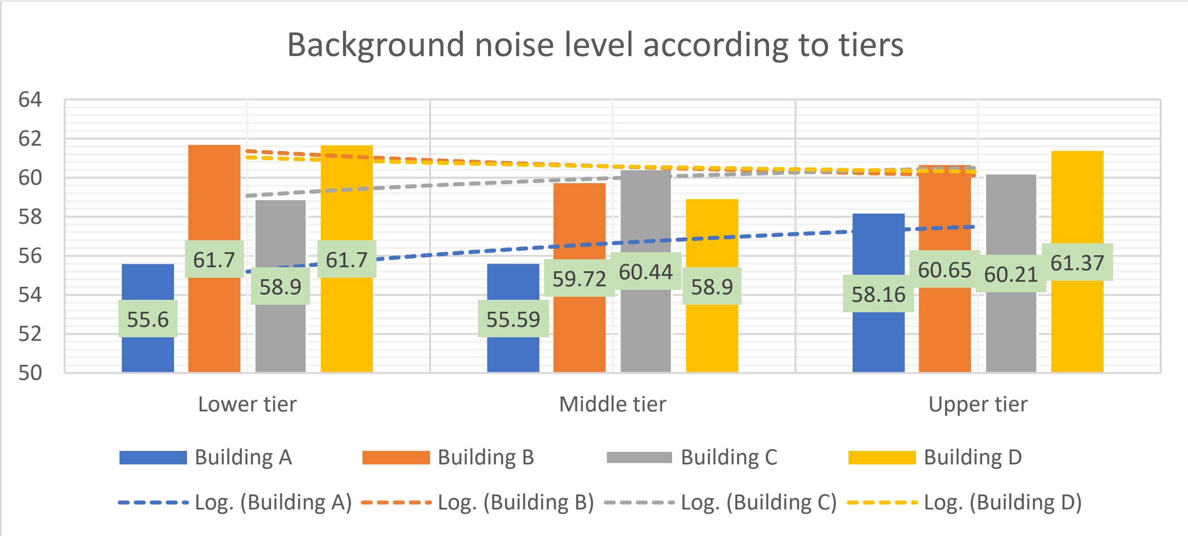


Fig. 4.7.2.a. Mean background noise levels in open office spaces measured according to tiers (Source: Author)

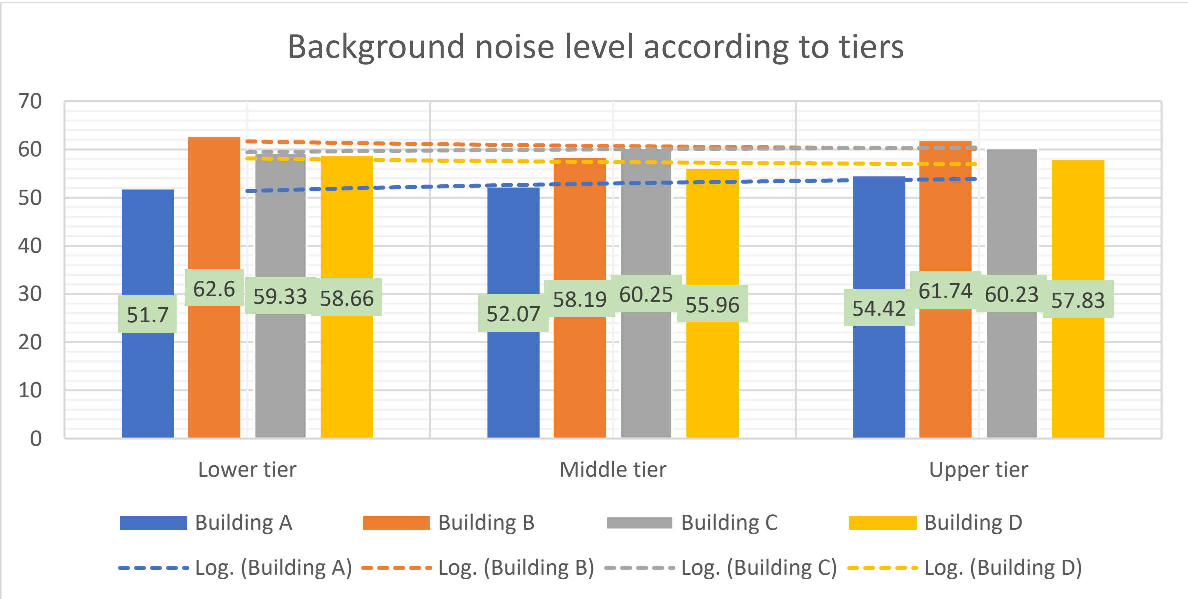


Fig. 4.7.2.b. Mean background noise levels in semi-private office spaces measured according to tiers (Source: Author)

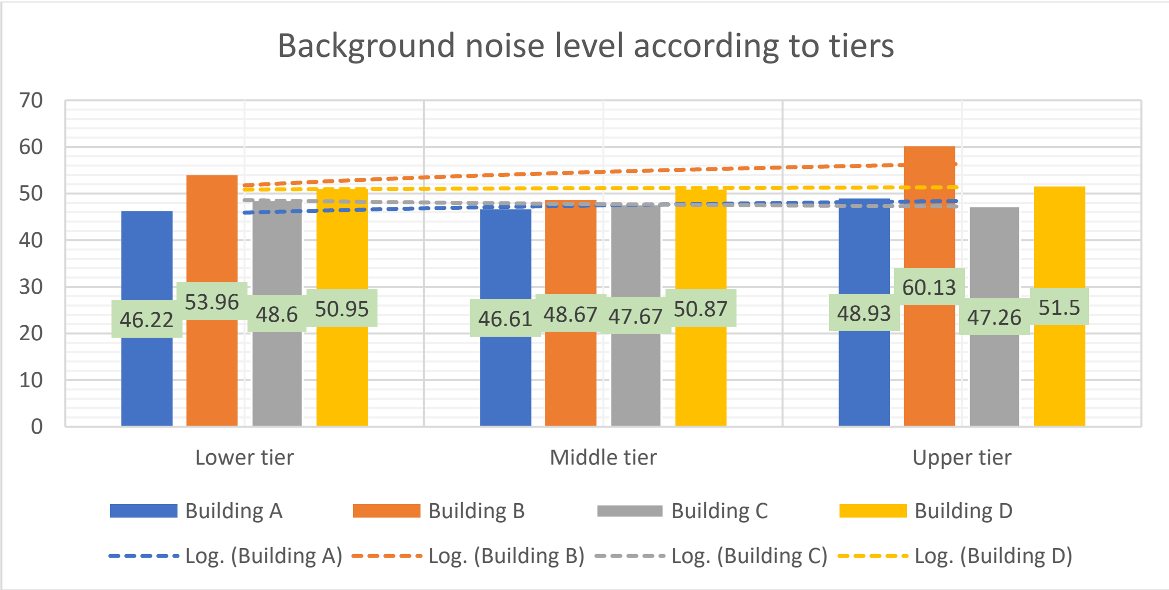


Fig. 4.7.2.c. Mean background noise levels in private office spaces measured according to tiers (Source: Author)

The ANOVA for mean background noise levels according to tier position in open, semi-private and private office spaces are summarized in the Table 4.7.2.a., 4.7.2.b. and 4.7.2.c. From the results in these Tables, it can be seen that for each office space, F value is less than F critical value. Therefore, the null hypothesis is not rejected and it could be stated that there are no statistically significant differences between mean background noise levels in open, semi-private or private office spaces and their locations in each building according to tier height. P-value was found to be greater than 0.05 in each case. Thus, there is not much strong evidence to reject this specific null hypothesis, and therefore it could be concluded that mean background noise levels for the office spaces did not vary significantly with vertical height.

Table 4.7.2.a. ANOVA for mean background noise levels in open office spaces according to tiers (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.142691	2	2.071345	0.418228	0.670374	4.256495
Within Groups	44.57401	9	4.952668			
Total	48.7167	11				

Table 4.7.2.b. ANOVA for mean background noise levels in semi-private office spaces according to tiers (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.112506	2	4.056253	0.279783	0.762289	4.256495
Within Groups	130.4809	9	14.49788			
Total	138.5934	11				

Table 4.7.2.c. ANOVA for mean background noise levels in private office spaces according to tiers (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24.7164	2	12.3582	0.789379	0.483209	4.256495
Within Groups	140.9004	9	15.6556			
Total	165.6168	11				

Fig. 4.7.2.d., 4.7.2.e. and 4.7.2.f. illustrate the mean background noise level measured in open, semi-private and private office spaces of each selected building according to off-peak hours (10.00 AM to 12.00 PM), peak hours – 01 (12.00 PM to 2.00 PM) and peak hours – 02 (4.00 PM to 6.00 PM).

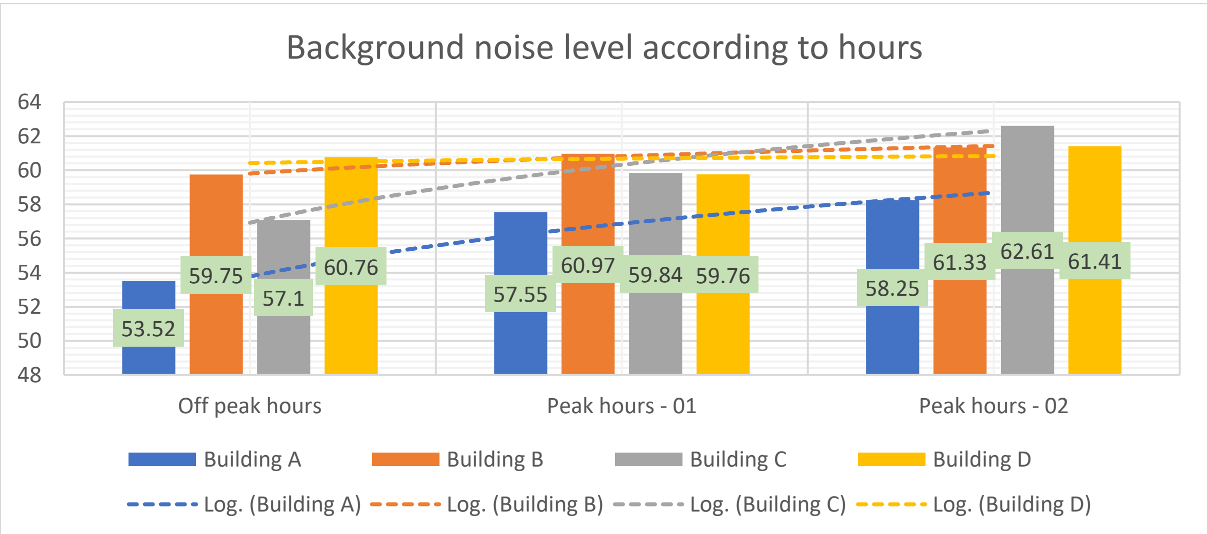


Fig. 4.7.2.d. Mean background noise levels in open office spaces measured according to office hours (Source: Author)

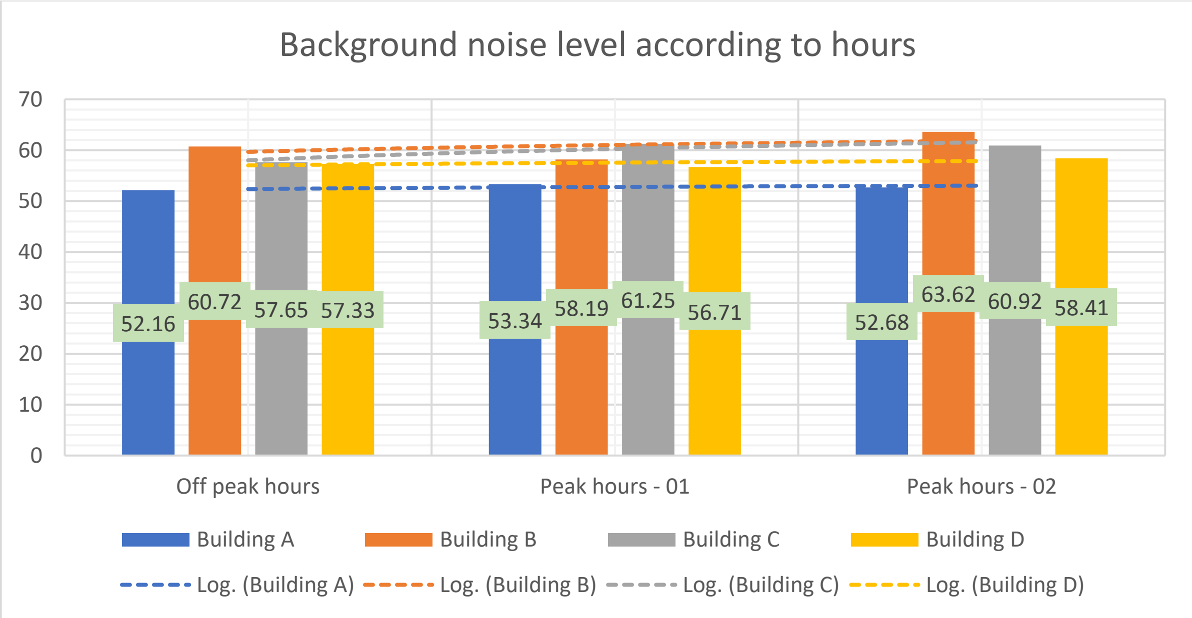


Fig. 4.7.2.e. Mean background noise levels in semi-private office spaces measured according to office hours (Source: Author)

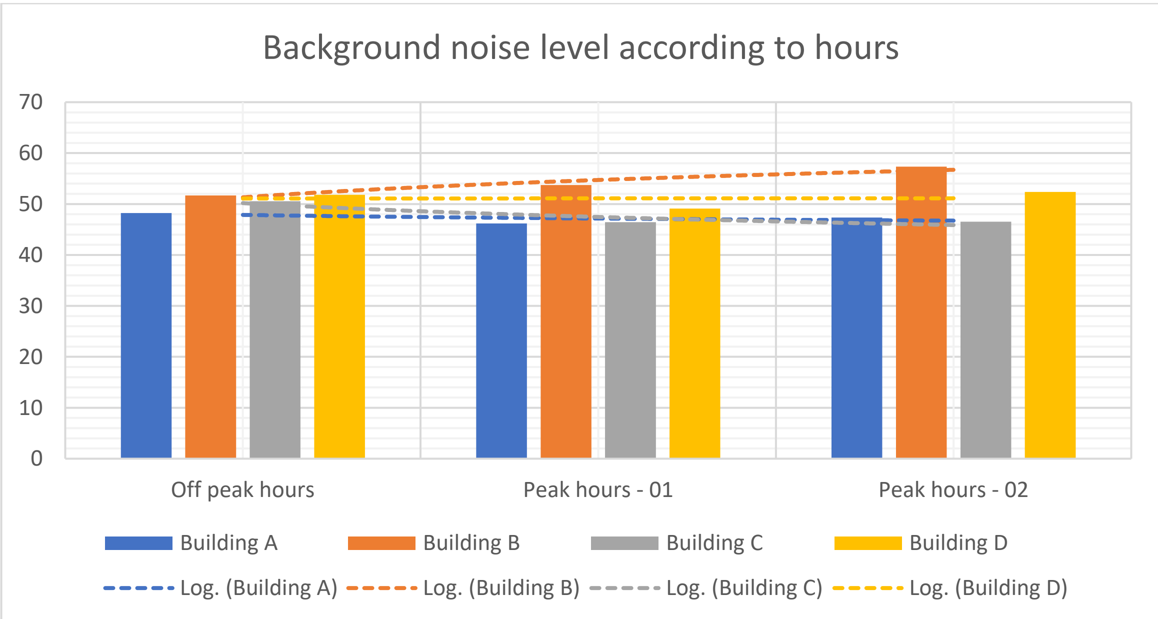


Fig. 4.7.2.f. Mean background noise levels in private office spaces measured according to office hours (Source: Author)

The ANOVA for mean background noise levels according to office hours is summarized in Table 4.7.2.d., 4.7.2.e. and 4.7.2.f.

Table 4.7.2.d. ANOVA for mean background noise levels in open office spaces according to office hours (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.53262	2	9.766308	1.834781	0.214617	4.256495
Within Groups	47.90588	9	5.322875			
Total	67.43849	11				

Table 4.7.2.e. ANOVA for mean background noise levels in semi-private office spaces according to office hours (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.394117	2	4.197058	0.278811	0.762987	4.256495
Within Groups	135.4809	9	15.05343			
Total	143.875	11				

Table 4.7.2.f. ANOVA for mean background noise levels in private office spaces according to office hours (Source: Author)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.393867	2	4.696933	0.350493	0.713543	4.256495
Within Groups	120.6084	9	13.40094			
Total	130.0023	11				

Table 4.7.2.d., 4.7.2.e. and 4.7.2.f. show that F value is lower than F critical value for each case. Therefore, the null hypothesis is not rejected and it can be stated that there are no statistically significant differences between mean background noise levels in open, semi-private and private office spaces and different office hours. P-value is greater than 0.05 in each case. Thus, there is not much strong evidence against this specific null hypothesis either, and

it can be concluded that mean background noise level did not vary significantly during specific office hours.

Results of ANOVA testing conclude that the deviations of background noise levels in open, semi-private and private office spaces from standards and recommendation is not considerably affected by the vertical location of office spaces in the building, or the peak and off-peak working hours.

4.8 Data Obtained from Subjective Qualitative Survey

Subjective qualitative survey was carried out on selected participants to determine the perception on noise, speech privacy and speech intelligibility of open, semi-private and private office employees. Appendix 02 contains the occupant perception questionnaire followed in this research. Fig. 4.8.a. shows the level of satisfaction with work environment among open, semi-private and private office spaces. Most of the participants were “moderately” to “strongly” satisfied with their work environment. 40% of the participants from private office space and 48% of open office participants were “strongly” satisfied with their work environment, while 39% of semi-private participants were “moderately” satisfied with their work environment.

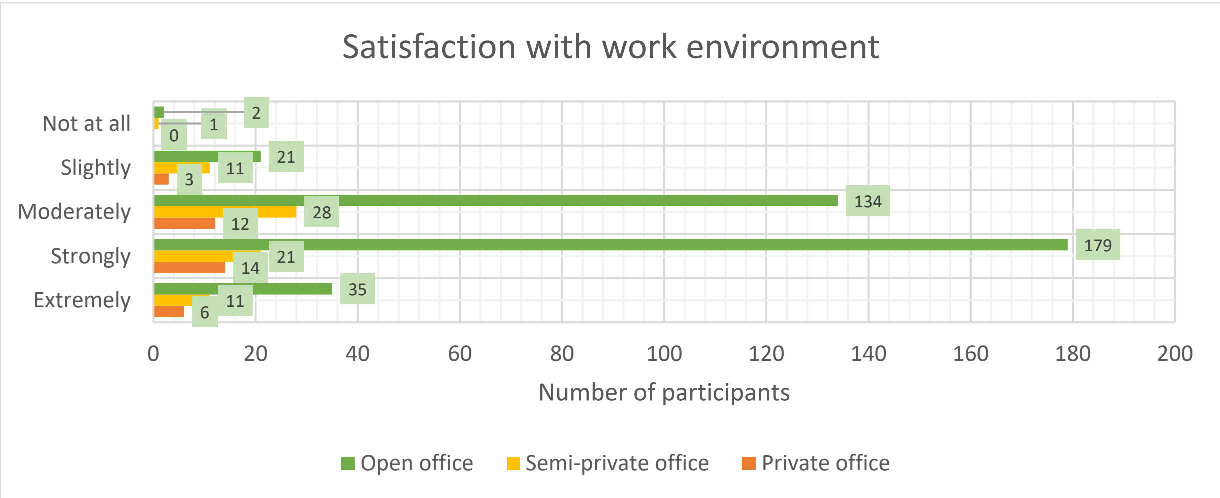


Fig. 4.8.a. Level of satisfaction with overall work environment among open, semi-private and private office employees (Source: Author)

4.8.1 Observations on background noise

Almost half of all the survey participants in open office spaces stated that they were moderately satisfied with the level of background noise control measures taken in their workplace, while around a quarter of the participants expressed that they were strongly satisfied (Fig. 4.8.1.a.). 40% of private office participants strongly agreed that level of noise control measures taken in their workspace was satisfactory. More than two-thirds of semi-private office participants marked "slightly" and "moderately" when asked to give their opinion on their level of satisfaction with background noise control measures.

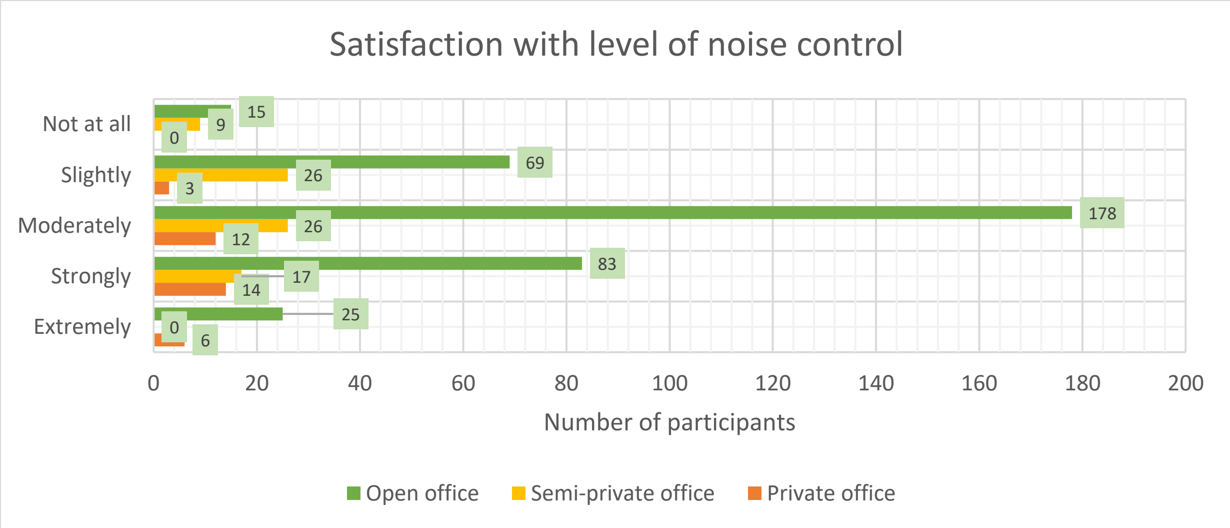


Fig. 4.8.1.a. Level of satisfaction with background noise control measures (Source: Author)

Fig. 4.8.1.b. illustrates how often participants believed that high background noise levels persisted in their workplaces, and increased with background activity for e.g., number of occupants, increased load of work, increased movement and conversation of occupants. 40% of the open office participants thought that their workplace "often" gets noisy, especially with increase in background activity. This is a stark contrast to the results shown in fig. 4.8.1.a. This may imply that though they felt their workplace sometimes encountered noise issues, it was not a significant concern. 50% of the semi-private office participants felt that their workplace "often" got noisy, and this result corresponded with the outcome of the previous survey question (Fig. 4.8.1.a). Most private office participants only "sometimes" or "rarely" faced noise issues in their workstations.

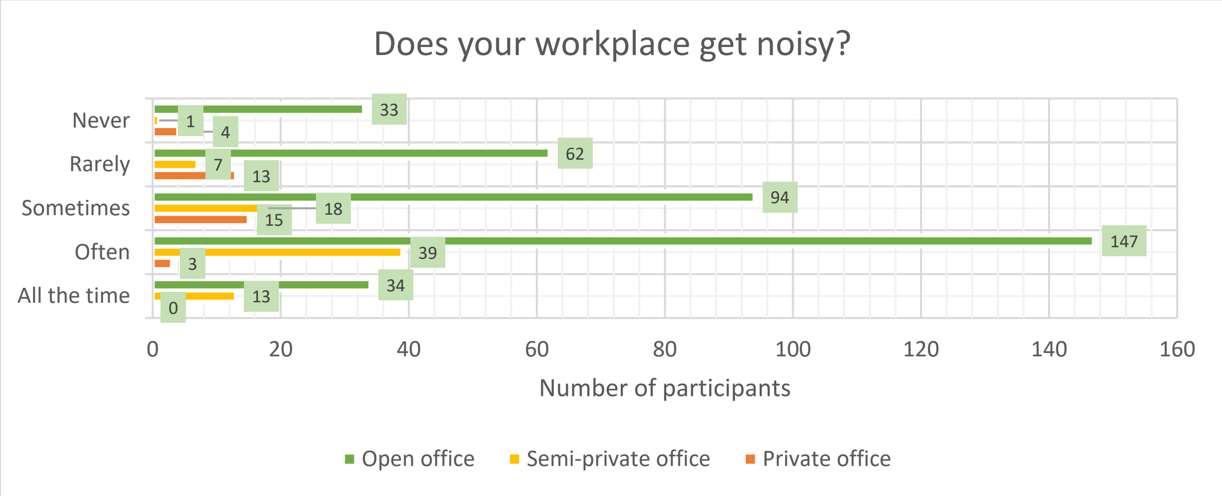


Fig. 4.8.1.b. How often participants perceived their workplace as noisy (Source: Author)

Fig. 4.8.1.c. and 4.8.1.d. display the perception of office participants on the frequency of external and internal noises in their workplace. Almost 50% of open office participants felt that external noise was not a significant issue. Most of the semi-private and private office participants were not affected with external noise sources. Most of the open and semi-private participants expressed they "often" were exposed to internal background noises (Fig. 4.8.1.d.). Majority of these participants felt internal noise usually originated from others' conversations and activities, and public areas (Fig. 4.8.1.e.). More than 70% of private office participants "never" or "rarely" faced any difficulties due to internal noises in their workspace.

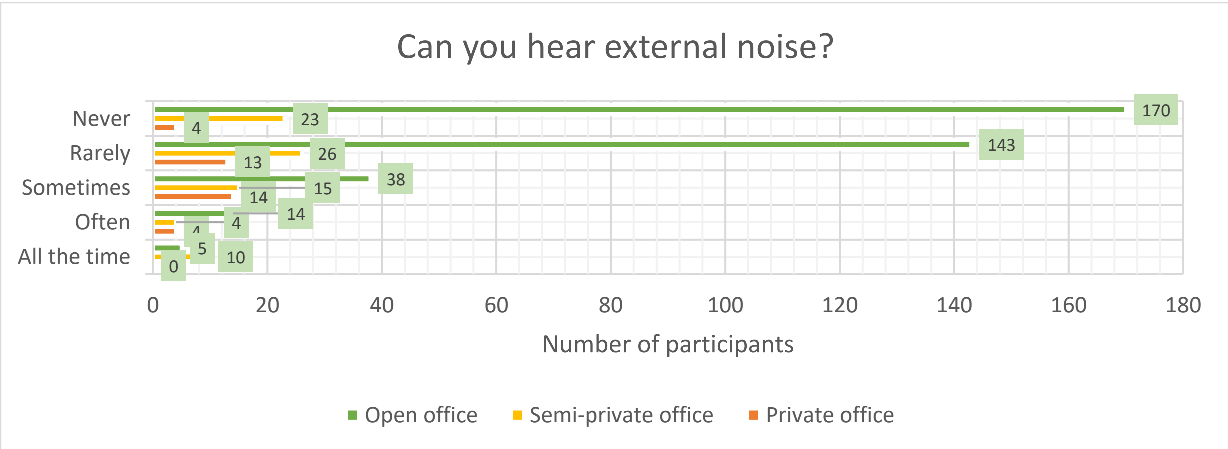


Fig. 4.8.1.c. How often participants experienced external noise in their workplaces (Source: Author)

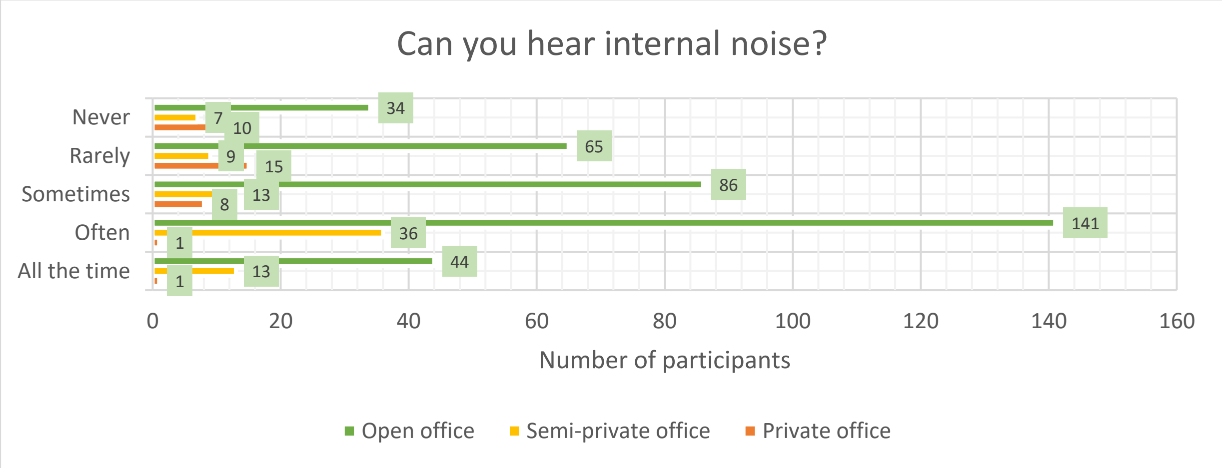


Fig. 4.8.1.d. How often participants experienced internal noise in their workplaces (Source: Author)

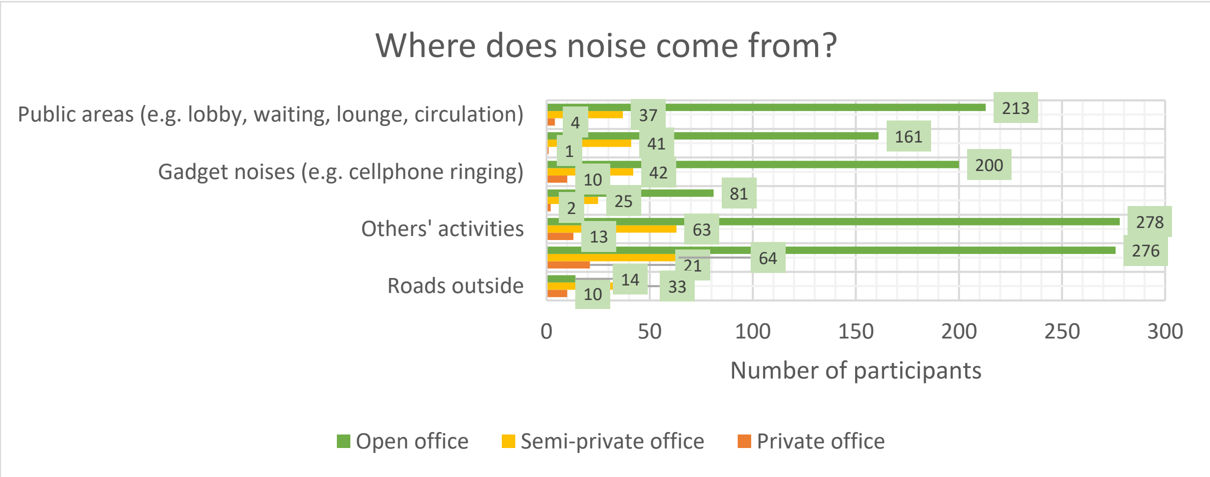


Fig. 4.8.1.e. Sources of noise in workplace (Source: Author)

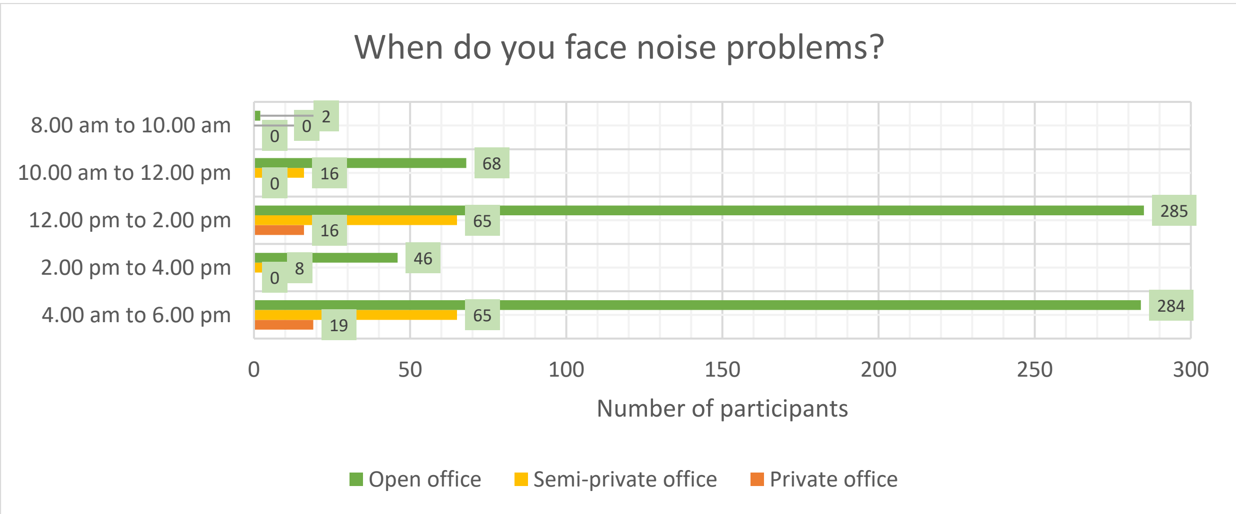


Fig. 4.8.1.f. Time period when participants faced noise problems in their workplaces (Source: Author)

Fig. 4.8.1.f. shows that majority of the open office participants mostly encountered noise problems during 12.00 PM to 2.00 PM and 4.00 PM to 6.00 PM, i.e., during peak hours – 01 and peak hours – 02.

