GUIDELINES FOR ACOUSTICAL DESIGN OF THE CONTEMPORARY OFFICE BUILDING

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF ARCHITECTURE

By

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the dissertation, entitled **"GUIDELINES FOR ACOUSTICAL DESIGN OF THE CONTEMPORARY OFFICE BUILDING"** in partial fulfilment of the requirement for the award of the degree of **Master of Architecture**, submitted to the Department of Architecture and Planning, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2009 to June 2010 under the supervision of **Prof. Rita Ahuja**, Department of Architecture and Planning, Indian Institute of Technology Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Place: Roorkee
Date: 30th June 2010

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CERTIFICATE

This is to certify that the above statement made by the candidate **Mr. Sunny Kumar** is correct to the best of my knowledge.

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Sunny Kumar

[Sunny Kumar]

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LIST OF ABBREVIATIONS

AC	Articulation class
AI	Articulation index
HVAC	Heating ventilation air conditioning
IEQ	Indoor environmental quality
NC	Noise criteria
SAA	Sound absorption average
SII	Sound intelligibility index
SP	Sound pressure
STC	Sound transmission coefficient

INTRODUCTION

1.1 Introduction

1.2 Background

1.3 Identification of problem

1.4 Aim & objectives

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1.6 Methodology

CHAPTER 1

INTRODUCTION

"Acoustics" is a science of sound, which deals with origin, propagation and auditory sensation of sound, and also with design & construction of different building units to set optimum conditions for producing &listening speech, music, etc. It is one of the new environmental sciences that have just become a recognized and respected discipline within the past half century. Every space that man occupies possesses an acoustical environment.

In recent years there has been an increased interest in office buildings, factory spaces and dwellings when the acoustics is of concern. Open office system came in existence (because It provides functional flexibility of spaces than enclosed offices by using moveable partitions or systems furniture to form individual workspaces, the initial cost for open office environments is less than that for enclosed offices, It promotes transparent planning in order to increase the employee's interaction which leads to work efficiency and reconfiguration can be done rapidly at minimal cost) causes problems of acoustical inefficiency. It is acknowledged that reducing noise levels in the living environment of people does improve the quality of life and also contributes to an improvement in health.

Sound is an old as the command "let there be light". But the knowledge to control sound is a new concept of science, still not complete, still dependent upon consolidation. Every architect should be knowledgeable enough to protect himself and his clients from acoustical surprises in his complicated buildings. In present-day building practice, the enormous increase of noise levels and noise sources means that the acoustical performance of a building will ultimately depends upon the attention given by the architect to acoustical requirements in designing, detailing, specifying, and supervising the project. Architects have responsibility to design functional and safe environments. It is very difficult to meet these goals without considering acoustics. Acoustics is essential to the functioning of almost every type of environment, from open offices to worship centers.

So with all considered environmental aspect of architectural design, it is needed to give equal emphasis on acoustical aspect.

1.2 BACKGROUND

In history, the first reference to building acoustics is recorded by 'Vitruvius' for designing of ancient Greek open –air theatres. But the influence of acoustics on the design of buildings can be observed all through the ages. Extensive quantitative study of the subject had to wait until the 19^{th} century when 'W.C.Sabine' did his pioneer work on the practice of acoustic design; Lord Rayleigh *wrote his classical exposition "The theory of Sound". Today wide new fields* of study are opened.

1.3 PROBLEM IDENTIFICATION

In the present day competitive world, the work output /efficiency of the employees attains high importance, which in turn depends upon the user comfort, facilities, setup or directly the environment in which user work. Because of increased land price and increased property rate causes open office system came in existence have problems like-

- **Noise**
  - Air borne noise -
    - These are the noises which are generated in air & are transmitted through air. Such sounds travels from one part of the building to the other, or from outside of the building to inside by Openings like *door,* windows, ventilators, key holes, etc.
    - Forced vibrations set up in walls, ceilings, etc.
  - Structure borne noise - These are the sound, which originate and progress on the building structure. These are caused by structural vibrations originated due to impact. Ex- footsteps, movement of furniture, dropping of utensils, hammering, drilling, operation of machinery, etc.
- **Vibration**

  No piece of rotating, reciprocating, or vibrating equipment is perfectly balanced. The imbalance causes it as well as its supporting structure (floor, beam, etc.) to vibrate. If unchecked, the vibration may be felt or heard as noise, often a considerable distance from the equipment. There are no standards as such.

- **Duct** (HVAC system and Lift)
  - Noise, as from ventilation fans or due to turbulence in the airstreams, propagates along ducts and enters rooms through the air supply and return grilles.
  - A 1996 study published in *Indoor and Built Environment examined* low frequency noise of 7 Hz in several offices. Many occupants experienced the symptoms as a result of exposure to the noise: fatigue, headache, nausea, concentration difficulties, disorientation, seasickness, digestive disorders, cough, vision problems, and dizziness. This study demonstrated that low frequency noise from the ventilation system.

- **Lack of privacy at place of work**

People require a high degree of confidentiality need even within an overall open plan arrangement of office. It causes problem of acoustical inefficiency causing employees distraction, stress etc.

- **No attention during project planning and design**

- **Inadequacy of sound insulation regulations**

There are no as such guidelines for acoustical design of public buildings which can guide at different stages of development. A number of green building rating systems formalize the implementation of sustainable design practices. The question arises as to whether a building that is not comfortable acoustically and therefore not fit for its purpose is actually a sustainable building for its occupants.

- **Health problems**

  In 1997 study published in the *International Journal of Epidemiology examined the role of work-related stress as a* factor in SBS (sick building syndrome). A questionnaire was used to assess symptoms and the perception of the physical and the psychosocial environment among 2160 individuals in 67 Singapore offices. The study found that poor acoustics was a factor associated with the occurrence of SBS-related stress.

1.4 AIM & OBJECTIVES

To understand and analyze issues related to acoustic and to frame guidelines for the acoustical design for office building.

To attain the set aim of the thesis, various objectives have been formalized.

- To study human behavior (psychology) in acoustical environment
- Understanding the issues related to acoustics in office buildings.
- To study passive and active techniques for good acoustical indoor environmental quality(IEQ)
- Frame guidelines for the acoustical design for office buildings.

1.6 SCOPE AND LIMITATION

- The thesis will be limited in studying and analyzing architectural considerations only
- Study will be limited to the acoustic based issues of office buildings
- Formulation of guidelines will be for the office buildings, it may not be applicable to other buildings types.

1.7 METHODOLOGY

The methodology of the study to achieve the above aim and objective begins with the identification of problem, framing the aims and objectives followed by simultaneous theoretical review and case studies. Based on the study and analysis, strategies and guidelines are framed.

IDENTIFICATION OF PROBLEMS

LITERATURE SURVEY/REVIEW

- Important technical terms
- Office building design requirements
- Issues related to acoustic based design
- Acoustical Analysis in Office Environments

CASE STUDIES

ANALYSIS & INFERENCES

FORMULATION OF DESIGN GUIDELINES

CONCLUSION AND AREA FOR FURTHER STUDY

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2.1 Historical context of office workspaces

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CHAPTER 2

Preamble

Literature review is one of the important aspects, which are directly related to the study. It helps to understand the existing studies that are dealt with, application of methods, their recommendations and conclusion.

The literature review includes behavior of sound in an enclosed space, human ear and hearing, noise, human response, noise & speech privacy, acoustical phenomenon in enclosure & acoustical defects, acoustical properties of common building materials, special acoustical materials.

2.1 HISTORICAL CONTEXT OF OFFICE WORKSPACES

2.1.1 The Office Facility

Throughout history, people have met to exchange information, make decisions, develop plans, and to buy and sell goods or services. They may have conducted these activities while seated on a carpet, in the consulting room of a professional, or in an aristocrat's study. For businesses today, the office has become the setting of choice for the generation, coordination, and communication of information. It is a facility in which people can interact with each other, with their information, and with their information processing tools.

Our current concept of an office as a facility built especially for that purpose emerged in Europe in the mid-1800s. Office buildings of that time consisted of rooms that were rented to a single company or to several small firms for transacting clerical or executive business. Since the emergence of the single purpose office building, the office workplace has evolved with advances in construction technology, improvements in office equipment, and developments in organization theory.

2.1.2 Changing Styles of the Office

Office designs from the middle of the nineteenth century to today have primarily served the rapidly increasing clerical and administrative components of business. As organizations became larger, their growing clerical and administrative workforce, which had previously been housed in private and shared quarters, was accommodated in ever-larger general-purpose office spaces. The placement of enclosed offices on the perimeter created sizable interior spaces that became known as **'Bullpens'**. It was common to have dozens, even hundreds, of clerical work stations in these expansive interior spaces.

Bullpen layouts consisted of a rigid arrangement of desks, usually in rows. They provided individual workers with no visual or acoustic privacy and were typically noisy, poorly lit, and uncomfortable places to work. Ergonomics was not considered an issue in the office.
In the late 1950s, a new office design called the **'Burolandschaft'** (translated from German as "office landscape") was developed in Germany. Two brothers, Eberhard and Wolfgang Schnelle, leaders of the Quickborner Team of management consultants, heavily promoted it. The office landscape design sought to provide flexible, interesting interiors that could easily be adapted to individual tastes and group needs. Layouts were spacious and used high-quality furnishings. Arrangements of live plants, artwork, and other unconventional devices were employed to divide the space into individual work areas.
The concept underlying this design was for the physical layout to reflect a democratic and liberated style of management as well as to provide high-quality interiors tailored to the occupants' needs. It was a philosophy that fit well with the architectural design ideas that came into trend in the United States and Canada during the 1960s.
At about that time, Robert Propst, a U.S. inventor researcher, was developing an unconventional approach to furnishing offices for Herman Miller, a major office furnishings manufacturer. His idea, called the "Action Office Furniture System," was to replace such traditional office furniture as desks and credenzas with furniture components and panels that could be assembled into a wide range of work settings. Work surfaces, storage units, and other elements were hung on freestanding panels, which could be arranged as needed to form a complete office work setting. It was the beginning of what today is called **'Systems furniture'**.
As varying-height acoustic panels were introduced into the open office, floor-supported desks and storage units began to be integrated into the rectilinear panel system. This office layout of "cubicles" offered slightly more privacy while retaining space efficiency. Hundreds of office furniture designs are now based on this concept.

The use of systems furniture to create large open-plan areas was a divergence from the original office landscape design envisioned by' Propst and the Quickborner' Team. The office landscape employed high-quality furnishings and provided spacious work settings. By contrast, the open-plan systems furniture design was mainly used to increase the number of workers who could be housed in a given floor area.

Compared with the bullpen arrangement, an open-plan/systems furniture approach offered more privacy and more convenient storage of papers and files but less noise control. However, most occupants still preferred the private or shared enclosed offices of that time. Proponents of the open-plan arrangement emphasized more open communication among office workers as a major benefit, even though occupants felt the lack of communication was not a significant problem. Early on, occupants of the new open plan layouts complained of a lack of privacy, and insufficient space.

2.1.3 Today's office

It was the higher density of work settings that made the open-plan office most attractive to cost-conscious organizations. The goal was to squeeze as many people as possible into the minimum amount of space.

Now a day's increase in Open office environments is greatly used because

- It provide greater flexibility than enclosed offices by using easy to relocate low-height, moveable partitions or systems furniture to form individual workspaces, rather than employing full-height permanent partitions.
- the initial cost for open office environments is less than that for enclosed offices and
- Reconfiguration can be done rapidly at minimal cost.

Often, too little attention was paid to developing well designed, comfortable workplace environments. In the 1980s, systems furniture like desks, tables, and chairs that could be used interchangeably and could readily support personal computers began to replace fixed office furniture.

Nevertheless. it was not until the early 1990s, when downsizing, restructuring, and re-engineering efforts rushed through the American workforce, that 'Propst's and Quickborner's' business-driven approach really gained favor. The importance of having workspace that can adapt to the work needs, rather than adapting the work processes to fit the space, is once again being recognized

Today, the change to open environments is less about saving on operations costs than about reaping long-term benefits such as increased productivity and efficiency. While significant savings still result, organizations adopting this tactic will more likely convert the saved space into informal meeting rooms, snack areas, and project rooms or reinvest it into workplace tools that the employees themselves have identified as important for improving their productivity.

More and more, the office environments of today's front-running businesses reflect the business goals and work habits of that organization and possess the flexibility and suitability that can adapt to rapid changes with minimal cost, while supporting high productivity and providing employee satisfaction.

2.2 ACOUSTICAL PRIVACY – A SOCIOLOGICAL HUMAN NEED

Privacy

Privacy is a central regulatory human process by which persons make themselves more or less accessible to others. In an office environment, privacy may be manipulated through the use of partitions which protect the individual from physical, visual and acoustical intrusion. The plan of an office environment establishes the privacy level at which the office functions.

Privacy in terms of four overlapping components:

- Acoustical
- Visual
- Territorial
- Informational

Acoustical Privacy

"While some sounds may be meaningful to the person or group that creates them, those same sounds may be considered noise by the people they bother."-Workplace Privacy: Steelcase

People may feel they have acoustical privacy when they can work undisturbed by noise or when they can create noise of their own without disturbing other people.

A recent survey of office workers, co-sponsored by the American Society of Interior Designers, Steelcase, Armstrong World Industries, and other workplace industry manufacturers, found that

71 % of respondents find noise the most significant workplace distraction

81 % believe a quieter environment would help them be more productive

While people may be more easily bothered by sounds they can't control or don't expect, not all sound is bad. It can be bad if it's distracting people who are trying to concentrate on a task. It can be good when it motivates people to perform at higher levels. And while some people need high levels of quiet when they work, some people concentrate better with some sort of background hum. Having some background sound can help people feel more comfortable that what they're saying won't stand out against the backdrop of the office.

Just as too much noise can cause stress and impede productivity; too much quiet can actually interfere with the ability to focus. If it's so quiet you can hear the proverbial pin drop, the sound of that pin dropping will be distracting. Similarly, too much quiet can hamper effective communication. People may feel reluctant to discuss confidential information if they think other people will be able to understand their words.

Traditional drywall offices are not always a foolproof solution for people requiring conversational privacy. If the ceiling above a room isn't sealed, conversations may travel into adjacent work spaces.

2.3 BEHAVIOR OF SOUND IN AN ENCLOSED SPACE

Shape, dimensions, construction, and contents of any room will determine how sound is transmitted, reflected and absorbed.

The way in which sound behaves in an enclosed space depends on the following factors:

- Attenuation due to distance.
- Audience absorption of direct sound.
- Surface absorption of direct and reflected sound.
- Reflection from re-entrant angle - Sound entering right-angled corner of room will be reflected back towards source if surfaces are acoustically reflective. This can produce echoes in large spaces.

ACOUSTICAL PHENOMENON IN AN ENCLOSURE:

Studying the behavior of sound in a room can be simplified if the outwardly traveling layers of compression and rarefaction are replaced by imaginary sound rays perpendicular to the advancing wave front, traveling in straight lines in every direction within the space, quite similar to the beams of light.

Sound reflection

Hard, rigid and flat surfaces, such as concrete, brick, stone plaster or glass, reflect almost all-incident sound energy striking them. Convex reflecting surfaces tend to disperse and concave surfaces tend to concentrate the reflected sound waves in the room.

Sound absorption

Sound absorption is the change of sound energy into some other form; usually heat, in passing through a material or striking a surface.

The speed of the traveling sound wave is not affected by absorption. How efficient the sound absorption of a material is at a specified frequency is rated by the sound absorption coefficient. The sound absorption of a surface is measured in sabins.

Sound absorption coefficients and measurement of absorption -The ratio of the sound absorbed by one square meter surface to that absorbed by one square meter of open window is called coefficient of absorption for that surface. The absorption of a surface is the product of the area of the surface multiplied by its adsorption coefficient and is expressed in meter square sabins.

Sound diffusion

If the sound pressure is equal in all parts of an auditorium and it is probable that sound waves are traveling in all direction, the sound field is said to be homogeneous, in other words, sound diffusion or sound dispersion prevails in the room. Adequate sound diffusion is necessary acoustical characteristic of certain types of rooms because it promotes a uniform distribution of sound, accentuates the natural qualities of music & speech, and prevents the occurrence of undesirable acoustical defects.

Sound diffraction

Diffraction is the acoustical phenomenon, which causes sound waves to be bent or scattered around such obstacles as corners, columns, walls and beams. This is more pronouncing for low frequency than for high. Diffraction sometimes reduces the acoustical defect, but only in the lower portion of audio frequency range.

Reverberation

When a steady sound is generated in a room, the sound pressure gradually builds up, and it takes some time for it to reach its steady state value. Similarly, when the source of sound has stopped, a noticeable time will elapse before the sound will die away to inaudibility. This prolongation of sound as a result of successive reflections in an enclosed space after the Source of sound is turned off is called reverberation.

The importance of reverberation control in acoustical designs has necessitated the introduction of a relevant standard of measure, the reverberation time (RT). This is the time for the sound pressure level in a room to decrease 60 db after the sound is stopped.

Room resonance

An enclosed space with sound reflective interior surfaces undesirably accentuates certain frequencies, called the normal modes of vibration of the room. Rooms have large number of normal modes, depending on their shapes and dimensions. The deleterious effect of the normal modes is particularly noticeable at the lower frequencies, where these modes are unequally distributed. This is known as resonance, which is unwanted for good acoustics.

Acoustic resonance is the tendency of an acoustic system to absorb more energy when it is forced or driven at a frequency that matches one of its own natural frequencies of vibration (its resonance frequency) than it does at other frequencies.

2.4 HUMAN EAR AND HEARING

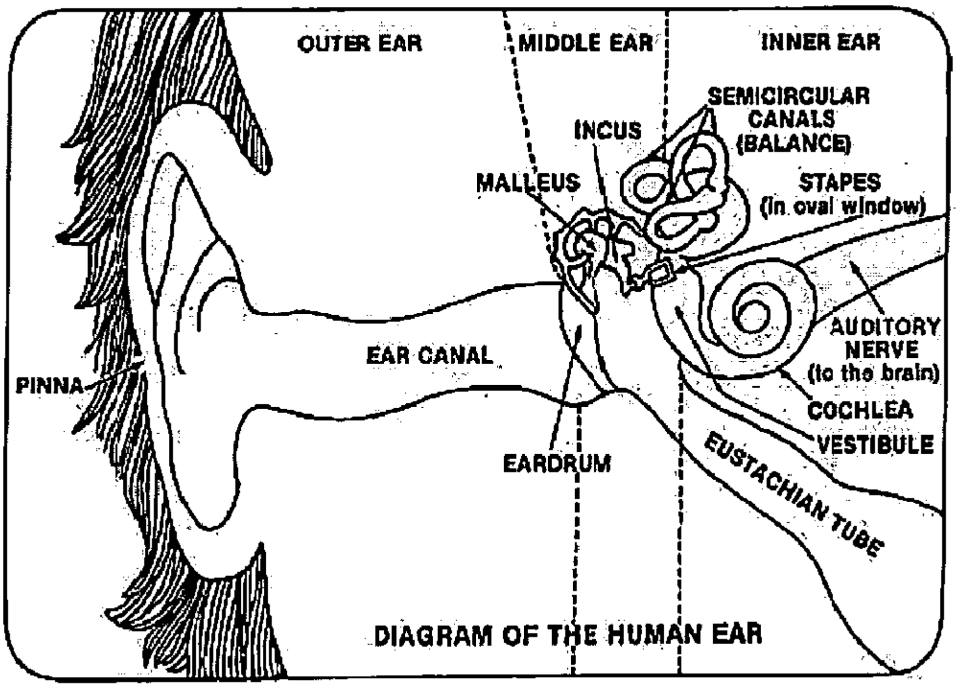


Figure 2.1: Diagram of Human Ear

Source- *http://www.abdn.ac.uk/langling/resources/ear*

- **Outer Ear**: Pinna and auditory canal concentrate pressure on to drum
- **Middle Ear**: Eardrum, Small Bones connecting eardrum to inner ear
- **Inner Ear**: Filled with liquid, cochlea with basilar membrane respond to stimulus of eardrum with the help of thousands of tiny, highly sensitive hair cells, different portions responding different frequencies of sound.

The movement of hair cells is conveyed as sensation of sound to the brain through nerve impulses.

The minimum sound pressure level of a sound that is capable of evoking an auditory sensation in the ears of an observer is called the **threshold of audibility** (0).

When the pressure level of the sound is increased, it eventually reaches a level of sound, which stimulates the ear to the point at which discomfort gives way to definite pain; this level of pressure is the **Threshold of pain** (130 db).

Unless there is a 3 dB difference in SPL, human beings cannot distinguish the difference in the sound. Masking takes place at the membrane; higher frequencies are masked by lower ones, degree depends on freq. difference and relative magnitudes of the two sounds.

Sound is perceived as doubled in its loudness when there is 10dB difference in the SPL.

(Note: 6dB change represents doubling of sound pressure.)

Ear is not equally sensitive at all frequencies. Highly sensitive at frequencies between 2 kHz to 5 kHz less at other freq. This sensitivity dependence on frequency is also dependent on SPL (sound pressure level).

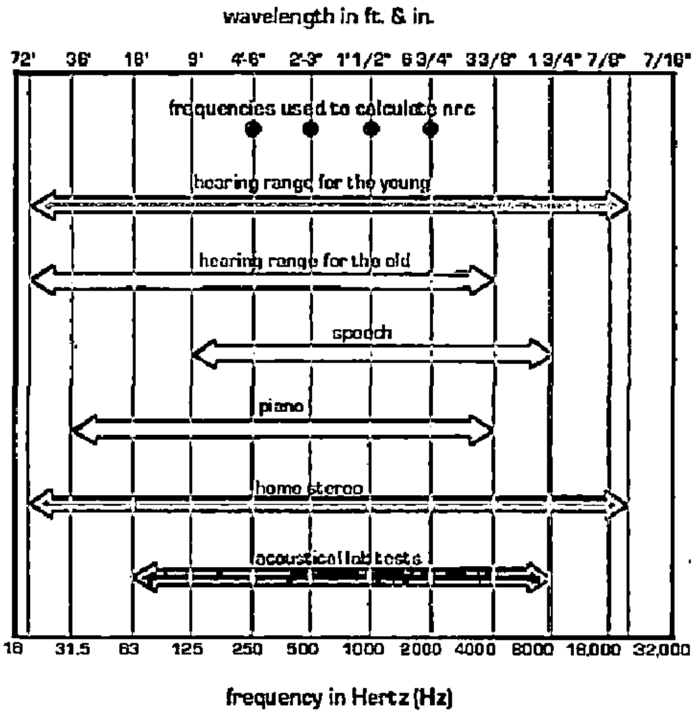


Figure2.2: Frequency range of Audible Sound

Source- Egan M. David, "Concepts in Architectural Acoustics"

2.5 HUMAN RESPONSE

The most common objection to vibration in buildings and other normal human environments is the audible effect, the surface and components of the environments vibrate strongly enough to turn them into secondary sound sources, often amplifying the original sound source appreciably.

The vibration-induced response called **felling** is a complex phenomenon which is not entirely understood, research is going on.

Subjective responses to characteristics of sound-

OBJECTIVE(SOUND)	SUBJECTIVE(HEARING)
AMPLITUDE PRESSURE INTENSITY	LOUDNESS
FREQUENCY	PITCH
SPECTRAL DISTRIBUTION OF ENERGY	QUALITY

Loudness – is the physical response to sound pressure and intensity.

Pitch-is the physical response to frequency. Low frequencies are identified as low in pitch , high frequencies as high pitched.

The frequency response of humans is interesting. For practical purposes, our hearing encompasses a range of frequencies from about 20Hz to 20000Hz.

Some important frequency range

	FREQUENCY RANGES IN HZ.(APPROX.)
RANGE OF HUMAN HEARING	20-20000
SPEECH INTELLIGIBILITY (containing the frequencies most necessary for understanding speech)	600-4800
SPEECH PRIVACY RANGE (containing speech sounds which intrude	250-2500

most objectionably into adjacent areas)	
MALE VOICE (Energy output tends to peak at about)	350
FEMALE VOICE (Energy output tends to peak at about)	700

It is apparent that low frequencies do not affect us very strongly, while those from 500 to 5000 cps (Hz) (where the ear is most sensitive) are very important.

Quality -Quality of sound refers to the spectral distribution of energy within a signal. Almost every source of sound has its own "voice-print" which identifies the sound with the source. The distribution of energy throughout the audible frequency range gives a distinct, unique character to the sound. Our ability to distinguish different sound spectra and to remember the character of the sounds permits us to identify the source and to evaluate the significance of the sounds.

2.6 NOISE & SPEECH PRIVACY

Noise (unwanted sound) is produced by so many sources. Almost all object or activity – human, natural, artificial or mechanical produces noise. The sounds which become noise include the sounds of communication, transportation, production, recreation, and all of the familiar activities of man. Occasionally, the sound of wind, weather, water, and even animals become noise. These sounds are an essential part of the environments in which and with which we operate.

We cannot tolerate silence for more than very brief periods. In very quiet acoustical environments we become conscious of our own bodily processes and the slightest movement and even insignificant sounds become disturbing. We almost always prefer some 'masking sound'-a form of acoustical perfume to cover up the little sounds which might otherwise become annoying or distracting.

Sounds loud enough to interfere with sleep or with listening tasks are usually undesirable. However we want **privacy** rather than **silence** in environment. We want to be protected against the intrusion of stimuli which interfere with our task or mood. Unless very loud , extraneous speech sounds do not particularly disturb us during our waking hours until they become distinct enough to carry information- that id=s until they are intelligible. Likewise we rarely worry about our own conversation being transmitted to other areas unless it has some private informational content which we do not wish to share. Therefore some background sound is usually not only acceptable but desirable.

On the basis of research into human response and preferences, acousticians have developed a set of contours, very similar to the equal loudness contours, to describe numerically various levels of acceptability of steady, constant background sound. Noise criteria curves are a sort of template which specifies the maximum level in any frequency band which will be acceptable in the environment being specified. When an 'NC-number' is used to specify an environment, it means that in no frequency band shall the sound pressure level in the space exceed the specific NC-curve (indicated by NC-number).(NC-levels usually refer to steady, continual background levels within a space or neighborhood ,as opposed to specific noises or intermittent activities occurring there.

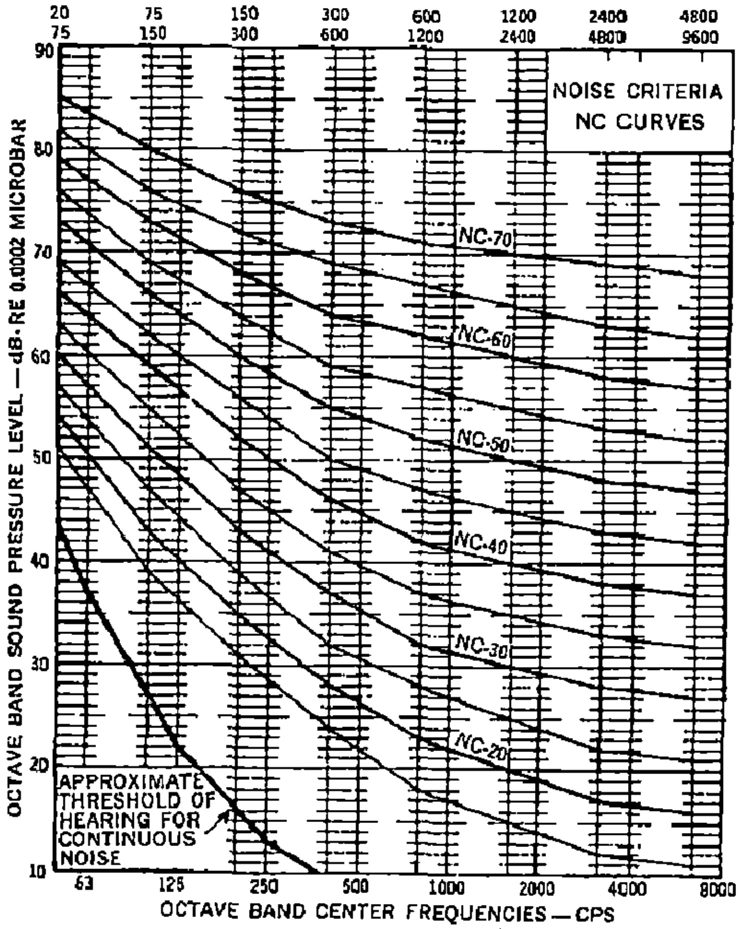


Figure 2.3: Noise Criteria Curve

Source :Lyle F.Yerges,"Sound, Noise and Vibration Control".1978, p.87.

FUNCTION	SPACE	NC
SPEECH	ASSEMBLY HALL	30
DISCUSSION	SEMINAR ROOMS CONFERENCE ROOMS	30 25-35
MENTAL AND CREATIVE TASKS	EXECUTIVE OFFICES NORMAL PRIVATE OFFICES STUDY ROOMS	30 35 35
PUBLIC SPACES	CORRIDORS LOBBIES REST ROOMS	40 40 40
DINING	RESTAURANTS KITCHENS	45 55
CLERICAL	STENOGRAPHYAND DUPLICATING STORES	50 40-50
TRANSPORTATION	GARAGES AND PARKING RAMPS	55-65
COMPUTING AND CALCULATING	ACCOUNTING ROOMS COMPUTER ROOMS	65-70 70
MACHINE ROOMS	BUILDING MECHANICAL EQUIPMENT	70

(NOTE-all numbers listed may vary as much as +-5points in specific cases)

Most people agree that environments with background sound levels under NC-30 are 'quiet' and those with levels above NC-55 are 'noisy'.For various activities, various background levels are acceptable. In large office areas, levels as high as NC-50 is tolerated without much complaint.

We have avoided calling background sound-noise, unless and until it exceeds the specified criterion. Noise is unwanted sound but sound below the specified criterion is wanted, and cannot be described as noise.

SPEECH PRIVACY

Speech privacy is a fundamental human right secured by many of the world's new privacy laws. In the open plan space one of the most important design problems is to provide acoustical privacy from the occupant's intelligible speech.

Speech privacy depends upon-

Speech Effort: Describes how people will talk in the room.

- Low: The situation in most open plan spaces that are heavily treated with sound absorbing materials. (A whispering voice, for example, would fall below the low voice level.)
- Conversational: Persons in the open plan must often learn to speak in at least a conversational voice level so they will not disturb their neighbors.
- Raised: In conference situations people can be expected to talk in a raised voice level to span the distance of conference tables.
- Loud: Workers in noisy business-machine spaces must speak in a loud voice to communicate.

Privacy Allowance: Deals with the kind of privacy which is desired.

- Normal: Means the occupant wants freedom from disturbing intruding speech. Generally, select normal privacy in design for most open plan privacy situations.

- Confidential: The occupant doesn't want his conversation overheard. Banks, financial offices, etc., are examples that usually require confidential privacy. Executives, supervisors, and counselors often need this degree of privacy to be able to converse with a select individual or group without being overheard.

Distance from Source to Listener (D): Accounts for the attenuation of voice levels with distance.

Room background noise level: masking sound available

Room background noise levels in the open plan space must be high enough to provide satisfactory speech privacy conditions.

Speaker and listener orientation: speaker orientation is an important factor in open plans. There is about 10dB difference in speech level between the front and rear of a speaker. Consequently, poor orientation of chairs or desks could contribute to unsatisfactory open plan privacy conditions.

SOUND MASKING

Sound masking is based on the phenomenon that when "low level background noise" is added to an environment, intruding speech and noises are less intelligible. The term **"white noise"** is widely used when referring to speech privacy or sound masking systems, although these systems don't actually use white noise.

WHITE NOISE

Consider a white noise or sound-masking system to maintain a constant level of speech privacy.

If office spaces are very quiet (less than NC-35 to 40 in prime speech frequencies), conversations are readily audible to adjacent occupants, especially in open-plan offices. This, in turn, reduces concentration and interferes with productivity. **A white noise system ensures a constant background noise level to maintain speech privacy**. In these systems an evenly distributed array of speakers concealed above the ceiling artificially raises the background noise level in the space. The sound is unobtrusive to occupants and is similar to that of an HVAC system. Central white sound systems for large offices incorporate amplifiers and equalizers that can adjust the spectrum shape of sound and intensity levels to best suit the objectives. Smaller systems use individual speaker cans with inboard amplification and equalization facilities. White noise systems are typically designed to provide an even background noise in the range of NC-38 to 42, depending upon whether a cellular or open-plan office arrangement is used.

DISCRIMINATION

Man has an unusual ability to discriminate among the elements of a complex sound and to discern, particular signals of interest to him. Various sounds may produce widely different effects in different individuals, depending upon the psychological attitude of the individuals at the time. Sometimes identical sounds often produce widely different responses in the same individual at different times.

SIGNALS AND NOISE

Signal-to-noise ratio is a frequently used term in communication terminology. Unwanted sound (whatever its nature) is noise. Wanted sound (whatever its nature) communicates information to us.

When the signal-to-noise ratio becomes sufficiently large, we detect the signal and the information becomes available to us. Thus the distinction between noise and communication is completely subjective; completely a matter of our own desires or needs of the moment. This concept is used in approaching any acoustical problem. Either the signal (the wanted sound) must be presented at a suitable level above the noise level, or the noise level must be reduced below the signal level or both.

For **intelligibility**, a signal-to-noise ratio of 10dB (signal sound pressure level is 10dB above the noise level) is sufficient but this may not mean that a comfortable or pleasant situation exists. There is a significant level where interesting effects are noticed-a noise level above which even loud, shouting speech is scarcely intelligible. This level approximately 85dB in the speech frequencies (universally accepted as very loud or even uncomfortable. It has been found that continued, long-term exposure to levels in excess of this level tends to produce permanent hearing loss. Even short term exposure to such levels often produces a temporary increase in the threshold of hearing of normal humans.

2.7 ACOUSTICAL DEFECTS

Echo

Sound wave after originating in an enclosure space spreads out and strikes the surfaces of ceiling, walls, floors and objects like furniture. Some of them are reflected back. These reflected waves get reunited and give rise to ECHOES. In other words, echo is an indirect or reflected voice heard just after the direct hearing of the voice coming from the same sound source.

The formation of echoes normally happens when the time lag between the two voices is about 1/17th of a second and the reflecting surfaces are situated at a distance greater than 15 m. This defect usually occurs when the shape of reflected surface is covered with smooth character.

Echoes cause disturbance and unpleasant hearing. These can be avoided by planning the shape and size of the room based on simple law of reflection, which state that the direction of travel of reflected sound should make the same angle with the wall as that of the incident sound.

Sound foci

In case of concave shaped reflecting interior surfaces or domed ceiling of an enclosure, depending upon the curvature of these surfaces, there is possibility of reflected sound rays to meet at a point, called sound focus. This causes concentration effect for the reflected echoes and consequently creates a sound of large intensity. These spots of unusual loudness or intensity are called as **sound foci.**

This defect can be eliminated providing suitably designed shapes of the interior faces or by providing the absorbent materials on focusing areas.

Dead spots

This defect is an outcome as a side effect of the sound foci. Due to high concentration of the sound rays at some points, these spots of low sound intensity causing unsatisfactory hearing for the audience are known as **dead Spots.**

This defect can be eliminated providing suitable diffusers, enabling uniform distribution of sound in the hall.

Long delayed reflection

This defect is similar to echo except that the time delay between the perception of direct and reflected sound is a little less.

Flutter echo

This is usually caused by the repetitive inter reflection of sound between opposite parallel or concave sound reflecting surfaces. Flutter is normally heard as a high frequency ringing or bussing, it can be prevented by shaping to avoid the parallel surfaces, providing deep sound absorbing treatment, or breaking up smooth surfaces with splayed or scalloped elements.

Sound Leaks

The relative significance of any direct sound leakage through a construction is quite apparent. In fixed permanent wall or floor/ceiling systems, the leakage at intersections with floors, side walls.

Sound leakage can be prevented by -

- "One-time" applied sealants during the initial installation.
- Degradation in performance by some 23 dB from a partition system potential performance of over 50 dB can be a very real concern in typical field situations.
- Hidden sound leaks can occur in spite of even the best field supervision of the installation (above suspended ceilings, behind convector covers, etc.
- With lightweight operable or demountable partition systems, the problem of sound leakage at the numerous panel joints, floor, ceiling tracks, and side wall intersections is even more demanding.
- Materials and systems must be detailed and specified to assure positive panel joint seals that will perform effectively over the expected life of the partition installation.
- A fixed partition is relatively easy to seal. In operable or demountable partitions, the seals themselves must also be operable and durable over the life cycle of the installation with minimum maintenance required

Flanking

Besides direct sound leaks within the perimeter of a given common wall or floor/ ceiling system, significant sound transmission may occur between adjacent rooms via so-called flanking paths. There are literally hundreds of possibilities for sound to "bypass" the obvious common partition path, and their relative importance is directly proportional to the sound isolation performance desired.

Flanking becomes increasingly important with higher sound isolation performance. The sound transmission path over the partition via a suspended ceiling, against which the partition terminates, is a common condition. Others include interconnecting air-conditioning ducts or plenums, doors opening to adjacent rooms via a common corridor, and adjacent exterior windows.

Partitions terminate at a common suspended ceiling over two adjacent rooms; a serious room-to-room sound-flanking problem may exist.

Acoustical Shielding

Acoustical shielding is provided by incomplete barriers, for example, the partial-height partitions often used in open office spaces. Performance is almost always limited by the barrier's size.

To be at all effective, the barrier must extend well beyond the line of sight between the source and the receiver, and sound must not be allowed to reflect over or around the barrier. In practice, barrier attenuation seldom exceeds 20 dB. More usually, it is much less than that. It is therefore unnecessary to build partial-height barriers of high- TL materials.

Vibration Isolation

Vibration isolation pertains specifically to mechanical equipment. No piece of rotating, reciprocating, or vibrating equipment is perfectly balanced. The imbalance causes it as well as its supporting structure (floor, beam, etc.) to vibrate. If unchecked, the vibration may be felt or heard as noise, often a considerable distance from the equipment. Attenuation is achieved through use of vibration isolators (spring and electrometric mounts or hangers, flexible sleeves and connections) that allow the equipment to float free of the structure. There are no standards as such. To be effective, the natural frequency of vibration -isolated equipment must be substantially lower than the driving frequency.

Duct Attenuation

Noise, as from ventilation fans or due to turbulence in the airstreams, propagates along ducts and enters rooms through the air supply and return grilles. (Note: sound travels almost equally with and against airflow)

2.8 ACOUSTICAL MATERIALS

All building materials are in a way acoustical because all affect the manner in which sound is reflected, absorbed, or transmitted. This includes both the most common materials and many products-some common, others not so common-that are or are perceived to be acoustical. It also includes a number of special devices, whose purpose is strictly acoustical.

2.8.1 ACOUSTICAL PROPERTIES OF COMMON BUILDING MATERIALS

Brick: - Brick is a modular building block, made of clay. It is used to build load-bearing as well as non-load-bearing walls, as a facing (brick veneer), and as a paving material.

Owing to its considerable mass [approximately 2.1 kg/dm3 (130 Ib/ft3)], brick attenuates airborne sound very well. Exceptionally high orders of attenuation can be achieved with two side-by-sides but unconnected brick walls. Joints must be fully mortared or otherwise sealed. Absorption is negligible since there is little or no porosity and the material is rigid. Consequently, brick is a good for all-frequency sound reflector.

Concrete :- Concrete is a mixture of Portland cement, stone and sand aggregates, and water, cured into a hard mass of superior compressive strength. It is often reinforced with steel and used for structural slabs and walls.

Normal-weight concrete [approximately 2.3 kg/dm3 (144Ib/ft3)] is among the best attenuators of airborne sound. Lightweight concrete is less effective, unless of equal mass per unit area. Like any hard material, concrete readily accepts and transmits impact sound. Concrete provides virtually no absorption. There are, however, aerated concretes that are intentionally porous. These can be fairly absorptive.

Glass: - Glass is a usually light-transparent sheet made of a mixture of silicates. It is used principally to glaze windows and other openings that need to be closed, but without excluding light. Despite its mass [approximately 2.5 kg/dm3 (156Ib/ft3)], glass is a marginal sound attenuator because it is thin and the mass per unit area is quite small. Superior performance is provided by well-separated double glazing and by certain types of laminated glass. Almost totally reflective in the higher frequencies, glass resonates and, through this mechanism, can absorb appreciable amounts of low frequency sound.

Masonry: - Masonry is any of a large variety of stone like materials. Acoustical properties vary, but in general they are comparable to those of brick, concrete and concrete masonry units.

Gypsum Board: - Gypsum board is a fire-resistive sheet material made of calcined gypsum and certain additives, sandwiched between sheets of special paper. Typically attached to studs, joists, or some form of furring, it is one of the most common walls and ceiling finishes in use today.

Although not very heavy [approximately 0.8 kg/dm3 (50 lb/ft3)] or thick, gypsum board partitions can provide a fair amount of sound attenuation. However, much depends on the way the construction is detailed. Best results are achieved with multiple layers of gypsum board, with resilient separation between the two faces of the partition, and with absorptive material in the stud space. Joints must be perfectly sealed. Gypsum board, unless attached directly (without an airspace) to a solid substrate, resonates and thus absorbs low-frequency sound. At higher frequencies, it is highly reflective.

Plaster: - Plaster is a pasty substance made of sand, water, and a binder such as gypsum. It is applied as a finish to either masonry or lath that is attached to studs or ceiling joists.

Plaster skins applied to studs or joists attenuate sound much like those made of gypsum board .If applied to masonry, the improvement over the unplastered masonry is small or negligible. Plaster provides very little absorption except in the low frequencies, if suspended out from a solid surface.

Wood Decking: - Wood decking is one of several structural materials supported by beams or trusses to form floors and roofs. It is often exposed as a finished ceiling.Owing to its relatively low mass (as compared to concrete), wood decking provides only nominal attenuation unless ballasted with heavier materials. Wood decks are generally reflective, but unsealed cracks between the boards have been known to contribute a fair amount of absorption.

Plywood: - Plywood is a laminate of several layers of wood veneer. It is used in wood construction as an underpayment for floors, as sheathing on studs or rafters, or as finished paneling on walls. Mainly because of its modest mass [approximately 0.6 kg/dm3 (36 lb/ft3)], specifically its mass per unit area, plywood is relatively ineffective as a sound attenuator. However, it is often adequate in combination with other materials or where high performance is not required. Thin plywood, if furred out from a solid wall, is a potent low-frequency absorber. Specially detailed resonant absorbers, made of plywood, are sometimes used to "tune" special-purpose rooms. At the higher frequencies, plywood is quite reflective.

Wood Paneling: - Wood paneling means a relatively thin finish made of wooden boards or panels. These are usually attached to furring and thus kept clear of the wall behind the paneling.

Wood paneling on a wall generally results in negligible improvement over the attenuation provided by the basic wall. Wood absorbs low-frequency sound by resonance and may lead to serious bass deficiency in music rooms unless it is thick and/ or well restrained; for example, attached directly (without airspace) to the solid wall.

Stone : - Stone is a natural material of considerable mass that is used for load bearing walls, as a facing (stone veneer), and as paving. In a broader sense, it includes reconstituted materials like terrazzo. Airborne sound attenuation of stone depends, once again, mainly on its mass. If thick and well sealed, walls built of stone can be very effective. However, as a paving, stone provides no impact isolation. Stone (e.g., marble) is among the acoustically most reflective materials, though this may not apply to some stones that are naturally porous.

Steel Joists and Trusses: - Steel joists and trusses are structural members of many different configurations, including beams, designed to support floors and roofs. (Similar properties hold for joists and trusses made of other structural materials.).On their own, these members do not attenuate sound, but their spacing and rigidity can affect attenuation, especially vibration isolation. In general, rigid structures, that is, stiff, closely spaced supports, are more favorable than long-span structures that deflect more. Joists and trusses in general do not absorb sound, but may diffuse sound if exposed.

2.8.2 SPECIAL MATERIALS FOR ACOUSTICAL TREATMENT

Acoustical Deck: - An acoustical deck is a structural deck, usually made of perforated steel, which is backed by an absorptive material such as fiberglass. The term also includes decks made entirely of fibrous materials. An acoustical deck absorbs sound. Its NRC ranges from about 0.50 to as high as 0.90. If exposed, as is usually intended, an acoustical deck can greatly reduce noise and reverberation in spaces.

Acoustical Foam: - Acoustical foam is one of a variety of cellular materials, usually made of polyurethane. Foams are manufactured either with open cells (air can be blown into and through the material) or with closed cells (each cell is sealed; the material is airtight). Open-cell foams are excellent sound absorbers, provided they are sufficiently thick.

The noise reduction coefficient ranges from approximately 0.25 for 6-mm (0.25-in.) foam to 0.90 and higher for 50-mm (2-in.) or thicker foams. Their uses include padding for upholstered theater seats to stabilize reverberation regardless of occupancy.

Closed-cell foams also absorb sound, but less efficiently and less predictably. They are more often applied to ringing surfaces, such as large metal plates, to provide damping.

Acoustical Plaster:-Acoustical plaster is a plaster like product, distinguished by its porosity after it dries. It was originally intended to create joint fewer surfaces (like those of ordinary plaster) that absorb sound, which ordinary plaster does not. The performance of acoustical plaster is highly dependent on the correct mix and application technique. Noise reduction coefficients on the order of 0.60 have been obtained under controlled conditions, but field installations usually yield much less. Acoustical plaster is not a reliable sound absorber.

Acoustical Tile: - Acoustical tile is a widely used ceiling material made of mineral or cellulose fibers or of fiberglass It is available in a variety of modular sizes from approximately 30 X 30 cm (12 X 12 in.) to 61 X 122 cm (24 X 48 in.) and larger. Acoustical tile is usually suspended in a metal grid, but some types of tile can be glued or otherwise attached to solid surfaces. It is prone to damage when contacted and is therefore not recommended for surfaces, especially walls that are within human reach.

The original purpose of acoustical tile was to absorb sound. Absorptive ranges from approximately NRC 0.50 for the least efficient tiles to NRC 0.95 for the best (typically fiberglass) lay-in panels.Suspended tile provide more low-frequency absorption than glued-on tile. Membrane faced tiles provide less high-frequency absorption than those whose faces are porous.

In general, the thicker the tile the better it absorbs.Many acoustical tiles also attenuate sound. Such tiles are usually made of mineral fiber and backed by a sealed coating or foil.

Carpet: - Carpet is any of a variety of soft floor finishes made of synthetic materials such as nylon or natural materials such as wool. It is either glued directly to the floor or installed over an underpayment of hair felt or foam rubber.

Carpet absorbs sound. It is, in fact, the only floor finish that absorbs sound. Absorptivity depends primarily on the total thickness of the pile and the porous or fibrous underlayment (if present and provided the carpet does not have an airtight backing). Noise reduction coefficients range from 0.20 to about 0.55. Absorptivity is confined mainly to the high frequencies.

Carpet also attenuates impact sounds because it prevents hard contact with the floor. If sufficiently thick, it can be extremely effective. However, on wood floors, it will not eliminate low-frequency thuds.

Cellulose Fiber:- Cellulose fiber is one of a variety of fibers that forms the basis for materials such as acoustical tile, wood wool, fibrous spray etc. Each of these materials is designed to absorb sound.

Curtains and Fabrics: - Curtains and fabrics include a range of textiles they are used on their own (as curtains) or as coverings for other materials that may or may not be sound absorbing. Curtains absorb sound if they are reasonably heavy [at least 500 g/m2 (15 oz/yd2)]. A light curtain may have an NRC of only 0.20, a heavy, flow-resistant fabric, draped to half area, and may rate NRC 0.70 or more. Fabrics attached directly to hard surfaces do not absorb sound. However, if stretched over materials such as fiberglass provided they are not airtight, they make an acoustically excellent finish that fully preserves the substrate's absorptivity.

Duct Lining. Duct lining is one of a few materials that are literally an acoustical insulation. It is usually made of fiberglass and comes in thicknesses of up to 50 sq. mm. The lining is mechanically fastened to the interior surfaces of sheet metal ventilation ducts. In high-velocity ducts, it may be faced with perforated metal to prevent erosion. Duct lining absorbs sound and thus attenuates noise as it propagates along ducts.