Fig. 4.8.1.g. displays whether office participants felt that excess background noise level affected their health and hearing. Majority of the open and private office participants believed that excessive noise levels did not pose any negative consequences on their health and hearing. More than 50% of the semi-private participants felt that their health and hearing were vulnerable due to excess noise.

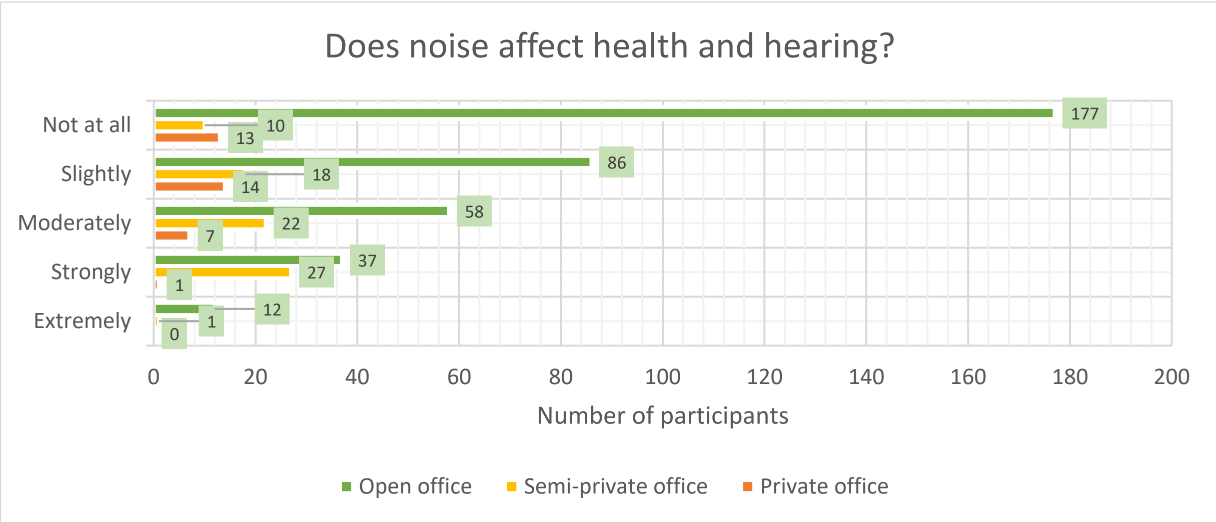


Fig. 4.8.1.g. Perception on health and hearing in terms of noise level of participants in their workplaces (Source: Author)

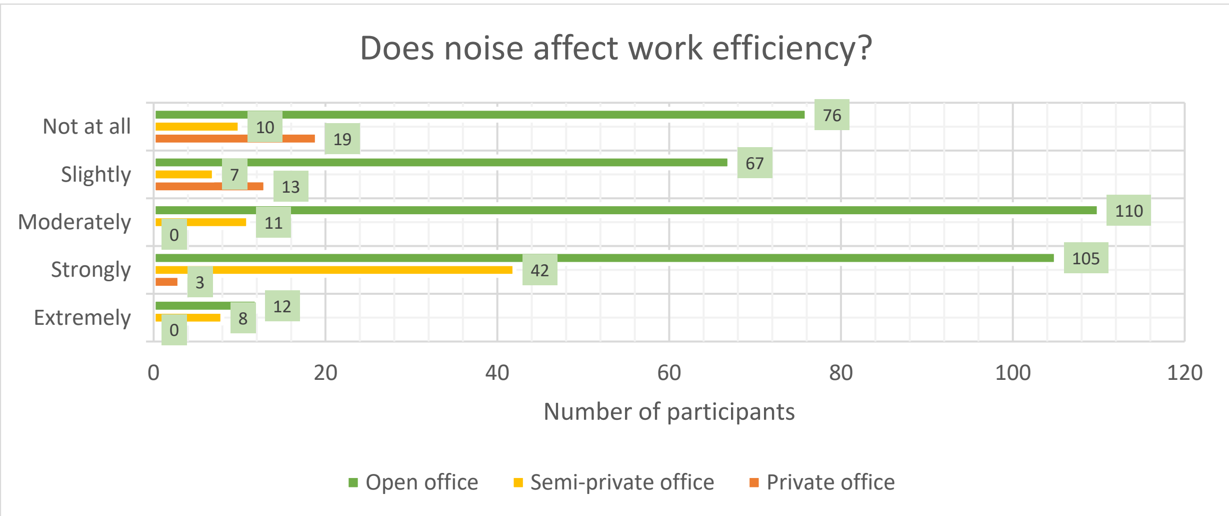


Fig. 4.8.1.h. Perception on work efficiency in terms of noise level of participants in their workplaces (Source: Author)

Fig. 4.8.1.h. shows whether participants felt noise had any negative effect on their work efficiency. Most of the open and semi-private office participants felt that noise problems “moderately” and “strongly” disrupted their work flow. More than 50% of private office participants claimed that noise levels in their workplace did not have any adverse effect on their work productivity.

Fig. 4.8.1.i. and 4.8.1.j. illustrate which work activities participants felt were hampered due to excessive noise in workplace, and how noise levels affected their emotional wellbeing. Most of the open and semi-private participants faced difficulties in conducting arithmetic tasks, routine work, complex verbal tasks and important conversations. Private office participants rarely faced any difficulties in their work activities due to noise, with only less than 50% of participants stating that important conversations and verbal tasks might get disrupted occasionally due to excessive noise from adjacent spaces. Most of the open and semi-private office participants had increased difficulties in concentration due to noise levels, and felt their work quality was being compromised. Private office participants in most instances did not have any major effect on their emotional wellbeing, with 60% of the participants stating that they occasionally felt irritated due to noise of other employees coming from adjacent spaces.

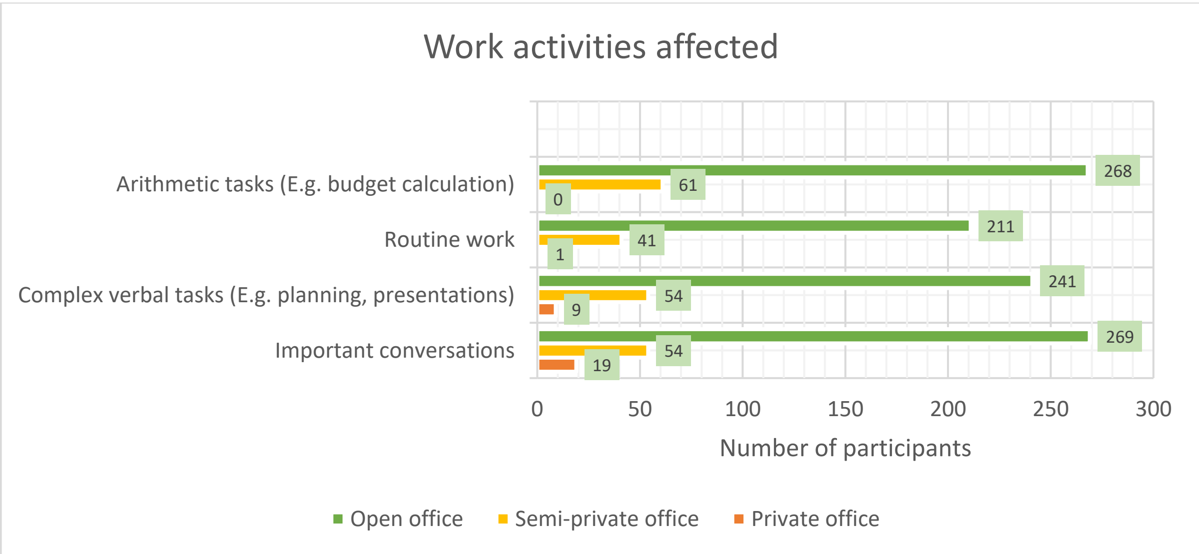


Fig. 4.8.1.i. Work activities affected due to noise in workplaces (Source: Author)

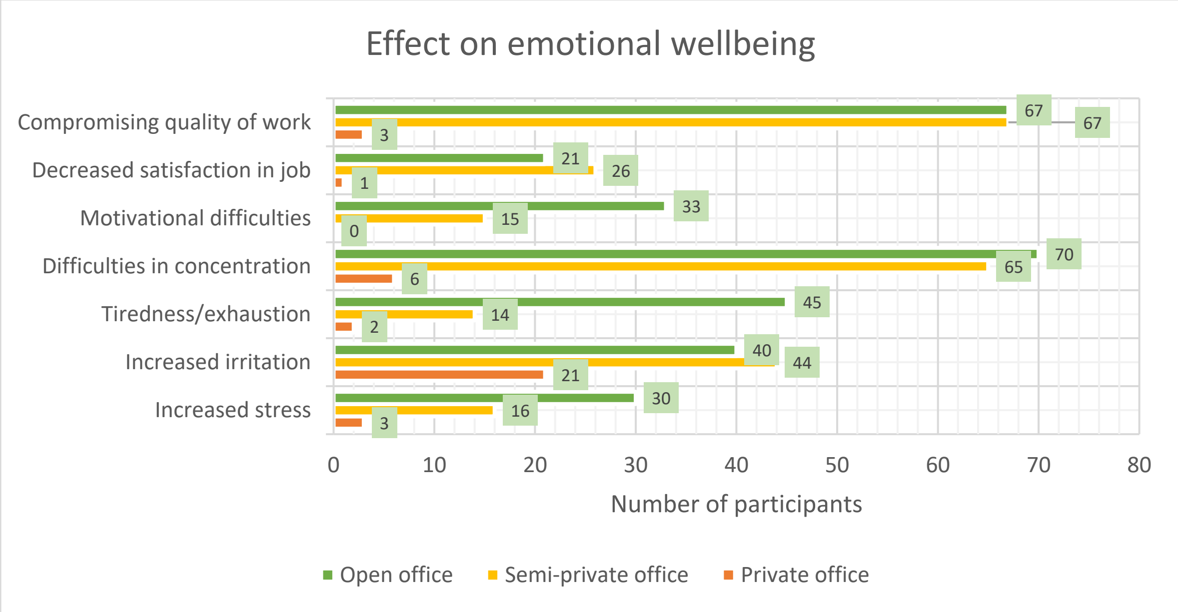


Fig. 4.8.1.j. Effect on emotional wellbeing due to noise in workplaces (Source: Author)

Fig. 4.8.1.k. shows the approaches usually taken to cope with excessive noise levels in workplace. Most of the open and semi-private office participants usually worked overtime and complained to their co-workers and managers about excessive noise levels in their workplaces. Some of the participants also opted for working somewhere quiet, quickly finishing pending work, giving more effort into their work or by taking frequent breaks from work. Private office participants seldom took any steps to tackle noise issues, with more than 50% of them complaining to their colleagues and other employees if they felt irritated by excessive noise.

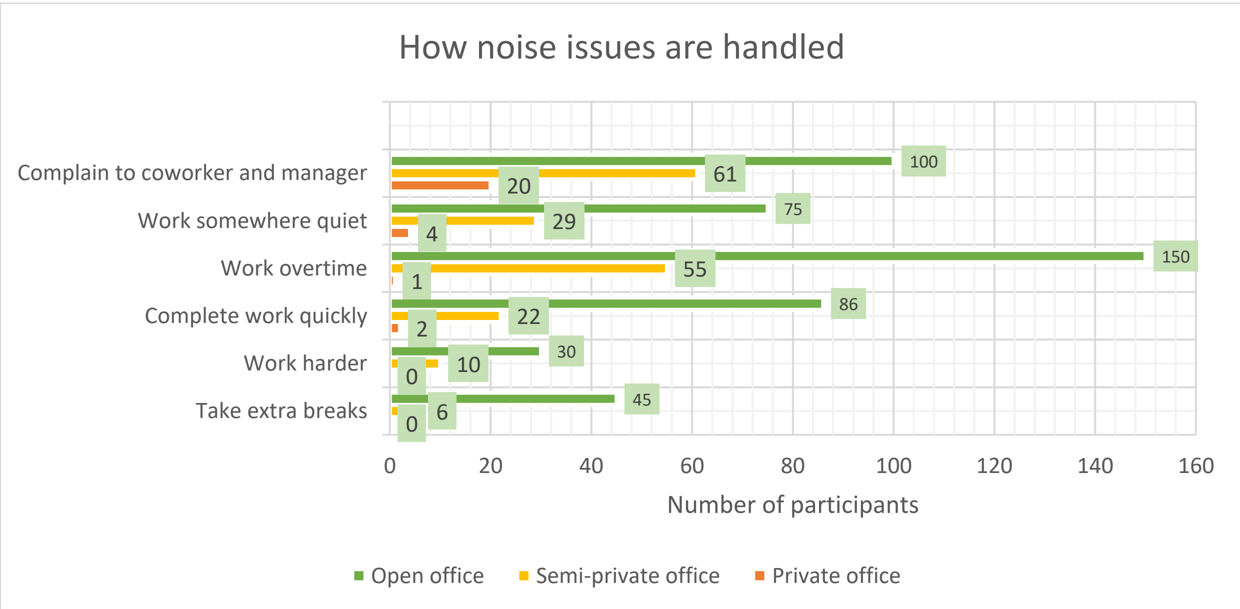


Fig. 4.8.1.k. Steps taken to tackle excessive noise in workplaces (Source: Author)

4.8.2 Observations on speech intelligibility

Fig. 4.8.2.a. illustrates the level of difficulty participants faced in understanding and having clear conversations with their colleagues in the workspaces. More than 50% open office participants and 70% private office participants reported that they did not face any complications in comprehending and taking part in conversations. More than 40% semi-private participants "strongly" stated that they often faced issues in understanding and having clear conversations with other individuals in their office spaces.

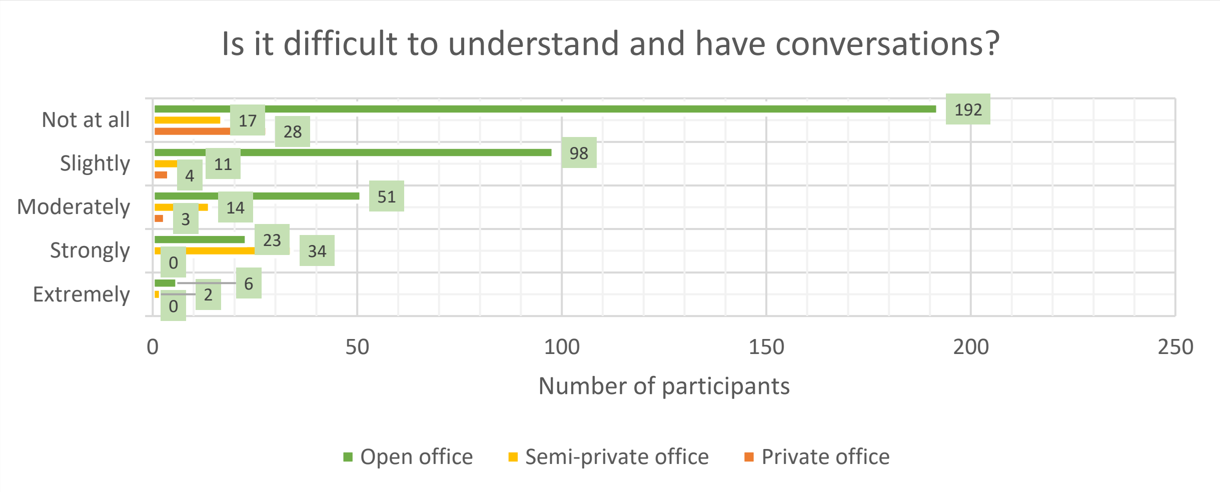


Fig. 4.8.2.a. Level of difficulty in understanding and having clear conversations in workplaces (Source: Author)

Fig. 4.8.2.b. shows that around 30% of open office participants "sometimes" had to raise their voice in order to be heard in their workplaces. More than 50% of semi-private office participants "often" had to speak loudly so that others could comprehend them. Around 50% private office participants stated that they "rarely" had to raise their voice to be understood by others.

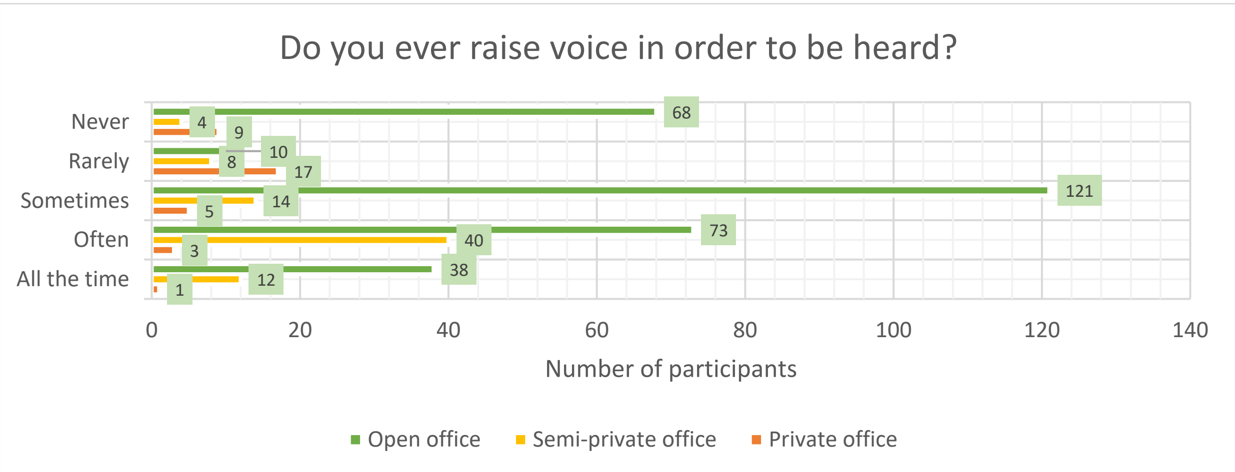


Fig. 4.8.2.b. Frequency of having to raise voice in workplaces (Source: Author)

Almost 30% open office participants declared that they "sometimes" had to go elsewhere to concentrate if it got too noisy in their workplaces (Fig. 4.8.2.c). More than 41% of semi-private office participants "often" had to leave their own workstations to work quietly somewhere else.

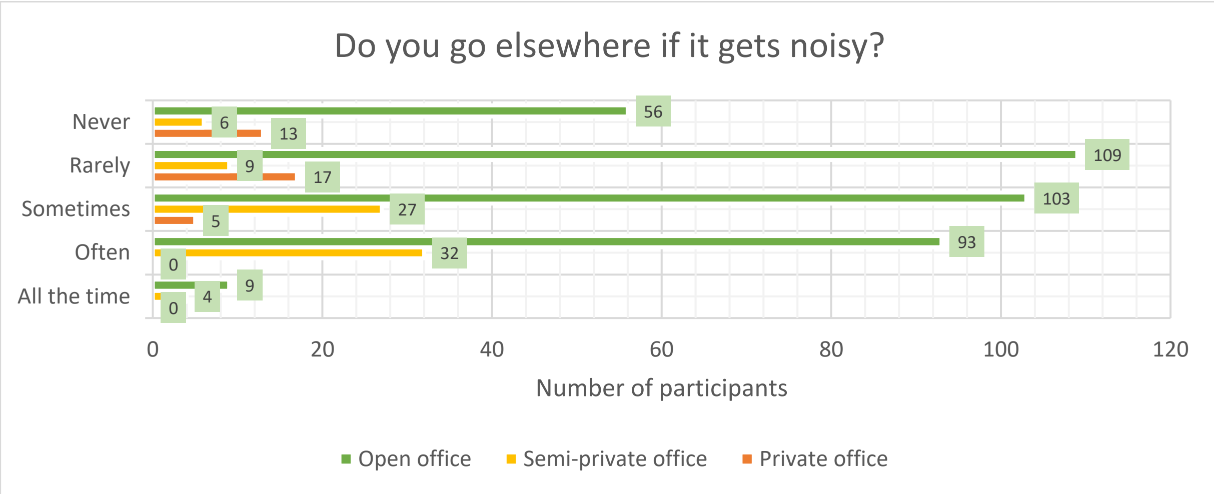


Fig. 4.8.2.c. How often participants had to go elsewhere to concentrate (Source: Author)

Additionally, most open and semi-private participants thought that high levels of background noise and conversations of others were the main reason behind speech intelligibility issues prevailing in their workspaces (Figure 4.8.2.d.). Noisy environment was not a concern for private office participants, with around 50% private office participants stating that they "rarely" had to go to another quiet space to work undisturbed. Less than 50% of these participants mentioned that others' loud conversations sometimes may have affected their speech intelligibility in their workspaces.

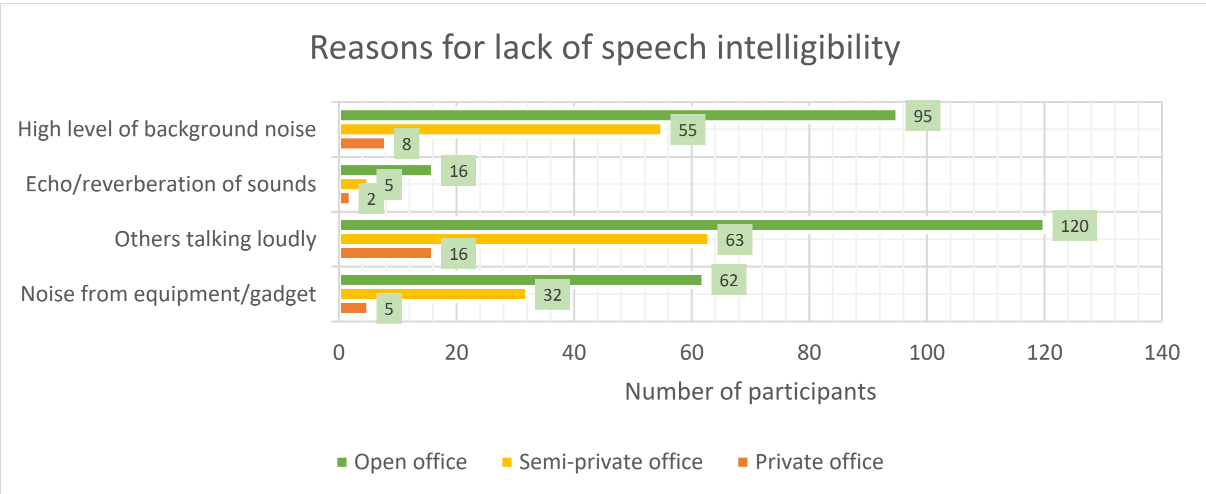


Fig. 4.8.2.d. Reasons behind lack of speech intelligibility in workplaces (Source: Author)

Most of the open, semi-private and private office participants agreed that there were no dedicated areas allocated for concentration in work in any of the office spaces (Fig. 4.8.2.e.). In case of participants who stated that there were spaces for speech intelligibility in their office spaces, they added that they used empty meeting rooms or conference rooms for that particular purpose. Meeting or conference rooms were not specifically designed for speech intelligibility purposes, and employees had to depend on these rooms being vacant in order to be used.

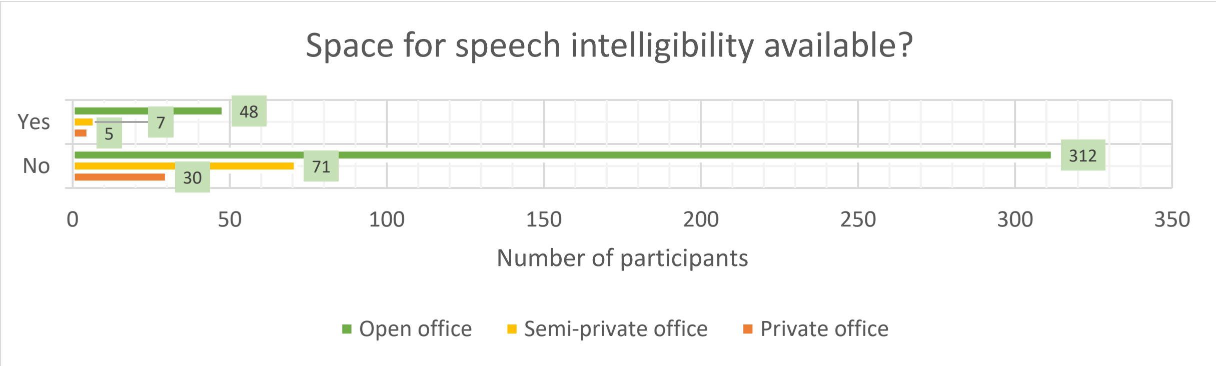


Fig. 4.8.2.e. Availability of spaces for speech intelligibility in workplaces (Source: Author)

4.8.3 Observations on speech privacy

More than 60% of open office participants stated that they "sometimes" or "often" could overhear others' private conversations in their workplaces (Fig. 4.8.3.a.). More than 60% of semi-private participants could accidentally hear discussions of neighbours, and frequently got interrupted by them. Most of the private office participants "never" overheard conversations from adjacent spaces, and thus never got interrupted during office work.

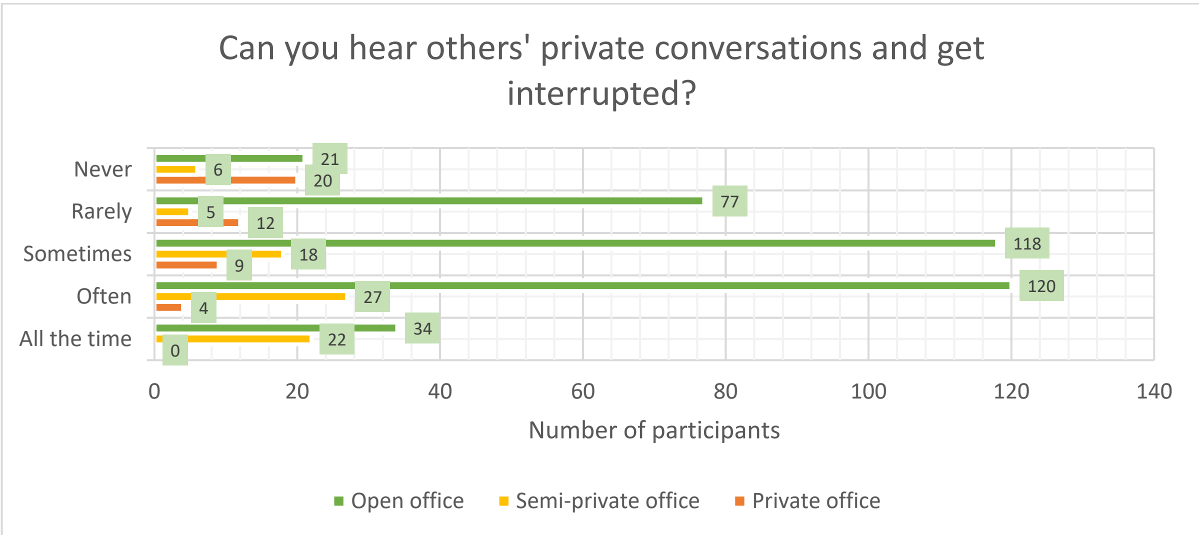


Fig. 4.8.3.a. Frequency of overhearing others' private conversations in workplaces (Source: Author)

Fig. 4.8.3.b. shows almost 40% of open office participants "rarely" worried about their private conversations being overheard by others in their workplaces. Almost 50% of semi-private office participants "often" worried that their private conversations may be overheard by others. Around 50% private office participants stated that they often could have private conversations in their workplaces without worrying about being eavesdropped. Most participants mentioned that others' conversations were the main reason behind lack of speech privacy in their workplaces (Fig. 4.8.3.c.).