Compared with an unlined metal duct, which may attenuate mid-frequency sound by: 5 dB/m (0.05 dB/ft), a duct with a 25-mm (1-in.) lining will yield 3 dB/m .Low-frequency attenuation is not as good. Ducts made entirely of fiberglass Exhibit similar properties, but due to their very low mass they allow sound to escape into the surrounding space.

Fiberglass:-Fiberglass, which is available in the form of batts, blankets, and boards, is an excellent sound absorber. The manufacturing process ensures consistent porosity at a very fine scale. Applications include a great many sound-absorbing treatments, insulation as in stud walls and ducts. Compressed blocks or sheets of fiberglass are also used to form resilient supports/hangers or as joint filers where rigid ties are to be avoided.

The absorptivity of fiberglass depends on flow resistance, which, in turn, is affected by the material's thickness, its density, and the diameter of the fibers. In most applications, the thickness of the board or blanket is the most important parameter.

Fibrous Batts and Blankets: - Usually made of fiberglass or mineral fiber, fibrous batts and blankets are among the most common forms of acoustical (also thermal) insulation in use today. They serve two distinct acoustical purposes.If exposed to the room, as a wall finish (behind fabric or an open grillage) or as a ceiling finish (behind perforated pans or spaced slats), they absorb sound and thus reduce noise and reverberation in the room. Performance depends on thickness and on the properties of the facing. It can be as high as NRC 0.90.

If used between the two faces of a partition (typically in the stud space, but also above suspended ceilings where the ceiling and the floor above form the partition), batts and blankets improve attenuation. They do it by absorbing sound that is in transit through the partition's cavity. If the cavity is bridged by rigid ties (e.g., wood studs), there is little improvement. With light-gauge steel studs, about 6 STC points are gained. Performance again depends on thickness, but the batt or blanket should never completely fill the cavity.

Fibrous Board:- Fibrous board works much like batts and blankets but is of higher density-up to approximately 0.32 kg/dm3 (20 lb/ft3), but more usually near 0.1 kg/dm3 (6 lb/ft3). Such rigid or semi rigid boards, especially those made of fiberglass, are excellent sound absorbers. They are available with a variety of sound-transparent (usually fabric) facings, for use as wall or ceiling panels. Ratings range from approximately NRC 0.75 for 25-mm (l-in.) fiberglass board to NRC 0.90 for 50-mm (2-in.) board. Less porous or thinner boards, such as those made of mineral fiber, are somewhat less absorptive.

Fibrous Plank: - Fibrous plank is a rigid (often structural) material, usually made of coarse fibers, such as wood fibers, embedded in a cementitious mix. The structural properties of certain planks allow them to be used as roof decking. The fibrous surface absorbs sound. Performance depends on thickness and ranges from approximately NRC 0.40 for 25-mm plank to NRC 0.65 for 75-mm plank. If exposed to the room, fibrous plank reduces noise and reverberation in the room.

Fibrous Spray:- Fibrous spray is any of a variety of sprayed-on insulating materials, often specified for fire-proofing reasons. Previously made of asbestos fibers, which are now known to be a health hazard, most contemporary sprays contain cellulose or mineral fibers of various descriptions. Fibrous spray is inherently porous and therefore absorptive. However, performance is highly dependent on thickness and application technique. A well-applied coat of 25-mm (l-in.) thickness may achieve or exceed NRC 0.60.

Laminated Glass:-Laminated glass is a sandwich of two or more sheets of glass with viscoelastic interlayer that provide damping as the sandwich is flexed. Certain types of laminated glass offer substantially better sound attenuation than an equal thickness of monolithic glass. For example, 13-mm (O.5-in.) plate glass rates in the low STC 30s, whereas 13-mm laminated glass may approach STC 40.

Lead Sheet:- In its purest form, lead sheet is sheet metal made of lead or a lead alloy. It is also available in combination with other materials, for example, as leaded vinyl. It is often used to close off the plenum above a room whose partitions extend only to a suspended ceiling. Lead provides excellent attenuation per unit thickness because it is heavy [approximately 11 kg/dm3 (700 lb/ft3)] and limp. Furthermore, lead is easily shaped to conform to irregularities, which helps avoid holes in barriers that must be tightly sealed.

Metal Pans: - Perforated metal pans, backed by fibrous batts are an alternative to acoustical tile ceilings. Similar panels can also be used on walls. The object is to absorb sound. The pan itself has little acoustical value, but the size and spacing of its perforations (not just the percent openness) affect performance.

Mineral Fiber:- Mineral fibers are a very common family of fibers used in the manufacture of acoustical tile, blankets and boards, fibrous spray.

Sealants:- Sealants are nonhardening compounds used to seal joints and cracks in many construction types. They are especially applicable to gypsum board partitions and where services (ducts, pipes) penetrate a partition. The acoustical value of sealants lies in their ability to render partitions airtight. Failing this, attenuation may be seriously compromised.

Slats and grilles: - Often believed to have acoustical value, slats and grilles (made of wood, metal, etc.) serve only to protect the material behind them. Typically, the material behind the fiber glass, which is absorptive. Absortivity is maintained if the slats or grille members are small and wide spaced. Increasing their size and / or reducing the space between them generally results in some high frequency reflectivity.

FACTORS AFFECTING ACOUSTIC ENVIRONMENT

3.1External factors

3.1.1 Topography

3.1.2 Orientation

3.1.3 Zoning

3.1.4 Site circulation

3.1.5 Landscaping

3.1.6 Building form

3.2Internal factors

3.2.1 Size

3.2.2 Shape

3.2.3 Internal landscaping

3.2.4 Layout & Orientation of spaces

3.2.5 Interior construction & materials

CHAPTER 3

3.1 EXTERNAL FACTORS

3.1.1 Topography

Site contour plays as a natural barrier for the sound hence building can be protected from heavynoise from nearby activity.

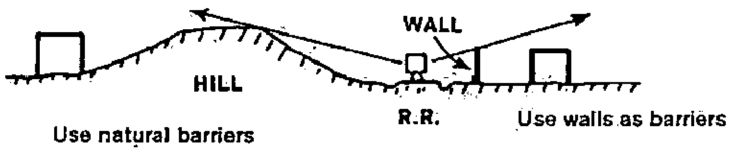


Figure 3.1: Site Topography

Source: Lyle F.Yerges,"Sound, Noise and Vibration Control".1978, p.91.

3.1.2 Orientation

Orient buildings to use less critical spaces to shield more critical spaces. Put buildings of noisier activities on the noisy exposutes, quieter activities on quieter exposures. Higher-frequency noise is easily shielded against lower frequencies tend to diffract around barriers.

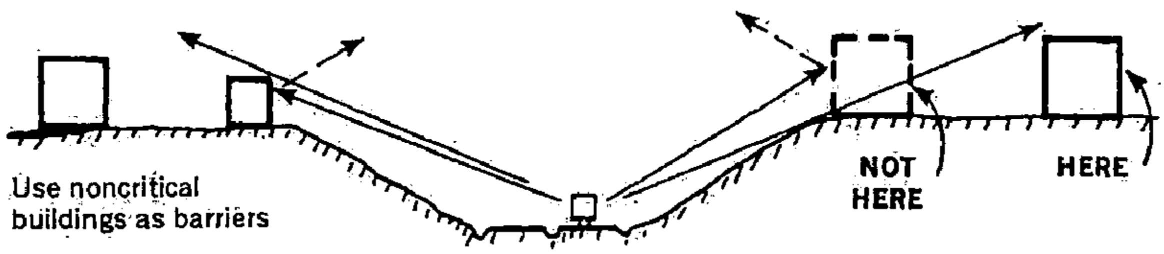


Figure 3.2: Orientation

Source: Lyle F.Yerges,"Sound, Noise and Vibration Control".1978, p.91.

3.1.3 Zoning

Divide the whole site according to use like private realm, semi-public realm and public realm so that there sound isolation requirement should be less.

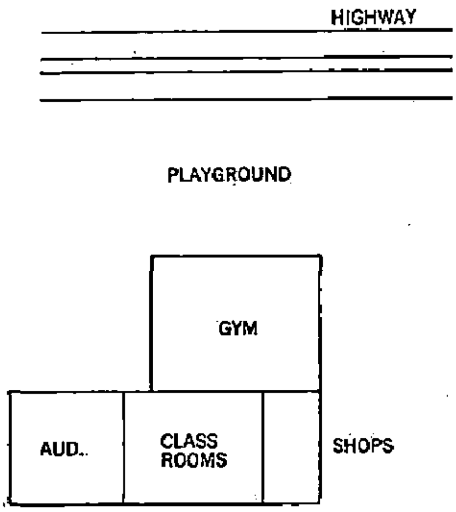


Figure 3.3: Zoning

Source :Lyle F.Yerges,"Sound, Noise and Vibration Control".1978, p.91.

3.1.4 Site circulation

There should be separate vehicular & pedestrian path which should not cross each other. If they cross, then noise causes traffic will come.

Vehicular circulation should be such that it will not cross the main activity area and also not near to building block. Peripheral vehicular path is preferable.

3.1.5 Landscaping

Trees, shrubbery and vegetation play as a sound absorber. Trees and shrubs have been used for many years to reduce traffic noise from busy roads.

Vegetation- Research on the acoustic effects of vegetation has generally been limited. Whilst most studies have predominantly centred on the reduction of sound transmission through trees in open fields, recently it has been demonstrated that vegetation would be more effective in urban areas.

To quantify the acoustic effect, the sound absorption coefficients of a number of plant species were measured –

Table of Absorption Coefficients						
Plant species	Sound Frequency (Hz)					
	125	250	500	1000	2000	4000

Ficus benjamina	0.06	0.06	0.10	0.19	0.22	0.57
Howea forsteriana	0.21	0.11	0.09	0.22	0.11	0.08
Dracaena fragrans	0.13	0.14	0.12	0.12	0.16	0.11
Spathiphyllum wallisii	0.09	0.07	0.08	0.13	0.22	0.44
Dracaena marginata	0.13	0.03	0.16	0.08	0.14	0.47
Schefflera arboricola	-	0.13	0.06	0.22	0.23	0.47
Philodendron scandens	-	0.23	0.22	0.29	0.34	0.72
Comparisons						
Bark mulch	0.05	0.16	0.26	0.46	0.73	0.88
Thick pile carpet	0.15	0.25	0.50	0.60	0.70	0.70
Plasterboard	0.30	0.15	0.10	0.05	0.04	0.05
Fresh snow, 100 mm	0.45	0.75	0.90	0.95	0.95	0.95

Table 3.1: Sound Absorption Coefficients of Plants

Source:-http://www.plants-in-buildings.com

Open field -It has been demonstrated experimentally that tall vegetation can cause significant sound reduction compared to open grassland (Heisler *et al.* 1987; Parry *et al.* 1993). Mature evergreen vegetation (say, >7m wide) may provide a modest attenuation of 2–4dBA if the belt is sufficiently high and long, has dense foliage extending to the ground and can be well maintained (Egan 1988). Wide belts of tall, dense trees of a depth of 15–40m appear to offer an extra noise attenuation of 6–8dB at low (around 250Hz) and high frequencies (>1kHz) (Kotzen and English 1999).

Tree and shrub arrangements are important. In random arrangements, the scattering contribution of trunks and branches is relatively minor and good sound attenuation requires high densities of foliage extending to ground level. Regular tree planting arrangements have been shown to offer useful 'sonic crystal' effects including 'stop-bands', giving rise to more than 15dB reduction in transmitted sound in a particular frequency range, as long as the filling ratio is sufficiently high (Umnova *et al.* 2006).

Leaves absorption -Some research was also carried out based on individual plants, especially in terms of the absorption by leaves. It was shown that factors affecting leaf absorption included biomass,size and orientation of leaves (Burns 1979; Martens 1980; Martens and Michelsen 1981; Watanabe and Yamada 1996). Tests were made in anechoic chambers and reverberation boxes, and a laser Doppler vibrometer system was used to measure the leaf vibration.

Earth mound -Strategically designed earth mounds can be effective in reducing noise. A noise barrier maybe erected on top of an earth mound to reduce the horizontal land take, although there is inconclusive evidence that this could in some cases diminish the acoustic performance of the earth mound (Ekici 2004). Factors affecting the performance include the effective barrier height, scattering and double diffraction losses on the barrier top, absorption effects of grass-covered slopes, and the slope angle of the wedge (Hutchins *et al.* 1984a, 1984b;Hothersall *et al.* 1991a).

3.1.6 Building form

Building forms can be designed to be self-protective from external noise to certain extent.

- The podium, usually for commercial use, acts as a noise barrier.
- Higher floors, typically bedrooms are farther from the noise source and they are also protected by the lower building blocks due to the screening effect.
- Balconies can effectively stop the direct sound from the source to the interior.
- Big screening wall act as a sound ba

3.2 INTERNAL FACTORS

3.2.1 Size

Small spaces normally present few difficult problems, but the severity of acoustical problems tends to increase with the size of the room. In small rooms, time of travel of wave source-to-surfaces-to-listener, and surface-to-surface is short, so distinct echo rarely occur and reverberation time is usually quite short.

In large spaces, echoes, flutter, excessive reverberation, odd distribution of energy etc generally occurs. Research shows some room sizes proportions which are good for acoustics point of view. These are –

1: 2.16 : 2.96 , 1: 2.16 : 2.97 , 1: 2.16 : 2.98 , 1: 2.17 : 2.96 , 1: 2.17 : 2.97
1: 2.17 : 2.98 , 1: 2.17 : 2.99 , 1: 2.18 : 2.97 , 1: 2.18 : 2.98 , 1: 2.18 : 2.99
1: 2.18 : 3 , 1: 2.19 : 2.99 , 1: 2.19 : 3 , 1: 2.19 : 3.01 , 1: 2.19 : 3.02
1: 2.2 : 3.01 , 1: 2.2 : 3.02 , 1: 2.2 : 3.03 , 1: 2.21 : 3.02 , 1: 2.21 : 3.03 ,
1: 2.22 : 3.03 , 1: 2.22 : 3.04

(source: http://www.acoustics.salford.ac.uk/acoustics_info/room_sizing/?content=method)

3.2.2 Shape

Rectangular shape is more preferable than curved one. Curved form causes acoustical defects like sound foci, dead spot.

3.2.3 Internal landscaping

Research shows that plants help to reduce background noise levels inside buildings. Some plant species are more effective than others and the benefits are most pronounced in buildings with hard, reflective surfaces. Plants absorb, diffract and reflect sound. The balance varies with the frequency at which the sound is generated and the room's physical properties. The type of plant, its size, shape, the container, top dressings and the compost all have an effect on the sound reduction capabilities of plant displays.

3.2.3.1Absorption

Plants alter room acoustics by reducing the reverberation time. Plants work better in **acoustically live spaces**, such as those that have hard surfaces like marble walls, exposed concrete and stone floors. The impact of plants is less likely to be noticeable in an acoustically quiet space, containing soft furnishings, carpets, heavy curtains or well upholstered chairs, which have a much greater capacity to absorb sound.

Figure 3.4: Acoustically Live Space & Quiet Space

Source - http://www.plants-in-buildings.com

3.2.3.2 Diffraction and Reflection

At lower frequencies plants may diffract and reflect sound. This is because the leaf size is small by comparison to the noise wavelength. Plants with lots of small leaves are useful as they scatter and diffuse sound. At higher frequencies the leaves may reflect sound towards other surfaces that may then absorb the noise.

3.2.4 Layout & orientation of spaces

- Internal proximity of spaces should be according to their sound insulation value requirement.
- Use corridors, closets and "buffer" spaces to separate areas.

- Grouping should be according to background noise levels within rooms.
- Separate sound sources as far as possible.
- Use furniture and quiet areas to separate activity groups.
- Use traffic aisles to define areas.

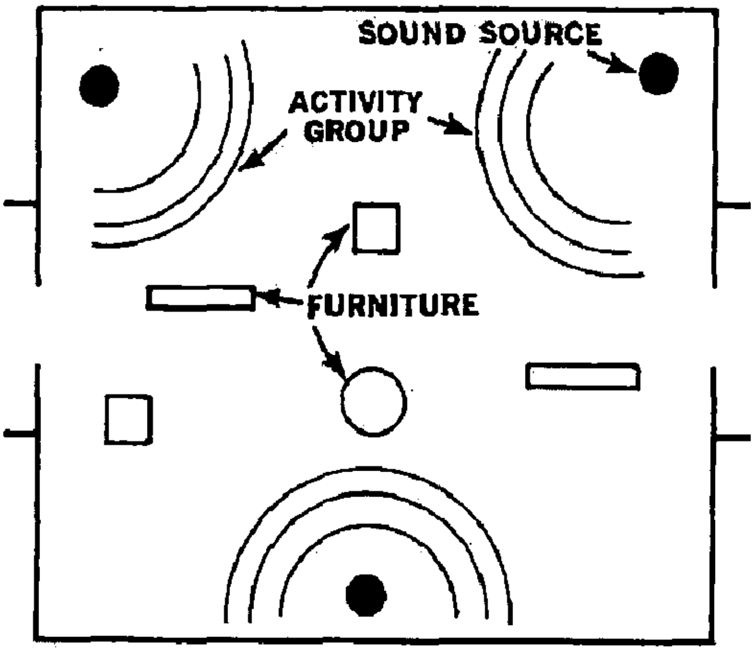


Figure 3.5: Layout of Spaces

Source: Lyle F.Yerges,"Sound, Noise and Vibration Control".1978, p.93.

3.2.5 Interior construction & materials

The interior construction systems and materials – floors, walls, and ceilings, serve as acoustical barriers, reflectors, and absorbers, in addition to all of their other functions. Materials and construction should be considered according to their ability to fulfill the acoustical requirements.

CASE STUDIES

CHAPTER-4

4.1 WIPRO OFFICE CAMPUS, GRATER NOIDA

4.1.1INTRODUCTION

Wipro Technologies Limited is an information technology services company headquartered in Bangalore, India. Wipro is the third-largest IT services company in India. It has interests varying from information technology, consumer care, lighting, engineering and healthcare businesses.

The new campus in Greater Noida is spread over the 50 acres land consists of customer centre/reception, cafeteria, offices, recreation facilities, guest block, training centers, multistoried parking etc. It was set up in the year 2007.

Wipro campus is also based upon green building concept. Green system is designed in whole campus such that it works as binding element for it.

4.1.2SITE ANALYSIS:

Location

- The site of campus is located in Greater Noida.

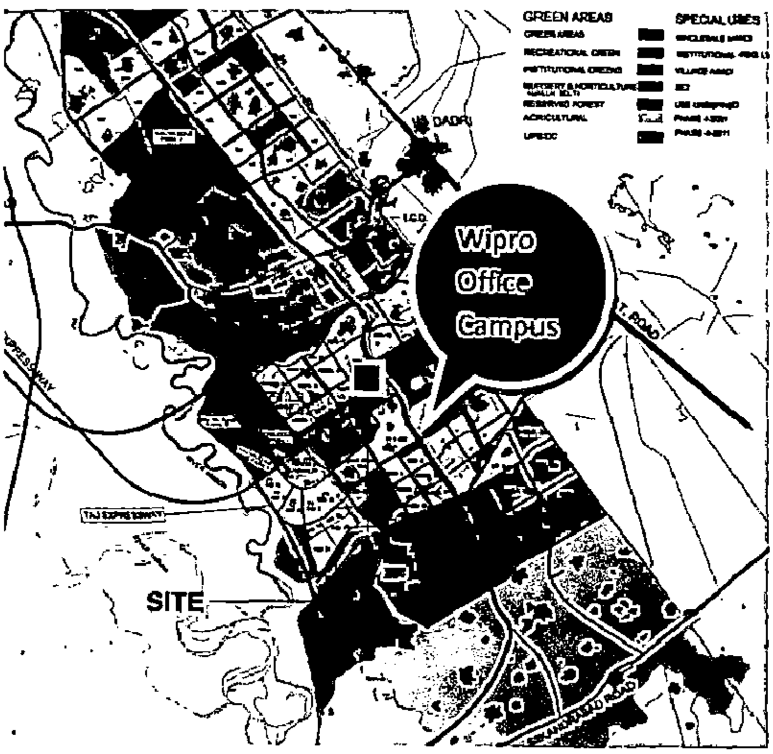


Figure 4.1.1: Greated Noida Map

Accessibility

Located dramatically with roads from three sides. The site has 150 mts. wide primary road followed by 60 mts and 40 mts wide road.

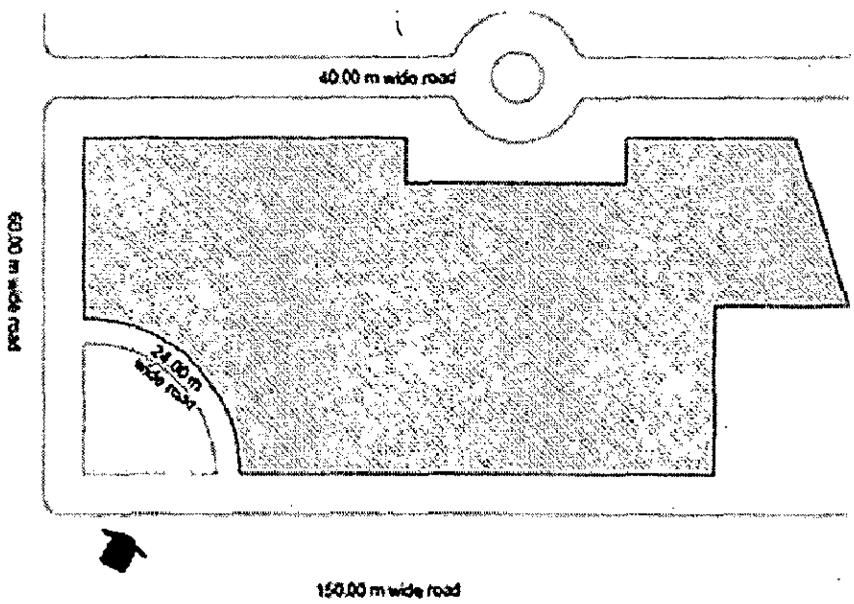


Figure 4.1.2: Site Accessibility

4.1.3 AREAS & SET BACKS

- Plot area =21,78,009 sq.ft (50 acres approx.)

  Built-up area=40,41,900 sq.ft.

  Total no. of people= 27000

  Front set back =22m

  Back setback=15m

  Side set back=16m

- As the site is surrounded by heavy traffic from three sides and GNIDA office bld. from north-east side. So because of setback for Front side sound pressure level from traffic is reduced by 2dB and for rest of the site it is remain the same

4.1.4 TOPOGRAPHY & BLOCKS PLACEMENT

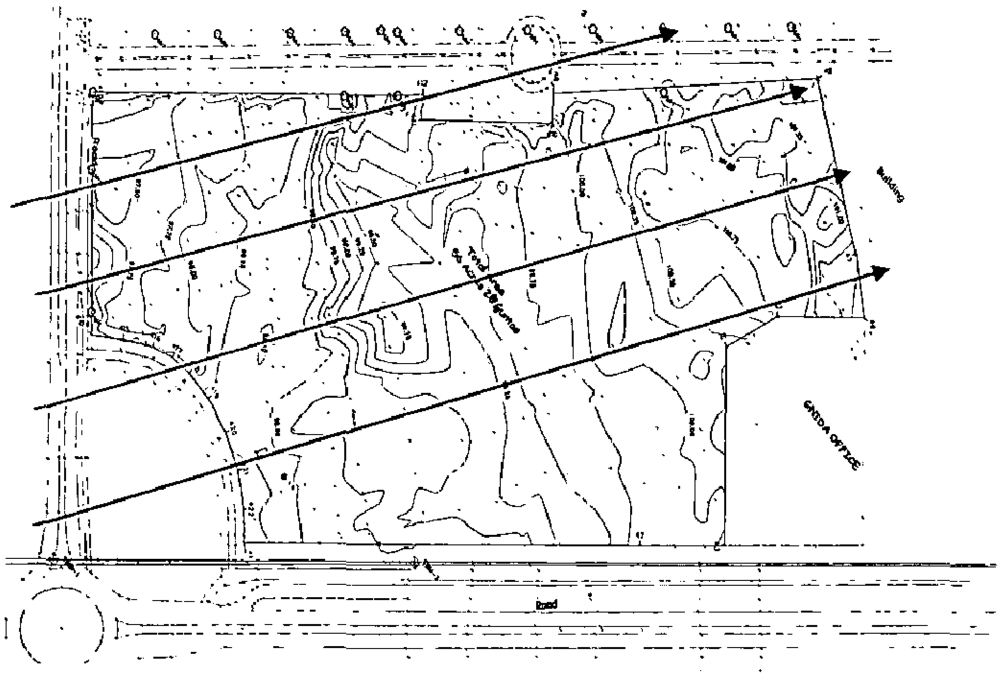


Figure 4.1.3: Topography of the Site

As the site have minor slope from S-W to N-E, so it is not helpful to restrict traffic noise to come inside.

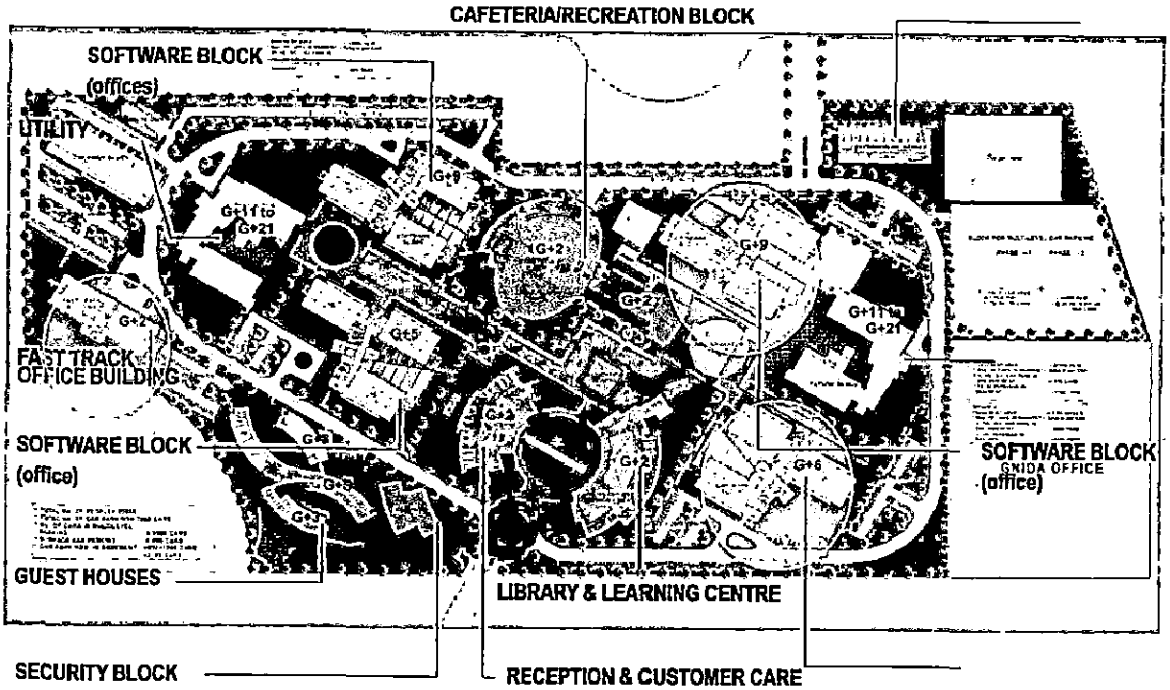


Figure 4.1.4: Site Plan

- Higher buildings are on the periphery of the site to minimize sound impact to inner environment but on the other hand some building block which needs well working environment is there.

- Since large and hard building façades can effectively reflect sound energy, so the arrangement of buildings is in such a way that the reflections can be directed to less sensitive areas.
- Reflective facades are made of absorbent or diffuse material like wood, double glazed windows, glass, granite which has sound absorption capacity.
- Curved façades should be given particular attention because they could focus sound energy to a small region in the receiving area and, thus, significantly increase the noise level.

4.1.5 ZONING OF THE SITE

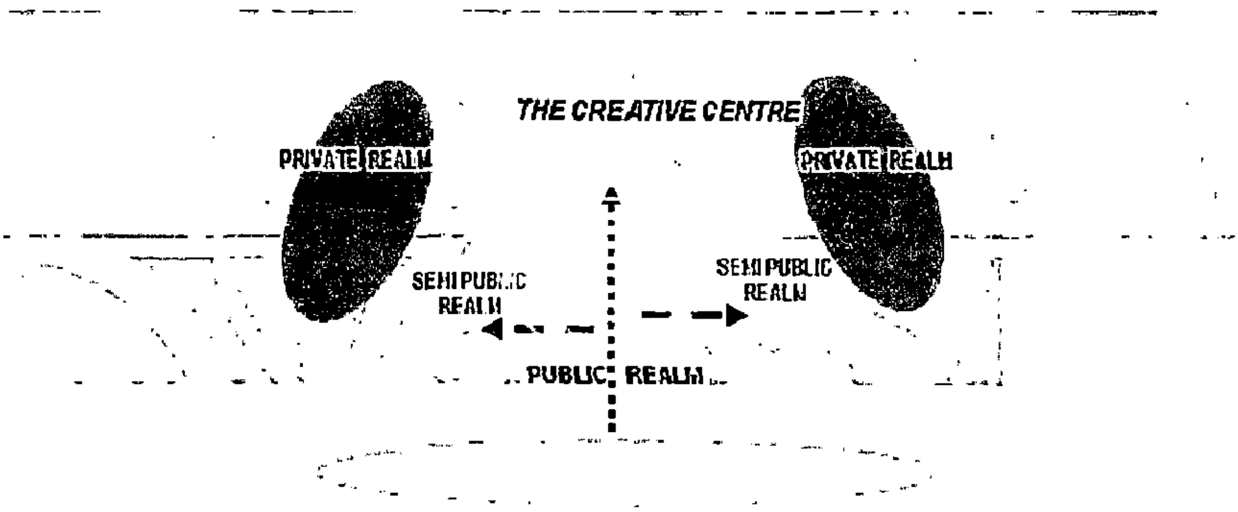


Figure 4.1.5: Zoning Plan

It is good to place the building blocks according to their sound isolation requirement. Here private spaces are placed farther distance from main traffic in compare to semi public spaces. Similarly semi public spaces are placed farther in comparison to public spaces.

4.1.6 SITE CIRCULATION

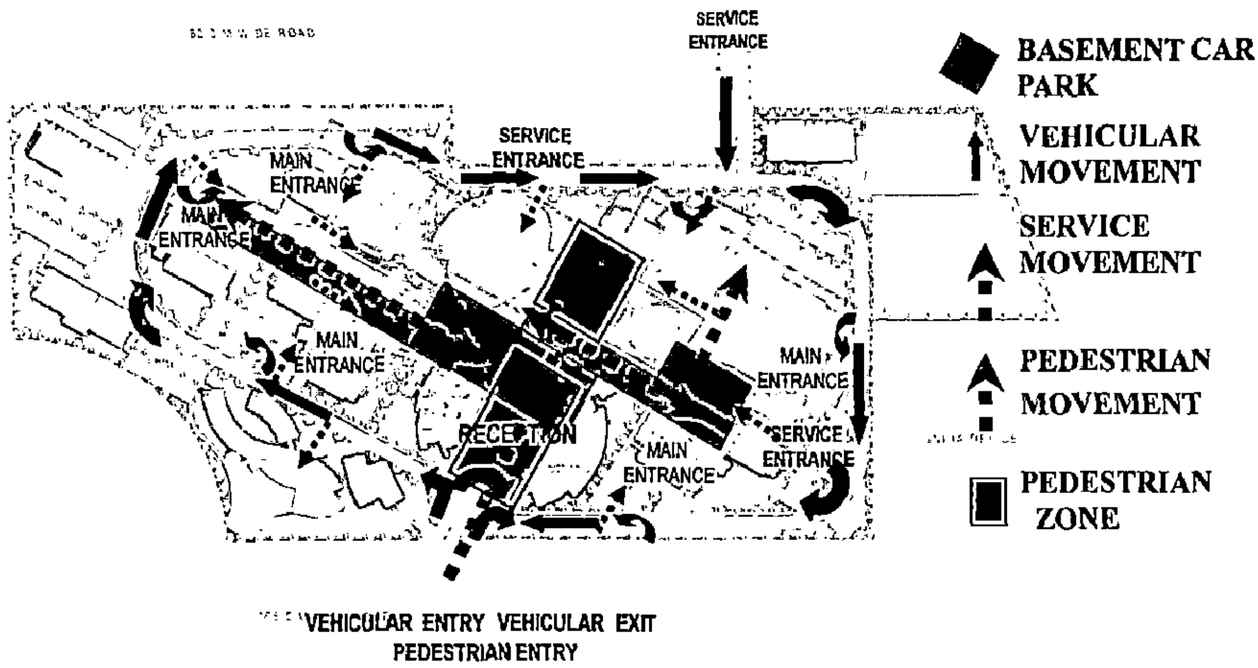


Figure 4.1.6: Site Circulation Plan

- Vehicular movement is restricted to the periphery making internal areas pedestrian without conflicting with vehicular movement's cause's prevention of traffic noise.
- Proximity of Way for the vehicle and the buildings are more close which create noise vibration in lower floors causes occupants distraction.

4.1.7 LANDSCAPING

- Total no. of trees used-1500 (approx) –
  Trees used - acacia auriculiformis(dalmoth), anthocephaulus cadamba(kadamb) ,areca catechu, alstonia scholaris(satwin), bombax malabaricum(silk cotton), bismarkia nobilis(bismarkia palm), bauhinia variegated(kachnar), chorisia speciosa(mexican silk cotton), cassia fistula(amalta), caryota urens(fish tail palm), delonix regia(gulmohar), jacaranda mimosifolia(neeli gulmohar), plumeria alba(champa)
- Anthocephaulus cadamba (kadamb), terminalia arjuna (arjun) - 1.5to 1.8 m ht. & 3-4m foliage – used for outer periphery- as it is low ht. can't reduce noise considerably.

- Tree and shrub arrangements are important. Here regular arrangements are found in whole the site especially near the segregation of office area to the public area and from road area so the scattering contribution of trunks and branches is relatively high and good sound attenuation.

Figure 4.1.7: Earth Mound inside the site

- Earth mound near the buildings helps to cut the direct noise.

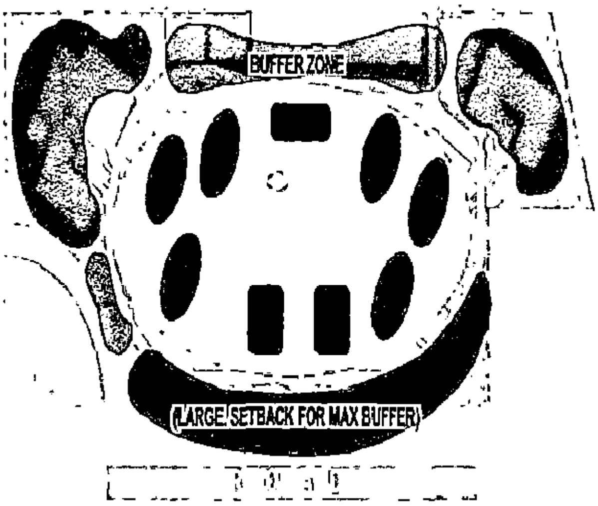


Figure 4.1.8: Buffer Zones of the site

- Buffer zones are provided to avoid direct noise from busy traffic.

4.1.8 BUILDING FORM

- Building forms are designed to be self-protective from external noise to a certain extent.

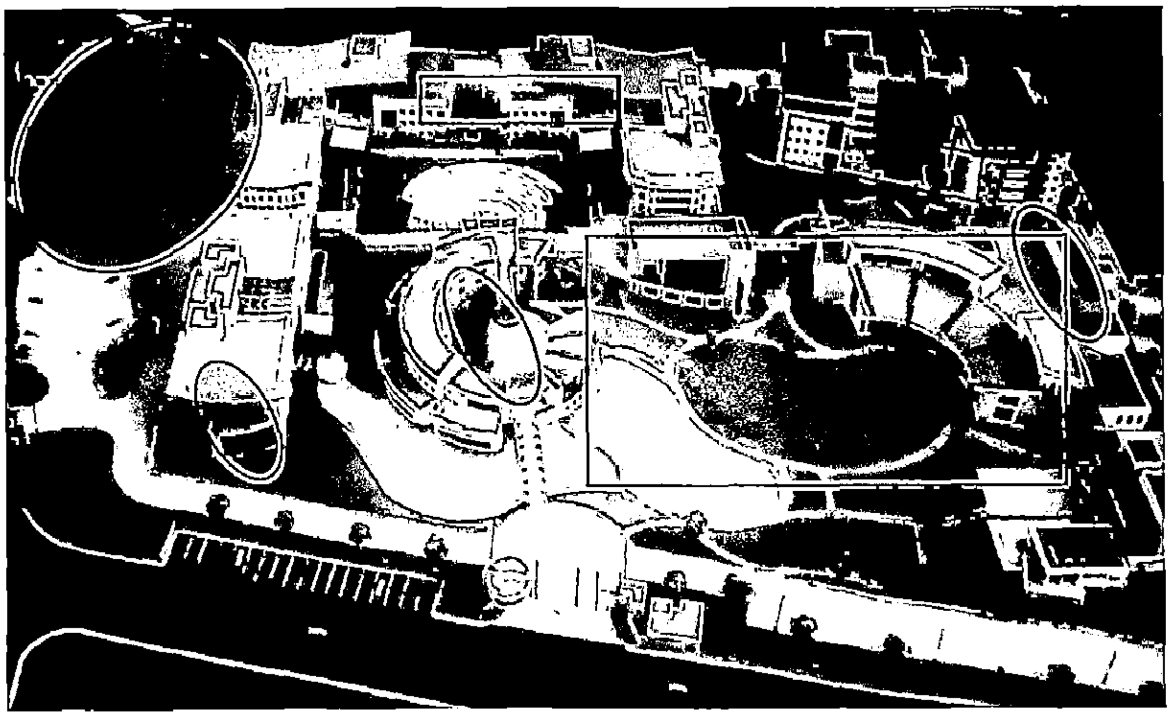


Figure 4.1.9: Site model showing Building Form

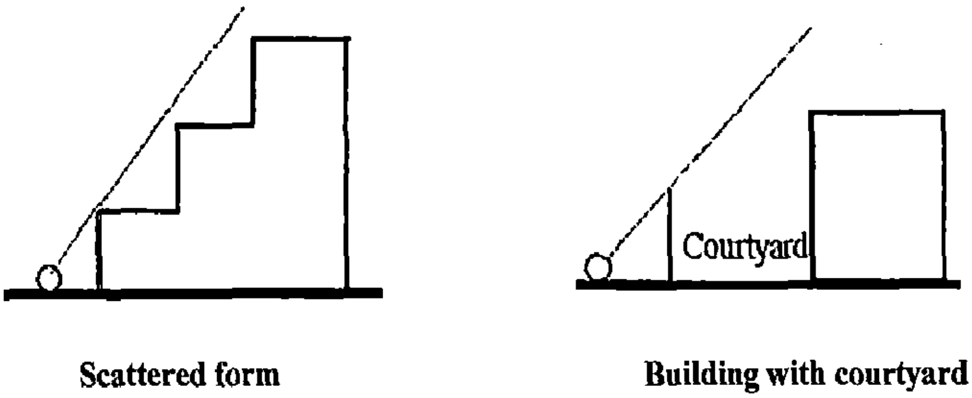


Figure 4.1.10: Building Forms

- Curved façades have given particular attention because they could focus sound energy to a small region in the receiving area and, thus, significantly increase the noise level so distance between curved form of buildings are more than 90ft.
- Most of the building blocks are rectangular in form which is good sound reflector and also for office internal arrangement and acoustics.

4.1.9 INTERNAL LAYOUT

4.1.9.1 Office block

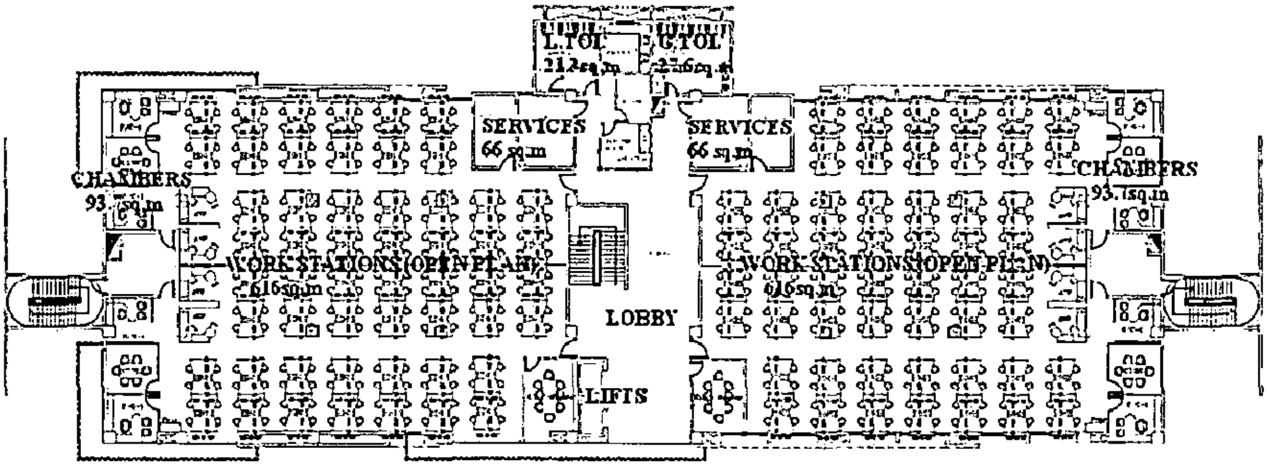


Figure 4.1.11: Typical Floor Plan

Floor Area=1850 sq.m

Floor to floor ht = 4.2 m

Floor to false ceiling ht=3.5 m

Area division

SL.N.	ACTIVITY	AREA	OCCUPANTS CAPACITY
1.	Work station (open plan)	1232 sq.m	432
2.	Chambers (full partition)	187.4 sq.m	48
3.	Toilets (ladies+gents)	48.9 sq,m	21(approx.)
4.	Services(AHU,ele. Room)	132 sq.m	--
5.	Lobby	191 sq.m	--

- Open plan work station is of size 27.2mX22.1mx3.5m, which is not suitable for good acoustic condition. (According to ***Audio Engineering Society journal paper***)

- **Proximity** – well segregated area according to sound isolation requirements.

S.N.	ROOM BEING CONSIDERED	ADJACENT AREA	SOUND ISOLATION REQ.
1.	Conference room	Work station	42
		Adjacent offices	32
		Exterior of building	42
2.	Work station	services	47
		lobby	32

Corridor is used as a buffer to separate open work station areas and lobby.

Work station area (ht. of partition=1.5m)

Figure 4.1.12: View of Open Plan Work Station Area

Materials used

Flooring -

Office area- vitrified tile

Services area – cota stone

Lobby - vitrified tile

Toilet - Bristol tile

False ceiling - Gypsum Board

Door - flush door with 2 hr. fire rating

Windows -structural glazing supported by aluminum frame

Work station – laminated wood

Construction

Floor- R.C.C floor with elevated floor finish

Impact noise is minimized.

Figure 4.1.13: Floor Construction Detail

Wall – 230mm wall made of aac blocks having sound absorption capacity more than normal brick and is cheap.

Roof- made of 125 mm thick r.c.c. having false ceiling of gypsum board.

4.1.9.2 CAFETERIA

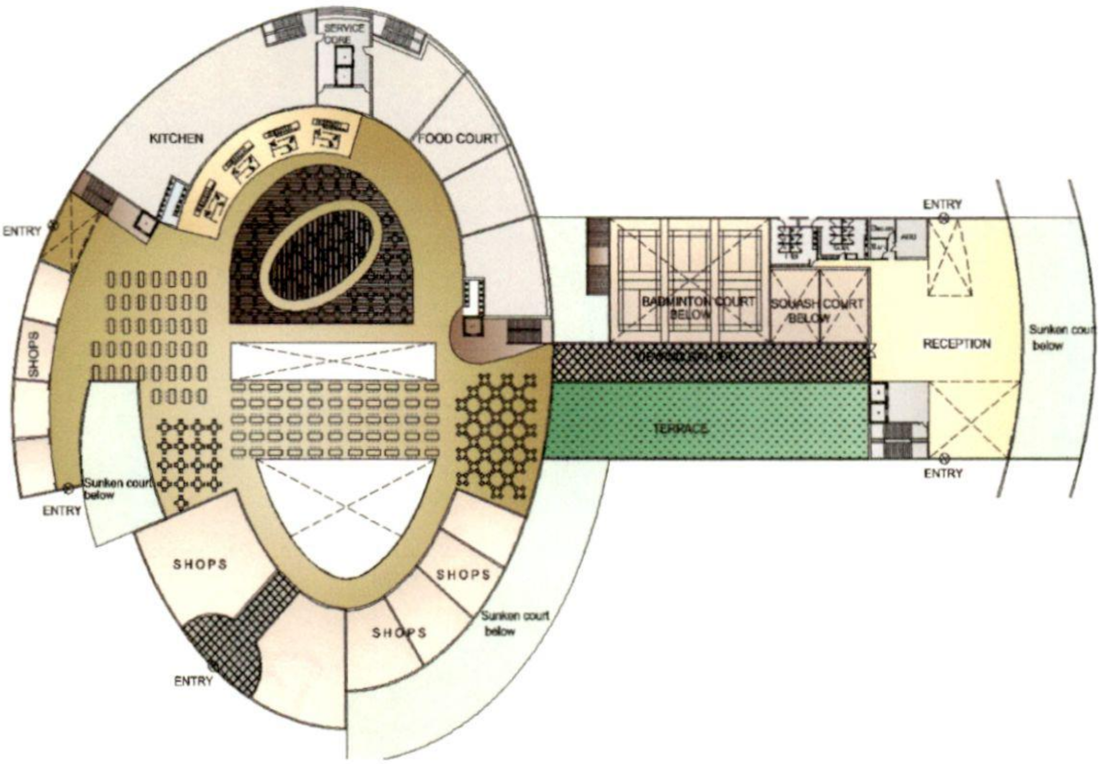


Figure 4.1.14: Cafeteria Plan

Figure 4.1.15: Cafeteria View

- One of the Noisy areas of the whole campus, so it is well segregated from other blocks using buffer zone like utility area and landscaping.
- Total built up area is 262000sq.ft. G+2 with lower ground floor bld. of 20meter height serve 12000 people.

Figure 4.1.16: View of Cafeteria showing Internal Arrangement

- Cutouts are the easy way of sound connection of two floors, so more noise level.
- Fabric roof tensile structure is provided over the cutouts above roof, which serves as good sound absorber.
- Floor is of vitrified tile, walls are painted with color, and glazed windows are used.
- Furniture's are made of laminated wood, steel etc.
- Well segregated noisy and less noise areas.
- Internal space is well planted efficient for absorbing high sound frequencies which are more profound there.

4.1.9.3 LIBRARY & LEARNING CENTRE

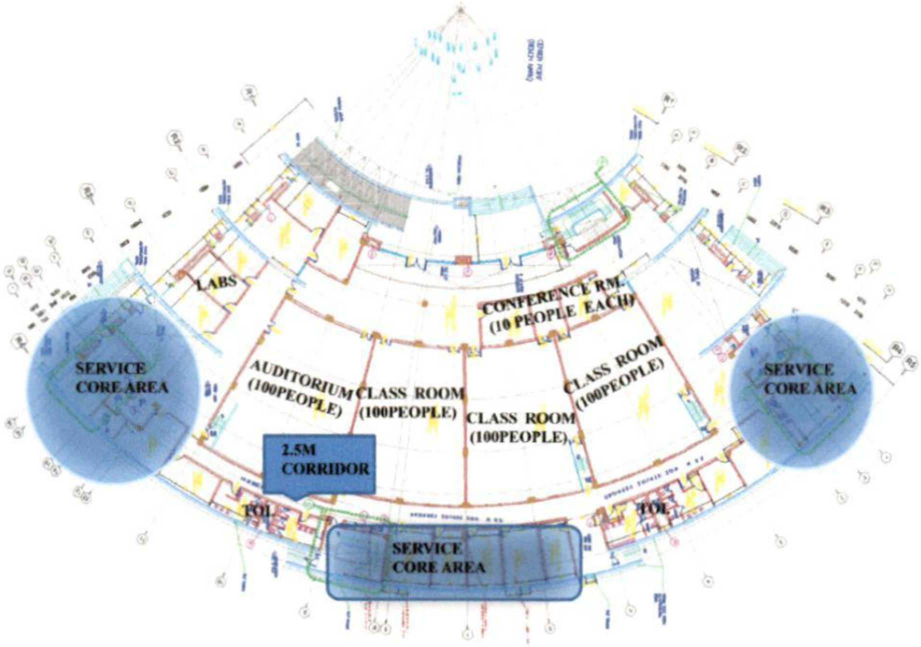


Figure 4.1.17: Area Breakup of Library & Learning Centre

- Centrally located in site.
- Total built up area is 299000sq.ft.