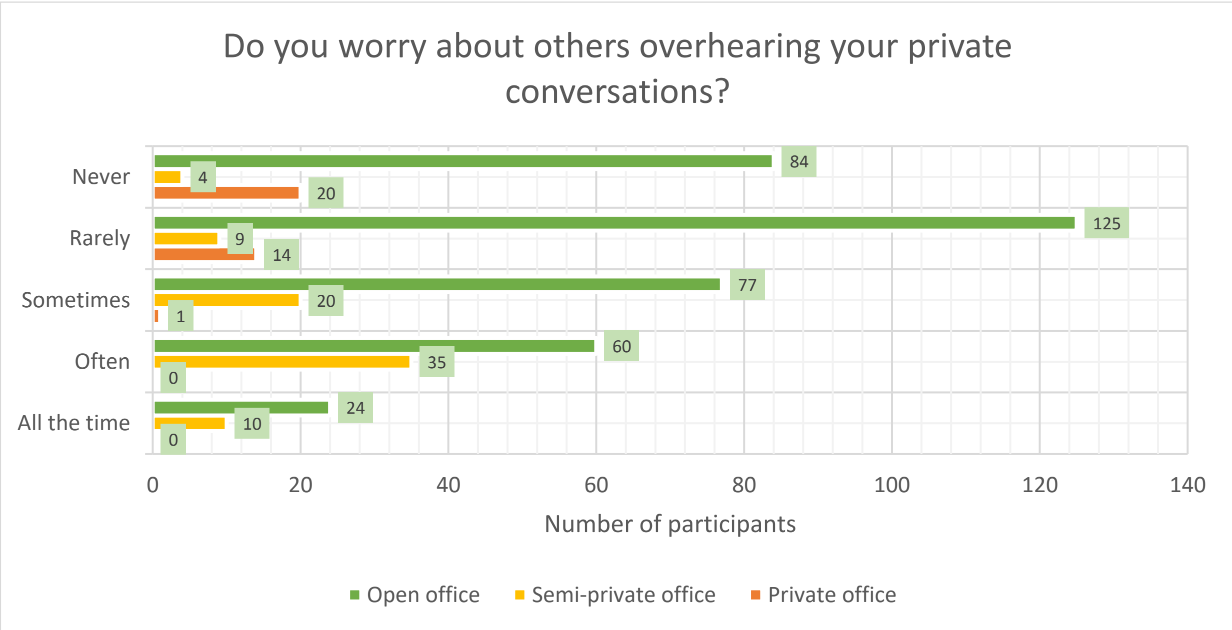


Fig. 4.8.3.b. Frequency of worrying about getting eavesdropped in workplaces (Source: Author)

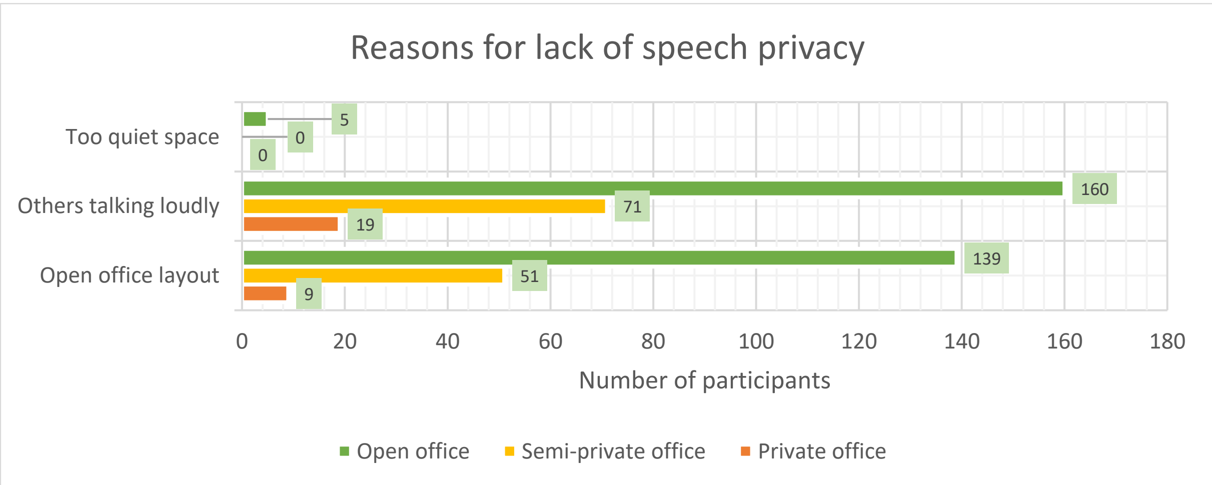


Fig. 4.8.3.c. Reasons behind lack of speech privacy in workplaces (Source: Author)

Most of the open, semi-private and private office participants agreed that there were no dedicated areas allocated for speech privacy in any of the office spaces (Fig. 4.8.3.d.). In case of participants who stated that there were spaces for speech privacy in their office spaces, they added that they used empty meeting rooms or conference rooms for that particular purpose. Meeting or conference rooms were not specifically designed for speech privacy purposes, and employees had to depend on these rooms being vacant in order to be used, similar to the results found from Fig. 4.8.2.e.

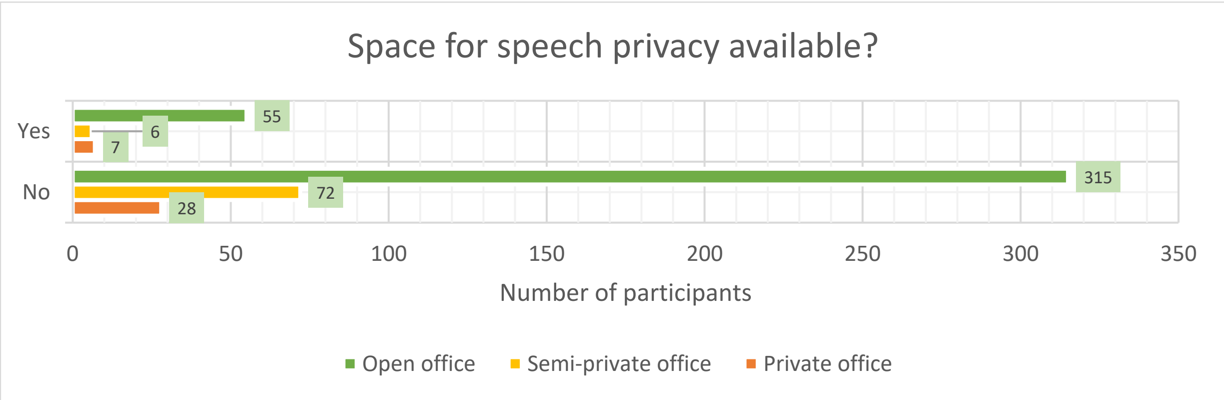


Fig. 4.8.3.d. Availability of spaces for speech privacy in workplaces (Source: Author)

4.8.4 Additional comments from participants in the questionnaire survey

In addition to the multiple-choice, Likert scale and demographic questions, the questionnaire survey included open-ended questions. These questions allowed participants to offer feedback in their own words which would aid in uncovering further information on acoustical performance that may have been overlooked during the physical survey. The remarks obtained from open, semi-private and private office participants are given below.

<u>Open-office participants:</u>

- "Not totally satisfied with the way administration has handled noise control measures in this workplace."
- "Awareness on appropriate work etiquette among employees is necessary."
- "The office space should not be 100% open."
- "Partitions between each workspace is required."
- "Partitions having greater heights should be installed."

- “The work desks should not be placed in such close proximities to each other.”
- “A designated area for speech privacy and speech intelligibility is required.”
- “Establishing dedicated loud and quiet zones inside the workspace.”
- “Indoor plants, carpet or engineered flooring system and masking sound system should be installed.”
- “Others’ conversations help us in masking our own private discussions.”
- “Private telephones should be placed on silent mode during working hours.”
- “All employees should converse at appropriate volume during working hours.”
- “Noise generating from HVAC systems, gadgets and equipment should be controlled.”

Semi-private office participants:

- “In most cases, the nature of work prevents noise to be effectively controlled. For instance, some work requires constant moving from one office space to the other, and long periods of conversation with fellow colleagues in between. Some tasks are urgent and manifested suddenly upon employees, so there is a rush and noisy period at that instance.”
- “Some of the desks and chairs should be rearranged.”
- “Each semi-private office cubicle or workstation should be placed further apart from each other.”
- “A designated area for speech privacy is required.”
- “Efficient provision for noise control is present.”
- “Masking sound system should be introduced in the office space.”
- “Noise generating from HVAC systems, gadgets and equipment should be controlled.”

Private office participants:

- “The work floor should be divided according to different departments and work processes. Each department should be segregated by using partitions.”

- "All employees should converse at appropriate volume during working hours."
- "Using private phones should be limited. A common telephone booth should be introduced if anyone needs to communicate urgently."
- "The office space should not be 100% open."
- "Glass partition between private office and adjacent spaces is not acoustically efficient enough to block transmission of noise from the adjacent areas."
- "Noise generating from HVAC systems, gadgets and equipment should be controlled."

4.9 Comparison Between Quantitative and Qualitative Findings

4.9.1 Open office spaces

Comparisons in initial observations of buildings:

In chapter 4.1.1, it was initially assumed that due to the active cooling system nature of these office buildings, external noise from roads and outside environment would not present a significant issue in increasing the background noise levels indoors. From the qualitative survey results (Fig. 4.8.1.c. and 4.8.1.e.), it was seen that open office occupants did not regard external noise to be a nuisance in their work routine. Discrepancies found in background noise level readings of open office space were not caused by noise generating from outdoors.

Table 4.2.b. showed that in initial observations, indoor noise was present during typical office hours. Qualitative survey results concurred with this viewpoint, with over 40% participants agreeing that their office space often got noisy during office hours, especially with an increase in background activity of occupants (Fig. 4.8.1.b. and 4.8.1.d.). Background noise levels were not perceived to be satisfactory in open office spaces.

Chapter 4.2 cites that indoor noise from mechanical sources, office equipment, gadgets and occupants were constantly prevailing in the surveyed office spaces during typical working hours. Spaces which were susceptible to noise were not located further away from noise sources. From Fig. 4.8.1.e., it was seen that most open office participants considered major sources of noise to be public areas with heavy traffic, office equipment, gadgets, and other open office occupants' conversations and activities. They felt that adjacent office spaces i.e., semi-private and private office spaces were not significant sources of noise for them.

Comparisons in background noise level:

From the readings of background noise level gathered in chapter 4.3.1, it was seen that the overall mean background noise level was greater than recommended standards. Fig. 4.8.1.b. and 4.8.1.d. attests to this, with most participants agreeing that they often found their workspaces to be noisy. Mean values recorded during peak hours – 01 (12.00 PM to 2.00 PM) and peak hours – 02 (4.00 PM to 6.00 PM) were found to exceed the recommended limits. From Fig. 4.6.a. and 4.6.b., it was seen that highest number of occupants were present in these workspaces during peak hours. Fig. 4.8.1.f. shows that most participants usually faced noise issues during these time periods in their office spaces. Hence, mean background noise levels were found to be unsatisfactory in open office spaces during peak working hours. However, Fig. 4.8.1.a. shows that most open office users were relatively satisfied with the level of noise control measures taken in their workspaces. This indicated that although they believed noise problems prevailed, they were not significantly concerned or bothered by it.

Comparisons in reverberation time:

From chapter 4.3.2, it was seen that mean reverberation time calculated in open office spaces was within the acceptable range. Most open office participants did not believe that echo or reverberation of sounds occurred frequently in their workspaces (Fig. 4.8.2.d.). Thus, issues in reverberation time were not significant in open office spaces.

Comparisons in speech intelligibility:

Mean value for PSA in open office spaces was found to be unsatisfactory and less than the minimum recommended value (Chapter 4.3.3). However, more than 50% of open office participants reported that they did not face difficulties in understanding and having clear conversations with others in their workspaces (Fig. 4.8.2.a.). Only a few stated that they sometimes had to raise their voice in order to be heard, and occasionally had to leave their workstations to concentrate someplace else if it ever got noisy (Fig. 4.8.2.b. and 4.8.2.c.). Hence, even though objective measurements indicated discrepancies in speech intelligibility, open office users were not considerably bothered with speech intelligibility issues in their workplaces.

Comparisons in speech privacy:

Mean value for PSA with regards to speech privacy was found to be satisfactory, and was lower than the maximum recommended value. However, more than 60% of open office participants claimed that they could often eavesdrop on other employees and occupants' conversations (Fig. 4.8.3.a.). On the other hand, most open office users themselves rarely worried about their own private conversations being overheard by others (Fig. 4.8.3.b.). Additionally, a majority of them believed that others' talking loudly was the main reason behind lack of speech privacy in their workspaces. This indicated that although open office users could often overhear others' private discussions, they benefitted from it by using this occurrence as a means to shield their own conversations from others, as deduced from the additional comments section of the questionnaire filled up by open office space participants.

4.9.2 Semi-private office spaces

Comparisons in initial observations of buildings:

Similar to chapter 4.9.1, it was seen that semi-private office users did not regard external noise to be a nuisance in their work routine (Fig. 4.8.1.c. and 4.8.1.e.). Hence, discrepancies found in background noise level readings of semi-private office space were not due to outside noise sources.

Table 4.2.b. displayed that indoor noise was present during typical office hours in semi-private office spaces. Most participants agreed that their office space often got noisy during typical office hours, especially with an increase in background activity of occupants (Fig. 4.8.1.b. and 4.8.1.d.). Thus, background noise levels were not perceived to be satisfactory in semi-private office spaces as well.

Fig. 4.8.1.e. illustrates that most semi-private office participants considered major sources of noise to be public areas with heavy traffic, office equipment, gadgets, and other open office occupants' conversations and activities. Unlike open office users, most semi-private office employees felt that noise often came from adjacent office spaces i.e., open office spaces. This showed that although open office users were not bothered with noise coming from semi-private spaces, semi-private users often felt disturbed with noise due to open office users.

<u>Comparisons in background noise level:</u>

From chapter 4.4.1, it was seen that the overall mean background noise level in semi-private office spaces was greater than recommended standards. Most semi-private office participants also often found their workspaces to be noisy (Fig. 4.8.1.b. and 4.8.1.d.). Mean values recorded during off-peak hours (10.00 AM to 12.00 PM), peak hours – 01 (12.00 PM to 2.00 PM) and peak hours – 02 (4.00 PM to 6.00 PM) were found to exceed the recommended limits. However, from Fig. 4.8.1.f., it was seen that most semi-private office participants faced noise concerns mostly occurred during peak hours - 01 and peak hours - 02. Conversely, from Fig. 4.6.a. and 4.6.b., it was seen that highest number of occupants were present in these workspaces during peak hours. Hence, even though mean background noise levels were found to be unsatisfactory during all working hours, it was a noticeable concern amongst occupants during peak hours only. Additionally, most semi-private office users were not completely satisfied with the level of noise control measures taken in their workspaces (Fig. 4.8.1.a.). Thus, concerns regarding excessive background noise levels were greater among semi-private office users rather than open office employees.

<u>Comparisons in reverberation time:</u>

From chapter 4.4.2, it was seen that mean reverberation time obtained in semi-private office spaces was within the acceptable range. Most semi-private office participants did not face issues regarding echo or reverberation of sounds in their workspaces (Fig. 4.8.2.d.). Thus, issues in reverberation time were not significant in semi-private office spaces as well.

<u>Comparisons in speech intelligibility:</u>

Mean value for PSA in semi-private office spaces was unsatisfactory and less than the minimum recommended value (Chapter 4.4.3). Most semi-private office users stated that they often faced difficulties in understanding and having clear conversations with others in their workspaces (Fig. 4.8.2.a.). Additionally, more than 50% of them had to raise their voice in order to be heard, and they regularly had to leave their workstations to concentrate someplace else if it ever got noisy (Fig. 4.8.2.b. and 4.8.2.c.). Hence, lack of speech intelligibility was a greater concern for semi-private office employees than open office space users.

<u>Comparisons in speech privacy:</u>

Mean value for PSA with regards to speech privacy was also found to be satisfactory in semi-private office spaces. However, more than 60% of semi-private office employees claimed they could often overhear other employees' and occupants' conversations (Fig. 4.8.3.a.). Additionally, most of them often worried about their own private conversations being overheard by others (Fig. 4.8.3.b.). Majority of them believed that others talking loudly was the main reason behind lack of speech privacy in their workspaces. This suggested that semi-private office users could often overhear others' private discussions in their workspaces and from adjacent open office spaces, and they worried about being eavesdropped more often than open office employees.

4.9.3 Private office spaces

<u>Comparisons in initial observations of buildings:</u>

Private office occupants also did not regard external noise to be a significant source of noise in their workspaces (Fig. 4.8.1.c. and 4.8.1.e.). Hence, any discrepancies found in background noise level readings of private office spaces were not due to noise generating from outdoors.

Table 4.2.b. showed that in initial observations, indoor noise was present during typical office hours. However, from results of qualitative survey, it was seen that most private office participants believed that their office space rarely got noisy during office hours (Fig. 4.8.1.b. and 4.8.1.d.). Thus, background noise levels were perceived to be satisfactory by private office employees.

Chapter 4.2 mentioned that indoor noise existed in the surveyed office spaces during typical working hours. However, from Fig. 4.8.1.e., it was seen that most private office participants did not face any sort of difficulties or distractions due to noise in their workplaces. This indicated that noise problems were not a significant concern for private office space users.

<u>Comparisons in background noise level:</u>

Overall mean background noise level in private office spaces was found to be greater than recommended standards. However, from Fig. 4.8.1.b. and 4.8.1.d., it was seen that most participants rarely found their workspaces to be noisy. Mean values recorded during peak hours – 01 (12.00 PM to 2.00 PM) and peak hours – 02 (4.00 PM to 6.00 PM) were found to exceed the recommended limits. Additionally, from Fig. 4.8.a. and 4.8.b., it was seen that highest number of occupants were present in these workspaces during peak hours. Fig. 4.8.1.f. indicated that some participants usually faced noise issues during these time periods in their office spaces. Hence, mean background noise levels were found to be unsatisfactory in private office spaces during peak working hours. However, Fig. 4.8.1.a. showed that like open office users, most private office employees were comparatively pleased with the level of noise control measures taken in their workspaces. This showed that though they believed noise problems were prevalent in adjacent workspaces, they were not significantly concerned or bothered by it.

Comparisons in reverberation time:

From chapter 4.5.2, it was seen that mean reverberation time calculated in private office spaces was unsatisfactory. However, most private office users did not believe that echo or reverberation of sounds occurred frequently in their workspaces (Fig. 4.8.2.d.). Thus, issues in reverberation time were not significant in private office spaces.

Comparisons in speech intelligibility:

Mean value for PSA in private office spaces was found to be unsatisfactory and lower than the minimum recommended value (Chapter 4.5.3). However, more than 70% of private office participants stated that they never faced difficulties in understanding and having clear conversations with others in their workspaces (Fig. 4.8.2.a.). Additionally, most employees rarely had to raise their voice in order to be heard, or had to leave their workstations to concentrate elsewhere if it ever got noisy (Fig. 4.8.2.b. and 4.8.2.c.). Therefore, even though objective measurements indicated discrepancies in speech intelligibility, but like open office users, private office employees did not face significant issues with speech intelligibility in their workplaces.

Comparisons in speech privacy:

Mean value for PSA with regards to speech privacy was found to be satisfactory in private office spaces. Most of the private office participants never overheard other employees and occupants' conversations (Fig. 4.8.3.a.). Moreover, most private office users never worried about their own private conversations being overheard by others (Fig. 4.8.3.b.). This implied that most private office users were fully satisfied with the level of speech privacy measures existing in their workspaces.

4.10 Conclusion

This chapter shows how the first, second and third objectives of the thesis have been achieved.

The first objective has been achieved by conducting an initial acoustical performance observation and measurements from field survey. Results from this survey shows that the current state of acoustical performance in green rated office buildings in Dhaka City was not satisfactory. Background noise levels, reverberation time and speech intelligibility conditions were found to be unsatisfactory in all buildings from the analysis of objective measurement data. Results from qualitative survey also suggested that an unsatisfactory state of acoustical performance existed in all the green rated office buildings surveyed in this research.

The second objective has been achieved by comparing the values for background noise level, reverberation time, PSA values for speech intelligibility and speech privacy derived from quantitative survey in each office space to the recommended standard values obtained from BNBC 2020 standards. It was seen that mean background noise levels obtained in all office spaces exceeded the recommended standards stated by BNBC 2020 guidelines. Mean reverberation time was found to be satisfactory in all office spaces except for private office spaces. PSA values for assessing speech intelligibility conditions were found to be unsatisfactory for all office spaces. PSA values for evaluating speech privacy settings in all office spaces was found to be satisfactory.

The third objective has been achieved by statistical and comparative analysis of quantitative and qualitative data. ANOVA test results indicated that deviations in average background noise levels in all office spaces were not dependent on off-peak or peak working hours, or on the location of these spaces in the vertical tiers of the buildings. Consequently, deviations in reverberation time, speech intelligibility and speech privacy were not dependent on specific hours or vertical location. Mean background noise levels in all office spaces were found to be unsatisfactory during peak working hours. From the results of human flow estimation, highest number of occupants were observed during these time periods as well. This suggests that excessive background noise levels were affected by increase in number of occupants, and consequently background activities, during certain time periods. High reverberation time calculated in private office spaces may have been due to lack of noise absorptive materials and objects present in the workstations. Low PSA values suggesting poor speech intelligibility conditions in all office spaces may have been due to higher ratio of office space volume to total absorption of the office space.

However, comparison between the two sets of quantitative and qualitative data suggest a striking contrast between what was typically expected from standards and the actual scenario observed in these spaces. Open office space users were not significantly disturbed by excessive noise emerging from occupants and activities of adjacent areas. This suggests that the maximum recommended value of 48 to 58 dBA for background noise level which has been advised for open office space in the standards is not practicable in reality, and may have to be re-evaluated. Most private office occupants believed that their office space rarely got noisy during office hours. The maximum recommended value of 38 to 48 dBA for background noise level set for private office may have to be reassessed as well. Most users from all the office spaces stated in the questionnaire surveys that they were adapted to high levels of prevailing noise in their day to day lives from other sources such as busy residentials areas, commuting in traffic areas with high levels of noise etc. Reverberation time calculated in private office spaces exceeded the recommended standards. However, qualitative survey results indicated that reverberation of noise was not a significant issue they faced. This concludes that the recommended maximum range for reverberation time of Bangla language of private office spaces may have to be re-examined. Open office users were not greatly bothered with speech intelligibility issues according to the questionnaire survey. Likewise, private office employees did not face significant issues with speech intelligibility in their workplaces. This implies that in addition of re-evaluation of recommended PSA values and other noise parameters, an assessment of typical employee behaviour in terms of noise and acoustical performance perception in the context of Bangladesh is necessary to evaluate the acoustical performance of green rated office buildings located in our setting.

CHAPTER 05: PROPOSITIONS AND CONCLUSION

CHAPTER 05: PROPOSITIONS AND CONCLUSION

Chapter 01 of this thesis introduces the research. Chapter 02 delivers the theoretical basis of this research and provides a clear understanding of the importance of acoustical performance in office spaces, a comprehensive review on green rated office buildings, general acoustical performance issues faced in green rated office buildings located outside Bangladesh, and standards and recommendations followed by standardization bodies for satisfactory acoustical performance in green rated office buildings. Chapter 03 describes in details the steps of the quantitative and qualitative research methods applied for the convergent parallel mixed methods research approach in this thesis. In chapter 04, objective measurements on various acoustical performance parameters and subjective qualitative survey on office occupants were carried out to assess the current condition of acoustical performance, levels of deviations from standards and recommendations, and derive probable causes behind deviations. This chapter summarizes the key findings of chapter 02 and chapter 04. This chapter summarizes the research by reviewing the achievements of the objectives mentioned in chapter 01, and recommends some propositions to improve the current acoustical performance of green rated office buildings in Dhaka city. It also provides suggestions for future research and scope of work.

5.1 Synopsis

This research focuses on the current acoustical performance of existing green-rated office buildings located in Dhaka city. Recent POE surveys conducted in green rated office buildings across the globe have indicated that although green rated office buildings had greater rating points in occupant environmental satisfaction (e.g., Air quality and daylighting), they scored extremely low in overall acoustical performance. These surveys also deduce poor acoustical performance to be the chief complaint among occupants of green certified office buildings. Even though poor acoustical performance in green rated office buildings has been a significant concern worldwide, there still has not been any study carried out till date to determine the performance of acoustical environment of any green rated buildings in Dhaka City. Moreover, majority of the office buildings in Dhaka city received LEED certification under LEED 2009 (LEED v3) version, in which no points were assigned for assessing acoustical performance. Previous LEED users were also allowed to enlist their projects under LEED 2009 scheme till October 2016. Designers seldom gave priority to acoustical performance while designing, and no awareness existed between a satisfactory acoustical environment and workers' performance. Consequently, there is an unsatisfactory level of acoustical performance present in green rated office buildings (when compared to recent inclusions in LEED criteria) in Dhaka city.

The research aimed to assess the current acoustical performance scenario of green rated office buildings in Dhaka city by achieving the following objectives.

i. To identify whether the current state of acoustical performance in green rated office buildings in Dhaka City was satisfactory or not.

ii. To assess the existing quantitative and qualitative levels of deviations from standards in acoustical performance of green rated office buildings in Dhaka city.

iii. To investigate the reasons behind levels of deviation in acoustical performance of green rated office buildings in Dhaka city.

The research initially hypothesized that levels of deviation in acoustical performance of green rated office buildings in Dhaka city was not satisfactory. The null hypothesis in this research was that no levels of deviation from standards and recommendations existed in acoustical performance of green rated office buildings in Dhaka city.

The main methodology followed in this research is based on descriptive and cross-sectional non-experimental research method, and collective or multiple case study research method. Quantitative research method involved measuring background noise levels, calculating reverberation times, PSA values for speech intelligibility and speech privacy, formulating human flow estimation graphs, and detailed observations of interior environment through checklist. Qualitative research method involved assessing these parameters using occupant perception questionnaire survey. Open, semi-private and private office spaces were surveyed in each building. Through integrating both quantitative and qualitative modes of research method, deviations of acoustical performance in these two types of surveys were examined.

5.2 Achievement of the Objectives

The achievement of the objectives of this thesis, developed in chapter 01 are discussed in this chapter.

5.2.1 Current state of acoustical performance in green rated office buildings in Dhaka City

The first objective in this research was to identify whether the current state of acoustical performance in green rated office buildings in Dhaka City was satisfactory or not. From the data gathered from background study and initial reconnaissance surveys, it was seen that a lack of awareness on appropriate acoustical measures existed in the design and planning of most green-rated buildings worldwide, including office buildings in Dhaka city. As a result, employees and occupants of these office spaces are regularly subjected to unfavourable acoustical issues, including increased exposure to high background noise levels, insufficient speech intelligibility and unsatisfactory speech privacy conditions. Initial acoustical performance observations indicated an overall lack of awareness persisted among the design team, contractors and clients on acoustical performance, and employing proper acoustical design and planning measures in buildings. No prerequisites for acoustical performance were included during any of the planning, construction and design phases. These surveyed buildings did not have any rating for acoustical performance, albeit having extremely satisfactory scores in other categories such as water efficiency and daylighting. No POE surveys were done in any of the buildings surveyed in this research. Even after receiving multiple reports of unsatisfactory acoustical performance from building occupants, they failed to take measures for alleviating the situation.

Objective measurements conducted in open, semi-private and private office spaces conclude that mean background noise levels were in general higher than the recommended limits in all three categories of office spaces. Mean reverberation times were found to be satisfactory in all office spaces, except private office spaces. However, PSA values for speech intelligibility conditions were not satisfactory in any of the office spaces, with the least satisfactory conditions found in open and semi-private zones. Conversely, all three office spaces had satisfactory PSA values for speech privacy conditions, with the most satisfactory conditions observed in open and semi-private office spaces.

In the subjective qualitative questionnaire surveys, most of the participants remarked on their satisfaction on the overall work environment. However, deviations found in objective measurements affected participants of semi-private office space the most, compared to occupants of open and private office spaces. Most semi-private office participants were dissatisfied with the inadequate levels of noise control measures and existing high background noise level conditions. They also expressed increased awareness on their compromised well-being due to noise, as well as reduced work efficiency, decreased concentration in tasks and decline in quality of work. Problems were mostly faced during arithmetic tasks, routine work, complex verbal tasks and important conversations. As a result, most of the occupants frequently worked extra hours and complained to their co-workers and managers. Most semi-private participants also faced difficulties in attaining a satisfactory speech intelligibility and speech privacy environment in their workplaces. On the contrary, most participants of private office spaces in general did not face any issues with acoustical performance in their work areas during operational hours. Nevertheless, most of the participants from all three office spaces were aware about the existing deviations in acoustical performance standards in their workplaces.

5.2.2 Existing quantitative and qualitative levels of deviations from standards in acoustical performance

The second objective in this research was to assess the existing quantitative and qualitative levels of deviations from standards in acoustical performance of green rated office buildings in Dhaka city. The two sets of quantitative and qualitative results were also compared to determine whether they confirm or disconfirm each other.

Table 5.2.2.a. Mean background noise levels during working hours for open office spaces (Source: Author)

Mean background noise levels during working hours (10.00 AM to 6.00 PM)		
Off peak hours	**Peak hours - 01**	**Peak hours - 02**
57.78 dBA	***59.53 dBA***	***60.90 dBA***
Lower tiers	**Middle tiers**	**Upper tiers**
59.45 dBA	***58.66 dBA***	***60.10 dBA***
Overall mean = 59.40 dBA > 48-58 dBA = Unsatisfactory		

According to Table 5.2.2.a., mean background noise levels measured for open office spaces exceeded the recommended standard range, and was found to be unsatisfactory. The mean value obtained was 2.41% greater than maximum recommended range of 48 to 58 dBA. In the questionnaire surveys, most open office participants also reported facing problems due to excess levels of background noise during peak hours 01 and 02, and were only moderately satisfied with the level of existing noise control measures being taken.

Table 5.2.2.b. Mean background noise levels during working hours for semi-private office spaces (Source: Author)

Mean background noise levels during working hours (10.00 AM to 6.00 PM)		
Off peak hours	**Peak hours - 01**	**Peak hours - 02**
56.97 dBA	***57.37 dBA***	***58.91 dBA***
Lower tiers	**Middle tiers**	**Upper tiers**
58.08 dBA	***56.62 dBA***	***58.55 dBA***
Overall mean = 57.75 dBA > 43-53 dBA = Unsatisfactory		

According to Table 5.2.2.b., mean background noise levels for semi-private office spaces surpassed the recommended standard range, and was found to be unsatisfactory. The mean value obtained was 8.96% greater than maximum recommended range of 43 to 53 dBA. Most semi-private office participants also reported facing problems due to excess levels of background noise during peak hours 01 and 02, and were only slightly satisfied with the level of existing noise control measures being taken.

Table 5.2.2.c. Mean background noise levels during working hours for private office spaces (Source: Author)

Mean background noise levels during working hours (10.00 AM to 6.00 PM)		
Off peak hours	**Peak hours - 01**	**Peak hours - 02**
50.57 dBA	***48.88 dBA***	***50.90 dBA***
Lower tiers	**Middle tiers**	**Upper tiers**
49.93 dBA	***48.46 dBA***	***51.96 dBA***
Overall mean = 50.12 dBA > 38-48 dBA = Unsatisfactory		

Table 5.2.2.c. shows that mean background noise levels private office spaces was also found to be unsatisfactory. The mean value obtained was 4.42% greater than maximum recommended range of 38 to 48 dBA. Most private office participants also reported facing problems due to excess levels of background noise during both the peak working hours. However, maximum of them stated that they were strongly satisfied with the level of existing noise control measures in their workstations.

The deviation in background noise levels from recommended standards was found to be greatest in semi-private office spaces.