  G+2 with 20meter height serve 800people.
- Stepped form of the building works as a safeguard against noise.
- Auditorium and classrooms are separated by corridor from service core noise(ups, electrical room,AHU etc)

Figure 4.1.18: View of Auditorium and Learning Centre

Figure 4.1.19: View of Conference Rooms

- Auditorium having acoustic absorbent panel on both sides. Wooden wall paneling is used for rear side of auditorium.
- Central space is used as sitting space having good sound quality.
- Sloping roof helps to avoid acoustical defects like dead spot or sound foci etc.
- Flooring is made of granite and wood.
- Conference rooms are near to class rooms as per sound isolation requirement.

4.1.10 HVAC

- There is separate unit for HVAC services for campus.
- Each block has separate room for HVAC connections (distribution) for that area.
- Iron sheets are used as duct for connection.

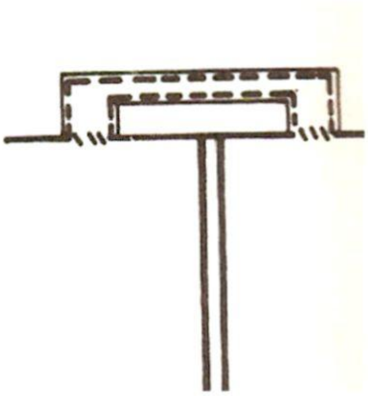


Figure 4.1.20: Ducting System

- Good ducting system in most of the spaces inside.
- Duct is not in contact with false ceiling cause low vibration inside space.

- In office block, duct is separated by rubber insulator from false ceiling.


Figure 4.1.21: Ducting System in Office Area & Reception Area

INFERENCES:-

- While layout Building block placement according to height, function etc plays an important role for good acoustic environment.
- In 3-D form, Stepped form is better option to avoid noise.
- Trees according to their feature help to avoid noise. (long leaves deciduous trees are good option)
- Landscaping features like earth mound etc are cutting for excessive noise.
- Site circulation plays an important role. There is some buffer space between building line and vehicular path to minimize noise due to vibration.
- For building interior, shape, size plays an important role. Where ever possible avoid circular form.
- Avoid cutouts in floor slab where acoustic is of prime important like office workstation area etc.
- Corridor, staircase and lift lobby used as buffer to separate spaces which require different sound isolation.
- R.C.C floor with elevated floor finish reduces Impact noise.
- Open- grille lights (parabolic-louvered luminaries) are used in most of the areas. In workstations area it is used directly above.
- Used large workstation area to increase speech privacy and reduce acoustical distraction.

4.2 PATNI CAMPUS, NOIDA

4.2.1 INTRODUCTION

Patni Computer Systems Ltd. is a provider of Information Technology services and business solutions. The company employs over 14,500 people, and has 23 international offices across the Americas, Europe and Asia-Pacific, as well as offshore development centre in 8 cities in India. Patni's clients include more than 200 Fortune 1000 companies.

The Patni Campus, situated in suburban sprawl of Noida, 5k.m away from Noida expressway, is the Second Largest Platinum rated LEED Certified Green Building by the IGBC (Indian Green Building Council), the highest form of honour to be bestowed by the council. Covering a built up expanse of 4,60,000 Sq ft.

4.2.2 SITE ANALYSIS:

Location

- The site of campus is located 5 k.m away from Noida expressway having plot no. 139-140 in NSEZ Noida , U.P.

Figure 4.2.1: NSEZ Noida Map

Accessibility

- The site has 160 mts. wide primary road In front side. Rest three sides, surrounded by buildings.

4.2.3 AREAS & SET BACKS

- Plot area =16,200sq.m

  Built-up area= 35,376 sq.m

  Total designed population= 2450

  Front set back =18m

  Back setback=15m

  Side set back=12m

- As the site has heavy traffic in front side but because of less setback in all sides as per required for decrease in sound pressure level, it will remain the same.

4.2.4 TOPOGRAPHY & BLOCKS PLACEMENT

- The building block in on the leveled ground so as per topography is concern, no effect on acoustical condition.

- Reflective facades are made of absorbent or diffuse material like wood, double glazed windows, glass, granite which has sound absorption capacity.

4.2.5 ZONING OF THE SITE

Compact planned rectangular building block having all facilities within their is oriented in such a manner that less exposed area towards the traffic.

4.2.6 SITE CIRCULATION

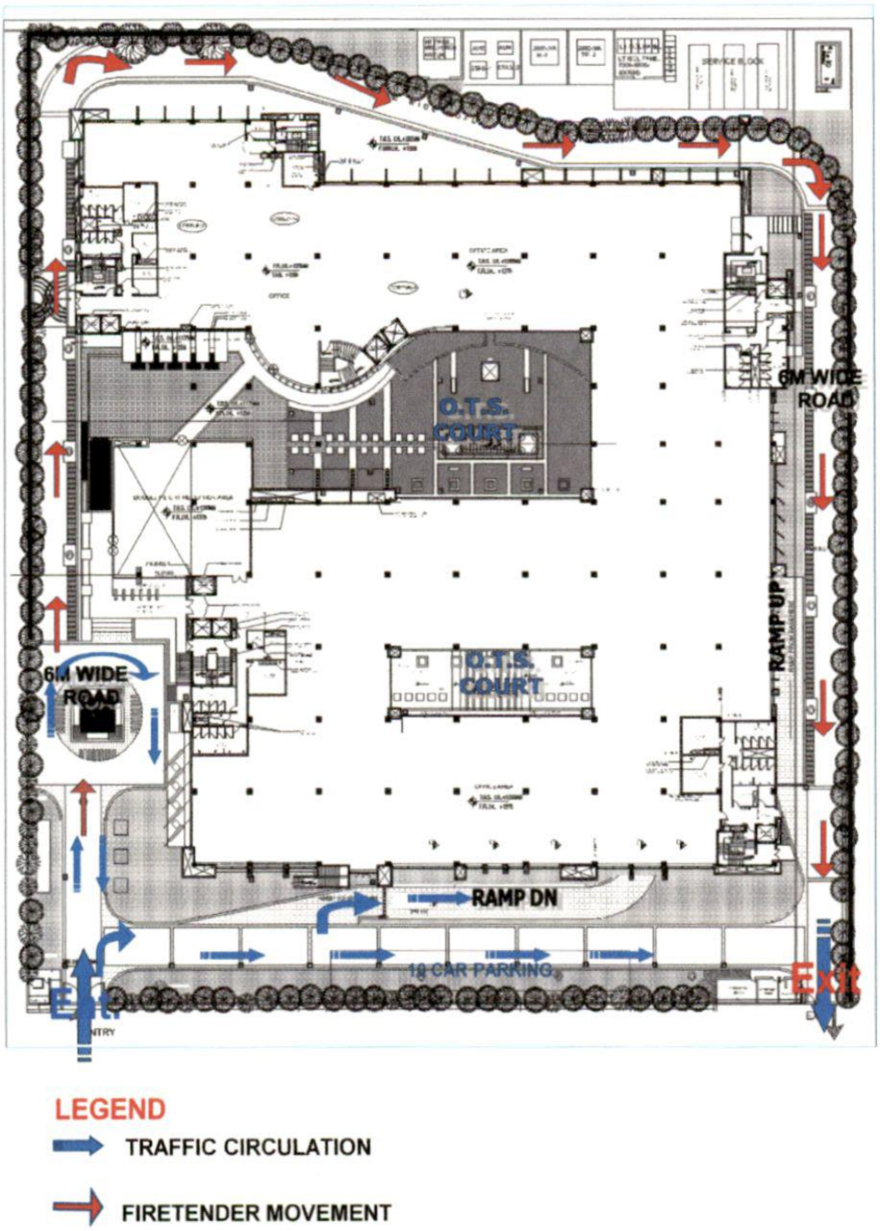


Figure 4.2.2: Site Circulation Plan

- 6m wide peripheral road proposed & 8 m wide separate entry and exits provided
- All parking provided in basement.
- Entry and exit ramp close to main entry and exit to reduce thorough traffic around the building thus reduces noise causes by vibration.

4.2.7 LANDSCAPING

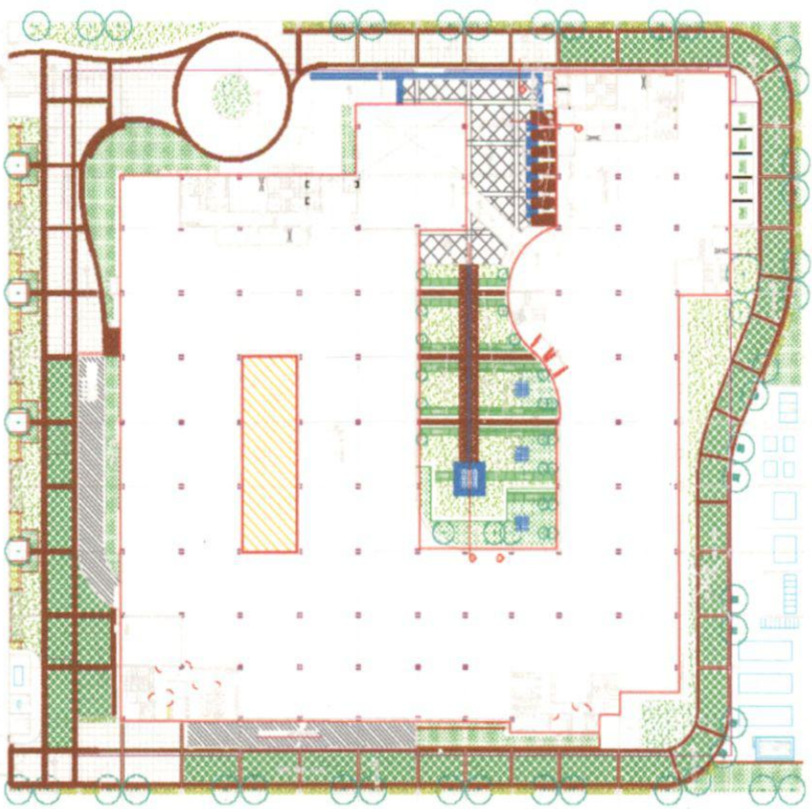


Figure 4.2.3: Landscaped Plan of the Site

- Approx. 4000 sq.m area designated as scattered green area
- Common native species of trees selected for plantation along the periphery to reduce direct noise.Green lawns provided at various places within the complex for better environment.
- Road is provided with grass patches in concrete blocks which having more sound absorbing capacity.
- Trees used - anthocephaulus cadamba(kadamb) ,alstonia scholaris(satwin), bauhinia variegated(kachnar), delonix regia(gulmohar), jacaranda mimosifolia(neeli gulmohar), plumeria alba(champa)
- Tree and shrub arrangements are important. Here regular arrangements are found in whole the site ,no special attention towards traffic side.

4.2.8 BUILDING FORM

Building forms are designed to be self-protective from external noise to a certain extent.The building block is rectangular in form which is good sound reflector and also for office internal arrangement and acoustics.

4.2.9 INTERNAL LAYOUT

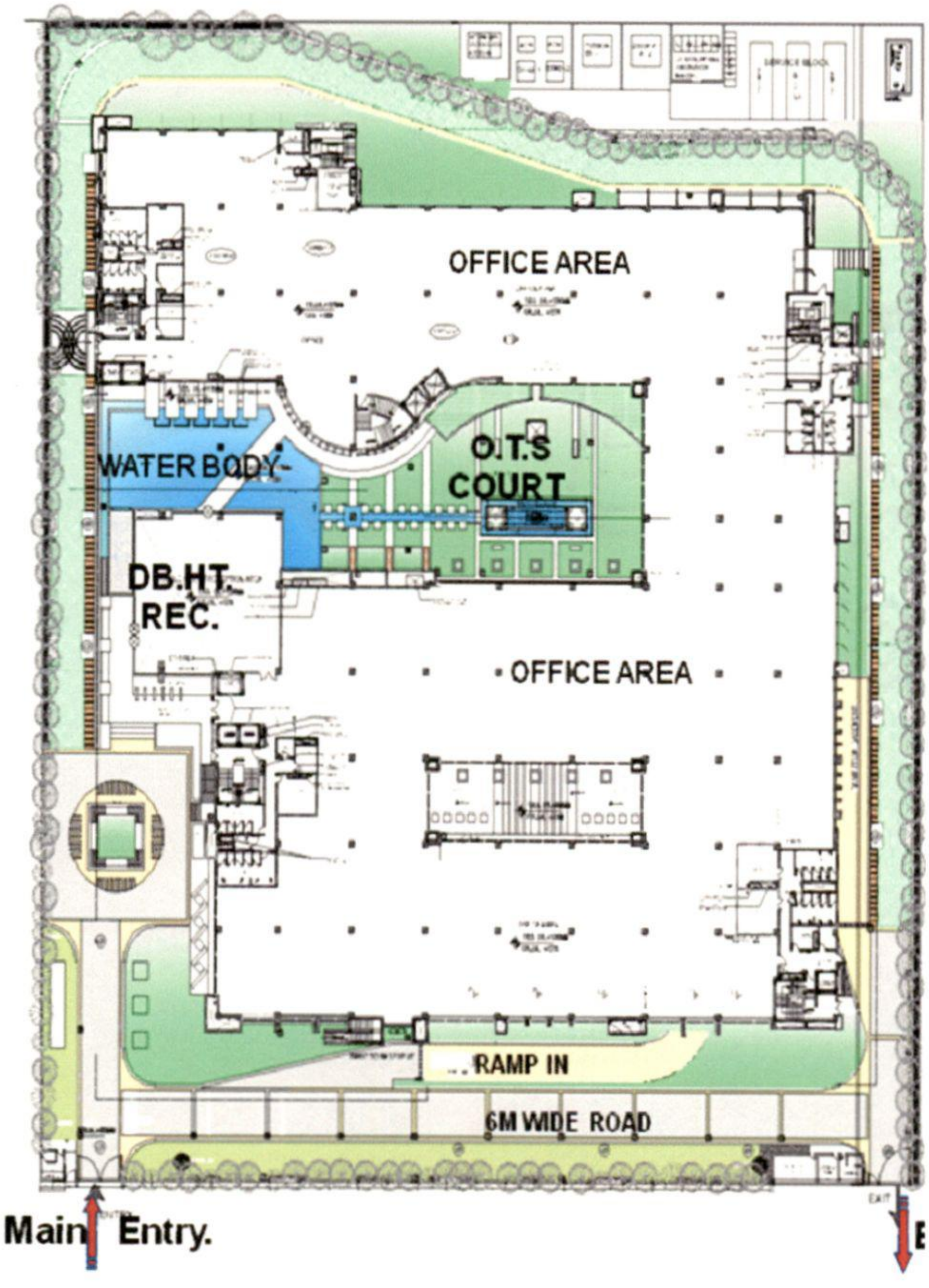


Figure 4.2.4: Typical Floor Plan

Figure 4.2.5: Internal Layout Plan

Floor Area=7520 sq.m

Floor to floor ht = 4.05 m

Floor to false ceiling ht=3.25 m

Area division

SL.N.	ACTIVITY	AREA	OCCUPANTS CAPACITY
1.	Work station (open plan)	3846 sq.m	612
2.	Chambers (full height partition)	1076.4 sq.m	144
3.	Toilets (ladies+gents)	512.2sq,m	
4.	Services(AHU,ele. Room)	1530 sq.m	--
5.	Lobby	554 sq.m	--

- Open plan work station is of sizes are 78.8mX19.9mx3.25m and 62.6mX18.8mX3.25 and which is near to suitable for good acoustic condition According to *Audio Engineering Society journal paper.*
- **Proximity** – well segregated area according to sound isolation requirements.

S.N.	ROOM BEING CONSIDERED	ADJACENT AREA	SOUND ISOLATION REQ.
1.	Conference room	Work station	42
		Adjacent offices	32
		Exterior of building	42
2.	Work station	services	47
		lobby	32

- Corridor is used as a buffer to separate open work station areas and lobby.
- Some area server room is used in between the work spaces cause noise & low frequency sound.
- Work station area (ht. of partition=1.5m)
- **Materials used**

For exterior - Dholpur stone ,Slate ,Kota ,Rajasthan granites,Sculptures by local artisans

Office area- vitrified tile

Services area – cota stone

Lobby - vitrified tile

Toilet – anti skid tile

False ceiling - Gypsum Board

Windows -structural glazing supported by aluminum frame

Work station –wooden

- **Construction**

Floor- r.c.c floor with floor finish

Wall – 230mm wall made of aac blocks with cavity having sound absorption capacity more than normal.

Roof- made of 125 mm thick r.c.c. having false ceiling of gypsum board.

- Cutouts are the easy way of sound transmission from one floor to the other, so avoid wherever possible.
- Well segregated noisy and less noise areas.
- Courtyard planning is a special feature of internal space which is well planted efficient for absorbing high sound frequencies.
- Training rooms are near to conference room having low sound isolation requirement.
- In conference room wooden wall paneling is used for all sides for better sound quality.
- Source of noise like DG sets(use only in case of power failure) is provided with adequate acoustic enclosure as per norms.
- Iron sheets are used as duct for connection.

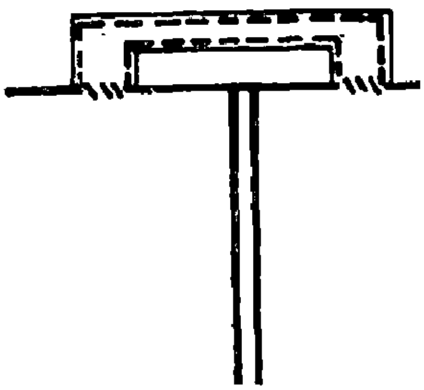


Figure 4.2.6: Ducting System

- Duct is not in contact with false ceiling cause low vibration inside space.

INFERENCES:-

- Office workstations area which is rectangular in plan is good to avoid acoustical defects.
- Trees are planted on the periphery of the site to minimize noise from traffic. It acts as green buffer for building.
- Large open space for workstations is better for sound privacy because masking sound is always there.
- Site circulation plays an important role. It should be such that, it not cross close to building block and pedestrian path.
- Sound absorbing material is used at the corner of each workstation which absorbs direct sound from source helps to maintain speech privacy.
- Corridor, lift & staircase lobby are used as a buffer to separate spaces which require special consideration for acoustic.
- Courtyard planning is good if well landscaped.
- Cutouts in floor slab are provided in workstation areas which is not good from acoustical point of view.

4.3 SPAZEDGE OFFICE BUILDING, GURGAON

4.3.1 INTRODUCTION

The project named as "Spazedge" is located in the Sector 47, Gurgaon , which is developed as commercial center As per approved Zoning plan. The project is lead to the development of an office complex. The whole site is spread over the 3.65 acres of land consists of four multistoried blocks and surface & basement parking etc. It was set up in the year 2008.

4.3.2 SITE ANALYSIS:

LOCATION

- The site of the office complex is beside NH-8, Mehrauli Gurgaon road, Gurgaon (Haryana).

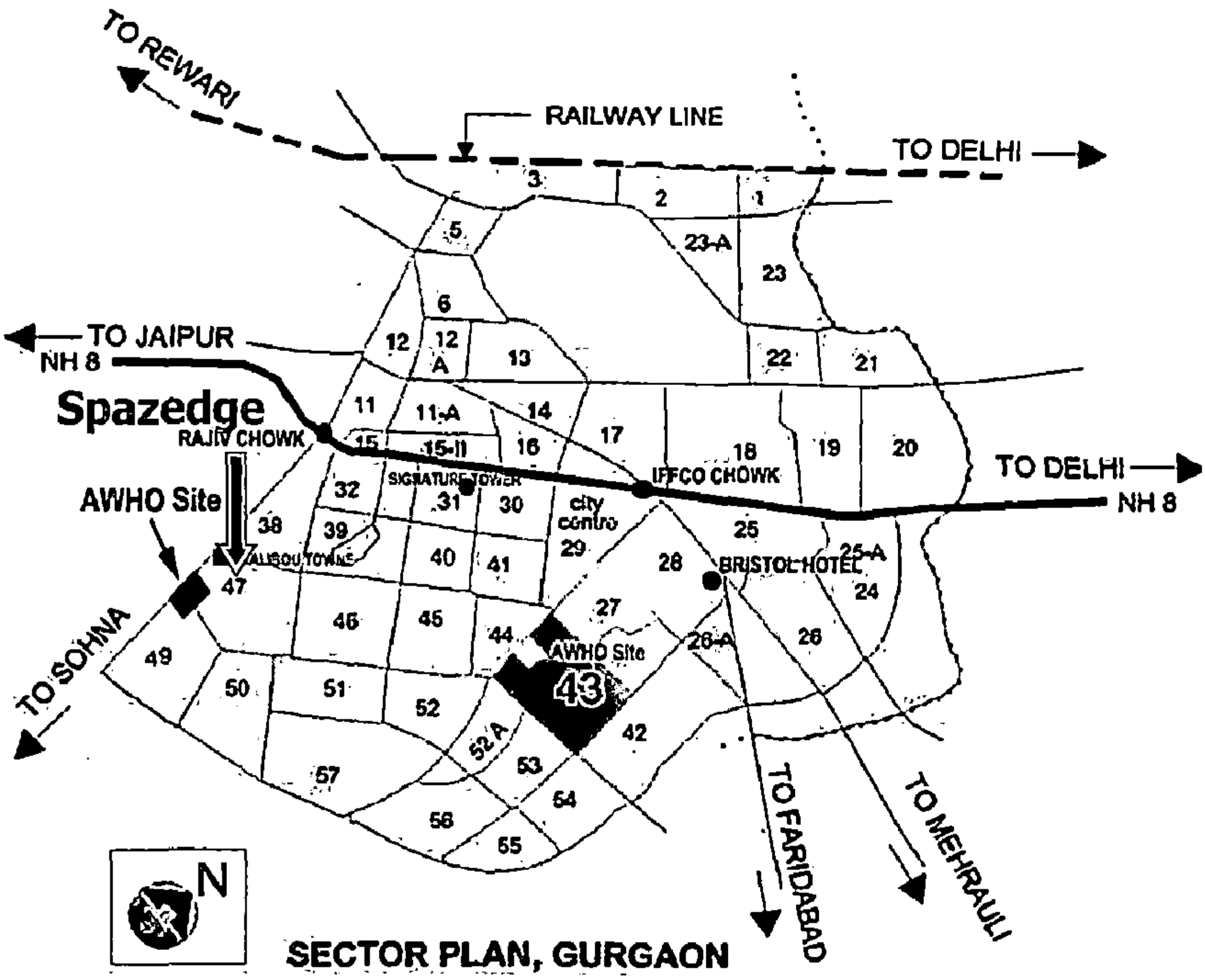


Figure 4.3.1: Sector Plan, Gurgaon

ACCESSIBILITY

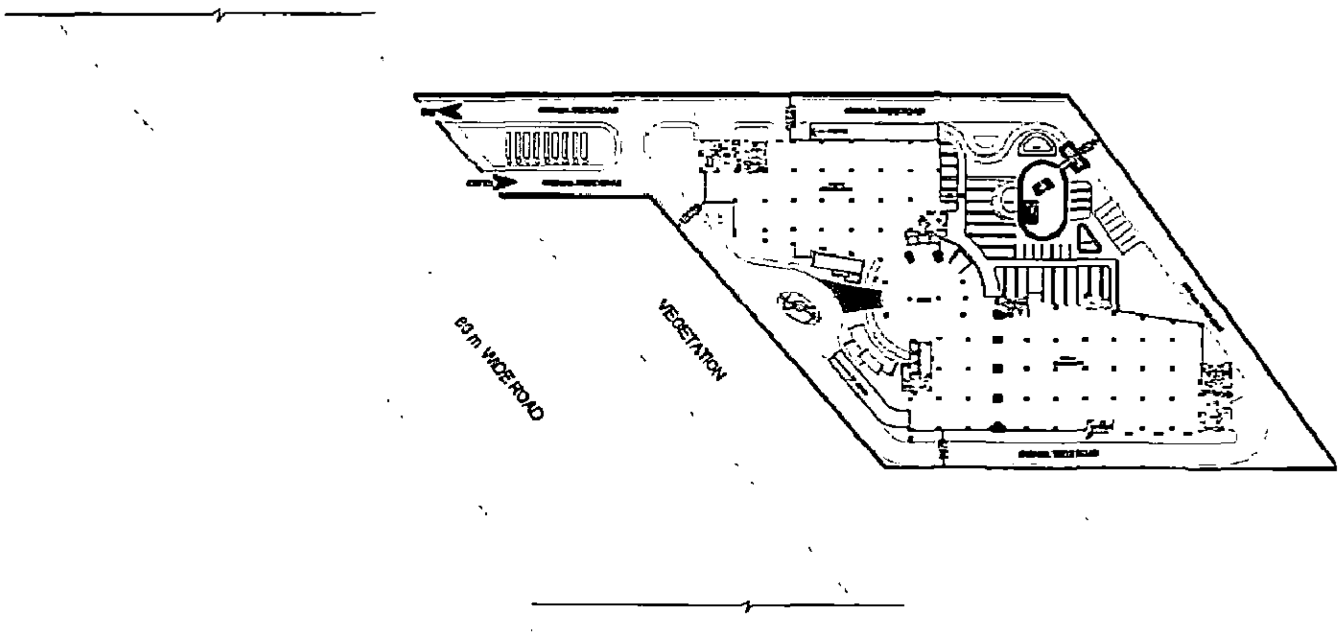


Figure 4.3.2: Site Accessibility

- The major roads in the vicinity of the site include NH-8, Mehrauli Gurgaon road etc. whereas Gurgaon – Sohna Road abuts the site.
- Indira Gandhi International Airport is about 15.5 km away from the project site.
- The nearest railway station is Gurgaon at 6.5km away from the project site.

4.3.3 AREAS & SET BACKS

Plot area =14,771 sq.m

Built-up area=27411.05 sq.m (office area=1507.84 sq.m)

Total no. of people= 3215(approx.)

Front set back =10m

Back setback=6.5m

Side set back=10m & 12.25m

- As the site is surrounded by heavy traffic in front side but because of large distance in Front side (54m) sound pressure level from traffic is reduced by 2dB and for rest of the site it will remain the same.

4.3.4 TOPOGRAPHY & BLOCKS PLACEMENT

- As the whole site has no any remarkable slope, so it won't affect the acoustic environment inside.

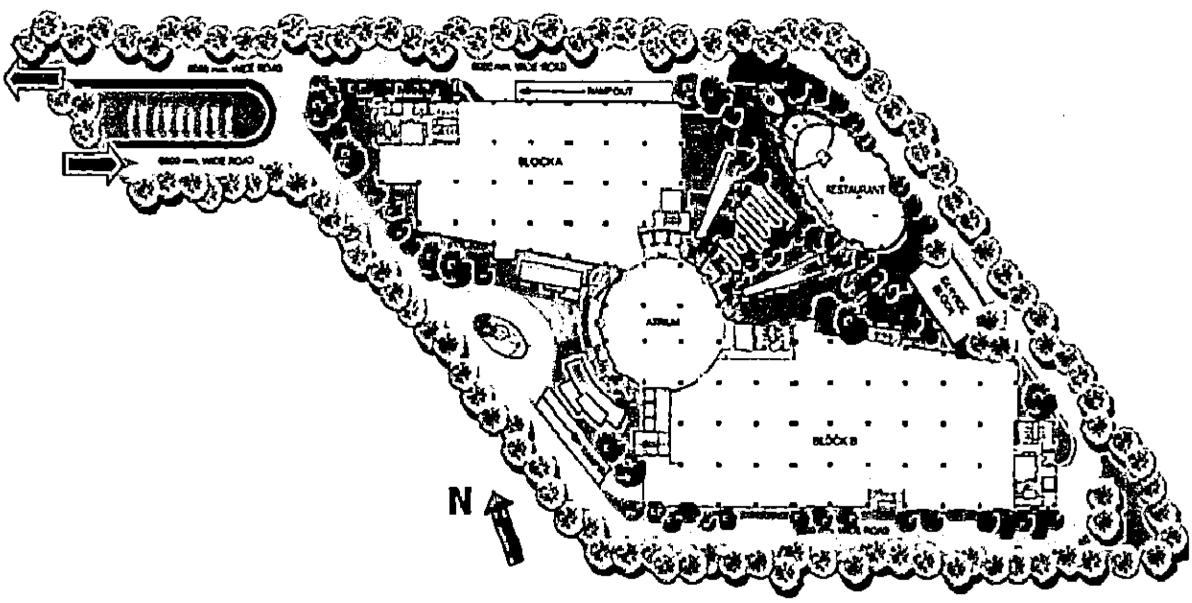


Figure 4.3.3: Site Plan

- Superstructure - Block A (office block) comprises of G+4,
  Block B (office block) comprises of G+5,
  Block C (restaurant) comprises of G+2,
  Block D (atrium+ entrance lobby) comprises of G+2.
- High altitude building is nearer to traffic which can resists direct sound to inner building blocks.

4.3.4 ZONING OF THE SITE

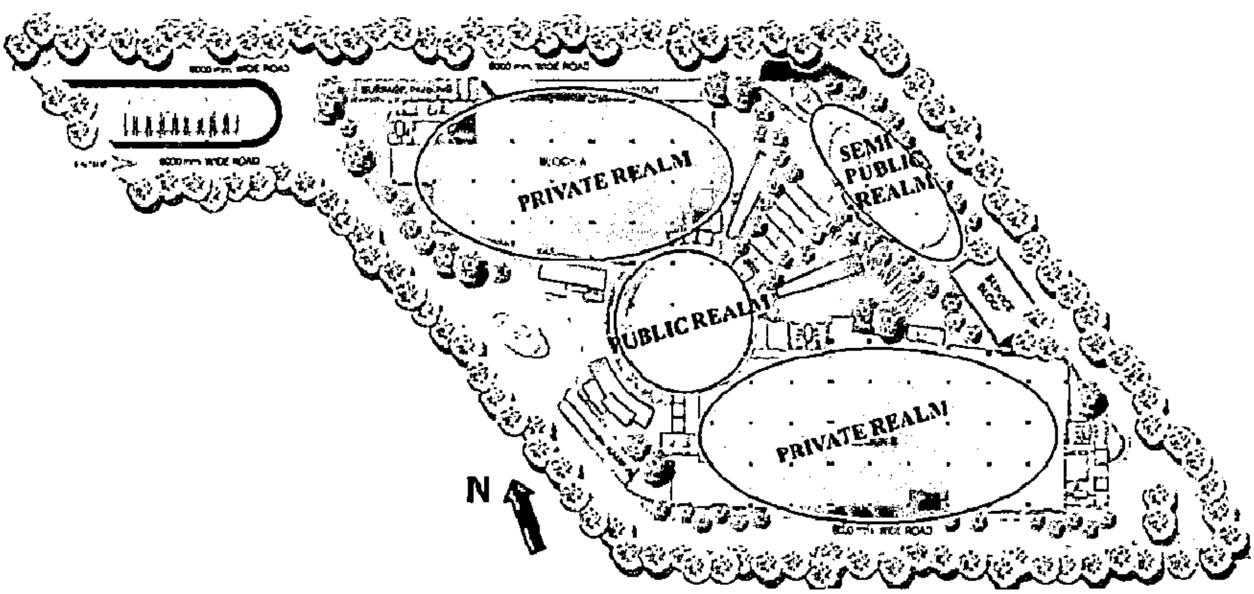


Figure 4.3.4: Zoning Plan

Mixed planning is prevailing in the site. Building blocks are not properly placed according to their sound isolation requirement. Here public realm is placed in between private realms causes' hindrance.

4.3.5 SITE CIRCULATION

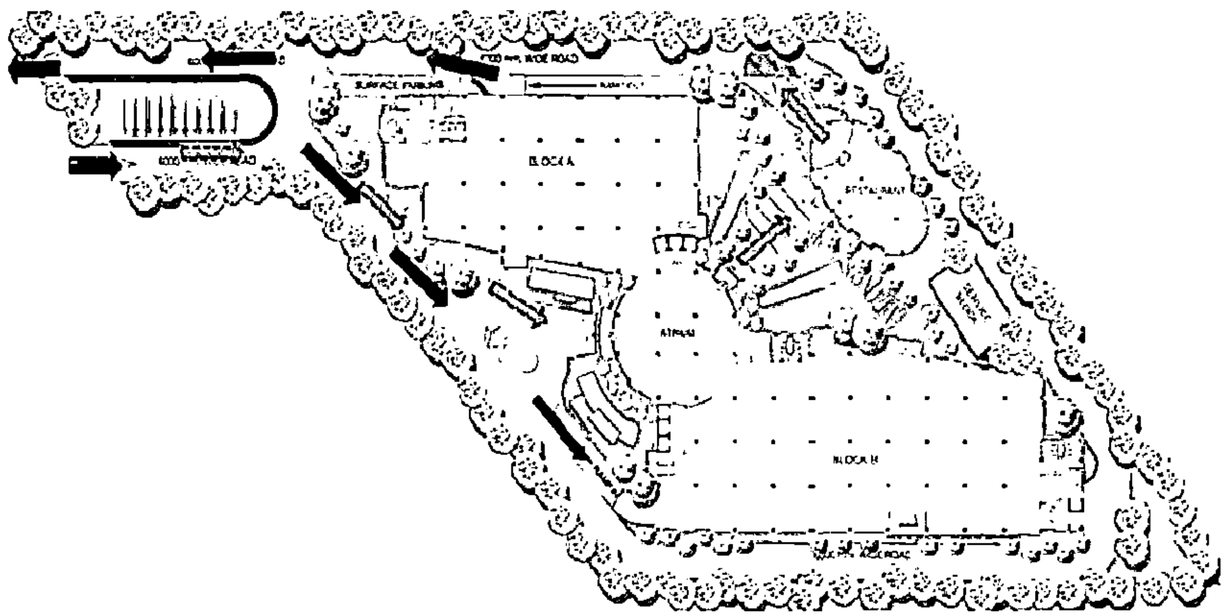


Figure 4.3.5 Site Circulation Plan

- No separate Vehicular way and pedestrian way are provided causes conflicting produces unusual noise.
- Minimum contact of vehicular way and the buildings causes less occupants distraction due to noise causes vibration.

4.3.6 LANDSCAPING

- Trees are used on the periphery of the site which is densely populated.
- Tree and shrub arrangements are important. Here regular arrangements are found in whole the site especially near the segregation of office area to the road area so the scattering contribution of trunks and branches is relatively high and good sound attenuation.

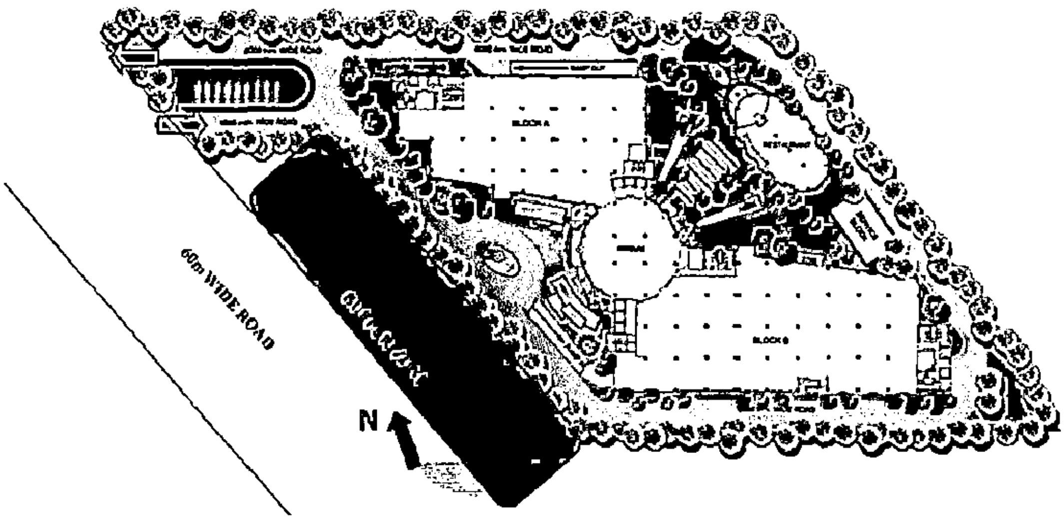


Figure 4.3.6: Landscaping & Buffer Zones of the Site

- Trees as a buffer are used to avoid direct noise from busy traffic.

4.3.7 BUILDING FORM

- Building forms are designed to be self-protective from external noise to a certain extent. Here Building blocks are mainly rectangular in plan and overall cuboids in form so no any direct noise cut from outside.
- Rectangular plan is good sound reflector and also for office internal arrangement and acoustics.

Figure 4.3.7: Perspective of the Buildings

4.3.8 INTERNAL LAYOUT

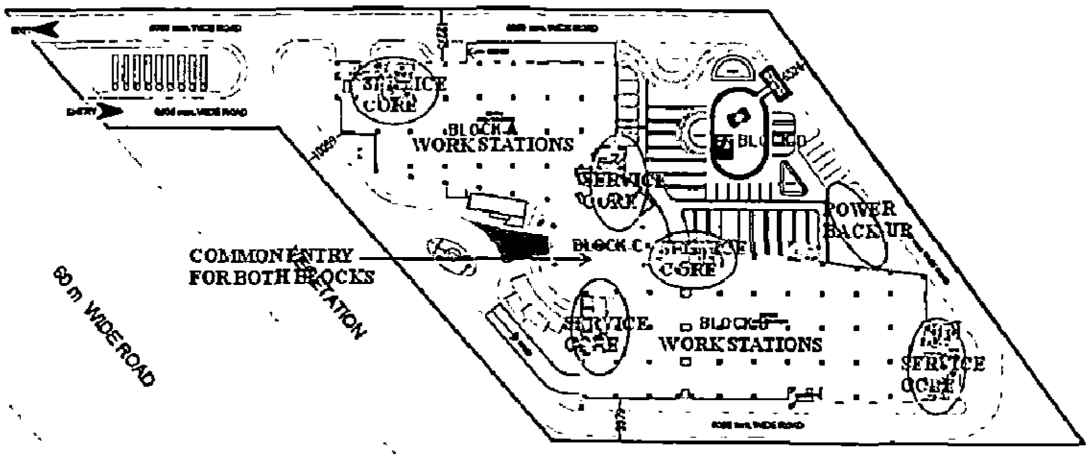


Figure 4.3.8: Typical Floor Plan

Floor Area

Block A = 1792.10sq.m

Block B = 2648.30sq.m

Block C = 432.14sq.m

Block D = 262.06sq.m

Height

Floor to floor height =3.8 m (except -Ground floor to first floor =5.0m)

Floor to false ceiling ht=3.0 m

Occupants load / floor

SL.N.	ACTIVITY	OCCUPANTS CAPACITY
1.	Work station (open plan)	376 (approx.)
2.	Chambers (full partition)	23 (approx.)
3.	Toilets (ladies+gents)	32 (approx.)
4.	Services(AHU,ele. Room)	--
5.	Lobby	--

- Open plan work station is of size 56.4Mx28.9mx3.5m (block-A) and 79.5mx32.2mx3.5m (block-B) which is not suitable for good acoustic condition. (According to *Audio Engineering Society journal paper*)

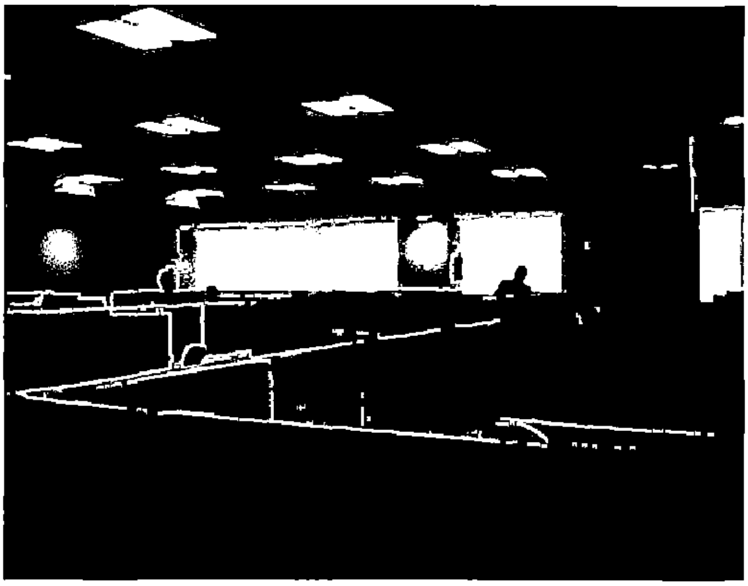


Figure 4.3.9: View of Workstation area

Work station area (ht. of partition=1.2m)

4.3.9 MATERIALS USED

Elevation-

Wood, Glass, Aluminum frame, ACP, Stone

Flooring -

Office area- vitrified tile

Services area – vitrified tile

Lobby - vitrified tile

Toilet – anti skid tile

False ceiling - Gypsum Board & somewhere wood

Door - flush door

Windows -structural glazing supported by aluminum frame

Work station – laminated wood with sound absorbing material coating

4.3.10 CONSTRUCTION

Floor- R.C.C. floor with tiles on top

Conference room- capet is used to minimized Impact noise.

Wall – 280(115+50+115) mm cavity wall made of burnt brick have sound resisting properties.

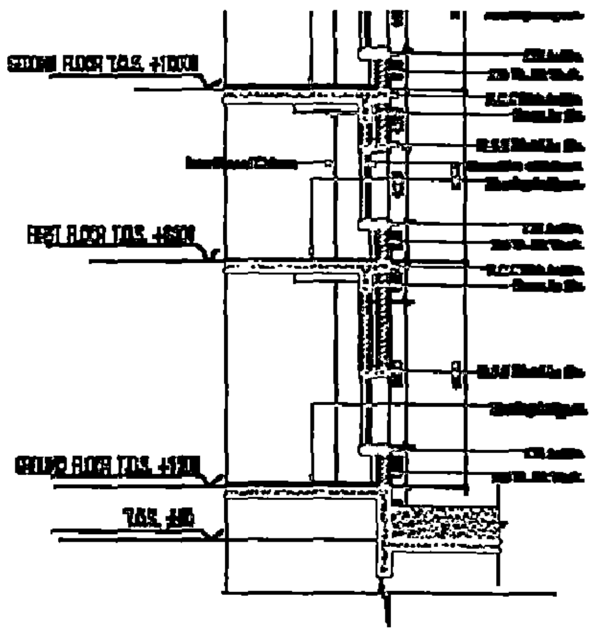


Figure 4.3.10: Building Skin Section

Roof- made of 125 mm thick r.c.c. having false ceiling of gypsum board.

4.3.11 HVAC

- HVAC unit is installed in basement area.
- Each block has separate room for HVAC connections (distribution) for that area.
- Iron sheets are used as duct for connection.

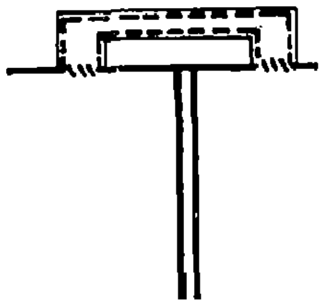


Figure 4.3.11: Ducting System

- Good ducting system in most of the spaces inside. Duct is not in direct contact with false ceiling cause low vibration inside space.
- Duct is separated by rubber insulator from false ceiling.

INFERENCES:-

- Separate Vehicular way and pedestrian way are provided to avoid conflict which produces unusual noise.
- Vehicular paths are optimal which is helpful to avoid unusual noise due to vibration.
- Trees are used to create buffer between noise source & receiver.
- Cavity wall construction technique is used to attenuate direct sound from outside like traffic etc.
- Iron sheets can be use as duct for connection to conditioned space where duct is separated by rubber insulator from false ceiling.
- In Work station area – laminated wood with sound absorbing material coating are used for good sound privacy and speech intelligibility.
- Occupants in workstation are oriented in such a manner that they face away from each other.
- Flat lens lights (prismatic-lensed luminaries) are used in between workstations.
- Power back-up machines are well isolated from building block.

4.4 TECH BOULEVARD OFFICE BUILDING, NOIDA

4.4.1 INTRODUCTION

The project named as "Tech Boulevard" is located in the Sector 127, Noida, which is developed by 3C Developers as an office building. The project is lead to the development of an office complex. The whole site is spread over the 20,000sq. m of land consists of three multistoried blocks and a separate block for multiuse with surface & basement parking etc. It was set up in the year 2007.

4.4.2SITE ANALYSIS:

LOCATION

- The site of the office complex is located in plot no.-6 , sector-127 , Noida which is developed as a commercial zone.

ACCESSIBILITY

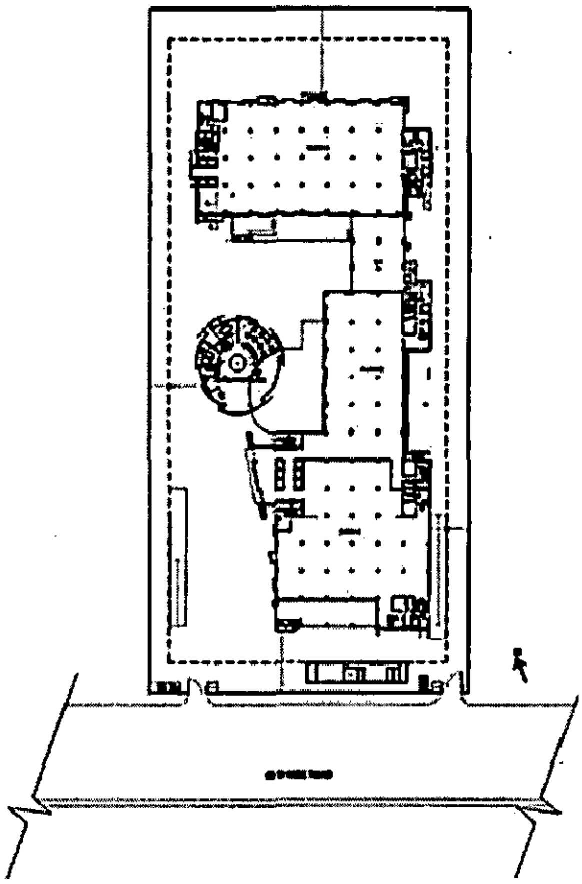


Figure 4.4.1: Site Accessibility

- The major roads in the vicinity of the site are in E-W direction which is 60m wide.
- The site is located near the heavy traffic.

4.4.3 AREAS & SET BACKS

Plot area =20,000 sq.m (approx.)

Built-up area=32200 sq.m

Total no. of people= 3960(approx.)

Front set back =19.2m

Back setback=26.1m

Side set back=14.6m & 12m

- As the site is surrounded by heavy traffic in front side but because of distance of 19m in Front side sound pressure level from traffic is reduced by 1dB and for rest of the site it will remain the same.

4.4.4 TOPOGRAPHY & BLOCKS PLACEMENT

- All building blocks are placed on the flat (almost) ground so it won't affect the acoustic environment inside.