Table 5.2.2.d. Mean reverberation time for open and semi-private office spaces (Source: Author)

Mean reverberation time		
Lower tiers	**Middle tiers**	**Upper tiers**
0.74 s	0.75 s	0.63 s
Overall mean = 0.70 s (within 0.5s to 0.8s) = Satisfactory		

Table 5.2.2.d. shows that mean reverberation time calculated for open office spaces was within the acceptable maximum recommended range of 0.5 to 0.8 s. In all buildings, semi-private office spaces were not enclosed by floor to ceiling height walls or partitions. They shared the same enclosed space as that of open office. Reverberation time of open and semi-private spaces were calculated together and was equal for both spaces, i.e., 0.70 s. Thus, mean reverberation time for semi-private office spaces was also found to be satisfactory. Qualitative survey reports for open and semi-private office spaces expresses that reverberation of noise was not a significant concern for users of these two office spaces.

Table 5.2.2.e. Mean reverberation time for private office spaces (Source: Author)

Mean reverberation time		
Lower tiers	**Middle tiers**	**Upper tiers**
0.93 s	*0.86 s*	*1.06 s*
Overall mean = 0.95 s > 0.5s to 0.8s = Unsatisfactory		

Mean reverberation time calculated for private office spaces was found to be unsatisfactory, and it exceeded the maximum recommended standard range (Table 5.2.2.e.). It was found to be 18% higher than recommended maximum range of 0.5 to 0.8 s.

Mean PSA value calculated for open office spaces was 39.04%, which was lower than the minimum recommended standard for satisfactory speech intelligibility conditions (Table 5.2.2.f.). The mean PSA value was 47.95% less than the minimum recommended value of 75% for Bangla language. Speech intelligibility conditions of open office spaces was thus found to be unsatisfactory. From the qualitative survey results, it was seen that most open office users never had difficulties in understanding and having intelligible conversations in their workstations. Most of them rarely had to move somewhere else to concentrate if conditions got noisy, and they only sometimes had to raise their voice in order to be heard properly. Even though objective measurements indicated discrepancies in speech intelligibility conditions, open office users were not considerably bothered with speech intelligibility issues in their workplaces.

Table 5.2.2.f. Mean PSA value for speech intelligibility in open and semi-private office spaces (Source: Author)

Mean value for Percentage Syllable Articulation (PSA)		
Lower tiers	**Middle tiers**	**Upper tiers**
38.19%	***39.09%***	***39.47%***
Overall mean = 39.04% < 75% = Unsatisfactory		

PSA values determined for open office spaces would be the same for semi-private office spaces, i.e., 39.04%, because these spaces share the same reverberation time. Speech intelligibility conditions of semi-private office spaces was found to be unsatisfactory. From the qualitative survey analysis, it was found that most semi-private office users often faced strong difficulties in understanding and having intelligible conversations. They often had to exit their workstations to concentrate elsewhere, and often had to raise their voices to be heard clearly. Lack of speech intelligibility was thus a greater concern for semi-private office employees than open office space users.

Table 5.2.2.g. Mean PSA value for speech intelligibility in private office spaces (Source: Author)

Mean value for Percentage Syllable Articulation (PSA)		
Lower tiers	**Middle tiers**	**Upper tiers**
41.43%	***43.33%***	***38.73%***
Overall mean = 41.16% < 75% = Unsatisfactory		

From Table 5.2.2.g., it can be seen that mean PSA value for determining speech intelligibility conditions in private office spaces was 41.16%, which is 45.12% less than the minimum recommended value of 75%. Speech intelligibility conditions of private office spaces was found to be unsatisfactory. The deviation from recommended value was lowest in private office spaces. However, results from qualitative survey analysis suggests that most private office space users never had difficulties in comprehending and having clear conversations. Most of them rarely had to go out of their workstations to concentrate, and rarely had to raise their voice in order to be heard properly. Even though objective measurements indicated discrepancies in speech intelligibility, but like open office users, private office employees did not face significant issues with speech intelligibility in their workplaces.

The deviation in PSA value for speech intelligibility from recommended value was lowest in private office spaces.

Table 5.2.2.h. Mean PSA value for speech privacy in open and semi-private office spaces (Source: Author)

Mean value for Percentage Syllable Articulation (PSA)
Overall mean = 39.04% < 75% = Satisfactory

Speech privacy is inversely proportional to speech intelligibility. A lower value for PSA indicates poor speech intelligibility and excellent speech privacy, and vice versa. Table 5.2.2.h. shows that mean PSA value to determine speech privacy for open office spaces was 39.04%, which is less than the recommended maximum limit. The PSA value is 47.95% less than the maximum recommended value of 75%. Therefore, speech privacy conditions in open office spaces were found to be satisfactory. Qualitative survey results indicated that most open office users often could hear others' private conversations from their workstations, but they rarely worried about others eavesdropping on their own discussions. This suggests that although open office users could often overhear others' private discussions, they benefitted from it by using this occurrence as a means to shield their own conversations from others, as seen from qualitative survey questionnaire analysis.

PSA values for speech privacy determined for open office spaces would be the same for semi-private office spaces, because these spaces share the same reverberation time. Mean PSA value to determine speech privacy for semi-private office spaces was 39.04%, which is 47.95% less than the maximum recommended value of 75%. Therefore, speech privacy conditions in semi-private office spaces were found to be satisfactory. Contrastingly, questionnaire results indicated that most users often got disturbed by overhearing others conversations, and they often worried that their own conversations were being heard by others. Semi-private office users could often overhear others' private discussions in their workspaces from adjacent open office spaces, and they worried about being eavesdropped more often than open office employees.

The deviation in PSA value for speech privacy from recommended value was highest in open and semi-private office spaces.

Table 5.2.2.i. Mean PSA value for speech privacy in private office spaces (Source: Author)

Mean value for Percentage Syllable Articulation (PSA)
Overall mean = 41.16% < 75% = Satisfactory

Mean PSA value for determining speech privacy conditions in private office spaces was 41.16%, which is 45.12% less than the minimum recommended value of 75%. Speech privacy conditions of private office spaces was found to be unsatisfactory. From the questionnaire surveys, it was seen that most users never had issues hearing others conversations or being interrupted, and they never worried about being eavesdropped. Thus, it can be concluded that most private office users were fully satisfied with the level of speech privacy measures existing in their workspaces.

Even though open office participants were aware of the unsatisfactory acoustical conditions in their workplace, but they were not significantly affected or bothered by it. This implies that the initially determined recommended standards for assessing the deviations in background noise levels and PSA values for speech intelligibility of open office space may have to be re-evaluated. Like open office space users, most of the private office occupants had fewer concerns with background noise levels, reverberation time and speech intelligibility of their workplaces, and expressed satisfaction with the existing conditions. Moreover, most users from all the office spaces expressed that they were familiarised to high levels of background noise in their day to day lives from other noisy sources. Hence, initially determined recommended standards for assessing the deviations in background noise level, reverberation time and speech intelligibility of private office space may have to be re-evaluated as well.

5.2.3 Reasons behind levels of deviation in acoustical performance of green rated office buildings

The third objective in this research was to investigate the reasons behind levels of deviation in acoustical performance of green rated office buildings in Dhaka city.

From ANOVA test results obtained in chapter 4.7.2, it was seen that deviations in mean background noise levels observed in all office spaces in this research were not reliant on their vertical location in the buildings nor specific working hours. Qualitative results indicated that most participants faced issues and disruptions due to increased background noise levels during peak hours - 01 and 02. During these two time periods, the number of occupants in the office was found to be the highest (Fig. 4.6.a.). Increase in number of occupants increases the level of background activities and conversations, which may have increased the level of existing background noise levels in the office spaces.

Mean reverberation time calculated in all office spaces did not vary significantly with the vertical position of the office spaces. Mean reverberation time in private office spaces was found to be unsatisfactory. From the calculations in Appendix 07, it could be seen that less amount of noise absorptive materials and objects were present in private workstations. This may have resulted in higher levels of reverberation time in private offices, compared to open and semi-private office spaces.

Mean PSA value for speech intelligibility calculated in all office spaces did not vary significantly with the vertical position of the office spaces. Speech intelligibility conditions in all office spaces were found to be unsatisfactory. This may have been due to higher ratio of office space volume to total absorption of the office space, as shown in the calculations of Appendix 07 of this thesis. Moreover, all these spaces had high values for k_r, as shown in Appendix 08, which may have also contributed to low values of PSA for speech intelligibility.

5.3 Propositions

Results from the objective and subjective surveys conclude that there is lack of adequate acoustical performance in green rated office buildings in Dhaka city. It is inevitable to take appropriate measures in order to provide satisfactory acoustical parameters for occupants in these spaces. Proper planning and segregation of the office departments with regards to typology and nature of work as well as noise generation is required. Dedicated quiet zones for speech intelligibility and speech privacy may aid in enhancing acoustical performance for users. Acoustical design measures such as masking sound systems and acoustically enhanced ceiling, walls, partitions and flooring materials should be employed in the final design and outlook of the workspaces. In addition, increased awareness among occupants of the workspace is necessary. Guidelines on appropriate work etiquette, especially focused on noise levels generating from conversations, work activities, private phone calls and office equipment, is vital and should be ensured, preferably by the higher management committee. The results of this investigation imply that a revised guideline is required for acoustical performance standards, with regards to open and private office spaces of green-rated office buildings.

5.4 Limitations

Some of the areas and floors in the buildings surveyed in this research were not considered for acoustical evaluation due to privacy and security issues and accessibility constraints. However, this did not have any impact on the final results of acoustical evaluation, calculations and analysis.

Background noise levels of selected areas of all the buildings were measured using only a single sound level meter throughout the entire research period. Conducting the survey using multiple sound level meters with the aid of a field assistant may have helped in measuring the background noise levels of all floors at the same time.

Measuring reverberation time of all the office spaces using impulse response method would have been easier and less time consuming compared to Sabine’s method followed in this research. However, employing this method would have created inconvenience for the users of the spaces, as elaborated in chapter 1.5.

5.5 Future Possibilities

The research outcome may help to increase awareness among architects, designers, planners and clients on the significance of adequate acoustical performance in green-rated office buildings, and may introduce opportunities for future studies on related issues. This research is primarily based on Post Occupancy Evaluation (POE) surveys of green rated office buildings. POE surveys are very popular abroad and it is widely carried out by designers, engineers and stakeholders of buildings worldwide at all phases. Subsequent researchers may conduct their investigations based on comparison of green rated buildings with non-green buildings.

Substantial number of POE surveys on green rated office buildings in Dhaka city will aid in identifying the sources of prevailing problems, and also the quantitative and qualitative nature of these issues. These findings are required prior to proposing any effective and sustainable solution to the prevailing problems. Subsequent researchers may carry out their investigations based on developing solutions for acoustical performance issues of green rated office buildings.

Additional research could be carried out on comparative analysis between the relationship of outside noise and internal noise due to variation with insulating materials, to get the characteristics of noise transmission through building envelopes and fenestrations.

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APPENDIX

Appendix 01: Specifications and details of measuring instruments

Name of the device: Lutron Sound Level meter, model no: SL-4023SD, ISO-9001, CE, IEC1010

Features:

- Large LCD display, easy to read.
- IEC 61672 class 2
- Auto range & manual range
- A & C frequency weighting
- Fast & Slow time weighting
- AC output for system expansion
- RS232 computer interface
- External calibration VR
- Hold & Memory record
- High accuracy condenser microphone
- Peak Hold
- Over and under load indicator
- LCD display
- Durable, strong light weight ABS-plastic housing case

Specifications:

Display	52 mm x 32 mm LCD (Liquid Crystal Display), 5 digits
Function	dB (A & C frequency weighting), Time weighting (Fast, Slow), Hold, Memory (max. & min.), Peak hold, AC & RS232 output.
Measurement Range	30 - 130 dBA
Resolution	0.1 dBA.
Accuracy (23 ± 5 ℃)	Frequency weighting meet IEC 61672 class 2, calibrating input signal on 94 dB(31.5 Hz to 8 kHz), then the accuracy of frequency weighting is specified as following: 31.5 Hz - ± 3.5 dB, 63 Hz - ± 2.5 dB, 125 Hz - ± 2.0 dB 250 Hz - ± 1.9 dB, 500 Hz - ± 1.9 dB, 1 kHz - ± 1.4 dB 2 kHz - ± 2.6 dB, 4 kHz - ± 3.6 dB, 8 kHz - ± 5.6 dB

Frequency weighting Network	Characteristics of A & C. A weighting - The characteristic is simulated as "Human Ear Listing" response. Typical, if making the environmental sound level measurement, always select to A weighting. C weighting - The characteristic is near the "FLAT" response. Typical, it is suitable for checking the noise of machinery (Q.C. check) & knowing the sound pressure level of the tested equipment.
Frequency	31.5 Hz to 8,000 Hz
Calibrator	B & K (Bruel & kjaer), multi-function acoustic calibrator, model: 4226.
Microphone type	Electric condenser microphone.
Size of microphone	1/2-inch standard size.
Range selector	Auto range: 30 to 130 dB Manual range: 3 range, 30 to 80 dB, 50 to 100 dB, 80 to 130 dB, 50 dB on each step, with over & under range indicating.
Time Weighting (Fast & Slow)	Fast - t= 200 ms, Slow - t = 500 ms, * "Fast" range is simulated the human ear response time weighting. "Slow" range is easy to get the average values of vibration sound level. * The "Fast" & "Slow" time weighting range are designed to IEC 61672 class 2 requirement
Output Signal	* AC output - AC 0.5 Vrms corresponding to each range step. Output impedance - 600 ohm. * RS232 output.
Output terminal	Terminal 1: RS232 computer interface terminal. Terminal 2: AC output terminal. * Terminal socket size: 3.5 mm dia. phone socket
Calibration VR	Build in external calibration VR, easy to calibrate on 94 dB level by screw driver
Operating Temp	0 to 50 (32 to 122)
Operating Humidity	Less than 80% RH
Power Supply	006P DC 9V battery (Alkaline or heavy-duty type).
Power Consumption	Approx. DC 6 mA.
Dimension	268 x 68 x 29 mm (10.6 x 2.7 x 1.1 inch).
Weight	295 g/0.65 LB.
Standard Accessories	Instruction Manual ....1 PC.
Optional	Sound Calibrator, model: SC-941 (94 dB). SC-942 (94 dB, 114 dB). Carrying case: CA-06 RS232 cable, Model: UPCB-02 USB cable, Model: USB-01 Application software, Model: SW-U801-WIN

Appendix 02: Questionnaire form for open, semi-private and private office participants

Survey on Acoustical Performance

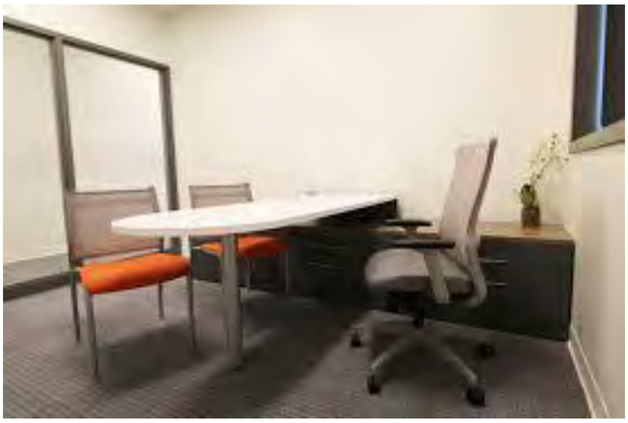
Welcome to the Survey on Acoustical Performance! This survey is intended to assess occupant comfort as it relates to the building's acoustical environment. Answers to these survey questions will help in designing better work environment for you in future. We ensure that all information you provide will be used for academic purpose only. Your answers are very important to us. Thank you for your participation in this survey!

Instructions:

Please answer the following questions by checking [√] the best answer or writing in the blank [______]. Please ask the surveyor for any explanation or guidance. Correctness of your answer is very important. Please be clear, if you have any confusion in any question. Thank you.

Date: ______________________________ ***Time:*** _____________________________

Section 1: Background Information	
1.	Gender ☐ Male ☐ Female
2.	Age group ☐ 18-24 years ☐ 25-34 years ☐ 35-44 years ☐ 45-54 years ☐ 55-64 years ☐ Greater than 65 years
3.	How do you assess the condition of your hearing health? ☐ I hear perfectly well ☐ I have very little difficulty in hearing ☐ I have some difficulty in hearing ☐ I have a lot of difficulty in hearing ☐ I use hearing aids for hearing
4.	How long have you worked in this office building? ☐ Less than 1 year ☐ 1-2 years ☐ 3-5 years ☐ More than 5 years
5.	How long do you spend working at your desk/cubicle in your office each day? ☐ 1-2 hours ☐ 3-5 hours ☐ 6-8 hours ☐ More than 8 hours ☐ Other (please specify): ____________________________________
6.	What type of office environment do you work in? ☐ Open office layout (many people working in a common open space)

	 □ Private room (single cubicle or desk, located in a personal enclosed room)  □ Shared room (group of employees/a department working in a separate enclosed room) 
7.	What type of workspace do you occupy?

	☐ Single private desk (no cubicle/partition)  ☐ Private cubicle (high partition)  ☐ Private cubicle (low partition)  ☐ Side by side open desks (no partition)

	
8.	Where is your desk/cubicle located in the office floor? You can choose multiple answers. ☐ Beside an outside window ☐ Beside a column ☐ Beside a solid brick or partition wall ☐ Beside a clear partition wall ☐ Close to public area (Example: Washrooms, lift lobby, cafeteria) ☐ Others (please specify): ________________________________
9.	Are you satisfied with your work environment? ☐ Not at all ☐ Slightly ☐ Moderately ☐ Strongly ☐ Extremely
Section 2: Information on Noise (i.e unwanted sound)	
1.	Are you satisfied with the level of noise control in your workplace? ☐ Not at all ☐ Slightly ☐ Moderately ☐ Strongly ☐ Extremely
2.	Does your workplace get noisy at times? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
3.	How often does the noise level in your workplace get louder as the area gets busier? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time

4.	How often can you hear external noise (Example: Noise from road) in your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
5.	How often can you hear internal noise (Example: Noise from A/C, ceiling fans, office equipment) in your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
6.	At what times do you usually face problem with noise levels in your workplace? You can choose multiple answers. ☐ Between 8:00 AM to 10:00 AM ☐ Between 10:00 AM to 11:00 AM ☐ Between 11:00 AM to 12:00 PM ☐ Between 12:00 PM to 1:00 PM ☐ Between 1:00 PM to 2:00 PM ☐ Between 2:00 PM to 3:00 PM ☐ Between 3:00 PM to 4:00 PM ☐ Between 4:00 PM to 5:00 PM ☐ After 5:00 PM ☐ None
7.	Do noise levels in your workplace prevent you, your colleagues and clients from hearing properly? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
8.	How often do you have to raise your voice in order to be heard properly in your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
9.	Do you feel noise levels in your workplace can negatively affect your health and hearing? ☐ Not at all ☐ Slightly ☐ Moderately ☐ Strongly ☐ Extremely

10.	Do you feel noise levels in your workplace negatively affect your work efficiency? ☐ Not at all ☐ Slightly ☐ Moderately ☐ Strongly ☐ Extremely If yes, please describe how it affects your work efficiency. ____ ____ ____ ____ ____
11.	What activities are negatively affected due to noise in your workplace? You can choose multiple options. ☐ Important conversations ☐ Complex verbal tasks (Example: planning, presentations) ☐ Routine work ☐ Arithmetic tasks (Example: budget calculation) ☐ Others (please specify): ____
12.	How does noise levels affect your daily routine in your workplace? You can choose multiple options. ☐ Increased stress ☐ Increased irritation ☐ Tiredness/exhaustion ☐ Difficulties in concentration ☐ Motivational difficulties ☐ Decreased satisfaction in job ☐ Compromising quality of work ☐ Others (please specify): ______________________________

13.	Where do you think most noise in your workplace comes from? You can choose multiple options. ☐ From the roads outside ☐ Others' conversations ☐ Others' activities ☐ Adjacent rooms ☐ Gadget noises (Example: cellphone ringing) ☐ Office equipment (Example: printer, typing on keyboard) ☐ Public areas (Example: lift lobby, washroom, kitchen) ☐ Others (please specify): ____
14.	How do you tackle excess noise levels in your workplace? You can choose multiple options. ☐ Take extra breaks ☐ Working harder ☐ Completing work quickly ☐ Working overtime ☐ Working somewhere quiet ☐ Complain to coworker and manager ☐ Others (please specify): ___________________________

Section 3: Information on Speech Privacy	
1.	How often can you hear others' conversations (including private conversations) in your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
2.	Can you and your colleagues hear each other across your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
3.	How often can you hear private conversations from meeting rooms? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time

4.	How often can you talk over private phones without feeling like you are being heard by others? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
5.	How often do you worry about other people in your workplace overhearing your private conversations? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
6.	Do you get interrupted by others' conversations while working? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
7.	What are the reasons behind lack of speech privacy in conversation in your workplace? You can choose multiple options. ☐ Open office layout ☐ Others talking loudly ☐ Too quiet space ☐ Others (please specify): ________________________________
8.	Is there provision in your workplace for speech privacy when needed? ☐ Yes ☐ No If yes, what facility is provided by your workplace provides speech privacy? ________________________________

Section 4: Information on Speech Intelligibility	
1.	Do you find it difficult to understand conversations clearly in your workplace? ☐ Not at all ☐ Slightly ☐ Moderately ☐ Strongly ☐ Extremely

2.	Can you have proper and clear one to one conversation in your workplace? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
3.	Do you have to go somewhere else to concentrate in a conversation when it gets too noisy? ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time
4.	What are the reasons behind lack of speech intelligibility in conversation in your workplace? You can choose multiple options. ☐ Noise from equipment or gadgets ☐ Others talking loudly ☐ Echo/reverberation of sounds ☐ High level of background noise ☐ Others (please specify): ____
5.	Is there provision in your workplace for concentration in tasks when needed? ☐ Yes ☐ No If yes, what facility is provided by your workplace for work concentration? ____

Section 5: Overall Comments	
1.	Do you have any suggestions for improving the overall acoustic environment of your workplace (in terms of noise control, speech privacy of conversation and intelligibility of speech)? ____ ____ ____

	______________________________ ______________________________ ______________________________ ______________________________ ______________________________
2.	Do you have any other comments in respect to your workplace, or any general comments? ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________

Appendix 03: Absorption coefficient values for materials

Table A3.1.1. Absorption Coefficient values for various materials (Source: www.acoustic.ua)

ABSORPTION COEFFICIENTS www.akustik.ua

MATERIAL	THICKNESS	125	250	500	1000	2000	4000
		FREQUENCY Hz					
MASONRY WALLS							
Rough concrete		0,02	0,03	0,03	0,03	0,04	0,07
Smooth unpainted concrete		0,01	0,01	0,02	0,02	0,02	0,05
Smooth concrete, painted or glazed		0,01	0,01	0,01	0,02	0,02	0,02
Porous concrete blocks (no surface finish)		0,05	0,05	0,05	0,08	0,14	0,2
Clinker concrete (no surface finish)		0,10	0,20	0,40	0,60	0,50	0,60
Smooth brickwork with flush pointing		0,02	0,03	0,03	0,04	0,05	0,07
Smooth brickwork with flush pointing, painted		0,01	0,01	0,02	0,02	0,02	0,02
Standard brickwork		0,05	0,04	0,02	0,04	0,05	0,05
Brickwork, 10mm flush pointing		0,08	0,09	0,12	0,16	0,22	0,24
Lime cement plaster on masonry wall		0,02	0,02	0,03	0,04	0,05	0,05
Glaze plaster on masonry wall		0,01	0,01	0,01	0,02	0,02	0,02
Painted plaster surface on masonry wall		0,02	0,02	0,02	0,02	0,02	0,02
Plaster on masonry wall with wall paper on backing paper		0,02	0,03	0,04	0,05	0,07	0,08
Ceramic tiles with smooth surface		0,01	0,01	0,01	0,02	0,02	0,02
Breeze block		0.20	0.45	0.60	0,40	0,45	0,40
Plaster on solid wall		0,04	0,05	0,06	0,08	0,04	0,06
Plaster, lime or gypsum on solid backing		0,03	0,03	0,02	0,03	0,04	0,05
STUDWORK AND LIGHTWEIGHT WALLS							
Plasterboard on battens, 18mm airspace with glass wool		0,30	0,20	0,15	0,05	0,05	0,05
Plasterboard on frame, 100mm airspace		0,30	0,12	0,08	0,06	0,06	0,05
Plasterboard on frame, 100mm airspace with glass wool		0,08	0,11	0,05	0,03	0,02	0,03
Plasterboard on 50mm battens		0,29	0,10	0,05	0,04	0,07	0,09
Plasterboard on 25mm battens		0,31	0,33	0,14	0,10	0,10	0,12
2 x plasterboard on frame, 50mm airspace with mineral wool	2 x 13mm	0,15	0,10	0,06	0,04	0,04	0,05
Plasterboard on cellular core partition		0,15	0,00	0,07	0,00	0,04	0,05
Plasterboard on frame 100mm cavity	13mm	0,08	0,11	0,05	0,03	0,02	0,03
Plasterboard on frame, 100mm cavity with mineral wool	13mm	0,30	0,12	0,08	0,06	0,06	0,05
2 x 13mm plasterboard on steel frame, 50mm mineral wool in cavity, surface painted	26mm	0,15	0,01	0,06	0,04	0,04	0,05
GLASS AND GLAZING							
4mm glass	4mm	0,30	0,20	0,10	0,07	0,05	0,02
6mm glass	6mm	0,10	0,06	0,04	0,03	0,02	0,02
Double glazing, 2-3mm glass, 10mm air gap		0,15	0,05	0,03	0,03	0,02	0,02
WOOD AND WOOD PANELLING							
3-4mm plywood, 75mm cavity containing mineral wool	1	0,5	0,3	0,1	0,05	0,05	0,05
5mm plywood on battens, 50mm airspace filled		0,40	0,35	0,20	0,15	0,05	0,05
12mm plywood over 50mm airgap	1	0,25	0,05	0,04	0,03	0,03	0,02
12mm plywood over 150mm airgap	1	0,28	0,08	0,07	0,07	0,09	0,09
12mm plywood over 200mm airgap containing 50mm mineral wool	1	0,14	0,10	0,10	0,08	0,10	0,08
Plywood mounted solidly		0,05		0,05		0,05	0,05
12mm plywood in framework with 30mm airspace behind	12mm	0,35	0,20	0,15	0,10	0,05	0,05
12mm plywood in framework with 30mm airspace containing glass wool	12mm	0,40	0,20	0,15	0,10	0,10	0,05
Plywood, hardwood panels over 25mm airspace on solid backing		0,30	0,20	0,15	0,10	0,10	0,05
Plywood, hardwood panels over 25mm airspace on solid backing with absorbent material in air space		0,40	0,25	0,15	0,10	0,10	0,05
12mm wood panelling on 25mm battens	12mm	0,31	0,33	0,14	0,10	0,10	0,12
Timber boards, 100mm wide, 10mm gaps, 500mm airspace with mineral wool	22mm	0,05	0,25	0,60	0,15	0,05	0,10

T & g board on frame, 50mm airspace with mineral wool	16mm	0,25	0,15	0,10	0,09	0,08	0,07
16-22mm t&g wood on 50mm cavity filled with mineral wool		0,25	0,15	0,1	0,09	0,08	0,07
Cedar, slotted and profiled on battens mineral wool in airspace		0,20	0,62	0,98	0,62	0,21	0,15
Wood boards on on joists or battens		0,15	0,20	0,10	0,10	0,10	0,10
20mm dense veneered chipboard over 100mm airgap		0,03	0,05	0,04	0,03	0,03	0,02
20mm dense veneered chipboard over 200mm airgap		0,06	0,10	0,08	0,09	0,07	0,04
20mm dense veneered chipboard over 250mm airgap containing 50mm mineral wool		0,12	0,10	0,08	0,07	0,10	0,08
6mm wood fibre board, cavity > 100mm, empty		0,3	0,2	0,2	0,1	0,05	0,05
22mm chipboard, 50mm cavity filled with mineral wool		0,12	0,04	0,06	0,05	0,05	0,05
Acoustic timber wall panelling		0,18	0,34	0,42	0,59	0,83	0,68
Hardwood, mahogany		0,19	0,23	0,25	0,30	0,37	0,42
Chipboard on 16mm battens	20mm	0,20	0,25	0,20	0,20	0,15	0,20
Chipboard on frame, 50mm airspace with mineral wool	22mm	0,12	0,04	0,06	0,05	0,05	0,05

MINERAL WOOL AND FOAMS

Melamine based foam 25mm		0,09	0,22	0,54	0,76	0,88	0,93
Melamine based foam 50mm		0,18	0,56	0,96	1,00	1,00	1,00
Glass wool 25mm 16 kg/m3		0,12	0,28	0,55	0,71	0,74	0,83
Glass wool 50mm, 16 kg/m3		0,17	0,45	0,80	0,89	0,97	0,94
Glass wool 75mm, 16 kg/m3		0,30	0,69	0,94	1,00	1,00	1,00
Glass wool 100mm, 16 kg/m3		0,43	0,86	1,00	1,00	1,00	1,00
Glass wool 25mm, 24 kg/m3		0,11	0,32	0,56	0,77	0,89	0,91
Glass wool 50mm, 24 kg/m3		0,27	0,54	0,94	1,00	0,96	0,96
Glass wool 75mm, 24 kg/m3		0,28	0,79	1,00	1,00	1,00	1,00
Glass wool 100mm, 24 kg/m3		0,46	1,00	1,00	1,00	1,00	1,00
Glass wool 50mm, 33 kg/m3		0,20	0,55	1,00	1,00	1,00	1,00
Glass wool 75mm, 33 kg/m3		0,37	0,85	1,00	1,00	1,00	1,00
Glass wool 100mm, 33 kg/m3		0,53	0,92	1,00	1,00	1,00	1,00
Glass wool 50mm, 48 kg/m3		0,30	0,80	1,00	1,00	1,00	1,00
Glass wool 75mm, 48 kg/m3		0,43	0,97	1,00	1,00	1,00	1,00
Glass wool 100mm, 48 kg/m3		0,65	1,00	1,00	1,00	1,00	1,00
Rock wool 50mm, 33 kg/m3 direct to masonry	17	0,15	0,60	0,90	0,90	0,90	0,85
Rock wool 100mm, 33 kg/m3 direct to masonry	17	0,35	0,95	0,98	0,92	0,90	0,85
Rock wool 50mm, 60 kg/m3 direct to masonry	17	0,11	0,60	0,96	0,94	0,92	0,82
Rock wool 75mm, 60 kg/m3 direct to masonry	17	0,34	0,95	0,98	0,82	0,87	0,86
Rock wool 30mm, 100 kg/m3 direct to masonry	17	0,10	0,40	0,80	0,90	0,90	0,90
Rock wool 30mm, 200 kg/m3 over 300mm air gap	17	0,40	0,75	0,90	0,80	0,90	0,85
Glass wool or mineral wool on solid backing	25mm	0,20	0,00	0,70	0,00	0,90	0,80
Glass wool or mineral wool on solid backing	50mm	0,30	0,00	0,80	0,00	0,95	0,90
Glass wool or mineral wool over air space on solid bs	25mm	0,40	0,00	0,80	0,00	0,90	0,80
Fibreglass super fine mat	50mm	0,15	0,40	0,75	0,85	0,80	0,85
Fibreglass scrim-covered sewn sheet	40mm	0,40	0,80	0,95	0,95	0,80	0,85
Fibreglass bitumen bonded mat	25mm	0,10	0,35	0,50	0,55	0,70	0,70
Fibreglass bitumen bonded mat	50mm	0,30	0,55	0,80	0,85	0,75	0,80
Fibreglass resin bonded mat	25mm	0,10	0,35	0,55	0,65	0,75	0,80
Fibreglass resin bonded mat	50mm	0,20	0,50	0,70	0,80	0,75	0,80
Fibreglass resin bonded board	25mm	0,10	0,25	0,55	0,70	0,80	0,85
Flexible polyurethane foam 50mm		0,25	0,50	0,85	0,95	0,90	0,90
Rigid polyurethane foam 50mm		0,20	0,40	0,65	0,55	0,70	0,70
12mm expanded polystyrene on 45mm battens		0,05	0,15	0,40	0,35	0,20	0,20
25mm expanded polystyrene on 50mm battens		0,10	0,25	0,55	0,20	0,10	0,15

WALL TREATMENTS & CONSTRUCTIONS

Cork tiles 25mm on solid backing		0,05	0,10	0,20	0,55	0,60	0,55
Cork board, 25mm on solid backing	25mm	0,03	0,05	0,17	0,52	0,50	0,52
Cork board, 25mm, 2.9kg/m2, on battens	25mm	0,15	0,40	0,65	0,35	0,35	0,30
Glass blocks or glazed tiles as wall finish		0,01	0,00	0,01	0,00	0,01	0,01
Muslin covered cotton felt	25mm	0,15	0,45	0,70	0,85	0,95	0,85
Pin up boarding - medium hardboard on solid backing		0,05	0,00	0,10	0,00	0,10	0,10
Fibreboard on solid backing	12mm	0,05	0,10	0,15	0,25	0,30	0,30
25mm thick hair felt, covered by scrim cloth on solid backing	25mm	0,10	0,00	0,70	0,00	0,80	0,80

Fibreboard on solid backing	soft 12mm	0,05	0,00	0,15	0,00	0,30	0,30
Fibreboard on solid backing - painted		0,05	0,00	0,10	0,00	0,15	0,15
Fibreboard over airspace on solid wall	12mm	0,30	0,00	0,30	0,00	0,30	0,30
Fibreboard over airspace on solid wall painted		0,30	0,00	0,15	0,00	0,10	0,10
Plaster on lath, deep air space		0,20	0,15	0,10	0,05	0,05	0,05
Plaster decorative panels, walls		0,20	0,15	0,10	0,08	0,04	0,02
Acoustic plaster to solid backing	25mm	0,03	0,15	0,50	0,80	0,85	0,80
9mm acoustic plaster to solid backing	9mm	0,02	0,08	0,30	0,60	0,80	0,90
9mm acoustic plaster on plasterboard, 75mm airspace	9mm	0,30	0,30	0,60	0,8	0,75	0,75
12.5mm acoustic plaster on plaster backing over 75mm air space	12.5mm	0,35	0,35	0,40	0,55	0,70	0,70
Woodwool slabs, unplastered on solid backing	25mm	0,10	0,00	0,40	0,00	0,60	0,60
Woodwool slabs, unplastered on solid backing	50mm	0,10	0,20	0,45	0,80	0,60	0,75
Woodwool slabs, unplastered on solid backing	75mm	0,20	0,00	0,80	0,00	0,80	0,80
Woodwool slabs, unplastered over 20mm airspace on solid backing	25mm	0,15	0,00	0,60	0,00	0,60	0,70
Plasterboard backed with 25mm thick bitumen-bonded fibreglass on 50mm battens	10mm	0,30	0,20	0,15	0,05	0,05	0,05
Curtains hung in folds against soild wall		0,05	0,15	0,35	0,40	0,50	0,50
Cotton Curtains (0.5kg/m2),draped to 75% area approx. 130mm from wall		0,30	0,45	0,65	0,56	0,59	0,71
Lightweight curtains (0.2 kg/m2) hung 90mm from wall		0,05	0,06	0,39	0,63	0,70	0,73
Curtains of close-woven glass mat hung 50mm from wall		0,03	0,03	0,15	0,40	0,50	0,50
Curtains, medium velour, 50% gather, over soild backing		0,05	0,25	0,40	0,50	0,60	0,50
Curtains (medium fabrics) hung straight and close to wall		0,05	0,00	0,25	0,00	0,30	0,40
Curtains in folds against wall		0,05	0,15	0,35	0,40	0,50	0,50
Curtains (medium fabrics) double widths in folds spaced away from wall		0,10	0,00	0,40	0,00	0,50	0,60
Acoustic banner, 0.5 kg/m2 wool serge, 300mm from wall		0,11	0,40	0,70	0,74	0,88	0,89
FLOORS							
Smooth marble or terrazzo slabs		0,01	0,01	0,01	0,01	0,02	0,02
Raised computer floor, steel-faced 45mm chipboard 800mm above concrete floor, no carpet		0,08	0,07	0,06	0,07	0,08	0,08
Raised computer floor, steel-faced 45mm chipboard 800mm above concrete floor, office-grade carpet tiles		0,27	0,26	0,52	0,43	0,51	0,58
Wooden floor on joists		0,15	0,11	0,10	0,07	0,06	0,07
Parquet fixed in asphalt, on concrete		0,04	0,04	0,07	0,06	0,06	0,07
Parquet on counterfloor		0,20	0,15	0,10	0,10	0,05	0,10
Linoleum or vinyl stuck to concrete		0,02	0,02	0,03	0,04	0,04	0,05
Layer of rubber, cork, linoleum + underlay, or vinyl+underlay stuck to concrete		0,02	0,02	0,04	0,05	0,05	0,10
5mm needle-felt stuck to concrete	5mm	0,01	0,02	0,05	0,15	0,30	0,40
6mm pile carpet bonded to closed-cell foam underlay	6mm	0,03	0,09	0,25	0,31	0,33	0,44
6mm pile carpet bonded to open-cell foam underlay	6mm	0,03	0,09	0,20	0,54	0,70	0,72
9mm pile carpet, tufted on felt underlay	9mm	0,08	0,08	0,30	0,60	0,75	0,80
Composition flooring		0,05	0,05	0,05	0,05	0,05	0,05
Haircord carpet on felt underlay	6mm	0,05	0,05	0,10	0,20	0,45	0,65
Medium pile carpet on sponge rubber underlay	10mm	0,50	0,10	0,30	0,50	0,65	0,70
Thick pile carpet on sponge rubber underlay	15mm	0,15	0,25	0,50	0,60	0,70	0,70
Rubber floor tiles	6mm	0,05	0,05	0,10	0,10	0,05	0,05
Carpet, thin, over thin felt on concrete		0,10	0,15	0,25	0,30	0,30	0,30
Carpet, thin, over thin felt on wood floor		0,20	0,25	0,30	0,30	0,30	0,30
Carpet, needlepunch	5mm	0,03	0,05	0,05	0,25	0,35	0,50
Stone floor, plain or tooled or granolithic finish		0,02	0,02	0,02	0,02	0,05	0,05
Corkfloor tiles	14mm	0,00	0,05	0,15	0,25	0,25	0,00
Sheet rubber (hard)	6mm	0,00	0,05	0,05	0,10	0,05	0,00
Woodblock/linoleum/rubber/cork tiles (thin) on solid floor (or wall)		0,02	0,04	0,05	0,05	0,10	0,05

Floor tiles, plastic or linoleum		0,03	0,00	0,03	0,00	0,05	0,05
Steel decking		0,13	0,09	0,08	0,09	0,11	0,11
PANELS AND DOORS							
Wood hollowcore door		0,30	0,25	0,15	0,10	0,10	0,07
Solid timber door		0,14	0,10	0,06	0,08	0,10	0,10
Acoustic door, steel frame, double seals, absorbent in airspace, Double sheet steel skin		0,35	0,39	0,44	0,49	0,54	0,57
CEILINGS							
Mineral wool tiles, 180mm airspace		0,42	0,72	0,83	0,88	0,89	0,80
Mineral wool tiles, glued/screwed to soffit		0,06	0,40	0,75	0,95	0,96	0,83
Gypsum plaster tiles, 17% perforated, 22mm		0,45	0,70	0,80	0,80	0,65	0,45
Metal ceiling, 32.5% perforated, backed by 30mm rockwool		0,12	0,45	0,87	0,98	1,00	1,00
Perforated underside of structural steel decking (typical, depends on perforations)		0,30	0,70	0,85	0,90	0,70	0,65
17% perforated plaster tiles, absorbent felt glued to back, 200mm ceiling void		0,43	0,70	0,88	0,52	0,42	0,35
100mm woodwool slabs on 25mm cavity, pre-screeded surface facing cavity		0,60	0,75	0,85	0,65	0,70	0,70
50mm woodwool slabs on 25mm cavity, pre-screeded surface facing cavity		0,30	0,40	0,50	0,85	0,50	0,65
100mm woodwool fixed directly to concrete, pre-screeded surface facing backing		0,25	0,80	0,85	0,65	0,70	0,75
75mm woodwool fixed directly to concrete, pre-screeded surface facing backing		0,15	0,40	0,95	0,60	0,70	0,50
Plasterboard 10mm thick backed with 25mm thick bitumen	10mm	0,30	0,20	0,15	0,05	0,05	0,05
Plasterboard 10mm thick, perforated 8mm diameter holes 2755m2 16% open area backed with 25mm thick bitumen bonded fibreglass on 50mm battens	10mm	0,25	0,70	0,85	0,55	0,40	0,30
Plywood, 5mm, on battens 50mm airspace filled with glass wool	5mm	0,40	0,35	0,20	0,15	0,05	0,05
Plywood, 12mm, with 30mm thick fibreglass backing between 30mm battens		0,40	0,20	0,15	0,10	0,10	0,05
Plywood 12mm thick perforated 5mm diameter holes 6200 m2 11% open area with 60mm deep air space behind		0,20	0,35	0,55	0,30	0,25	0,30
Plywood 12mm thick perforated 5mm diameter holes 6200 m2 11% open area backed with 60mm thick fibreglass between mounting battens		0,40	0,90	0,80	0,50	0,40	0,30
Hardboard, 25% perforated over 50mm mineral wool		0,27	0,87	1,00	1,00	0,98	0,96
0.8mm unperforated metal panels backed with 25mm thick resin bonded fibreglass, mounted on 22mm diameter pipes 135mm from wall	0.8mm	0,50	0,35	0,15	0,05	0,05	0,00
0.8mm perforated metal tiles 2mm diameter holes 29440/m2, 13% open area backed with 25mm thick resin-bonded fibreglass slab. No airspace.	0.8mm	0,10	0,80	0,80	0,75	0,80	0,80
50mm mineral wool (96 kg/m3) behind 25% open area perforated steel.	50mm	0,20	0,35	0,65	0,85	0,90	0,80
Wood panels, 18mm alternate 15mm slot & 35mm wooden slat	18mm	0,10	0,36	0,74	0,91	0,61	0,50
25mm rockwool backing, 32mm airspace behind Plaster decorative panels, ceilings		0,20	0,22	0,18	0,15	0,15	0,16
AUDIENCE AND SEATING							
Children, standing (per child) in m2 units		0,12	0,22	0,37	0,40	0,42	0,37
Children, seated in plastic or metal chairs (per child) in m2 units		0,28	0,00	0,33	0,00	0,37	0,37
Students seated in tablet arm chairs		0,30	0,41	0,49	0,84	0,87	0,84
Adults per person seated		0,33	0,40	0,44	0,45	0,45	0,45
Adults per person standing		0,15	0,38	0,42	0,43	0,45	0,45
Empty plastic or metal chairs (per chair) in m2 units		0,07	0,00	0,14	0,00	0,14	0,14

Seats, leather covers, per m2	0,40	0,50	0,58	0,61	0,58	0,50
Cloth-upholstered seats, per m2	0,44	0,60	0,77	0,89	0,82	0,70
Floor and cloth-upholstered seats, per m2	0,49	0,66	0,80	0,88	0,82	0,70
Adults in plastic and metal chairs in m2 units	0,30	0,00	0,40	0,00	0,43	0,40
Adults in wooden or padded chairs or seats (per item) in m2	0,16	0,00	0,40	0,00	0,44	0,40
Adults on timber seats, 1 per m2 per item	0,16	0,24	0,56	0,69	0,81	0,78
Adults on timber seats, 2 per m2 per item	0,24	0,40	0,78	0,98	0,96	0,87
Wooden or padded chairs or seats (per item) in m2	0,08	0,00	0,15	0,00	0,18	0,20
Seating, slightly upholstered, unoccupied	0,07	0,12	0,26	0,42	0,50	0,55
Seating, slightly upholstered, occupied	0,32	0,62	0,70	0,76	0,81	0,90
Fully upholstered seats (per item) in m2	0,12	0,00	0,28	0,00	0,32	0,37
Upholstered tip-up theatre seats, empty	0,33	0,51	0,64	0,71	0,77	0,81
Areas with audience, orchestra, or seats, including narrow aisles	0,60	0,74	0,88	0,96	0,93	0,85
Auditorium seat, unoccupied	0,13	0,33	0,59	0,58	0,61	0,62
Auditorium seat, occupied	0,37	0,48	0,68	0,79	0,77	0,74
Orchestra with instruments on podium, 1.5 m2 per person	0,27	0,53	0,67	0,93	0,87	0,80
Orchestral player with instrument (average) per person	0,37	0,80	1,00	1,00	1,00	1,00
Prosenium opening with average stage set per m2 of opening	0,20	0,00	0,30	0,00	0,40	0,50
Wood platform with large space beneath	0,40	0,30	0,20	0,17	0,15	0,10
Adult office furniture per desk	0,50	0,40	0,45	0,45	0,60	0,70
OTHER						
Water surface, ie swimming pool	0,01	0,01	0,01	0,01	0,02	0,02
Ventilation grille per m2	0,60	0,60	0,60	0,60	0,60	0,60

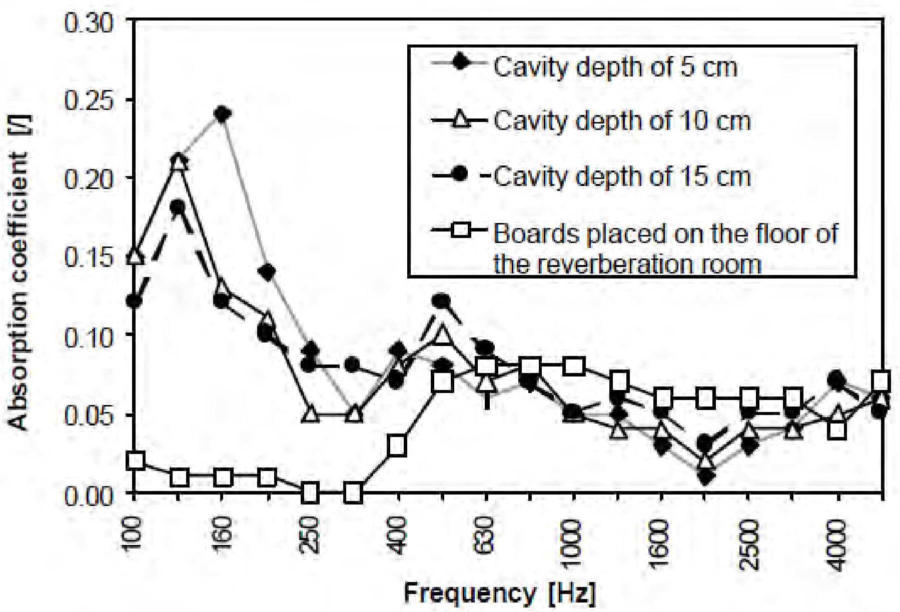


Fig. A3.1.1. Absorption coefficients for configurations with single layer of gypsum boards and different cavity depths (Source: Antonino et al. n.d.)

Table A3.1.2. Material list and sound absorption coefficients (Source: Su et al. 2007)

Material	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
%50 absorbent (voids)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Ceramic tiles with smooth surface	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Granite	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Gypsum board (under escalator, w:12.5 mm)	0.29	0.29	0.10	0.05	0.04	0.07	0.09	0.09
Steel trapeze profile (approximated)	0.40	0.30	0.25	0.20	0.10	0.10	0.15	0.15
Ballast, 3.2 cm aggregate, 45.7 cm depth	0.41	0.41	0.53	0.64	0.84	0.91	0.63	0.63
Concrete block, rough surface	0.36	0.36	0.44	0.31	0.29	0.39	0.25	0.82
Concrete block, painted	0.10	0.10	0.05	0.06	0.07	0.09	0.08	0.08
Large pane of glass	0.18	0.18	0.06	0.04	0.03	0.02	0.02	0.02
Suspended ceiling	0.45	0.45	0.80	0.65	0.72	0.78	0.74	0.74
Escalator	0.05	0.05	005	0.05	0.06	0.04	0.02	0.02
Steel door	0.05	0.05	0.05	0.05	0.06	0.04	0.02	0.02

Table A3.1.3. Absorption coefficients of elastomeric foam and glass wool (Source: Gurav et al. 2014)

Material Combination: Elastomeric Foam and Glass Wool				
Thickness of porous absorbers (mm)	**Angle of porous absorbers (deg)**	**Intensity of sound before sound attenuator (dB)**	**Intensity of sound after sound attenuator (dB)**	**Sound Absorbing Coefficient**
25-75	0	90.4	76.91	0.1496
25-75	2	90.4	76.37	0.1556
25-75	4	90.4	76.94	0.1492
50-50	0	90.4	77.21	0.1462
50-50	2	90.4	77.01	0.1484
50-50	4	90.4	77.69	0.1410
Material Combination: Elastomeric Foam and Glass Wool				
Thickness of porous absorbers (mm)	**Angle of porous absorbers (deg)**	**Intensity of sound before sound attenuator (dB)**	**Intensity of sound after sound attenuator (dB)**	**Sound Absorbing Coefficient**
75-25	0	90.4	76.83	0.1505
75-25	2	90.4	76.23	0.1571
75-25	4	90.4	76.36	0.1557

Table A3.1.4. Sound absorption coefficients of various materials (Source: Stein 2006)

General Building Materials and Furnishings[b]	Mfg[c]	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC[c]
		Absorption Coefficients (α)						
Brick, unglazed		0.03	0.03	0.03	0.04	0.05	0.07	0.005
Brick, unglazed, painted		0.01	0.01	0.02	0.02	0.02	0.03	0.00
Carpet, heavy, on concrete		0.02	0.06	0.14	0.37	0.60	0.65	0.29
Carpet, heavy, on 1.36 kg/m² hair felt or foam rubber		0.08	0.24	0.57	0.69	0.71	0.73	0.55
Concrete block, coarse		0.36	0.44	0.31	0.29	0.39	0.25	0.35
Concrete block, painted		0.10	0.05	0.06	0.07	0.09	0.08	0.05
Fabrics								
Light velour, 0.34 kg/m², hung straight, in contact with wall		0.03	0.04	0.11	0.17	0.24	0.35	0.15
Medium velour, 0.47 kg/m², draped to half area		0.07	0.31	0.49	0.75	0.70	0.60	0.55
Heavy velour, 0.61 kg/m², draped to half area		0.14	0.35	0.55	0.72	0.70	0.65	0.60
Floors								
Concrete or terrazzo		0.01	0.01	0.015	0.02	0.02	0.02	0.00
Linoleum, asphalt, rubber, or cork tile on concrete		0.02	0.03	0.03	0.03	0.03	0.02	0.05
Wood		0.15	0.11	0.10	0.07	0.06	0.07	0.10
Glass								
Large panes of heavy plate glass		0.18	0.06	0.04	0.03	0.02	0.02	0.05
Ordinary window glass		0.35	0.25	0.18	0.12	0.07	0.04	0.15
Gypsum board, 13 mm nailed to 50x100 mm stud 400 mm c/c		0.10	0.08	0.05	0.03	0.03	0.03	0.05
Marble or glazed tile		0.01	0.01	0.01	0.01	0.02	0.02	0.00
Openings								
Stage, depending on furnishings					0.25-0.75			
Deep balcony, upholstered seats					0.50-1.00			
Grilles, ventilating					0.15-0.50			
Plaster, gypsum or lime, smooth finish on tile or brick		0.013	0.015	0.02	0.03	0.04	0.05	0.05
Plaster, gypsum or lime, on lath		0.14	0.10	0.06	0.05	0.04	0.03	0.05
Plywood panelling, 9 mm thick		0.28	0.22	0.17	0.09	0.10	0.11	0.15
Rough wood, as tongue-and-groove cedar		0.24	0.19	0.14	0.08	0.13	0.10	0.14
Slightly vibrating surface (e.g., hollow core door)		0.02	0.02	0.03	0.03	0.04	0.05	0.03
Readily vibrating surface (e.g., thin wood panelling on 400 mm studs)		0.10	0.07	0.05	0.04	0.04	0.05	0.05
Water surface, as in swimming pool		0.008	0.008	0.013	0.015	0.020	0.025	0.00
Absorption of Seats and Audience[d]		**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**NRC**[c]
Audience, in upholstered seats, per 0.093 m² of floor area		0.60	0.74	0.88	0.96	0.93	0.85	-
Unoccupied cloth-upholstered seats, per 0.093 m² of floor area		0.49	0.66	0.80	0.88	0.82	0.70	-
Wooden pews, occupied, per 0.093 m² of floor area		0.57	0.61	0.75	0.86	0.91	0.86	-
Students in tablet-arm chairs, per 0.093 m² of floor area		0.30	0.42	0.50	0.85	0.85	0.84	-
Acoustic Absorptive Materials	**Mfg**[c]	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**NRC**[c]
High-performance vinyl-faced fibreglass								
Ceiling panels								
25 mm thick	E405	0.73	0.88	0.71	0.98	0.96	0.77	0.90
38 mm thick	E405	0.79	0.98	0.83	1.03	0.98	0.80	0.95
Painted nubby glass cloth panels								
6 mm thick	E405	0.81	0.94	0.65	0.87	1.00	0.96	0.85
25 mm thick	E405	0.78	0.92	0.79	1.00	1.03	1.10	0.95
Random fissured 19 mm-thick panels	E405	0.52	0.58	0.60	0.80	0.92	0.80	0.70
Perforated metal panel with infill 1 in. thick	E405	0.70	0.86	0.74	0.88	0.95	0.86	0.85
Typical averages, mineral fibre tiles and panels								
19 mm fissured	E405	0.47	0.50	0.52	0.76	0.86	0.81	0.65
19 mm textured	E405	0.49	0.55	0.53	0.80	0.94	0.83	0.70
16 mm fissured	E405	0.28	0.33	0.66	0.73	0.74	0.75	0.60
16 mm textured	E405	0.29	0.35	0.66	0.63	0.44	0.34	0.50
16 mm perforated	E405	0.27	0.29	0.55	0.78	0.69	0.53	0.60
75 mm in thick x 400 mm square on 600 mm centres	A	0.40	0.61	1.92	2.54	2.62	2.60	

Appendix 04: Scorecard of Indoor Environmental Quality of LEED certification rating of the four buildings

Table A4.1.1. Scorecard of Indoor Environmental Quality of LEED certification rating of the four buildings (Source: U.S. Green Building Council)

Indoor Environmental Quality of Building A

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 5 / 20
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	0 / 1
EQc3	Construction IAQ Mgmt plan - during construction	0 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6	Controllability of systems - thermal comfort	0 / 1
EQc7	Thermal comfort - design	1 / 1
EQc8.1	Daylight and views - daylight	1 / 1
EQc8.2	Daylight and views - views	1 / 1
EQpc123	Designing with Nature, Biophilic Design for the Indoor Environment	REQUIRED
EQpc124	Performance-based IAQ design and assessment	REQUIRED

Indoor Environmental Quality of Building B

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 8 / 20
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	1 / 1
EQc3	Construction IAQ Mgmt plan - during construction	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1 / 1
EQc5	Indoor chemical and pollutant source control	1 / 1
EQc6	Controllability of systems - thermal comfort	0 / 1
EQc7	Thermal comfort - design	1 / 1
EQc8.1	Daylight and views - daylight	1 / 1
EQc8.2	Daylight and views - views	0 / 1
EQpc123	Designing with Nature, Biophilic Design for the Indoor Environment	REQUIRED
EQpc124	Performance-based IAQ design and assessment	REQUIRED

Indoor Environmental Quality of Building C

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 8 / 20
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	1 / 1
EQc3	Construction IAQ Mgmt plan - during construction	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	0 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6	Controllability of systems - thermal comfort	0 / 1
EQc7	Thermal comfort - design	1 / 1
EQc8.1	Daylight and views - daylight	1 / 1
EQc8.2	Daylight and views - views	1 / 1
EQpc123	Designing with Nature, Biophilic Design for the Indoor Environment	REQUIRED
EQpc124	Performance-based IAQ design and assessment	REQUIRED

Indoor Environmental Quality of Building D

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 9 / 23
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	0 / 1
EQc6.2	Controllability of systems - thermal comfort	0 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	1 / 1
EQc8.2	Daylight and views - views	1 / 1
EQpc123	Designing with Nature, Biophilic Design for the Indoor Environment	REQUIRED
EQpc124	Performance-based IAQ design and assessment	REQUIRED

Appendix 05: Floor plans of selected floors of each studied building

- Building A (Lower tier):

Fig. A5.1.1. Floor plan of Building A: Lower tier (Source: Building A contractor, edited by author)

- Building A (Middle tier):

Fig. A5.1.2. Floor plan of Building A: Middle tier (Source: Building A contractor, edited by author)

- Building A (Upper tier):

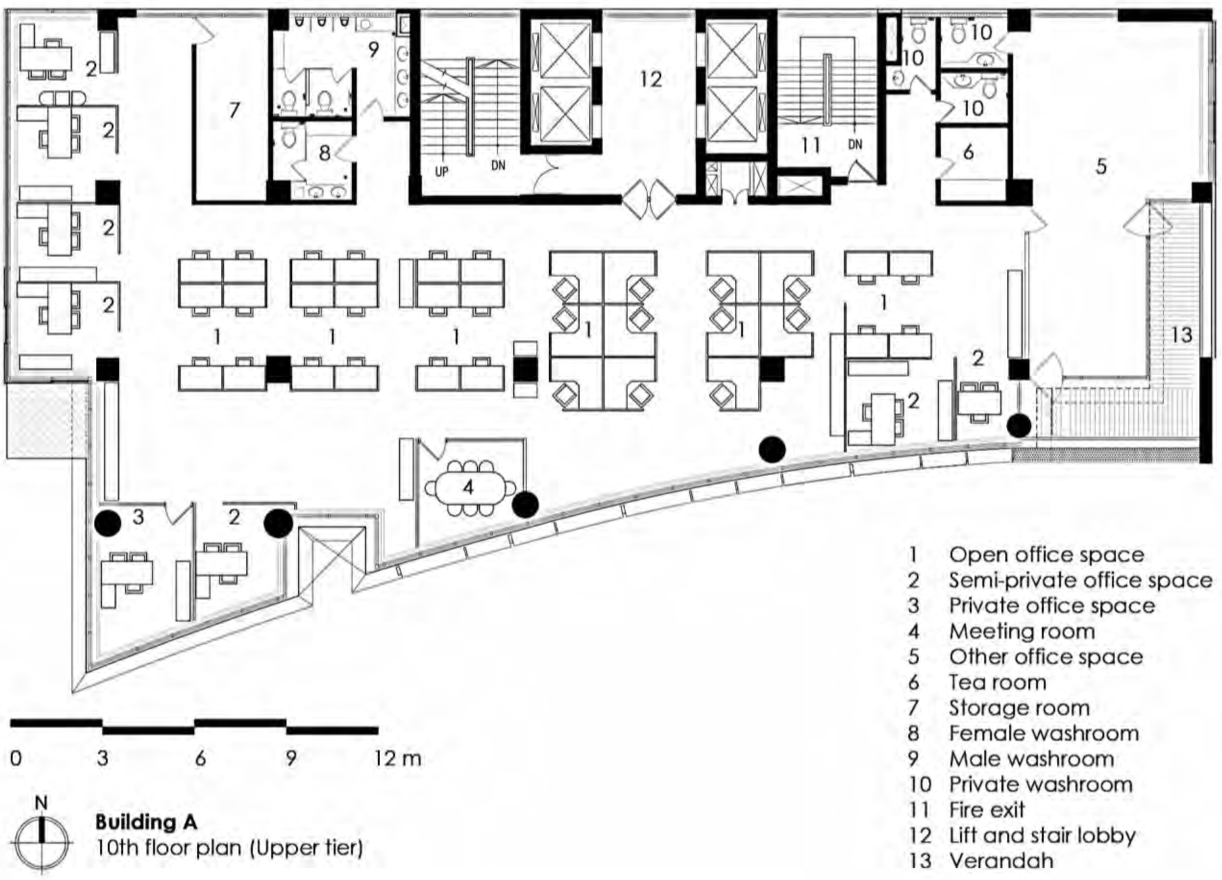


Fig. A5.1.3. Floor plan of Building A: Upper tier (Source: Building A contractor, edited by author)

- Building B (Lower tier):

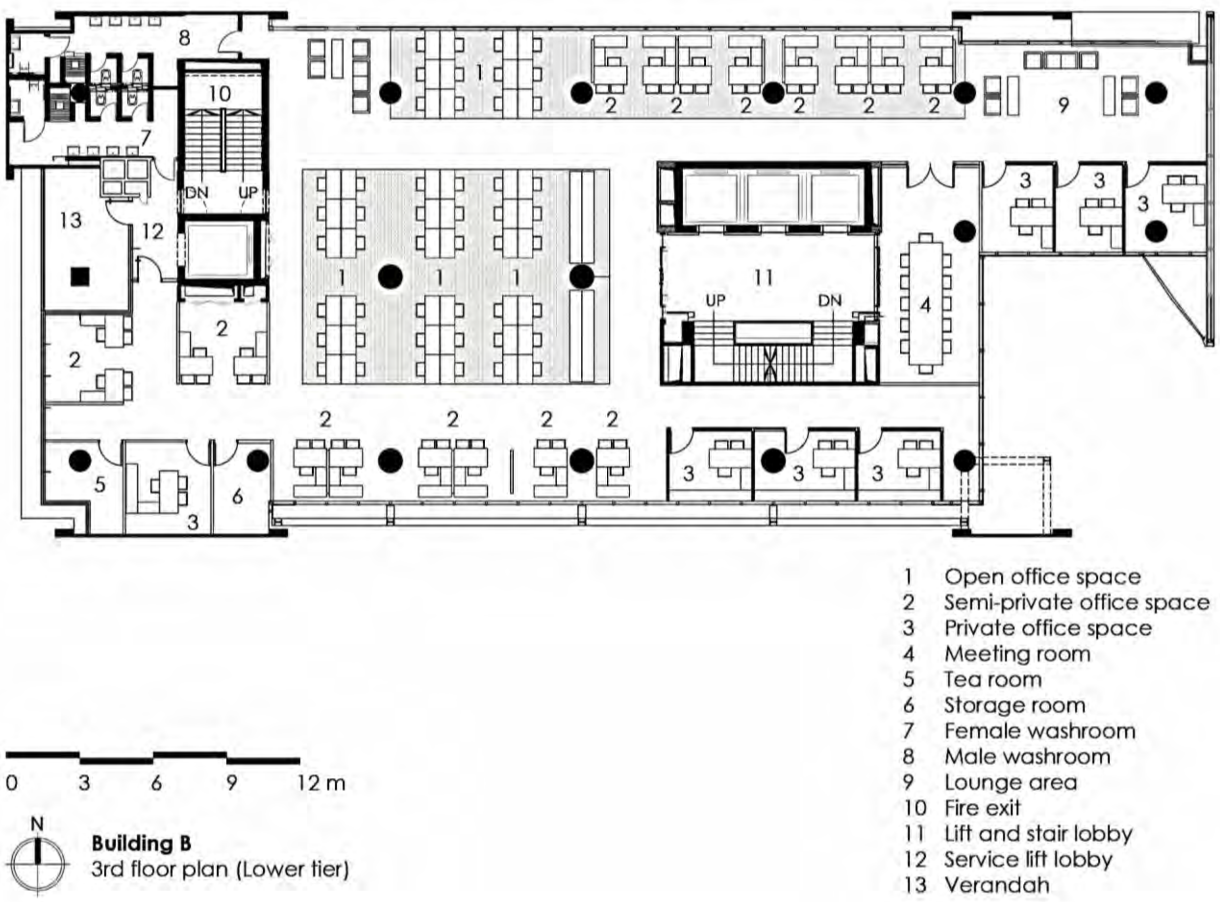


Fig. A5.2.1. Floor plan of Building B: Lower tier (Source: Building B interior designers, edited by author)