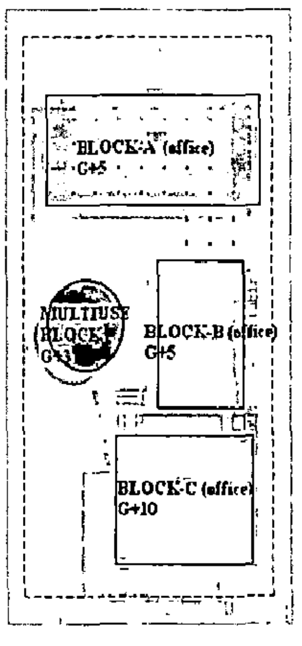


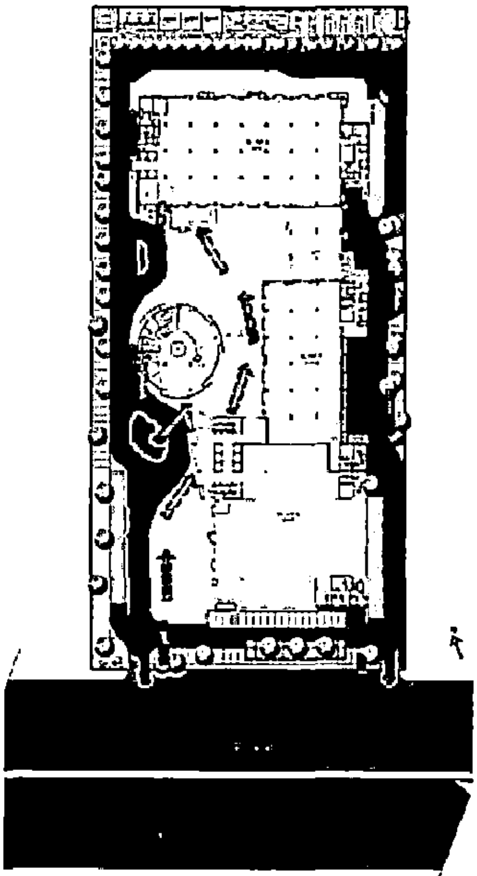
Figure 4.4.2: Site Plan

- Superstructure -

Block A (office block) comprises of G+5,
Block B (office block) comprises of G+5,
Block C (office block) comprises of G+10,
Multiuse block comprises of G+3.

- High altitude building block (block-c) is nearer to traffic which resists direct noise from outside to block – A&B.

4.4.5 SITE CIRCULATION



- Paths for Vehicles and pedestrian are separate and not making nodes at any point so causes less unusual noise.
- Internal work space area of office block is separated by vehicular noise (due to vibration etc) wherever passing near to building block through buffers which are due to lift area, toilets etc.

Figure 4.4.3: Site Circulation Plan

4.4.6 LANDSCAPING

- Trees are used on the periphery of the site.
- Here D.G sets are installed rear side of the site which creates noise when in use. Densely planted trees are used as a buffer for such direct noise.

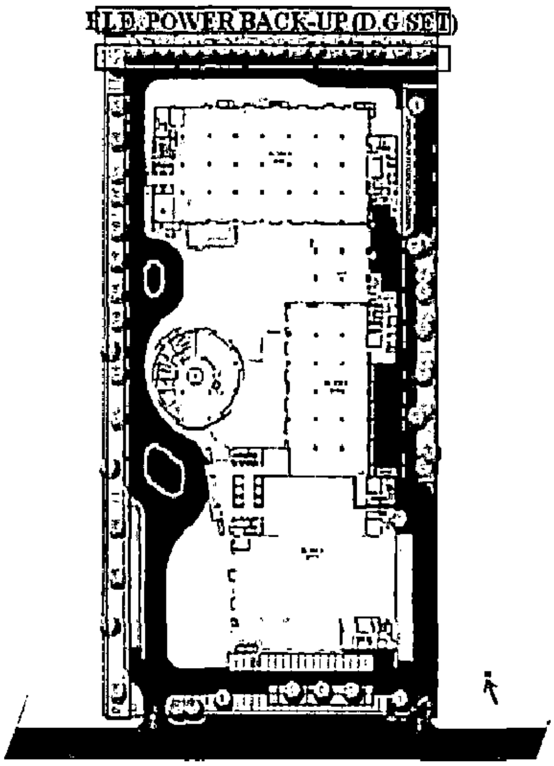


Figure 4.4.4: Landscaped Plan of the Site

4.4.7 BUILDING FORM

- Building blocks are rectangular (block-A&B) & square (block-C) in plan.
- Buildings are cuboids in form so no any direct noise cut from outside.
- Rectangular plan is good from acoustical point of view (avoid sound foci & dead spot) and for office internal arrangement also.

4.4.8 INTERNAL LAYOUT

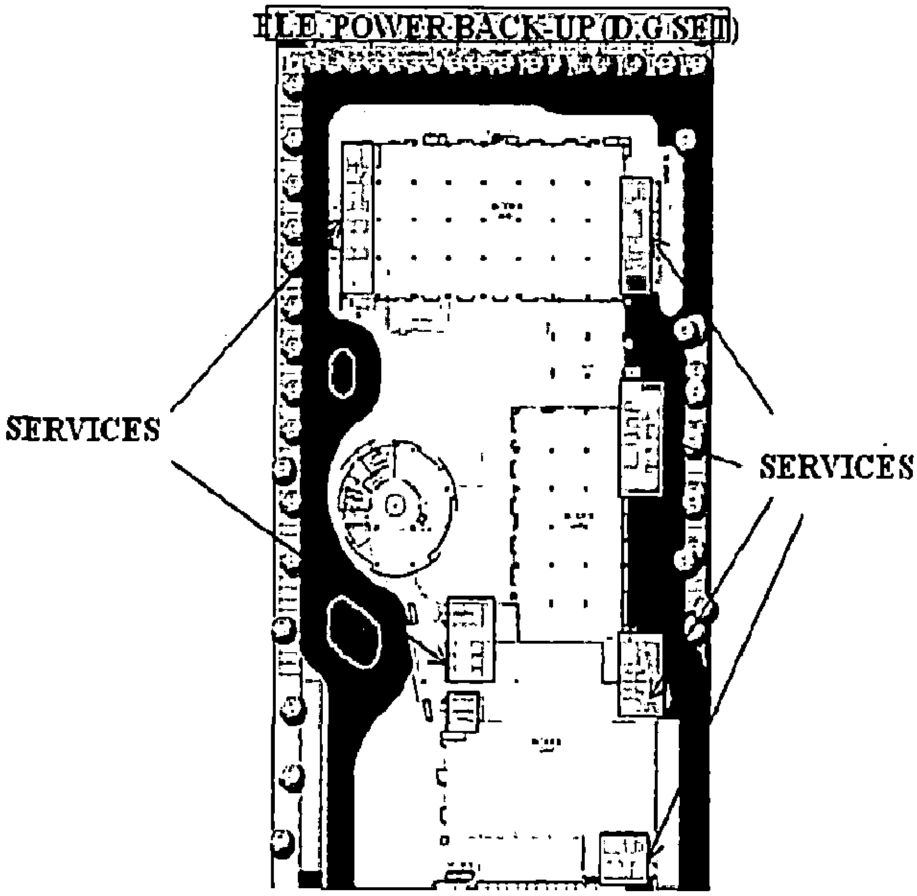


Figure 4.4.5: Typical Floor Plan

Floor Area

Block A = 1867.9sq.m

Block B = 1176.3sq.m

Block C = 2296.5sq.m

Multiuse block = 509.8sq.m

Floor to floor ht

Floor to floor height =3.6 m (except -Ground floor to first floor =5.0m)

Floor to false ceiling ht=2.9 m

Occupants load / floor

SL.N.	ACTIVITY	OCCUPANTS CAPACITY
1.	Work station (open plan)	80 (approx.)
2.	Chambers (full partition)	20 (approx.)
3.	Meeting rooms	204(approx.)
4.	Toilets (ladies+gents)	28 (approx.)
5.	Services(AHU,ele. Room)	--
6.	Lobby	--

- Open plan work station is of size 32.0Mx58.3mx3.8m(block-A) ,24.0mx48.8mx3.8m (block-B) and 47.3Mx48.3mx3.8m which is not suitable for good acoustic environment. (According to ***Audio Engineering Society journal paper***)
- Work station area (ht. of partition=1.5m)

4.4.9 MATERIALS USED

Flooring -

Office area- vitrified tile

Services area –

Lobby - vitrified tile

Toilet – anti skid tile

False ceiling - Gypsum Board

Door - flush door with fire rating

Windows - double glass supported by aluminum frame

Work station – laminated wood with fabric cover

4.4.10 CONSTRUCTION

Floor- r.c.c floor with finishes

Wall – 230 mm burnt brick wall which have good sound resisting properties.

Roof- made of 125 mm thick r.c.c. having false ceiling of gypsum board.

4.4.11 HVAC

- HVAC unit is installed in rear side of the site.
- Each block has separate room for HVAC connections /distribution (A.H.U) for that area.
- Iron sheets are used as duct for connection.
- Good ducting system in most of the spaces inside. Duct is not in direct contact with false ceiling cause low vibration inside space.
- Duct is separated by plastic sheet from false ceiling.

INFERENCES:-

- Vehicular paths are on the periphery of the site so here lift lobby, toilets, store room etc are used as buffer between vehicular noise (due to vibration) and internal workplace.

- Minimum of 8m distance between site circulation path and building block is good for reduction of noise due to vibration

- Power backup (D.G set) room is isolated from building.
- Densely planted trees are used as buffer between heavy noise from power backup system and building interior.
- Full height Partitions with acoustic fabric are used for Chambers which are in workstation area for speech privacy.

4.5 LIST OF INFERENCES

- While layout Building block placement according to height, function etc plays an important role for good acoustic environment.
- In 3-D form, Stepped form is better option to avoid noise.
- Trees according to their feature help to avoid noise. (long leaves deciduous trees are good option)
- Landscaping features like earth mound etc are cutting for excessive noise.
- Site circulation plays an important role. There is some buffer space between building line and vehicular path to minimize noise due to vibration.
- For building interior, shape, size plays an important role. Where ever possible avoid circular form.
- Avoid cutouts in floor slab where acoustic is of prime important like office workstation area etc.
- Corridor, staircase and lift lobby used as buffer to separate spaces which require different sound isolation.
- R.C.C floor with elevated floor finish reduces Impact noise.
- Open- grille lights (parabolic-louvered luminaries) are used in most of the areas. In workstations area it is used directly above.
- Used large workstation area to increase speech privacy and reduce acoustical distraction.
- Office workstations area which is rectangular in plan is good to avoid acoustical defects.
- Trees are planted on the periphery of the site to minimize noise from traffic. It acts as green buffer for building.
- Large open space for workstations is better for sound privacy because masking sound is always there.
- Site circulation plays an important role. It should be such that, it not cross close to building block and pedestrian path.

- Sound absorbing material is used at the corner of each workstation which absorbs direct sound from source helps to maintain speech privacy.
- Corridor, lift & staircase lobby are used as a buffer to separate spaces which require special consideration for acoustic.
- Courtyard planning is good if well landscaped.
- Cutouts in floor slab are provided in workstation areas which is not good from acoustical point of view.

- Separate Vehicular way and pedestrian way are provided to avoid conflict which produces unusual noise.
- Vehicular paths are optimal which is helpful to avoid unusual noise due to vibration.
- Trees are used to create buffer between noise source & receiver.
- Cavity wall construction technique is used to attenuate direct sound from outside like traffic etc.
- Iron sheets can be use as duct for connection to conditioned space where duct is separated by rubber insulator from false ceiling.
- In Work station area – laminated wood with sound absorbing material coating are used for good sound privacy and speech intelligibility.
- Occupants in workstation are oriented in such a manner that they face away from each other.
- Flat lens lights (prismatic-lensed luminaries) are used in between workstations.
- Power back-up machines are well isolated from building block.

- Vehicular paths are on the periphery of the site so here lift lobby, toilets, store room etc are used as buffer between vehicular noise (due to vibration) and internal workplace.

- Minimum of 8m distance between site circulation path and building block is good for reduction of noise due to vibration

- Densely planted trees are used as buffer between heavy noise from power backup system and building interior.
- Full height Partitions with acoustic fabric are used for Chambers which are in workstation area for speech privacy.

4.6 COMPARATIVE ANALYSIS

S. N		WIPRO OFFICE CAMPUS, GREATER NOIDA	PATNI OFFICE BUILDING, NOIDA	SPAZEDGE OFFICE BUILDING, GURGAON	TECH BOULEVARD OFFICE BUILDING, NOIDA
1.	CONCEPT	BASED ON GREEN BUILDING CONCEPT	SECOND LARGEST PLATINUM RATED LEED CERTIFIED GREEN BUILDING (COURTYAD PLANNING)		
2.	AREA	50 ACRES	4 ACRES	3.65 ACRES	4.1 ACRES
3.	ACCESSIBILITY	ROADS FROM THREE SIDES	ROAD FROM ONE SIDE	60M WIDE ROAD ON ONE SIDE	60M WIDE ROAD ON ONE SIDE
4.	BUILDINGS	SEPARATE BLOCKS FOR OFFICE,CAFETERIA,RECEPTION & CUSTOMER CARE BLOCK , LIBRARY ,SERVICES	ONE BUILDING BLOCK HAVING, OFFICES, CAFETERIA, RECEPTION, SERVICES ETC.	FOUR BUILDING BLOCKS TWO BLOCKS FOR OFFICES ,ONE FORCOMMON USE SPACE AND ONE SEPARATE CAFETARIA BLOCK	THREE BUILDING BLOCKS FOR OFFICES
5.	TOPOGRAPHY	SLIGHT SLOPE FROM S-W TO N-E	FLAT LAND	FLAT LAND	FLAT LAND
6.	SITE CIRCULATION	PERIPHERAL VEHICULAR ROAD,INTERNAL AREAS FOR PEDESTRIANS	NOT SEGRIGATED VEHICULAR ROAD CROSSES PEDESTRIANS PATH	❑ VEHICULAR ROAD CROSSES PEDESTRIANS PATH ❑ VEHICULAR ROAD IS MINIMUM IN LENGTH	SEPARATE PEDESTRIANS PATH AND VEHICULAR ROAD WITH NO ANY NODE.
7.	LANDSCAPING	CRATED BUFFER ZONE ,EARTH MOUND ,OVER 1500 TREES ARE PLANTED	NATIVE SPECIES OF TREES ARE USED FOR 4000SQ.M GREEN AREA	REGULAR ARRANGEMENTS ON THE PERIPHERY OF THE SITE	TREES ARE USED ON THE PERIPHERY OF THE SITE AND NEAR D.G SET AREA

8.	BUILDING FORM	CURVILINEAR & RECTANGULAR	RECTANGULAR	TRAPIZOIDAL IN PLAN	RECTANGULAR IN PLAN AND OVERALL CUBOID
9.	MATERIALS	VITRIFIED TILE , COTA STONE, BRISTOL TILE, GYPSUM BOARD, LAMINATED WOOD, STRUCTURAL GLAZING	VITRIFIED TILE , COTA STONE, ANTI SKID TILE, GYPSUM BOARD, LAMINATED WOOD, STRUCTURAL GLAZING	WOOD, GLASS, ALUMINUM FRAME, ACP ,STONE, VITRIFIED TILE , GYPSUM BOARD, STRUCTURAL GLAZING	VITRIFIED TILE , ANTI SKID TILES, GYPSUM BOARD, DOUBLE GLASS GLAZING WITH ALUMINIUM FRAME
10.	CONSTRUCTION	FLOOR - R.C.C FLOOR WITH ELEVATED FLOOR FINISH WALL – 230MM WALL OF AAC ROOF -125 MM THICK R.C.C	FLOOR - R.C.C FLOOR WITH FLOOR FINISH WALL – 230MM WALL OF AAC ROOF -125 MM THICK R.C.C	FLOOR - R.C.C FLOOR WITH FLOOR FINISH CAVITY WALL(115+50+115) ROOF -125 MM THICK R.C.C	FLOOR - R.C.C FLOOR WITH FLOOR FINISH WALL – 230MM ROOF -125 MM THICK R.C.C
11.	HEIGHTS	FLOOR TO FLOOR = 4.2 M FLOOR TO FALSE CEILING HT=3.25 M BUILDING HT. = 9.4 M TO 47M	FLOOR TO FLOOR =4.05M FLOOR TO FALSE CEILING HT=3.25 M BUILDING HT. = 10M	FLOOR TO FLOOR =3.8M FLOOR TO FALSE CEILING HT=3.0 M BUILDING HT. = 10M TO 23.8M	FLOOR TO FLOOR =3.6M FLOOR TO FALSE CEILING HT=3.0 M BUILDING HT. = 12M TO 18M

DESIGN GUIDELINES

CHAPTER-5

Preamble

Maintaining acoustic comfort in the office is more than just reducing loud office noises. The acoustic environment in the office comprises of all the sounds that occur throughout the day. Some of these sounds are welcoming and essential in some form, such as a telephone ring. However, when sounds annoy and distract office occupants, they are perceived as noise and will hinder your office productivity.

It is often in the case of office buildings that noise from the conversations of others is a major irritation for workers, especially in open-plan offices.

To achieve occupant acoustic satisfaction in office, speech privacy and comfortable sound levels are required. Speech privacy is a function of the ratio of sound energy from speech and other ambient sounds. If an office is quiet with little background noise, overheard speech can be perfectly intelligible and therefore more annoying, because of its information content, unpredictability, and uncontrollability.

The acoustic environment inside a building is dependent on the following-

- External sources such as traffic, building services plant
- Occupiers' use of the space including the equipment
- The level of sound insulation of walls, floors, internal partition etc.

Various types of spaces are there in offices which are of different functions and having special acoustical requirements. Without considering acoustical requirements of each and every space, we cannot make office environment better.

Main considerations-

5.1 external factors

5.2 internal factors

5.3 type of spaces in open plan office building

5.1 EXTERNAL FACTORS

5.1.1 SITE SELECTION

5.1.2 ZONING

5.1.3 SITE CIRCULATION

5.1.4 ORIENTATION

5.1.5 BUILDING FORM

5.1.6 LANDSCAPING

5.1.1 Site selection

- Ensure compatibility with existing facilities. Avoid sites in high noise areas like airfields, highways, factories, and railways.
- Determine what is planned for the site in the future so that significant remedial measures can be applied to achieve the interior sound environment to an acceptable level.

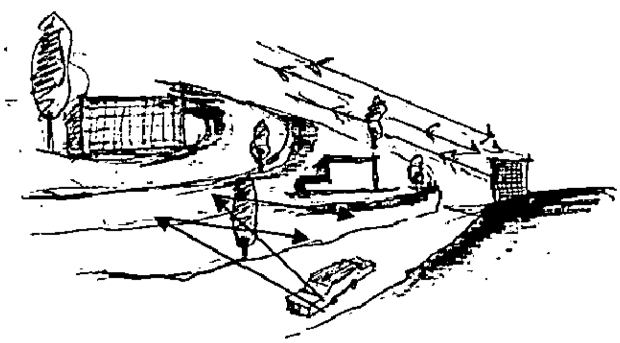


Figure-5.1: Contour site

- Choose contoured site which cuts direct noise from outside.

5.1.2 Zoning

- Zoning of the site should be according to the function of space. Frequently used public spaces e.g. reception area, cafeteria may be placed near noisy side.
- Private realm, semi-public realm and public realm should be segregated according to sound isolation requirement.

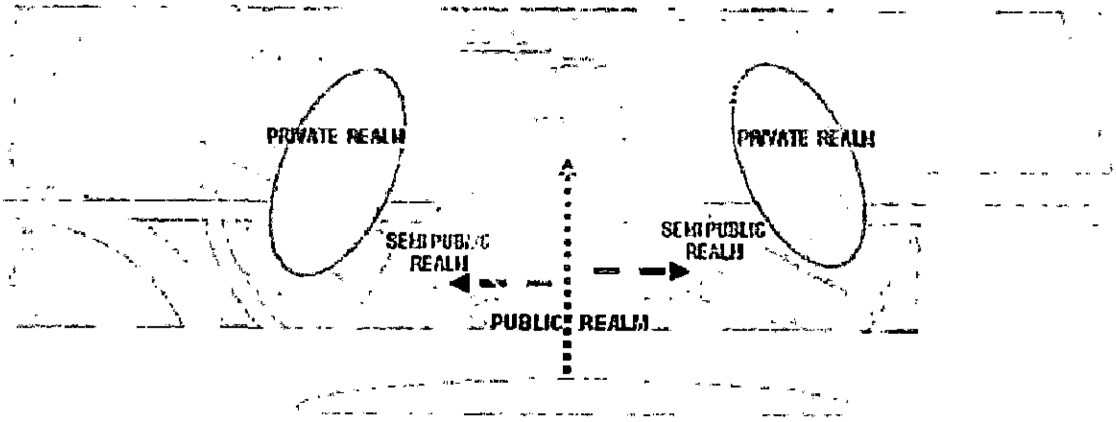


Figure-5.2: Zoning of the site

5.1.3 Site circulation

- The vehicular roads & pedestrian paths should be segregated and should not cross each other.

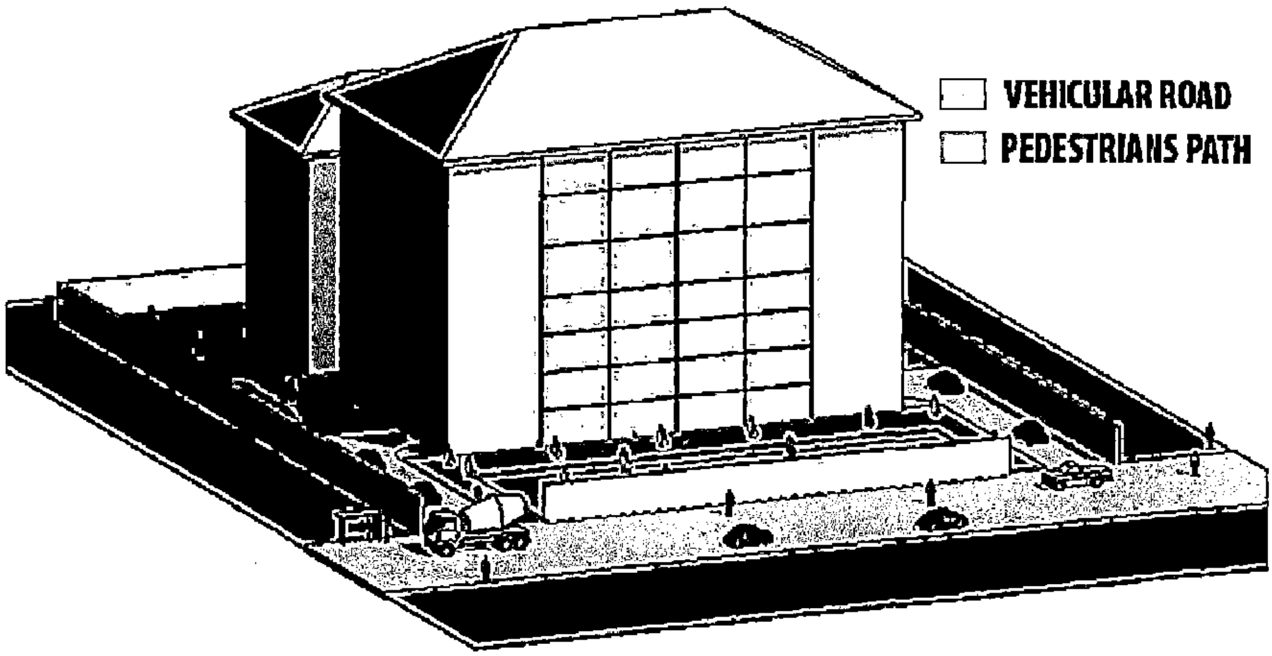


Figure-5.3: Site Circulation

- As far as possible shorten the vehicular way as it is helpful to avoid noise due to vibration.
- There should be a minimum buffer of 8m between vehicular road and building block line to minimize noise due to vibrations.