- Building B (Middle tier):

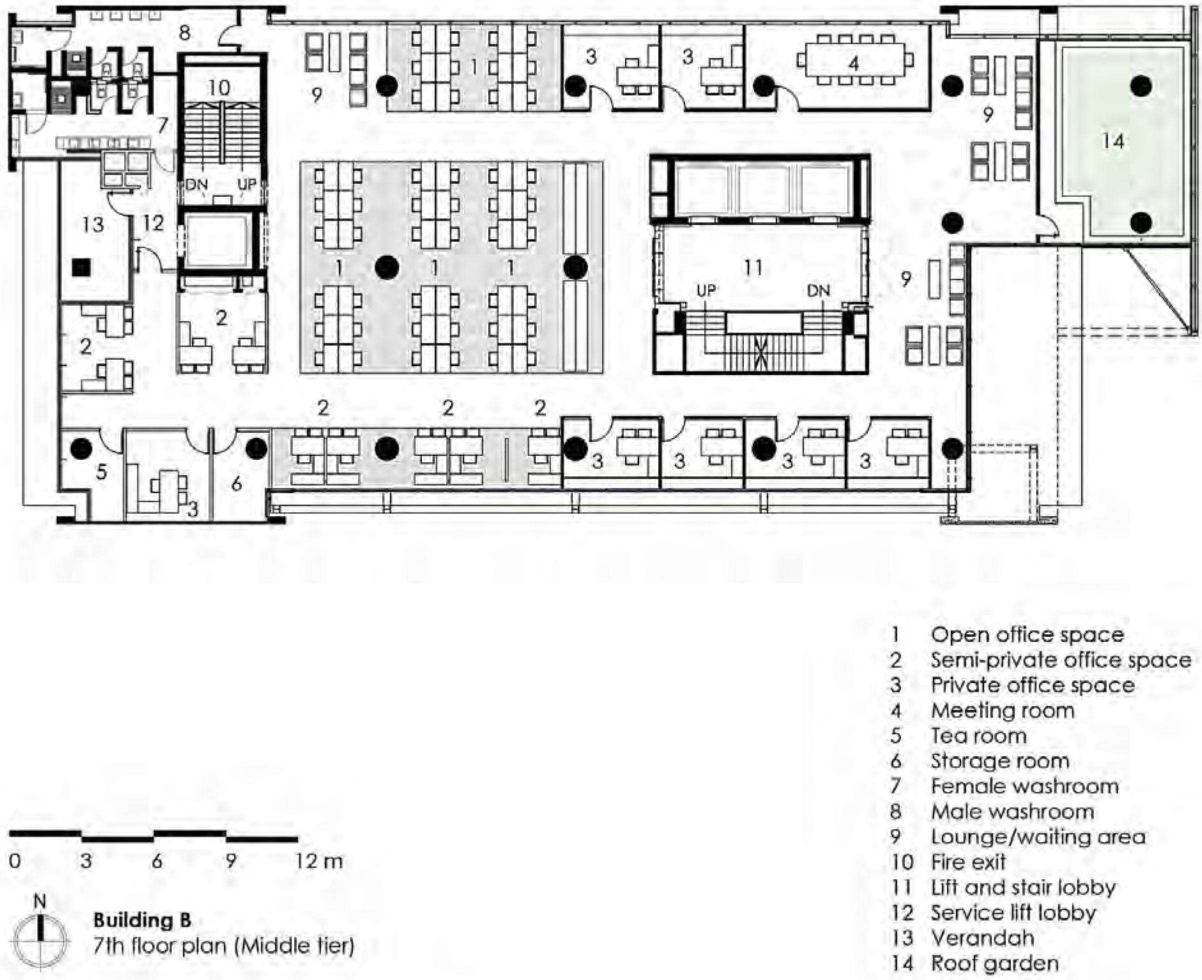


Fig. A5.2.2. Floor plan of Building B: Middle tier (Source: Building B interior designers, edited by author)

- Building B (Upper tier):

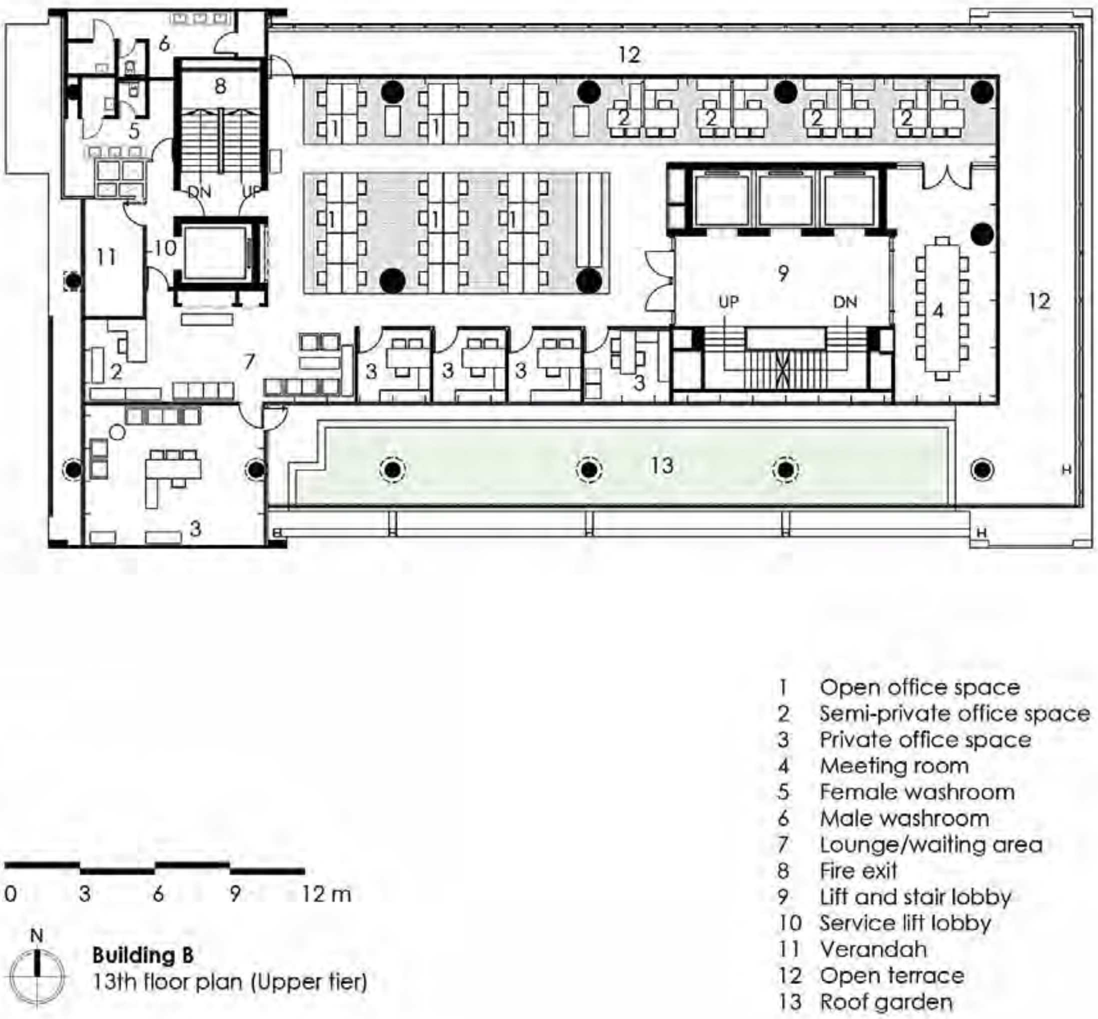


Fig. A5.2.3. Floor plan of Building B: Upper tier (Source: Building B interior designers, edited by author)

- Building C (Lower tier):

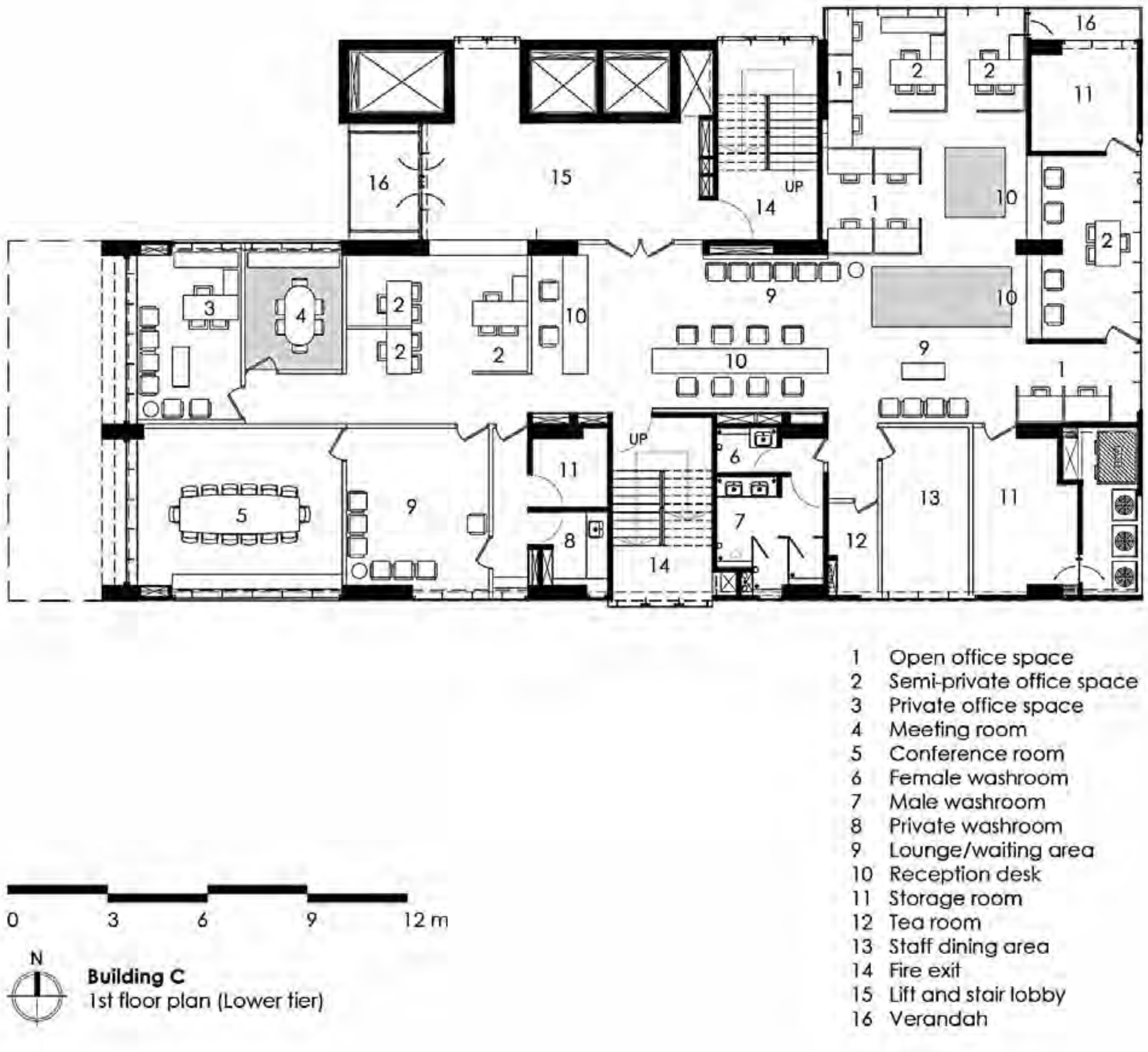


Fig. A5.3.1. Floor plan of Building C: Lower tier (Source: Building C architects, edited by author)

- Building C (Middle tier):

Fig. A5.3.2. Floor plan of Building C: Middle tier (Source: Building C architects, edited by author)

- Building C (Upper tier):

Fig. A5.3.3. Floor plan of Building C: Upper tier (Source: Building C architects, edited by author)

- Building D (Lower tier):

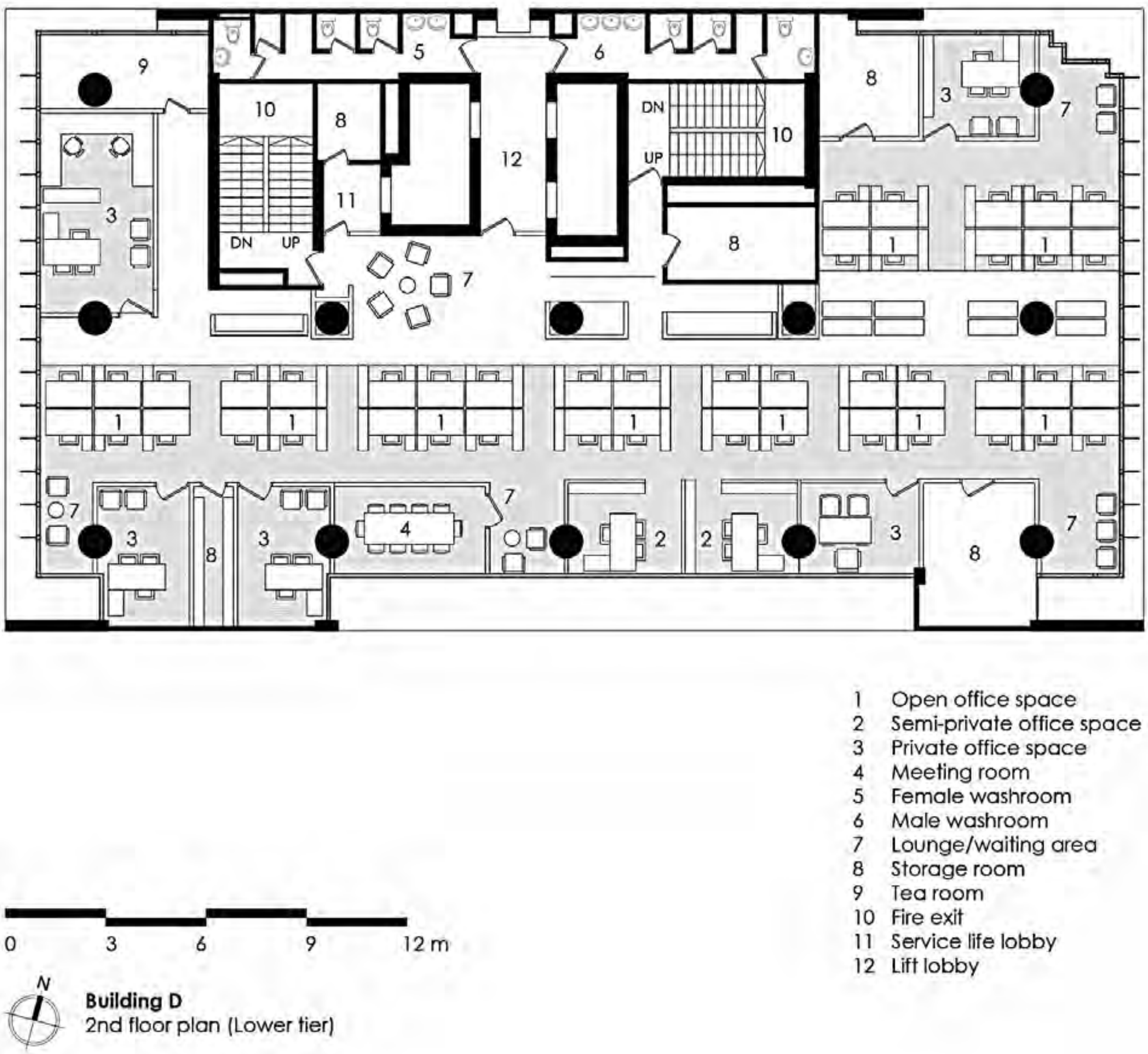


Fig. A5.4.1. Floor plan of Building D: Lower tier (Source: Building D management, edited by author)

- Building D (Middle tier):

Fig. A5.4.2. Floor plan of Building D: Middle tier (Source: Building D management, edited by author)

- Building D (Upper tier):

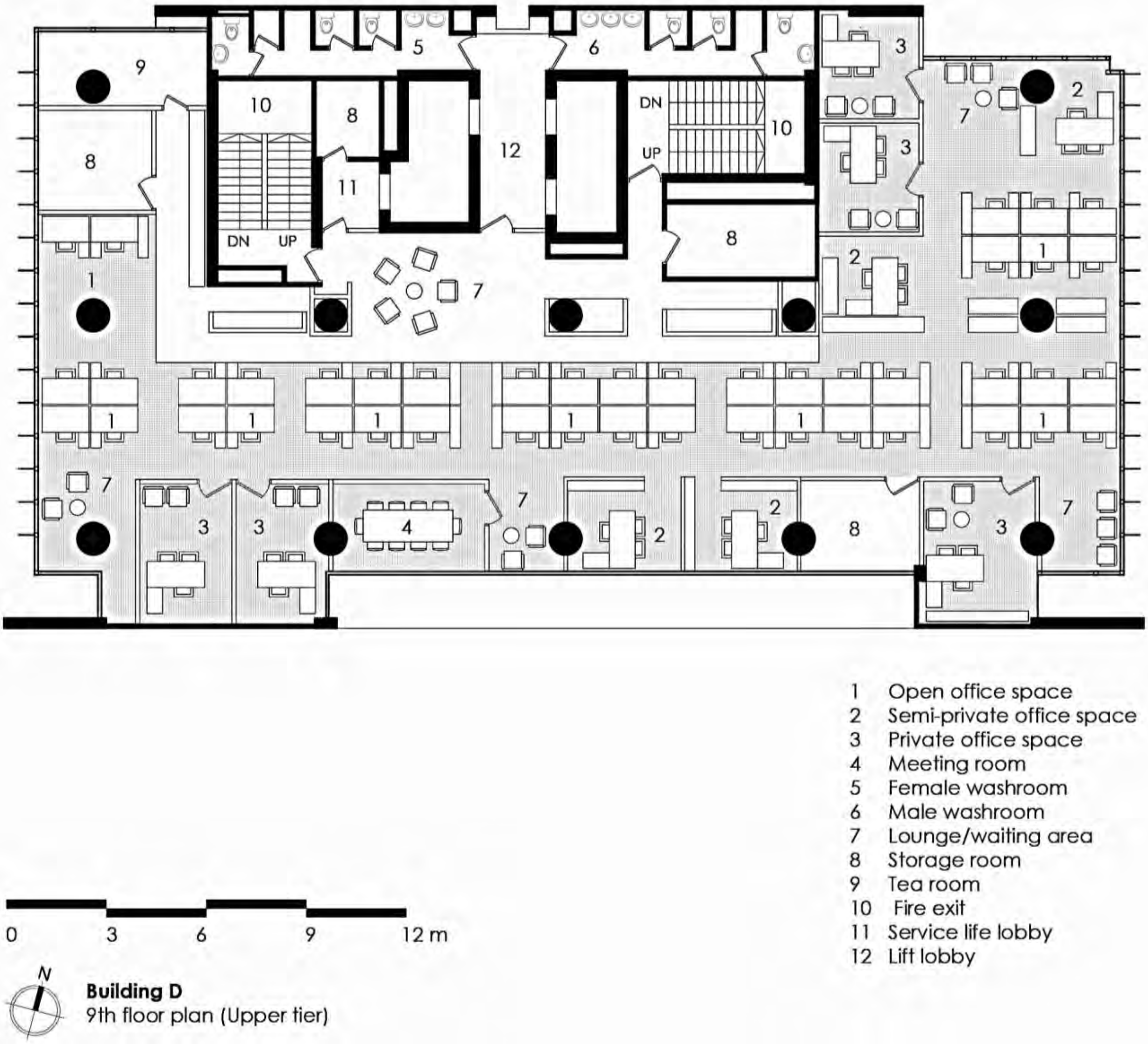


Fig. A5.4.3. Floor plan of Building D: Upper tier (Source: Building D management, edited by author)

Appendix 06: Mean, Standard Deviation, Standard Error and 95% Confidence Intervals of background noise levels

Table A6.1.1. Mean, Standard Deviation, Standard Error and 95% Confidence Intervals of background noise levels (Source: Author)

Building A (Lower tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	53.28	7.32	0.42	± 0.83	53.73	4.56	0.26	± 0.52	56.67	4.46	0.26	± 0.51
	2	52.72	5.83	0.34	± 0.66	54.77	4.99	0.29	± 0.57	54.33	4.77	0.28	± 0.54
	3	55.66	5.03	0.29	± 0.57	53.07	5.4	0.31	± 0.61	53.37	5.96	0.35	± 0.69
	4	50.16	4.15	0.24	± 0.47	57.88	5.18	0.3	± 0.59	59.56	7.7	0.44	± 0.87
	5	52.6	4.75	0.27	± 0.54	58.3	6.58	0.38	± 0.75	62.05	6.88	0.4	± 0.78
	6	51.11	3.42	0.2	± 0.39	56.12	5.13	0.3	± 0.58	52.8	4.5	0.26	± 0.51
	7	59.85	5.12	0.29	± 0.58	58.97	4.26	0.25	± 0.48	60.07	5.04	0.29	± 0.57

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	58.89	7.12	0.41	± 0.81	51.42	5.74	0.33	± 0.65	50.19	5.64	0.32	± 0.64
	2	52.47	4.67	0.27	± 0.53	54.57	5.12	0.3	± 0.58	53.9	5.63	0.33	± 0.64
	3	48.33	4.15	0.24	± 0.47	51.14	6.46	0.37	± 0.73	50.45	4.5	0.26	± 0.51
	4	49.2	6.32	0.36	± 0.72	49.09	4.82	0.28	± 0.55	48.97	4.12	0.24	± 0.47
	5	44.63	4.54	0.26	± 0.51	53.99	7.93	0.46	± 0.90	58.18	6.12	0.35	± 0.69

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	49.87	1.1	0.06	± 0.12	45.49	3.54	0.2	± 0.40	45.83	2.99	0.17	± 0.34
	2	46.07	3.92	0.23	± 0.45	44.61	3.37	0.19	± 0.38	45.42	2.43	0.14	± 0.28

Building A (Middle tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	53.49	7.27	0.42	± 0.83	54.07	4.51	0.26	± 0.51	57.84	4.46	0.26	± 0.51
	2	53.24	5.53	0.32	± 0.63	55.14	4.95	0.29	± 0.56	55.49	4.89	0.28	± 0.56
	3	55.84	4.95	0.29	± 0.56	53.26	5.34	0.31	± 0.61	54.2	6.11	0.36	± 0.71
	4	50.73	4.22	0.24	± 0.48	58.55	5.11	0.3	± 0.58	60.62	7.41	0.43	± 0.84
	5	53.65	4.68	0.27	± 0.53	58.96	6.46	0.37	± 0.73	62.75	6.73	0.39	± 0.76
	6	51.82	3.59	0.21	± 0.41	57.28	5.16	0.3	± 0.59	53.69	5.09	0.29	± 0.58

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	59.56	6.73	0.39	± 0.76	52.03	5.69	0.33	± 0.65	50.25	5.41	0.31	± 0.61
	2	52.62	4.64	0.27	± 0.53	55.3	5.2	0.3	± 0.59	54.51	5.56	0.32	± 0.63
	3	48.45	4.13	0.24	± 0.47	52.36	7.03	0.41	± 0.80	50.99	4.62	0.27	± 0.52
	4	49.35	6.19	0.36	± 0.70	49.99	5.14	0.3	± 0.58	49.47	4.05	0.23	± 0.46

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	49.71	1.32	0.08	± 0.15	45.38	3.83	0.22	± 0.44	46.36	3.02	0.17	± 0.34
	2	46.29	3.89	0.22	± 0.44	45.91	3.98	0.23	± 0.45	46.01	2.85	0.16	± 0.32

Building A (Upper tier)

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
OPEN OFFICE													
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	54.16	7.01	0.4	± 0.80	59.62	6.23	0.36	± 0.71	59.78	5.19	0.3	± 0.59
	2	53.91	6	0.35	± 0.68	59.06	7.05	0.41	± 0.80	57.78	6.09	0.35	± 0.69
	3	56.39	5.07	0.29	± 0.57	56.14	7.67	0.44	± 0.87	57.56	7.85	0.46	± 0.91
	4	51.58	4.16	0.24	± 0.47	63.36	6.47	0.37	± 0.74	64.21	6.77	0.39	± 0.77
	5	54.41	4.84	0.28	± 0.55	61.91	7.05	0.41	± 0.80	65.11	6.69	0.39	± 0.76
	6	52.42	3.76	0.22	± 0.43	61.82	7.29	0.42	± 0.83	57.64	7.62	0.44	± 0.87
SEMI PRIVATE OFFICE													
Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	60.17	6.55	0.38	± 0.74	57.25	7.36	0.42	± 0.83	53.64	6.72	0.39	± 0.76
	2	53.24	4.58	0.26	± 0.52	57.32	6.45	0.37	± 0.73	57.81	6.51	0.38	± 0.74
	3	49.06	4.15	0.24	± 0.47	55.24	8.22	0.47	± 0.93	54.98	6.75	0.39	± 0.77
	4	50.67	6.51	0.38	± 0.74	52.44	6.12	0.35	± 0.69	51.17	4.89	0.28	± 0.55
PRIVATE OFFICE AND MEETING ROOM													
Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	50.28	1.65	0.1	± 0.19	48.07	4.72	0.27	± 0.54	50.48	5.93	0.34	± 0.67
	2	47.1	4.05	0.23	± 0.46	47.75	5.56	0.32	± 0.63	49.92	6.38	0.37	± 0.72

Building B (Lower tier)

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
OPEN OFFICE													
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	53.4	3.73	0.21	± 0.42	60.93	3.65	0.21	± 0.41	63.72	3.98	0.23	± 0.45
	2	59.45	4.34	0.25	± 0.49	65.98	4.73	0.72	± 0.54	62.84	3.74	0.22	± 0.43
	3	62.82	4.76	0.27	± 0.54	59.81	3.24	0.19	± 0.37	61.97	3.53	0.2	± 0.40
	4	65.51	4.42	0.25	± 0.50	58.87	4.49	0.26	± 0.51	63.85	3.13	0.18	± 0.35
	5	63.78	5.19	0.3	± 0.59	61.17	5.38	0.31	± 0.61	61.97	3.59	0.21	± 0.41
	6	59.86	5.37	0.31	± 0.61	59.52	3.01	0.17	± 0.34	64.82	3.46	0.2	± 0.39
	7	62.13	4.11	0.24	± 0.47	67.93	4.47	0.26	± 0.51	54.92	2.53	0.15	± 0.29
SEMI PRIVATE OFFICE													
Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	62.96	4.52	0.26	± 0.51	60.63	5.45	0.31	± 0.62	69.36	4.36	0.25	± 0.50
	2	59.59	3.6	0.21	± 0.41	64.25	5.47	0.32	± 0.62	67.16	4.11	0.24	± 0.47
	3	60.04	3.8	0.22	± 0.43	55.31	3.61	0.21	± 0.41	64.15	4.6	0.27	± 0.52
PRIVATE OFFICE AND MEETING ROOM													
Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	49.35	1.79	0.1	± 0.20	51.82	2.75	0.16	± 0.31	65.96	3.79	0.21	± 0.42
	2	50.96	2.76	0.16	± 0.31	51.47	3.61	0.21	± 0.41	51.34	2.58	0.15	± 0.29
	3	50.49	2.88	0.17	± 0.33	48.7	3.67	0.19	± 0.38	69.99	5.56	0.32	± 0.63
	4	49.32	2.06	0.12	± 0.23	49.09	3.34	0.19	± 0.38	64.98	4.06	0.23	± 0.46

Building B (Middle tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	54.74	3.92	0.23	± 0.44	60.42	3.06	0.18	± 0.35	60.76	3.2	0.18	± 0.36
	2	56.86	2.68	0.15	± 0.30	61.12	3.34	0.19	± 0.38	60.88	3.72	0.22	± 0.42
	3	55.71	4.52	0.26	± 0.51	59.58	3	0.17	± 0.34	60.26	2.54	0.15	± 0.29
	4	57.39	3.7	0.21	± 0.42	59.13	4.1	0.24	± 0.46	61.91	3.08	0.18	± 0.35
	5	56.37	2.93	0.17	± 0.33	59.66	3.79	0.22	± 0.43	60.95	3.43	0.2	± 0.39
	6	57.01	3.06	0.18	± 0.35	59.74	2.94	0.17	± 0.33	63.17	4.17	0.24	± 0.47
	7	60.47	3.1	0.18	± 0.35	67.54	4.69	0.27	± 0.53	60.33	3.98	0.23	± 0.45

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	59.11	3.55	0.2	± 0.40	57.63	3.37	0.19	± 0.38	57.58	3.14	0.18	± 0.36
	2	59.55	2.9	0.17	± 0.33	57.81	3.84	0.22	± 0.44	57.32	3.4	0.2	± 0.39
	3	59.31	2.51	0.14	± 0.28	55.73	3.27	0.19	± 0.37	59.64	4.04	0.23	± 0.46

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	48.83	1.9	0.12	± 0.22	47.17	2.75	0.16	± 0.31	61.47	5.06	0.29	± 0.56
	2	49.1	3.38	0.19	± 0.38	47.3	2.74	0.16	± 0.31	47.12	1.64	0.09	± 0.19
	3	48.81	3.01	0.17	± 0.34	47.16	1.44	0.08	± 0.16	46.48	2.5	0.14	± 0.28
	4	47.7	2.26	0.13	± 0.26	46.81	1.47	0.08	± 0.17	46.08	1.31	0.08	± 0.15

Building B (Upper tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	54.42	3.31	0.19	± 0.38	59.44	3.54	0.2	± 0.40	61.9	4.33	0.25	± 0.49
	2	59.57	3.67	0.21	± 0.42	63.53	4.32	0.25	± 0.49	61.32	3.6	0.21	± 0.41
	3	63.97	4.63	0.27	± 0.52	58.14	3.73	0.22	± 0.42	59.51	3.37	0.19	± 0.38
	4	64.5	4.34	0.25	± 0.49	56.63	3.41	0.2	± 0.39	62.55	2.84	0.16	± 0.32
	5	64.08	3.91	0.23	± 0.44	58.08	3.65	0.21	± 0.41	60.34	3.18	0.18	± 0.36
	6	62.65	3.08	0.18	± 0.35	56.27	1.95	0.11	± 0.22	63.54	3.77	0.22	± 0.43
	7	59.95	5.11	0.29	± 0.58	66.81	4.31	0.25	± 0.49	56.36	3.28	0.19	± 0.37

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	67.54	4.25	0.24	± 0.48	59.41	4.5	0.26	± 0.51	68.26	4.46	0.26	± 0.51
	2	58.94	3.07	0.18	± 0.35	60.06	5.88	0.34	± 0.67	66.2	4.76	0.27	± 0.54
	3	59.5	3.4	0.2	± 0.39	52.85	2.43	0.14	± 0.28	62.87	5.33	0.31	± 0.61

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	49.44	2.19	0.13	± 0.25	59.03	5.54	0.32	± 0.63	66.12	4.11	0.23	± 0.46
	2	58.45	5.01	0.29	± 0.57	64.18	6.04	0.35	± 0.68	54.92	2.53	0.15	± 0.29
	3	62.95	3.61	0.21	± 0.41	69.05	5.18	0.3	± 0.59	56.88	3.73	0.22	± 0.42
	4	60.75	3.06	0.18	± 0.35	63.04	4.34	0.25	± 0.49	56.73	3.03	0.17	± 0.34

Building C (Lower tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	60.36	6.79	0.55	± 1.09	63.3	5.88	0.48	± 0.94	56.44	7.77	0.63	± 1.25
	2	56.77	6.31	0.51	± 1.01	57.63	5.84	0.47	± 0.94	66.18	5.84	0.48	± 0.94
	3	57.55	5.97	0.49	± 0.96	57.15	5.84	0.48	± 0.94	55.73	5.78	0.47	± 0.93
	4	54.05	5.64	0.46	± 0.91	57	6.24	0.51	± 1.00	62.97	5.94	0.48	± 0.96
	5	55.03	4.38	0.36	± 0.70	58.66	8.9	0.72	± 1.43	64.7	6.07	0.49	± 0.98

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	53.8	6.79	0.55	± 1.09	56.29	6.86	0.56	± 1.10	53.33	4.66	0.38	± 0.75
	2	57.59	7.91	0.64	± 1.27	63.83	7.83	0.64	± 1.26	59.88	7.69	0.63	± 1.24
	3	56.25	7.96	0.65	± 1.28	58.45	8.43	0.69	± 1.36	66.7	8.03	0.65	± 1.29
	4	61.61	5.87	0.48	± 0.94	62.38	6.38	0.52	± 1.03	62.21	6.27	0.51	± 1.06
	5	57.55	5.48	0.45	± 0.88	61.86	7.3	0.59	± 1.17	58.29	4.83	0.39	± 0.78

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	55.13	8.46	0.69	± 1.36	46.72	2.77	0.23	± 0.45	47.44	2.02	0.16	± 0.33
	2	48.82	3.48	0.28	± 0.56	46.71	3.68	0.3	± 0.59	46.73	3.66	0.3	± 0.59

Building C (Middle tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	54.68	2.9	0.24	± 0.47	62.53	5.71	0.46	± 0.92	63.06	5.59	0.46	± 0.90
	2	54.33	3.21	0.26	± 0.52	58.91	5.13	0.42	± 0.82	66.78	5.67	0.46	± 0.91
	3	59.05	5.69	0.46	± 0.91	60.34	4.89	0.4	± 0.79	62.17	4.59	0.37	± 0.74
	4	55.6	4.12	0.34	± 0.66	60.52	4.9	0.4	± 0.79	64.93	4.92	0.4	± 0.79
	5	55.24	3.78	0.31	± 0.61	62.13	6.65	0.54	± 1.07	66.27	6	0.49	± 0.97

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	55.27	3.88	0.32	± 0.62	57.23	6.5	0.53	± 1.05	58.35	4.35	0.35	± 0.70
	2	54.68	4.02	0.33	± 0.65	61.04	7.98	0.65	± 1.28	61.62	5.29	0.43	± 0.85
	3	56.75	6.36	0.52	± 1.02	61.5	6.13	0.5	± 0.99	67.95	7.57	0.62	± 1.22
	4	58.96	5.7	0.46	± 0.92	63.8	5.8	0.47	± 0.93	63.53	6.08	0.49	± 0.98
	5	57.87	4.91	0.4	± 0.79	65.33	6.9	0.56	± 1.11	59.91	4.9	0.4	± 0.79

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	54.26	3.42	0.28	± 0.55	46.83	2.7	0.22	± 0.43	46.37	1.53	0.12	± 0.25
	2	46.56	1.43	0.12	± 0.23	46	3.18	0.26	± 0.51	45.98	1.62	0.13	± 0.26

Building C (Upper tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	59.68	5.44	0.44	± 0.88	63.63	5.77	0.47	± 0.93	56.87	5.54	0.45	± 0.89
	2	59.07	4.69	0.38	± 0.75	57.84	5.74	0.47	± 0.92	66.64	5.48	0.45	± 0.88
	3	59.4	4.73	0.38	± 0.76	58.57	5.39	0.44	± 0.87	57.89	4.76	0.39	± 0.77
	4	58.23	5.16	0.42	± 0.83	58.4	4.88	0.4	± 0.79	63.81	5.52	0.45	± 0.89
	5	57.46	4.04	0.33	± 0.65	60.98	7.13	0.58	± 1.15	64.68	6.06	0.49	± 0.97

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	56.74	5.13	0.42	± 0.82	58.09	4.98	0.41	± 0.80	55.19	4.4	0.36	± 0.71
	2	59.54	6.09	0.5	± 0.98	64.41	6.62	0.54	± 1.06	60.41	7.28	0.59	± 1.17
	3	59.3	5.67	0.46	± 0.91	60.15	6.43	0.52	± 1.03	66.69	7.63	0.62	± 1.23
	4	59.76	5.25	0.43	± 0.84	61.93	6.04	0.49	± 0.97	61.25	5.33	0.43	± 0.86
	5	59.12	4.35	0.35	± 0.70	62.47	6.76	0.55	± 1.09	58.46	4.62	0.38	± 0.74

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	51.17	5.7	0.46	± 0.92	46.16	1.35	0.12	± 0.22	46.57	1.88	0.15	± 0.30
	2	47.39	1.73	0.14	± 0.28	46.25	2.06	0.17	± 0.33	46.02	2.3	0.19	± 0.37

Building D (Lower tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	59.86	4.97	0.29	± 0.56	58.85	4.31	0.25	± 0.49	58.87	5.66	0.33	± 0.64
	2	61.65	3.96	0.23	± 0.45	61.56	4.57	0.26	± 0.52	59.4	4.56	0.26	± 0.52
	3	66.17	5.18	0.3	± 0.56	62.75	4.97	0.29	± 0.56	62.64	6.13	0.35	± 0.70
	4	62.71	4.71	0.27	± 0.53	63.2	4.69	0.27	± 0.53	60.12	5.53	0.32	± 0.63
	5	60.14	4.26	0.25	± 0.48	61.39	3.79	0.22	± 0.43	59.17	4.72	0.27	± 0.54
	6	59.47	4.29	0.25	± 0.49	63.36	4.82	0.28	± 0.55	58.49	3.46	0.2	± 0.39
	7	64.49	4.02	0.23	± 0.46	65.5	4.8	0.28	± 0.54	60.8	3.95	0.23	± 0.45
	8	61.51	4.7	0.27	± 0.53	60.73	3.99	0.23	± 0.45	59.93	4.32	0.25	± 0.49
	9	62.33	4.73	0.27	± 0.54	65.53	5.45	0.31	± 0.62	64.06	5.57	0.32	± 0.63

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	58.16	3.7	0.21	± 0.42	63.66	5.39	0.31	± 0.61	54.73	4.47	0.26	± 0.51
	2	58.38	4.12	0.24	± 0.47	61.14	5.29	0.3	± 0.60	55.93	4.61	0.27	± 0.52

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	46.35	5.41	0.31	± 0.61	49.83	4.81	0.28	± 0.55	45.63	4.69	0.27	± 0.53
	2	49.19	5.76	0.33	± 0.65	48.54	5.24	0.3	± 0.59	46.56	6	0.35	± 0.68
	3	54.56	4.55	0.26	± 0.52	61.23	6.37	0.37	± 0.72	56.64	7.13	0.41	± 0.81

Building D (Middle tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	60.49	5.66	0.33	± 0.64	54.07	4.51	0.26	± 0.51	62.97	5.36	0.31	± 0.61
	2	61.19	4.47	0.26	± 0.51	55.14	4.95	0.29	± 0.56	59.77	4.09	0.24	± 0.46
	3	59.61	4.99	0.29	± 0.57	53.26	5.34	0.31	± 0.61	65.15	5.46	0.31	± 0.62
	4	62.42	5.56	0.37	± 0.72	58.55	5.11	0.3	± 0.58	62.08	7.01	0.4	± 0.79
	5	53.49	7.27	0.42	± 0.83	58.96	6.46	0.37	± 0.73	60.7	4.6	0.27	± 0.52
	6	53.24	5.53	0.32	± 0.63	57.28	5.16	0.3	± 0.59	64.88	4.74	0.27	± 0.54
	7	55.84	4.95	0.29	± 0.56	57.84	4.46	0.26	± 0.51	59.93	4.76	0.27	± 0.54

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	56.17	4.6	0.27	± 0.52	52.03	5.69	0.33	± 0.65	59.57	3.64	0.21	± 0.41
	2	59.56	6.73	0.39	± 0.76	55.3	5.2	0.3	± 0.59	62.86	3.97	0.23	± 0.45
	3	52.62	4.64	0.27	± 0.53	52.36	7.03	0.41	± 0.80	61.61	3.39	0.2	± 0.38
	4	48.45	4.13	0.24	± 0.47	49.99	5.14	0.3	± 0.58	61.04	3.72	0.21	± 0.42

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	57.33	7.74	0.45	± 0.88	45.38	3.83	0.22	± 0.44	55.88	4.62	0.27	± 0.52
	2	52.08	4.27	0.25	± 0.48	45.91	3.98	0.23	± 0.45	49.98	5.85	0.34	± 0.66
	3	49.71	1.32	0.08	± 0.15	46.01	2.85	0.16	± 0.32	55.58	3.53	0.2	± 0.40

Building D (Upper tier)

OPEN OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	60.42	4.44	0.26	± 0.50	65.03	5.4	0.31	± 0.61	62.06	6.04	0.35	± 0.69
	2	65.89	5.49	0.32	± 0.62	61.74	6.05	0.35	± 0.69	61.03	4.39	0.25	± 0.50
	3	63.68	6.03	0.35	± 0.68	60.29	4.78	0.28	± 0.54	62.45	4.33	0.25	± 0.49
	4	60.39	3.69	0.21	± 0.42	60.34	5.5	0.32	± 0.62	62.43	4.6	0.27	± 0.52
	5	62.01	7.33	0.42	± 0.83	63.99	7.04	0.41	± 0.80	60	4.07	0.23	± 0.46
	6	61.58	4.9	0.28	± 0.56	57.27	5.31	0.31	± 0.60	64.12	5.78	0.33	± 0.66
	7	58.14	3.9	0.23	± 0.44	57.47	4.5	0.26	± 0.51	60.98	5.77	0.33	± 0.65
	8	65.44	4.84	0.28	± 0.55	56.26	3.59	0.21	± 0.41	59.92	4.56	0.26	± 0.52

SEMI PRIVATE OFFICE

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	58.6	3.92	0.23	± 0.44	54.68	4.69	0.27	± 0.53	56.55	3.74	0.22	± 0.42
	2	60.22	4.78	0.28	± 0.54	57.31	3.76	0.22	± 0.43	58.91	6.84	0.39	± 0.78
	3	58.87	4.25	0.24	± 0.48	55.46	3.6	0.21	± 0.41	58.68	3.09	0.18	± 0.35
	4	60.45	3.67	0.21	± 0.42	53.82	4.43	0.26	± 0.50	60.37	3.6	0.21	± 0.41

PRIVATE OFFICE AND MEETING ROOM

Quantity	Location	Off Peak (10:00 am to 11:00 am)				Peak (12:00 pm to 1:00 pm)				Peak (4:00 pm to 6:00 pm)			
		Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean	Mean	SD	Standard error	95% CI for mean
Background noise level (in dBA)	1	49.7	3.02	0.17	± 0.34	49.08	2.91	0.17	± 0.33	51.62	2.03	0.12	± 0.23
	2	49.23	2.07	0.12	± 0.24	48.4	1.69	0.1	± 0.19	50.41	1.15	0.07	± 0.13
	3	58.14	8.88	0.51	± 1.02	47.69	5.84	0.34	± 0.66	59.26	3.78	0.22	± 0.43

Appendix 07: Calculations for total absorption coefficient values

Building A: Open and semi-private office, Lower tier

Table A7.1.1. Absorption coefficients and total absorption of open and semi-private office space for Building A lower tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	346.87	0.03	10.57
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	346.87	0.05	17.34
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	13.09	0.03	0.39
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	52.43	0.03	1.57
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	72.95	0.03	2.18
Interior façade	**RCC column**	16	Smooth concrete, painted	96.56	0.02	1.93
	Brick wall	1	Painted plaster surface on masonry wall	56.48	0.02	1.12
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	51.77	0.06	3.10
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	34.04	0.03	1.75
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	12.16	0.06	
	Glass door	3	2.1m X 12 mm thick toughened glass, held by SS U channel	7.47	0.03	0.22
	Steel door	5	Steel frame door	11.40	0.06	0.68
	Wooden door	2	Solid timber door	4.34	0.08	0.34
People	**Adults on padded seat**	44	1 per m2 per item	44.00	0.90	39.60

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Furniture/equipment	Padded seats	18	Empty padded seats (per item) in m2	18.00	0.42	7.56
	Open office cubicle	35	Glass wool on 52.55 mm thick solid particle board backing	92.88	0.71	65.95
	Open office desk	35	Adult office furniture per desk	35.00	0.45	15.75
	Cabinet	17	Wooden platform with large space inside	72.59	0.17	12.34
	Semi private cubicle	9	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	31.50	0.71	22.37
	Side table	1	Adult office furniture per table	1.00	0.45	0.45
	A/C	1	Ventilation grille per m2	34.68	0.15	5.20
	Semi private desk	9	Adult office furniture per desk	9.00	0.45	4.05
Total Absorption in 1 kHz Frequency (A):						**214.35**

<u>Building A: Open and semi-private office, Middle tier</u>

Table A7.1.2. Absorption coefficients and total absorption of open and semi-private office space for Building A middle tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	337.31	0.03	10.45
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	337.31	0.05	16.87
Exterior façade	North	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	13.09	0.03	0.39
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	52.36	0.03	1.57
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	72.59	0.03	2.17
Interior façade	RCC column	16	Smooth concrete, painted	98.92	0.02	1.97

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Brick wall	1	Painted plaster surface on masonry wall	63.39	0.02	1.26
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	40.01	0.06	2.40
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	31.37	0.03	1.61
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	11.21	0.06	
	Glass door	3	2.1m X 12 mm thick toughened glass, held by SS U channel	7.47	0.03	0.22
	Steel door	5	Steel frame door	11.40	0.06	0.68
	Wooden door	2	Solid timber door	4.34	0.08	0.34
People	**Adults on padded seat**	40	1 per m2 per item	40.00	0.90	36.00
Furniture/equipment	**Padded seats**	16	Empty padded seats (per item) in m2	16.00	0.42	6.72
	Side table	1	Adult office furniture per table	1.00	0.45	0.45
	Cabinet	14	Wooden platform with large space inside	59.78	0.17	10.16
	Open office cubicle	33	Glass wool on 52.55 mm thick solid particle board backing	82.50	0.71	58.57
	Open office desk	33	Adult office furniture per desk	33.00	0.45	14.85
	Semi private cubicle	7	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	24.50	0.71	17.39
	A/C	1	Ventilation grille per m2	33.73	0.15	5.05
	Semi private desk	7	Adult office furniture per desk	7.00	0.45	3.15
			Total Absorption in 1 kHz Frequency (A):			**194.74**

Building A: Open and semi-private office, Upper tier

Table A7.1.3. Absorption coefficients and total absorption of open and semi-private office space for Building A upper tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	339.19	0.03	10.51
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	339.19	0.05	16.96
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	13.09	0.03	0.39
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	52.43	0.03	1.57
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	77.44	0.03	2.32
Interior façade	**RCC column**	16	Smooth concrete, painted	98.92	0.02	1.97
	Brick wall	1	Painted plaster surface on masonry wall	63.39	0.02	1.26
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	40.01	0.06	2.40
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	31.37	0.03	1.61
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	11.21	0.06	
	Glass door	3	2.1m X 12 mm thick toughened glass, held by SS U channel	7.47	0.03	0.22
	Steel door	5	Steel frame door	11.40	0.06	0.68
	Wooden door	2	Solid timber door	4.34	0.08	0.34
People	**Adults on padded seat**	40	1 per m2 per item	40.00	0.90	36.00
Furniture/equipment	**Cabinet**	13	Wooden platform with large space inside	55.51	0.17	9.44

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Padded seats	16	Empty padded seats (per item) in m2	16.00	0.42	6.72
	Side table	1	Adult office furniture per table	1.00	0.45	0.45
	Open office cubicle	33	Glass wool on 52.55 mm thick solid particle board backing	82.50	0.71	58.57
	Open office desk	33	Adult office furniture per desk	33.00	0.45	14.85
	A/C	1	Ventilation grille per m2	33.91	0.15	5.08
	Semi private cubicle	7	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	24.50	0.71	17.39
	Semi private desk	7	Adult office furniture per desk	6.00	0.45	2.70
				Total Absorption in 1 kHz Frequency (A):		**214.91**

Building B: Open and semi-private office, Lower tier

Table A7.2.1. Absorption coefficients and total absorption of open and semi-private office space for Building B lower tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	304.51	0.03	9.43
		1	Carpet, thin, over thin felt on concrete	193.55	0.30	58.06
Exposed ceiling		1	Exposed HVAC ducts lined with 12 mm thick polyester absorber	99.61	0.15	14.94
		1	150 mm thick smooth unpainted concrete	498.06	0.02	9.96
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	114.41	0.03	3.43

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	50.72	0.03	1.52
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	28.91	0.03	0.86
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	25.15	0.03	0.75
Interior façade	**RCC column**	9	Smooth concrete, unpainted	73.67	0.02	1.47
	Brick wall	1	Painted plaster surface on masonry wall	54.73	0.02	1.09
	RCC wall	1	Smooth concrete, unpainted	41.04	0.02	0.82
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	34.16	0.02	0.68
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	75.3	0.03	3.87
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	26.89	0.06	
	Steel door	1	Steel frame door	2.28	0.06	0.1368
	Wooden door	4	Solid timber door	8.68	0.08	0.69
People	**Adults on padded seat**	66	1 per m2 per item	66.00	0.90	59.40
Furniture/equipment	**Open office desk separator**	48	Glass wool on 52.55 mm thick solid particle board backing	120.00	0.71	85.20
	Open office desk	48	Adult office furniture per desk	48.00	0.45	21.60
	A/C	1	Ventilation grille in m2	9.96	0.15	1.49
	Cabinet	18	Wooden platform with large space inside	76.86	0.17	13.07

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Side table/coffee table	3	Adult office furniture per table	3.00	0.45	1.35
	Padded seats	36	Empty padded seats (per item) in m^2	36.00	0.42	15.12
	Unoccupied sofa seats	14	Seats, leather covers, per m^2	4.20	0.61	2.56
	Semi private hanging glass partition	12	1.98 m length 12 mm thick tempered glass	236.22	0.03	7.08
	Semi private desk	18	Adult office furniture per desk	18.00	0.45	8.1.
			Total Absorption in 1 kHz Frequency (A):			**322.43**

<u>Building B: Open and semi-private office, Middle tier</u>

Table A7.2.2. Absorption coefficients and total absorption of open and semi-private office space for Building B middle tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	310.56	0.03	9.62
		1	Carpet, thin, over thin felt on concrete	135.06	0.30	40.51
Exposed ceiling		1	Exposed HVAC ducts lined with 12 mm thick polyester absorber	89.12	0.15	13.36
		1	150 mm thick smooth unpainted concrete	445.63	0.02	8.91
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	50.77	0.03	1.52
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	38.88	0.03	1.16
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	27.17	0.03	0.81

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	62.36	0.03	1.87
Interior façade	**RCC column**	7	Smooth concrete, unpainted	57.30	0.02	1.14
	Brick wall	1	Painted plaster surface on masonry wall	59.36	0.02	1.18
	RCC wall	1	Smooth concrete, unpainted	41.04	0.02	0.82
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	48.86	0.02	0.97
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	111.01	0.03	5.70
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	39.65	0.06	
	Steel door	1	Steel frame door	2.28	0.06	0.13
	Wooden door	4	Solid timber door	8.68	0.08	0.69
People	**Adults on padded seat**	56	1 per m2 per item	56.00	0.90	50.40
Furniture/equipment	**Open office desk separator**	48	Glass wool on 52.55 mm thick solid particle board backing	120.00	0.71	85.20
	Open office desk	48	Adult office furniture per desk	48.00	0.45	21.60
	Side table/coffee table	5	Adult office furniture per desk	5.00	0.45	2.25
	Padded seats	16	Empty padded seats (per item) in m^2	16.00	0.42	6.72
	A/C	1	Ventilation grille in m2	8.91	0.15	1.33

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Cabinet	9	Wooden platform with large space inside	38.43	0.17	6.53
	Unoccupied sofa seats	24	Seats, leather covers, per m^2	7.20	0.61	4.39
	Semi private hanging glass partition	6	1.98 m length 12 mm thick tempered glass	117.00	0.03	3.51
	Semi private desk	9	Adult office furniture per desk	9.00	0.45	4.05
				Total Absorption in 1 kHz Frequency (A):		**274.16**

<u>Building B: Open and semi-private office, Upper tier</u>

Table A7.2.3. Absorption coefficients and total absorption of open and semi-private office space for Building B upper tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	107.01	0.031	3.31
		1	Carpet, thin, over thin felt on concrete	130.32	0.30	39.09
Exposed ceiling		1	Exposed HVAC ducts lined with 12 mm thick polyester absorber	33.04	0.15	4.95
		1	150 mm thick smooth unpainted concrete	165.21	0.02	3.30
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	83.81	0.03	2.51
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	19.95	0.03	0.59
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.72	0.03	0.29
Interior façade	**RCC column**	6	Smooth concrete, unpainted	51.02	0.02	1.02

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Brick wall	1	Painted plaster surface on masonry wall	17.61	0.02	0.35
	RCC wall	1	Smooth concrete, unpainted	35.74	0.02	0.71
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	77.05	0.03	2.55
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	3.99	0.06	
	Steel door	1	Steel frame door	2.28	0.06	0.13
	Wooden door	4	Solid timber door	8.68	0.08	0.69
People	**Adults on padded seat**	45	1 per m2 per item	45.00	0.90	40.50
Furniture/equipment	**Open office desk separator**	37	Glass wool on 52.55 mm thick solid particle board backing	92.50	0.71	65.67
	Open office desk	37	Adult office furniture per desk	37.00	0.45	16.65
	A/C	1	Ventilation grille in m2	3.30	0.15	0.49
	Padded seats	16	Empty padded seats (per item) in m^2	16.00	0.42	6.72
	Unoccupied sofa seats	10	Seats, leather covers, per m^2	3.00	0.61	1.83
	Side table/coffee table	1	Adult office furniture per desk	1.00	0.45	0.45
	Cabinet	17	Wooden platform with large space inside	72.59	0.17	12.34
	Semi private hanging glass partition	4	1.98 m length 12 mm thick tempered glass	78.00	0.03	2.34
	Semi private desk	8	Adult office furniture per desk	8.00	0.45	3.60
			Total Absorption in 1 kHz Frequency (A):			**210.04**

Building C: Open and semi-private office, Lower tier

Table A7.3.1. Absorption coefficients and total absorption of open and semi-private office space for Building C lower tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	173.52	0.03	5.37
		1	12.5 mm Woodblock tiles on solid floor	11.70	0.05	0.58
Exposed ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	185.22	0.05	9.26
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	23.24	0.03	0.69
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	22.35	0.03	0.67
Interior façade	**RCC column**	1	Smooth concrete, painted	10.77	0.02	0.21
	Brick wall	1	Painted plaster surface on masonry wall	56.70	0.02	1.13
	RCC wall	1	Smooth concrete, painted	29.56	0.02	0.59
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	55.08	0.02	1.10
	Wooden panel	1	12 mm Fibreboard over airspace on solid wall	28.02	0.25	7.01
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	42.57	0.03	2.18
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	15.20	0.06	
	Steel door	2	Steel frame door	4.56	0.06	0.27
	Wooden door	2	Solid timber door	4.34	0.08	0.34

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
People	Adults on padded seat	25	1 per m2 per item	25.00	0.90	22.50
Furniture/equipment	Open office cubicle	9	Glass wool on 52.55 mm thick solid particle board backing	22.50	0.71	15.97
	Open office desk	9	Adult office furniture per desk	9.00	0.45	4.05
	Reception table	4	Adult office furniture per table	4.00	0.45	1.80
	Side Table/Coffee table	2	Adult office furniture per table	2.00	0.45	0.90
	Padded seats	16	Empty padded seats (per item) in m^2	16.00	0.42	6.72
	Unoccupied sofa seats	10	Seats, leather covers, per m^2	3.00	0.61	1.83
	A/C	1	Ventilation grille in m2	18.52	0.15	2.77
	Cabinet	1	Wooden platform with large space inside	4.27	0.17	0.73
	Semi private cubicle	5	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	17.50	0.71	12.42
	Semi private desk	5	Adult office furniture per desk	5.00	0.45	2.25
				Total Absorption in 1 kHz Frequency (A):		**101.23**

<u>Building C: Open and semi-private office, Middle tier</u>

Table A7.3.2. Absorption coefficients and total absorption of open and semi-private office space for Building C middle tier (Source: Author)

Surface and elements	No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor	1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	230.54	0.03	7.14

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	230.54	0.05	11.52
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	30.89	0.03	0.92
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	10.14	0.03	0.30
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	22.06	0.03	0.66
Interior façade	**RCC column**	1	Smooth concrete, painted	10.77	0.02	0.21
	Brick wall	1	Painted plaster surface on masonry wall	65.60	0.02	1.31
	RCC wall	1	Smooth concrete, painted	33.53	0.02	0.67
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	45.15	0.02	0.90
	Wooden panel	1	12 mm Fibreboard over airspace on solid wall	28.02	0.25	7.00
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	51.26	0.03	2.63
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	18.31	0.06	
	Steel door	2	Steel frame door	4.56	0.06	0.27
	Wooden door	2	Solid timber door	4.34	0.08	0.34
People	**Adults on padded seat**	32	1 per m2 per item	32.00	0.90	28.80
Furniture/equipment	**Open office cubicle**	14	Glass wool on 52.55 mm thick solid particle board backing	35.00	0.71	24.85
	Open office desk	14	Adult office furniture per desk	14.00	0.45	6.30

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	A/C	1	Ventilation grille in m2	23.05	0.15	3.45
	Reception table	4	Adult office furniture per table	4.00	0.45	1.80
	Side Table/Coffee table	2	Adult office furniture per table	2.00	0.45	0.90
	Padded seats	18	Empty padded seats (per item) in m^2	18.00	0.42	7.56
	Unoccupied sofa seats	10	Seats, leather covers, per m^2	3.00	0.61	1.83
	Cabinet	2	Wooden platform with large space inside	8.54	0.17	1.45
	Semi private cubicle	4	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	14.00	0.71	9.94
	Semi private desk	8	Adult office furniture per desk	8.00	0.45	3.60
			Total Absorption in 1 kHz Frequency (A):			**124.19**

<u>Building C: Open and semi-private office, Upper tier</u>

Table A7.3.3. Absorption coefficients and total absorption of open and semi-private office space for Building C upper tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	293.13	0.03	9.08
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	293.13	0.05	14.65
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	35.30	0.03	1.05
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	30.44	0.03	0.91

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	23.38	0.03	0.70
Interior façade	**RCC column**	1	Smooth concrete, painted	10.77	0.02	0.21
	Brick wall	1	Painted plaster surface on masonry wall	60.82	0.02	1.21
	RCC wall	1	Smooth concrete, painted	48.10	0.02	0.96
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	37.80	0.02	0.75
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	45.93	0.03	2.36
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	16.40	0.06	
	Steel door	2	Steel frame door	4.56	0.06	0.27
	Wooden door	2	Solid timber door	4.34	0.08	0.34
People	**Adults on padded seat**	36	1 per m2 per item	36.00	0.90	32.40
Furniture/equipment	**Open office cubicle**	30	Glass wool on 52.55 mm thick solid particle board backing	75.00	0.71	53.25
	Open office desk	30	Adult office furniture per desk	30.00	0.45	13.50
	A/C	1	Ventilation grille in m2	29.31	0.15	4.39
	Side Table/Coffee table	18	Adult office furniture per table	18.00	0.45	8.10
	Padded seats	12	Empty padded seats (per item) in m^2	12.00	0.42	5.04
	Cabinet	11	Wooden platform with large space inside	46.97	0.17	7.98
	Semi private cubicle	6	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	21.00	0.71	14.91

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Semi private desk	6	Adult office furniture per desk	6.00	0.45	2.70
					Total Absorption in 1 kHz Frequency (A):	**174.54**

Building D: Open and semi-private office, Lower tier

Table A7.4.1. Absorption coefficients and total absorption of open and semi-private office space for Building D lower tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	90.45	0.03	2.80
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	269.05	0.05	13.4525
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	10.88	0.03	0.32
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	37.21	0.03	1.11
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	21.77	0.03	0.65
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	42.06	0.03	1.26
Interior façade	**RCC column**	3	Smooth concrete, unpainted	26.47	0.02	0.52
	Brick wall	1	Painted plaster surface on masonry wall	92.59	0.02	1.85
	RCC wall	1	Smooth concrete, unpainted	62.73	0.02	1.25
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	73.18	0.02	1.46
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	87.49	0.03	4.49

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	31.25	0.06	
	Steel door	2	Steel frame door	4.56	0.06	0.27
People	**Adults on padded seat**	46	1 per m2 per item	46.00	0.90	41.40
Furniture/equipment	**Open office desk separator**	44	Glass wool on 52.55 mm thick solid particle board backing	110.00	0.71	78.10
	Open office desk	44	Adult office furniture per desk	44.00	0.45	19.80
	A/C	1	Ventilation grille in m2	26.90	0.15	4.03
	Side Table/Coffee table	3	Adult office furniture per table	3.00	0.45	1.35
	Padded seats	4	Empty padded seats (per item) in m^2	4.00	0.42	1.68
	Unoccupied sofa seats	14	Seats, leather covers, per m^2	4.20	0.61	2.56
	Cabinet	13	Wooden platform with large space inside	55.51	0.17	9.44
	Semi private cubicle	2	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	7.00	0.71	4.97
	Semi private desk	2	Adult office furniture per desk	2.00	0.45	0.90
				Total Absorption in 1 kHz Frequency (A):		**193.63**

<u>Building D: Open and semi-private office, Middle tier</u>

Table A7.4.2. Absorption coefficients and total absorption of open and semi-private office space for Building D middle tier (Source: Author)

Surface and elements	No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor	1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	68.97	0.03	2.13

<table>
<tr><th colspan="2">Surface and elements</th><th>No. of units</th><th>Material Description</th><th>Area/Item (Sq m)</th><th>Absorption Coefficients (α) 1 kHz</th><th>Total Absorption 1 kHz</th></tr>
<tr><td colspan="2"></td><td>1</td><td>Carpet, thin, over thin felt on concrete</td><td>224.41</td><td>0.30</td><td>67.32</td></tr>
<tr><td colspan="2">Suspended ceiling</td><td>1</td><td>12.5mm thick gypsum/mineral board with 0.5 m deep air space behind</td><td>293.38</td><td>0.05</td><td>14.66</td></tr>
<tr><td rowspan="4">Exterior façade</td><td>North</td><td>1</td><td>6 mm Double Glazed Unit (DGU) filled with 12 mm helium</td><td>20.15</td><td>0.03</td><td>0.60</td></tr>
<tr><td>South</td><td>1</td><td>6 mm Double Glazed Unit (DGU) filled with 12 mm helium</td><td>51.85</td><td>0.03</td><td>1.55</td></tr>
<tr><td>West</td><td>1</td><td>6 mm Double Glazed Unit (DGU) filled with 12 mm helium</td><td>30.22</td><td>0.03</td><td>0.90</td></tr>
<tr><td>East</td><td>1</td><td>6 mm Double Glazed Unit (DGU) filled with 12 mm helium</td><td>41.92</td><td>0.03</td><td>1.25</td></tr>
<tr><td rowspan="8">Interior façade</td><td>RCC column</td><td>7</td><td>Smooth concrete, unpainted</td><td>61.78</td><td>0.02</td><td>1.23</td></tr>
<tr><td>Brick wall</td><td>1</td><td>Painted plaster surface on masonry wall</td><td>86.12</td><td>0.02</td><td>1.72</td></tr>
<tr><td>RCC surface</td><td>1</td><td>Smooth concrete, unpainted</td><td>37.14</td><td>0.02</td><td>0.74</td></tr>
<tr><td>Steel door</td><td>2</td><td>Steel frame door</td><td>4.56</td><td>0.06</td><td>0.27</td></tr>
<tr><td>Wooden door</td><td>1</td><td>Solid timber door</td><td>2.17</td><td>0.08</td><td>0.17</td></tr>
<tr><td rowspan="2">Glass partition wall (with door)</td><td rowspan="2">1</td><td>2.1m X 12 mm thick toughened glass, held by SS U channel</td><td>84.76</td><td>0.03</td><td rowspan="2">4.35</td></tr>
<tr><td>0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space</td><td>30.27</td><td>0.06</td></tr>
<tr><td>Gypsum wall</td><td>1</td><td>12.5 mm thick gypsum board on frame, 75 mm air space</td><td>71.12</td><td>0.02</td><td>1.42</td></tr>
<tr><td>People</td><td>Adults on padded seat</td><td>40</td><td>1 per m2 per item</td><td>40.00</td><td>0.90</td><td>36.00</td></tr>
<tr><td>Furniture/equipment</td><td>Open office desk separator</td><td>36</td><td>Glass wool on 52.55 mm thick solid particle board backing</td><td>90.00</td><td>0.71</td><td>63.90</td></tr>
</table>

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Open office desk	36	Adult office furniture per desk	36.00	0.45	16.20
	A/C	1	Ventilation grille in m2	29.33	0.15	4.40
	Side Table/Coffee table	7	Adult office furniture per table	7.0	0.45	3.15
	Padded seats	8	Empty padded seats (per item) in m^2	8.00	0.42	3.36
	Unoccupied sofa seats	21	Seats, leather covers, per m^2	6.30	0.61	3.84
	Cabinet	20	Wooden platform with large space inside	85.40	0.17	14.52
	Semi private cubicle	3	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	10.5	0.71	7.45
	Semi private desk	4	Adult office furniture per desk	4.00	0.45	1.80
			Total Absorption in 1 kHz Frequency (A):			**252.94**

<u>Building D: Open and semi-private office, Upper tier</u>

Table A7.4.3. Absorption coefficients and total absorption of open and semi-private office space for Building D upper tier (Source: Author)

Surface and elements	No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Floor	1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	63.28	0.03	1.96
	1	Carpet, thin, over thin felt on concrete	222.66	0.30	66.79
Suspended ceiling	1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	285.94	0.05	14.29

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	18.01	0.03	0.54
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	41.92	0.03	1.25
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	30.22	0.03	0.90
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	42.06	0.03	1.26
Interior façade	**RCC column**	6	Smooth concrete, unpainted	52.95	0.02	1.05
	Brick wall	1	Painted plaster surface on masonry wall	93.62	0.02	1.87
	RCC surface	1	Smooth concrete, unpainted	40.37	0.02	0.80
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	76.65	0.02	1.53
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	80.64	0.03	4.14
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	28.80	0.06	
	Steel door	2	Steel frame door	4.56	0.06	0.27
	Wooden door	1	Solid timber door	2.17	0.08	0.17
People	**Adults on padded seat**	48	1 per m2 per item	48.00	0.90	43.20
Furniture/equipment	**Open office desk separator**	44	Glass wool on 52.55 mm thick solid particle board backing	110.00	0.71	78.10
	Open office desk	44	Adult office furniture per desk	44.00	0.45	19.80
	A/C	1	Ventilation grille in m2	28.59	0.15	4.28
	Side Table/Coffee table	4	Adult office furniture per table	4.00	0.45	1.80

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
	Padded seats	8	Empty padded seats (per item) in m^2	8.00	0.42	3.36
	Unoccupied sofa seats	15	Seats, leather covers, per m^2	4.50	0.61	2.75
	Cabinet	20	Wooden platform with large space inside	88.30	0.17	15.01
	Semi private cubicle	2	Glass wool on 52.55 mm thick solid particle board backing, with 12 mm thick polycarbonate window panel	7.00	0.71	4.97
	Semi private desk	4	Adult office furniture per desk	4.00	0.45	1.80
				Total Absorption in 1 kHz Frequency (A):		**268.66**

<u>Building A: Private office and meeting rooms, Lower tier</u>

Table A7.5.1. Absorption coefficients and total absorption of private office and meeting room for Building A lower tier (Source: Author)

Private office space						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	13.20	0.03	0.40
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	13.20	0.05	0.66
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	11.69	0.03	0.35
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	10.29	0.03	0.30
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15

	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	6.62	0.03	0.34
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	2.36	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Cabinet**	1	Wooden platform with large space inside	4.27	0.17	0.73
	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	A/C	1	Ventilation grille per m2	1.32	0.15	0.19
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**5.32**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	9.87	0.03	0.30
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.87	0.05	0.49
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	10.37	0.03	0.31
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	14.72	0.03	0.75
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.26	0.06	
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	5.07	0.06	0.30

Furniture/equipment	**Chairs**	9	Empty plastic chair in m2 unit per chair	9.00	0.14	1.26
	A/C	1	Ventilation grille per m2	0.98	0.15	0.148
	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**4.17**

<u>Building A: Private office and meeting rooms, Middle tier</u>

Table A7.5.2. Absorption coefficients and total absorption of private office and meeting room for Building A middle tier (Source: Author)

Private office space						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	12.75	0.03	0.39
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	12.75	0.05	0.63
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	14.26	0.03	0.42
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.41	0.03	0.28
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	14.24	0.03	0.73
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.09	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Cabinet**	1	Wooden platform with large space inside	4.27	0.17	0.73

	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	A/C	1	Ventilation grille per m2	1.27	0.15	0.19
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**5.72**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	7.40	0.03	0.22
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	7.40	0.05	0.37
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	8.97	0.03	0.26
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	12.22	0.03	0.62
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.37	0.06	
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	5.07	0.06	0.30
Furniture/equipment	**Chairs**	9	Empty plastic chair in m2 unit per chair	9.00	0.14	1.26
	A/C	1	Ventilation grille per m2	0.74	0.15	0.11
	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**3.77**

Building A: Private office and meeting rooms, Upper tier

Table A7.5.3. Absorption coefficients and total absorption of private office and meeting room for Building A upper tier (Source: Author)

Surface and elements		No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Private office space						
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	12.71	0.03	0.39
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	12.71	0.05	0.63
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	11.69	0.03	0.35
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.41	0.03	0.28
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	14.24	0.03	0.73
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.09	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Cabinet**	1	Wooden platform with large space inside	4.27	0.17	0.73
	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	A/C	1	Ventilation grille per m2	1.27	0.15	0.19
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**5.64**

Surface and elements	No. of units	Material Description	Area/Item (Sq m)	Absorption Coefficients (α) 1 kHz	Total Absorption 1 kHz
Meeting room					

Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	9.85	0.03	0.30
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.85	0.05	0.49
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	8.97	0.03	0.26
Interior façade	**RCC column**	1	Smooth concrete, painted	7.57	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	12.22	0.03	0.62
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.37	0.06	
	Partition wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	5.07	0.06	0.30
Furniture/equipment	**Chairs**	9	Empty plastic chair in m2 unit per chair	9.00	0.14	1.26
	A/C	1	Ventilation grille per m2	0.98	0.15	0.14
	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**4.00**

Building B: Private office and meeting rooms, Lower tier

Table A7.6.1. Absorption coefficients and total absorption of private office and meeting room for Building B lower tier (Source: Author)

Private office space 01					
Surface and elements	**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor	1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	11.78	0.03	0.36

Exposed ceiling		1	Exposed HVAC ducts lined with 12 mm thick polyester absorber	2.35	0.15	0.35
		1	150 mm thick smooth unpainted concrete	11.78	0.02	0.23
Exterior façade	**South**	1	100 mm thick smooth unpainted concrete	11.92	0.02	0.23
Interior façade	**RCC column**	1	Smooth concrete, unpainted	9.09	0.02	0.18
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	19.53	0.03	1.00
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.98	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Cabinet**	1	Wooden platform with large space inside	4.27	0.17	0.73
	Padded seats	2	Empty padded seats (per item) in m^2	2.00	0.42	0.84
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**5.28**

Private office space 02

Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	10.29	0.03	0.31
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.29	0.05	0.51
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	8.38	0.03	0.25
Interior façade	**West**	1	12.5 mm thick gypsum board on frame, 75 mm air space	10.30	0.06	0.61
	Glass partition wall	1	2.1m X 12 mm thick toughened glass, held by SS U channel	13.55	0.03	0.70

	(with door)		0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.84	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m^2	2.00	0.42	0.84
	A/C	1	Ventilation grille in m2	1.02	0.15	0.15
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**4.74**

Private office space 03						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	11.83	0.03	0.36
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	11.83	0.05	0.59
Exterior façade	**East**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	10.3	0.03	0.30
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.61	0.03	0.28
Interior façade	**RCC column**	1	Smooth concrete, unpainted	8.19	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	14.45	0.03	0.74
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.16	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	A/C	1	Ventilation grille in m2	1.18	0.15	0.18
	Private Desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**4.82**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	35.43	0.03	1.09
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	35.43	0.05	1.77
Exterior façade	**East**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	14.97	0.03	0.44
Interior façade	**RCC column**	1	Smooth concrete, unpainted	8.19	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	15.96	0.03	0.82
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.70	0.06	
	South	1	12.5 mm thick gypsum board on frame, 75 mm air space	11.81	0.06	0.70
	Brick wall	1	Painted plaster surface on masonry wall	14.99	0.02	0.29
Furniture/equipment	**A/C**	1	Ventilation grille in m2	3.54	0.15	0.53
	Padded seats	12	Empty padded seats (per item) in m2	12.00	0.42	5.04
	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
					Total Absorption in 1 kHz Frequency (A):	**11.30**

<u>Building B: Private office and meeting rooms, Middle tier</u>

Table A7.6.2. Absorption coefficients and total absorption of private office and meeting room for Building B middle tier (Source: Author)

Private office space 01					
Surface and elements	**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor	1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	13.66	0.03	0.42

Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	16.33	0.05	0.81
Exterior façade	**North**	1	100 mm thick smooth unpainted concrete	11.43	0.02	0.22
Interior façade	**RCC column**	1	Smooth concrete, unpainted	8.18	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	22.83	0.03	1.17
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	8.15	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Cabinet**	1	Wooden platform with large space inside	4.27	0.17	0.73
	Padded seats	2	Empty padded seats (per item) in m^2	2.00	0.42	0.84
	A/C	1	Ventilation grille in m2	1.63	0.15	0.24
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**5.95**

Private office space 02						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	9.64	0.03	0.29
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.64	0.05	0.48
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.76	0.03	0.29
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	19.09	0.03	0.98

			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.82	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m^2	2.00	0.42	0.84
	Cabinet	1	Wooden platform with large space inside	4.27	0.17	0.73
	A/C	1	Ventilation grille in m2	0.96	0.15	0.14
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**5.11**

Private office space 03						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	9.69	0.03	0.30
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.69	0.05	0.48
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.76	0.03	0.29
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	19.09	0.03	0.98
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.82	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Cabinet	1	Wooden platform with large space inside	4.27	0.17	0.73
	A/C	1	Ventilation grille in m2	0.96	0.15	0.14

	Private Desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**5.11**
Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	26.26	0.03	0.81
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	26.26	0.05	1.31
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	21.97	0.03	0.65
Interior façade	**RCC column**	1	Smooth concrete, unpainted	8.18	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	30.47	0.03	1.56
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	10.88	0.06	
Furniture/equipment	**A/C**	1	Ventilation grille in m2	2.62	0.15	0.39
	Padded seats	10	Empty padded seats (per item) in m2	10.00	0.42	4.20
	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**9.53**

Building B: Private office and meeting rooms, Upper tier

Table A7.6.3. Absorption coefficients and total absorption of private office and meeting room for Building B upper tier (Source: Author)

Private office space 01						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	39.61	0.03	1.22
Exposed ceiling		1	Exposed HVAC ducts lined with 12 mm thick polyester absorber	7.92	0.15	1.18
		1	150 mm thick smooth unpainted concrete	39.61	0.02	0.79
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	16.41	0.03	0.49
	East	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	16.12	0.03	0.48
	South	1	100 mm thick smooth unpainted concrete	20.68	0.02	0.41
Interior façade	**RCC column**	1	Smooth concrete, unpainted	5.47	0.02	0.10
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	20.68	0.03	0.68
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	1.07	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90

Furniture/equipment	**Side table/coffee table**	1	Adult office furniture per table	1.00	0.45	0.45
	Padded seats	3	Empty padded seats (per item) in m^2	3.00	0.42	1.26
	Unoccupied sofa seats	6	Seats, leather covers, per m^2	1.80	0.61	1.10
	Cabinet	2	Wooden platform with large space inside	8.54	0.17	1.45
	A/C	1	Ventilation grille in m2	3.96	0.15	0.59
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**11.56**

Private office space 02						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	8.26	0.03	0.25
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	8.26	0.05	0.41
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	8.38	0.03	0.25
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	24.97	0.03	0.82
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	1.29	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m^2	2.00	0.42	0.84
	Cabinet	1	Wooden platform with large space inside	4.27	0.17	0.73

	A/C	1	Ventilation grille in m2	0.82	0.15	0.12
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**4.78**

Private office space 03						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	9.78	0.03	0.30
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.78	0.05	0.48
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	9.92	0.03	0.29
Interior façade	**Brick wall**	1	Painted plaster surface on masonry wall	8.29	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	18.21	0.03	0.6
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	0.94	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	Cabinet	1	Wooden platform with large space inside	4.27	0.17	0.73
	A/C	1	Ventilation grille in m2	0.97	0.15	0.14
	Private Desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**5.28**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm thick glazed ceramic tiles plastered over RCC slab	37.99	0.03	1.17
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	37.99	0.05	1.89
Exterior façade	**East**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	26.83	0.03	0.8
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	11.69	0.03	0.35
Interior façade	**RCC column**	1	Smooth concrete, unpainted	8.20	0.02	0.16
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel,	21.90	0.03	0.72
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	1.13	0.06	
	RCC wall	1	Smooth concrete, unpainted	6.69	0.02	0.13
	Brick wall	1	Painted plaster surface on masonry wall	11.75	0.02	0.23
Furniture/equipment	**Padded seats**	12	Empty padded seats (per item) in m2	12.00	0.42	5.04
	A/C	1	Ventilation grille in m2	3.79	0.15	0.56
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**11.51**

Building C: Private office and meeting rooms, Lower tier

Table A7.7.1. Absorption coefficients and total absorption of private office and meeting room for Building C lower tier (Source: Author)

Private office space						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	16.47	0.05	0.82
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	16.47	0.05	0.82
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	14.63	0.03	0.43
	North	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	6.17	0.03	0.18
Interior façade	**Brick wall**	1	Painted plaster surface on masonry wall	1.54	0.02	0.03
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	2.35	0.02	0.04
	Wooden panel	1	12 mm Fibreboard over airspace on solid wall	9.11	0.25	2.27
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	11.26	0.03	0.57
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.02	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Side table/Coffee table**	2	Adult office furniture per table	2.00	0.45	0.90
	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.42	0.84

	Unoccupied sofa seats	6	Seats, leather covers, per m2	1.80	0.61	1.10
	A/C	1	Ventilation grille in m2	1.64	0.15	0.24
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**9.53**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	11.33	0.05	0.56
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	11.33	0.05	0.56
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	8.6	0.03	0.25
Interior façade	**RCC wall**	1	Smooth concrete, painted	1.10	0.02	0.022
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	21.61	0.03	1.11
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	7.72	0.06	
Furniture/equipment	**Padded seats**	6	Empty padded seats (per item) in m2	6.00	0.42	2.52
	A/C	1	Ventilation grille in m2	1.13	0.15	0.16
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**6.39**

<u>Building C: Private office and meeting rooms, Middle tier</u>

Table A7.7.2. Absorption coefficients and total absorption of private office and meeting room for Building C middle tier (Source: Author)

Private office space						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	18.53	0.05	0.92
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	18.53	0.05	0.92
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	16.10	0.03	0.48
	North	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	7.94	0.03	0.23
Interior façade	**RCC column**	1	Smooth concrete, unpainted	2.42	0.02	0.04
	Wooden panel	1	12 mm Fibreboard over airspace on solid wall	9.11	0.25	2.27
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	10.73	0.03	0.55
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	3.83	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Side table/Coffee table**	2	Adult office furniture per table	2.00	0.45	0.90
	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.88	1.76
	Unoccupied sofa seats	6	Seats, leather covers, per m2	1.80	0.61	1.10
	A/C	1	Ventilation grille in m2	1.85	0.15	0.27

	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**11.57**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	11.53	0.05	0.57
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	11.53	0.05	0.57
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	4.19	0.03	0.12
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	22.45	0.03	1.15
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	8.02	0.06	
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	2.35	0.02	0.047
	Brick wall	1	Painted plaster surface on masonry wall	2.05	0.02	0.041
Furniture/equipment	**Padded seats**	6	Empty padded seats (per item) in m2	6.00	0.42	2.52
	A/C	1	Ventilation grille in m2	1.15	0.15	0.17
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**6.39**

Building C: Private office and meeting rooms, Upper tier

Table A7.7.3. Absorption coefficients and total absorption of private office and meeting room for Building C upper tier (Source: Author)

Private office space						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	32.06	0.05	1.60
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	32.06	0.05	1.60
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	14.34	0.03	0.43
	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	13.16	0.03	0.39
Interior façade	**RCC column**	2	Smooth concrete, painted	8.45	0.02	0.16
	Brick wall	1	Painted plaster surface on masonry wall	1.76	0.02	0.035
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	10.37	0.02	0.20
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	16.32	0.03	0.83
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	5.83	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Side table/Coffee table**	2	Adult office furniture per table	2.00	0.45	0.90
	Padded seats	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Unoccupied sofa seats	6	Seats, leather covers, per m2	1.80	0.61	1.10

	A/C	1	Ventilation grille in m2	3.20	0.15	0.48
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45

Total Absorption in 1 kHz Frequency (A): **10.68**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	12.5 mm Woodblock tiles on solid floor	26.54	0.05	1.32
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	26.54	0.05	1.32
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	7.94	0.03	0.23
	West	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	16.47	0.03	0.49
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	11.19	0.03	0.57
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.00	0.06	
	RCC column	2	Smooth concrete, unpainted	8.75	0.02	0.17
	Gypsum wall	1	12.5 mm thick gypsum board on frame, 75 mm air space	2.35	0.02	0.04
	Brick wall	1	Painted plaster surface on masonry wall	0.44	0.02	0.008
Furniture/equipment	**Padded seats**	10	Empty padded seats (per item) in m2	10.00	0.42	4.20
	A/C	1	Ventilation grille in m2	2.65	0.15	0.39
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73

	Conference table	1	Adult office furniture per desk	1.00	0.45	0.45
					Total Absorption in 1 kHz Frequency (A):	**9.97**

Building D: Private office and meeting rooms, Lower tier

Table A7.8.1. Absorption coefficients and total absorption of private office and meeting room for Building D lower tier (Source: Author)

Private office 01						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.39	0.30	3.11
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.39	0.05	0.51
Exterior façade	**West**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	3.97	0.03	0.11
	South	1	Painted plaster surface on masonry wall	6.83	0.02	0.13
Interior façade	**RCC surface**	2	Smooth concrete, unpainted	11.69	0.02	0.23
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	17.56	0.03	0.9
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.45	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	A/C	1	Ventilation grille in m2	1.03	0.15	0.15
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
					Total Absorption in 1 kHz Frequency (A):	**7.74**

Private office 02						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	9.40	0.30	2.82
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.40	0.05	0.47
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	1.54	0.03	0.046
Interior façade	**RCC surface**	2	Smooth concrete, unpainted	3.97	0.02	0.079
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	17.39	0.03	0.89
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.21	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	A/C	1	Ventilation grille in m2	0.94	0.15	0.14
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**7.73**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.93	0.05	0.54

Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.93	0.05	0.54
Exterior façade	South	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	12.79	0.03	0.38
Interior façade	RCC surface	1	Smooth concrete, unpainted	85.04	0.02	1.70
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	17.91	0.03	0.92
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.40	0.06	
Furniture/equipment	Empty chairs	10	Empty plastic seats (per item) in m2	10.00	0.14	1.40
	A/C	1	Ventilation grille in m2	1.09	0.15	0.16
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**8.85**

Building D: Private office and meeting rooms, Middle tier

Table A7.8.2. Absorption coefficients and total absorption of private office and meeting room for Building D middle tier (Source: Author)

Private office 01						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.99	0.30	3.29
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.99	0.05	0.54
Exterior façade	**South**	1	Painted plaster surface on masonry wall	7.72	0.02	0.15
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	22.89	0.03	1.17

			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	8.18	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	A/C	1	Ventilation grille in m2	1.09	0.15	0.16
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**7.90**

Private office 02						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	8.74	0.30	2.62
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	8.74	0.05	0.43
Exterior façade	**North**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	6.61	0.03	0.19
Interior façade	**RCC surface**	1	Smooth concrete, unpainted	5.81	0.02	0.11
	Brick wall	1	Painted plaster surface on masonry wall	7.50	0.02	0.15
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	11.95	0.03	0.61
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	4.27	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Empty seats**	1	Empty plastic chairs (per item) in m^2	1.00	0.14	0.14
	Cabinet	1	Wooden platform with large space beneath	4.27	0.17	0.73

	A/C	1	Ventilation grille in m2	0.87	0.15	0.13
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**6.49**

Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.93	0.30	3.27
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.93	0.05	0.54
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	12.79	0.03	0.38
Interior façade	**RCC surface**	1	Smooth concrete, unpainted	85.04	0.02	1.70
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	17.91	0.03	0.92
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.40	0.06	
Furniture/equipment	**Empty chairs**	10	Empty plastic chairs (per item) in m2	10.00	0.14	1.40
	A/C	1	Ventilation grille in m2	1.09	0.15	0.16
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**8.85**

Building D: Private office and meeting rooms, Upper tier

Table A7.8.3. Absorption coefficients and total absorption of private office and meeting room for Building D upper tier (Source: Author)

Private office space 01						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.99	0.30	3.29
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.99	0.05	0.54
Exterior façade	**South**	1	Painted plaster surface on masonry wall	7.72	0.02	0.15
Interior façade	**Glass partition wall (with door)**	1	2.1m X 12 mm thick toughened glass, held by SS U channel	22.89	0.03	1.17
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	8.18	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	A/C	1	Ventilation grille in m2	1.09	0.15	0.16
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**7.90**

Private office space 02					
Surface and elements	**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor	1	Carpet, thin, over thin felt on concrete	9.27	0.30	2.78
Suspended ceiling	1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	9.27	0.05	0.46

Interior façade	**RCC surface**	1	Smooth concrete, unpainted	5.29	0.02	0.105
	Brick wall	1	Painted plaster surface on masonry wall	3.97	0.02	0.07
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	18.88	0.03	0.97
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.74	0.06	
People	**Adults on padded seat**	1	1 per m2 per item	1.00	0.90	0.90
Furniture/equipment	**Padded seats**	2	Empty padded seats (per item) in m2	2.00	0.42	0.84
	Side table/Coffee table	1	Adult office furniture per table	1.00	0.45	0.45
	Unoccupied sofa seats	2	Seats, leather covers, per m2	0.60	0.61	0.37
	A/C	1	Ventilation grille in m2	0.92	0.15	0.13
	Private desk	1	Adult office furniture per desk	1.00	0.45	0.45
				Total Absorption in 1 kHz Frequency (A):		**7.55**
Meeting room						
Surface and elements		**No. of units**	**Material Description**	**Area/Item (Sq m)**	**Absorption Coefficients (α) 1 kHz**	**Total Absorption 1 kHz**
Floor		1	Carpet, thin, over thin felt on concrete	10.93	0.30	3.27
Suspended ceiling		1	12.5mm thick gypsum/mineral board with 0.5 m deep air space behind	10.93	0.05	0.54
Exterior façade	**South**	1	6 mm Double Glazed Unit (DGU) filled with 12 mm helium	12.79	0.03	0.38
Interior façade	**RCC surface**	1	Smooth concrete, unpainted	85.04	0.02	1.70
	Glass partition wall (with door)	1	2.1m X 12 mm thick toughened glass, held by SS U channel	17.91	0.03	0.92
			0.75 m long 12.5 mm thick gypsum board on frame above, 75 mm air space	6.40	0.06	

Furniture/equipment	**Empty chairs**	10	Empty plastic chairs (per item) in m2	10.00	0.14	1.40
	A/C	1	Ventilation grille in m2	1.09	0.15	0.16
	Conference table	1	Adult office furniture per table	1.00	0.45	0.45
			Total Absorption in 1 kHz Frequency (A):			**8.85**

Appendix 08: Calculations for PSA values of open, semi-private and private office spaces

According to Eq. 3.6.1.b, for Bangla language, PSA was calculated using the following formula.

$$PSA = 93k_ik_rk_nk_s \ (\%)$$

Table A8.1.1. PSA values calculated for open and semi-private office spaces (Source: Author)

Building A (Lower tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.69	0.65	1.00	41.52
Building A (Middle tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.67	0.64	1.00	40.43
Building A (Upper tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.69	0.62	1.00	40.03
Building B (Lower tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.70	0.56	1.00	36.13
Building B (Middle tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.69	0.59	1.00	37.89
Building B (Upper tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.75	0.57	1.00	39.70
Building C (Lower tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.67	0.59	1.00	36.50
Building C (Middle tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.66	0.58	1.00	35.52
Building C (Upper tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.68	0.58	1.00	36.66

Building D (Lower tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.72	0.58	1.00	38.61
Building D (Middle tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.75	0.61	1.00	42.34
Building D (Upper tier)				
k_i	k_r	k_n	k_s	PSA value (%)
1.00	0.76	0.58	1.00	41.46

Table A8.1.2. PSA values calculated for private office spaces (Source: Author)

Building A (Lower tier)					
	k_i	k_r	k_n	k_s	PSA value (%)
Private office	1.00	0.60	0.71	1.00	39.76
Meeting room	1.00	0.61	0.73	1.00	41.32
Building A (Middle tier)					
	k_i	k_r	k_n	k_s	PSA value (%)
Private office	1.00	0.63	0.71	1.00	41.26
Meeting room	1.00	0.65	0.72	1.00	43.63
Building A (Upper tier)					
	k_i	k_r	k_n	k_s	PSA value (%)
Private office	1.00	0.62	0.69	1.00	39.76
Meeting room	1.00	0.60	0.70	1.00	39.25
Building B (Lower tier)					
	k_i	k_r	k_n	k_s	PSA value (%)
Private office space 01	1.00	0.62	0.65	1.00	37.55
Private office space 02	1.00	0.63	0.67	1.00	39.33
Private office space 03	1.00	0.60	0.62	1.00	34.75
Meeting room	1.00	0.55	0.64	1.00	32.54

Building B (Middle tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office space 01	1.00	0.62	0.66	1.00	37.88
Private office space 02	1.00	0.66	0.70	1.00	43.16
Private office space 03	1.00	0.66	0.71	1.00	43.31
Meeting room	1.00	0.58	0.71	1.00	38.30
Building B (Upper tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office space 01	1.00	0.53	0.60	1.00	29.35
Private office space 02	1.00	0.68	0.59	1.00	37.08
Private office space 03	1.00	0.66	0.55	1.00	33.73
Meeting room	1.00	0.54	0.58	1.00	28.79
Building C (Lower tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office	1.00	0.68	0.69	1.00	43.16
Meeting room	1.00	0.67	0.71	1.00	44.23
Building C (Middle tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office	1.00	0.69	0.69	1.00	44.47
Meeting room	1.00	0.67	0.72	1.00	44.71
Building C (Upper tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office	1.00	0.56	0.70	1.00	36.45
Meeting room	1.00	0.59	0.72	1.00	38.98
Building D (Lower tier)					
	k_i	k_r	k_n	k_s	**PSA value (%)**
Private office space 01	1.00	0.72	0.71	1.00	47.75

Private office space 02	1.00	0.72	0.61	1.00	40.37
Meeting room	1.00	0.74	0.70	1.00	48.16
Building D (Middle tier)					
	$\boldsymbol{k_i}$	$\boldsymbol{k_r}$	$\boldsymbol{k_n}$	$\boldsymbol{k_s}$	**PSA value (%)**
Private office space 01	1.00	0.72	0.65	1.00	43.72
Private office space 02	1.00	0.72	0.68	1.00	45.69
Meeting room	1.00	0.74	0.69	1.00	47.38
Building D (Upper tier)					
	$\boldsymbol{k_i}$	$\boldsymbol{k_r}$	$\boldsymbol{k_n}$	$\boldsymbol{k_s}$	**PSA value (%)**
Private office space 01	1.00	0.72	0.68	1.00	45.52
Private office space 02	1.00	0.74	0.63	1.00	43.52
Meeting room	1.00	0.74	0.69	1.00	47.32