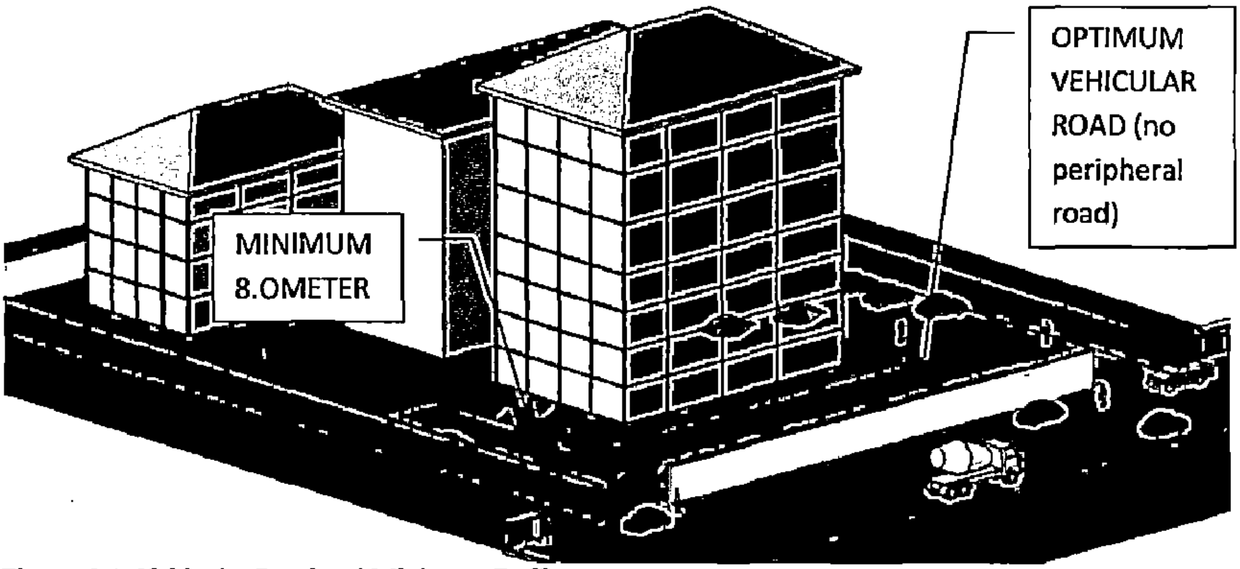


Figure-5.4: Vehicular Road and Minimum Buffer

- In case of peripheral vehicular ways, these should be planned in such a way that it does not cross the main activity area and building block.

5.1.4 Orientation

- Orient buildings in such a way that it shields more critical spaces. Place buildings of noisier activities on the noisy exposures e.g. mechanical and electrical equipment rooms, gymnasiums etc and quieter activities on quieter exposures.

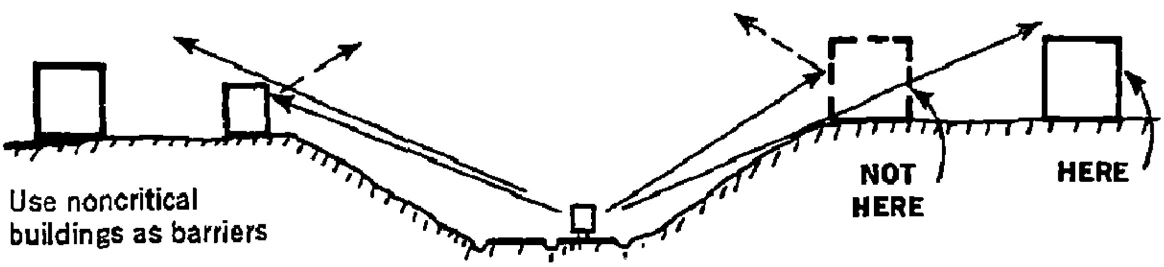
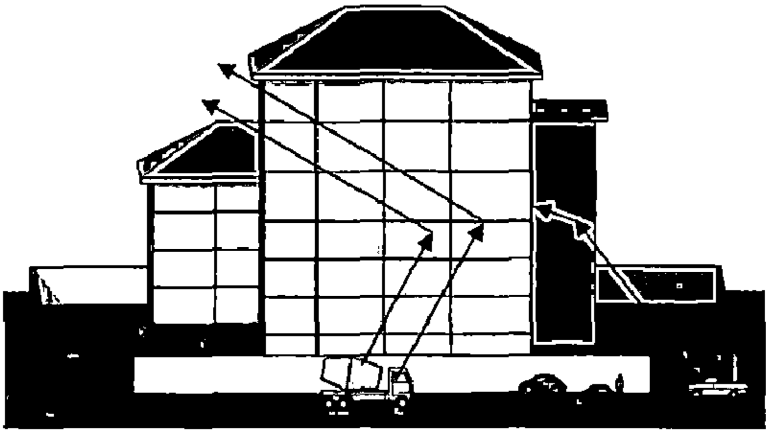


Figure-5.5: Building Block Orientation

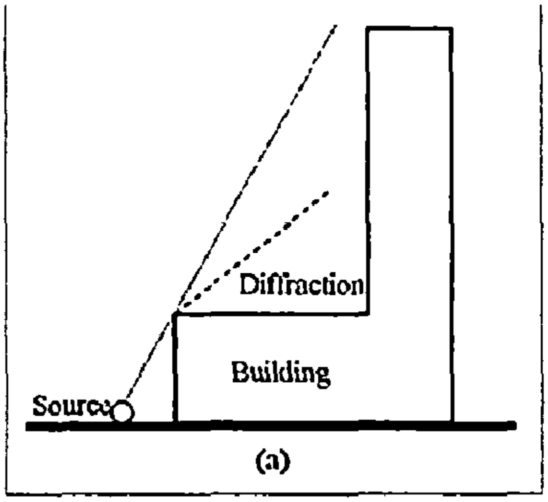


- If more than one building block is to be placed on a site, then layout should be such that higher buildings of lesser noise-sensitivity should be closer to the noise sources and place buildings with quieter requirements in the shadow of that.

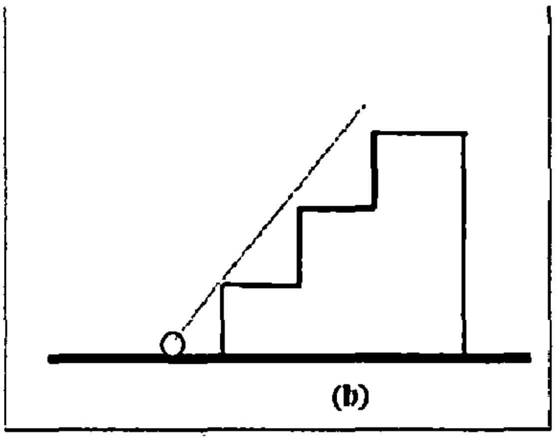
Figure-5.6: Building Layout in Site

5.1.5 Building form

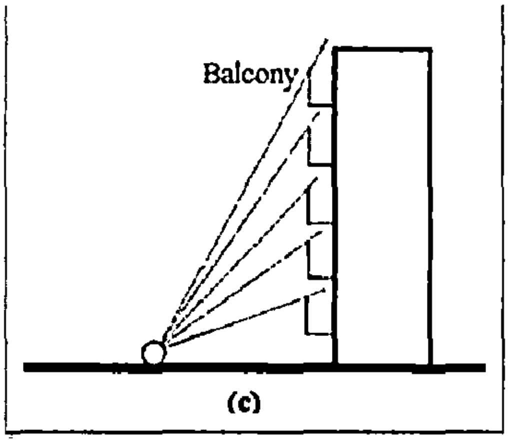
Building forms should be chosen so that it helps to attenuate external noise to a certain extent.



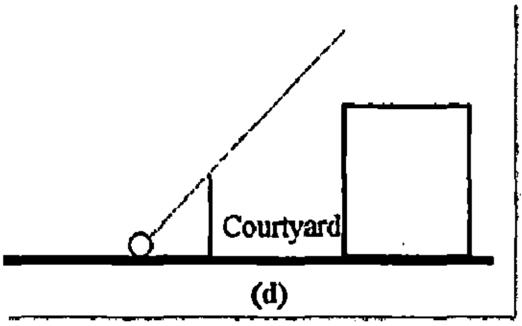
In Figure (a), the podium, usually for commercial use, acts as a noise barrier for the main building which is typically residential



In Figure (b), the higher floors are farther from the noise source and they are also protected by the lower building blocks due to the screening effect



In Figure(c), balconies can effectively stop the direct sound from the source to the interior



In four (d), big screening wall acts as a sound barrier

Figure 5.7: Sound & Building Forms

5.1.6 Landscaping

- Howea forsteriana (Kentia Palm), Plasterboard, Thick pile carpet etc are the plant species which are good in low frequency sound absorption, which comes from HVAC.
- Tall trees should be planted near the noise sources which give significant sound reduction compared to open grassland.
- 7m wide green belt with sufficient height having dense foliage should be provided to attenuate the sound.

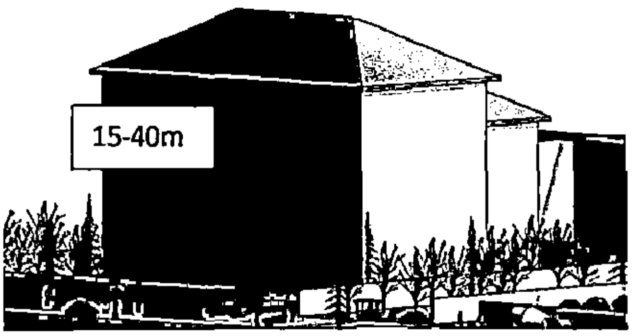


Figure5.8: Plantation & Building Setback

- Plant wide belts of tall dense trees in the setback areas having 15–40m depth which offer extra noise attenuation.

- Trees and shrubs should be planted densely near the heavy noise source for good sound attenuation.
- Trees should be planted in such a manner that its leaves are oriented towards the noisy sources. Trees having big size leaves are beneficial from this point of view.
- The earth mound with low-growth drought-tolerant plants should be used as a barrier for traffic noise.
- A noise barrier on top of an earth mound should be provided to reduce the noise.

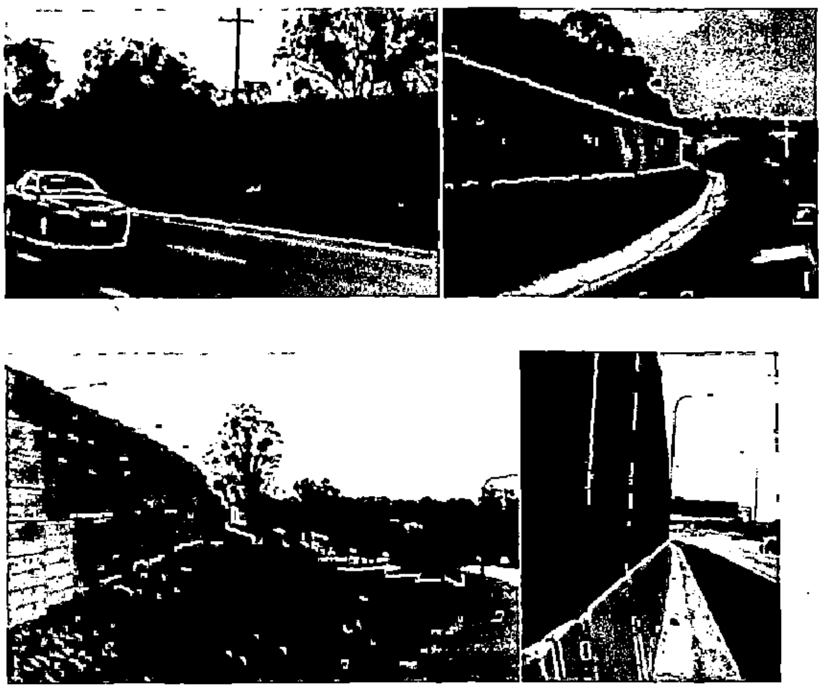


Figure 5.9: Earth mound with barriers

5.2 INTERNAL FACTORS-

5.2.1 SIZE

5.2.2 SHAPE

5.2.3 INTERNAL LANDSCAPING

5.2.4 LAYOUT & ORIENTATION OF SPACES

5.2.5 CONSTRUCTION TECHNIQUE, MATERIALS & FINISHES

5.2.1 Size

Consideration must be given to the height, width and length of the room.

- One should follow proportions with respect to H-L-W :-

  1: 5.7: 4.5 , 1: 2.16: 2.96,

  1: 2.19: 3.01, 1: 2.22: 3.04

- Provide optimum size of the room as acoustical problem increases with increase in size.

5.2.2 Shape

- Rectangular shape should be preferred than curved one for most of the spaces e.g. workstation area, conference rooms etc.
- Avoid square, circular, elliptical shaped room wherever possible as these shapes cause the problem of sound focusing.

5.2.3 Internal landscaping

- Noisy areas e.g. reception, cafeteria etc should be well planted. And planters should be made of sound absorbing material and be of irregular in shape to diffract sound.
- Internal landscaping by plants should be provided near and adjacent to the hard and reflecting surfaces. e.g. - Marble walls, exposed concrete and stone floors etc
- Use plants with lot of small leaves as these are useful to scatter and diffuse the sound.
- Dense plantation should be used as a sound buffer between spaces of different functions.

5.2.4 Layout & orientation of spaces

- Internal proximity of spaces should be according to their sound insulation value requirement.

	WORK-STATIO N AREA	CONF-RENCE ROOM	CAFÉ-TERIA	LIBR-ARY	GYMN-ASIUM	CORRIDOR/ COMMON AREA	ELE.& HVAC RM.	STAIR-CASE & LIFT
WORK-STATION AREA		VN	VF	VN	VF	N	VF	N
CONFE-RENCE ROOM	VN		VF	VN	VF	N	VF	VF
CAFÉ-TERIA	VF	VF		VF	N	VN	VN	N
LIBRARY	VN	VN	VF		VF	N	VF	N
GYMN-ASIUM	VF	VF	N	VF		N	VN	N
CORRIDOR / COMMON AREA	N	N	VN	N	N		N	N
ELE. & HVAC RM.	VF	VF	VN	VF	VN	N		VF
STAIR-CASE & LIFT	N	N	N	N	N	N	N	

'VN' – Very Near, 'N' – Near, 'VF' – Very Far

Table 5.1: Internal Proximity of Spaces

- Use corridors, closets as a buffer to separate areas of different sound isolation value.
- Use furniture and plants for achieving quiet areas and segregation of different activities.
- Different sound sources should be placed as far as possible from each other.

	WORK-STATION AREA	CONF-RENCE ROOM	CAFÉ-TERIA	LIBR-ARY	GYMN-ASIUM	CORRIDOR / COMMON AREA	ELE. & HVAC RM.	STAIR-CASE & LIFT
WORK-STATION AREA		VN	VF	VN	VF	N	VF	N
CONFE-RENCE ROOM	VN		VF	VN	VF	N	VF	VF
CAFÉ-TERIA	VF	VF		VF	N	VN	VN	N
LIBRARY	VN	VN	VF		VF	N	VF	N
GYMN-ASIUM	VF	VF	N	VF		N	VN	N
CORRIDOR / COMMON AREA	N	N	VN	N	N		N	N
ELE. & HVAC RM.	VF	VF	VN	VF	VN	N		VF
STAIR-CASE & LIFT	N	N	N	N	N	N	N	

'VN' – Very Near, 'N' – Near, 'VF' – Very Far

Table 5.1: Internal Proximity of Spaces

- Use corridors, closets as a buffer to separate areas of different sound isolation value.
- Use furniture and plants for achieving quiet areas and segregation of different activities.
- Different sound sources should be placed as far as possible from each other.

* Grouping of activity should be according to background noise levels.

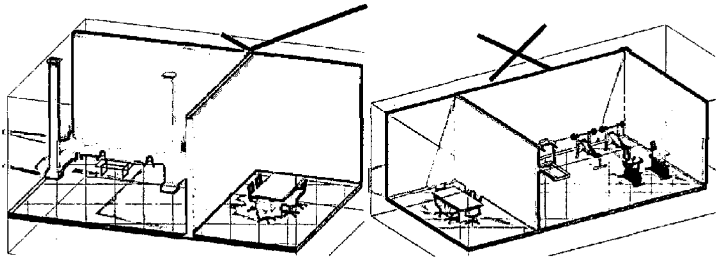


Figure 5.10: Grouping of Activity

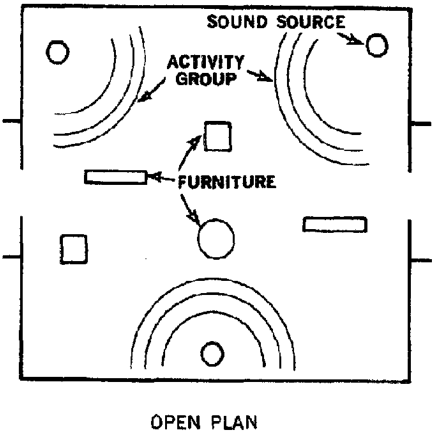


Figure5.11: Layout of Spaces

* Use aisles for circulation to define different areas.

5.2.5 Construction technique, materials & finishes

* Cavity wall should be used for external wall of building to cut down excessive outside noise. Use of sound insulating materials in between the cavity is more effective.
* Elevated floor with absorbing floor finish should be used in area where acoustic is very important e.g. workstation area etc.

- Avoid cut-outs in floor slabs where acoustic is of prime importance e.g. workstations, library, conference room etc.
- Construction of false ceiling is good for acoustics as well as for heat insulation and laying of different conduits/services.
- Materials having good sound energy absorption should be used for false ceiling in workstation area, conference room and library etc.

5.3 Type of spaces in open plan office building

5.3.1 WORKSTATION AREA

5.3.2 CONFERENCE ROOM/ MEETING ROOM

5.3.3 CAFETERIA / LOUNGE

5.3.4 LIBRARY

5.3.5 GYMNASIUM

5.3.6 CORRIDOR / COMMON AREA

5.3.7 ELECTRICAL ROOM & HVAC ROOM

5.3.8 STAIRCASE & LIFT

5.3.1 Workstation area

As sound travels in an open-plan office, it meets obstacles: floor, ceiling, partitions (partial-height screens), light fixtures, furniture, etc. These obstacles are the elements of open plan office acoustics. These elements will change the path of sound. While designing an open-plan workstation to block sound, designers must consider all of these paths -Direct Propagation, Reflection, Diffraction, Sound Transmission, and Attenuation.

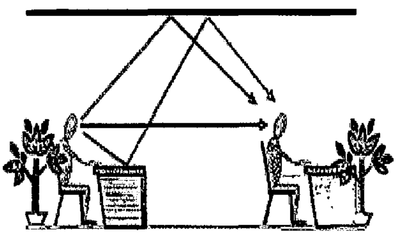
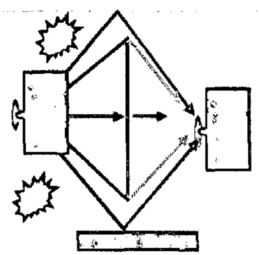


Figure5.12: Sound paths inside open office



Elements of Open-plan workstation Acoustics:

Ceiling and floor

Partitions (partial-height screens)

Lighting fixtures

Air Supply and Return Grilles

Workstation and Occupant Orientation

Sound Masking System

All these features play a role in the acoustical design strategies and should be used to control sound propagation. Good acoustical conditions can be created only if all workstation elements are at or near optimum levels.

It is impossible to block all direct, reflection, diffraction, and transmission paths in an open-plan office because cubicle occupants move around their workstations, changing the conditions constantly. So it is effective to create good conditions where they are required: seated, standing, in front of computer, etc.

Ceiling and Floor

- Make the ceiling sound absorbent to reduce reflections with the help of materials having high value of sound absorption average.
- Absorptive ceilings broken by coffers are less reflective than unbroken ceiling planes. So ceiling with coffers are a better option.
- Place light fixtures, air supply diffusers, return grilles, and any other ceiling elements in the passages or in between workstation area to avoid sound reflection towards the occupants.
- Use higher ceiling with good absorbent for speech privacy.
- Use carpets on floor to reduce the reflection and impact noise due to walking, moving furniture etc.

- Sound propagation paths through the floor are generally blocked by partitions, desks, cabinets, chairs, and people, but carpet and furniture reduce any problems created by gaps between the floor and partitions.

Partition (partial-height screens)

- Partition material should be massive or heavy enough to attenuate the sound passing through it. Sound transmission loss indicates a partition's ability to block sound.
- Partition material should have density at least 1/4 pound per square foot which gives STC of approximately 13. STC 20 is an acceptable minimum for good sound attenuation.
- Use partitions with as high Sound Transmission Class (STC) as possible. The higher the STC, the lesser the sound which travels through the partition into the neighboring workstation.
- Recommended SAA (sound absorption average) for partitions in open plan offices is 0.9.
- If it is not possible to make all the partitions absorbent, then partitions between workstations and all parallel partitions must be absorbent to stop reflections bouncing off from back wall and over the partition.
- Suitable absorbent materials which can be used for partition are-fiberglass, acoustical open-cell foams, or other porous, dense materials etc.
- Make free-standing partitions reasonably wide to reduce horizontal diffraction. A minimum width of 1.8m should be used. Modular furniture minimizes horizontal diffraction as they have closed corners.

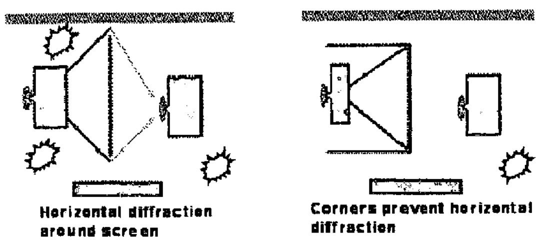


Figure5.13: Horizontal Sound Diffraction Path

- Sound propagation paths through the floor are generally blocked by partitions, desks, cabinets, chairs, and people, but carpet and furniture reduce any problems created by gaps between the floor and partitions.

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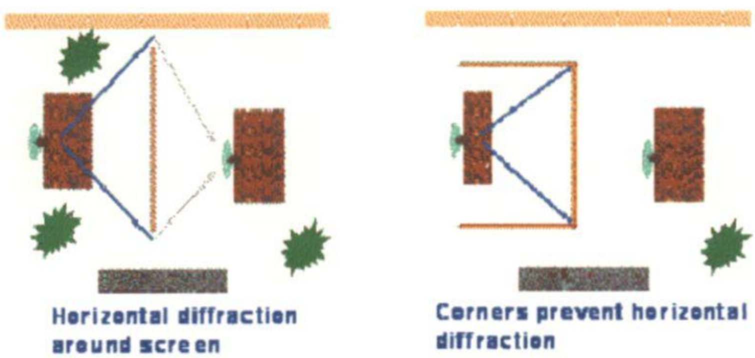


Figure5.13: Horizontal Sound Diffraction Path

- Ensure that the partitions have no holes in them. Gaps for electrical cords and outlets must be covered to prevent noise from getting through holes.
- Use higher partitions which will attenuate the sound. Height between 1.5m to 1.7m is recommended for optimum result.

Lighting Fixtures

Light fixtures can reflect sound and make ceilings less absorbent. Both light fixture type and placement are important.

- Flat lens lights (prismatic-lensed luminaries) are undesirable when placed over the separating partitions but it works better over the centre of the workstations.
- Open-grill lights (parabolic-louvered luminaries) are undesirable when placed at the centre of workstation but it works better over the separating partitions.
- According to requirement of SII value, we should be provided lighting fixture type and placement.

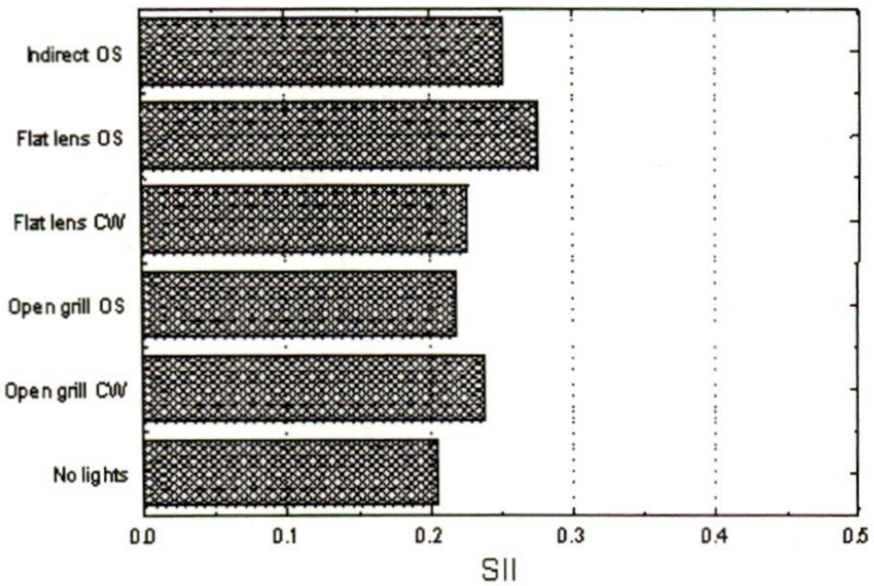


Figure5.14: Lighting configurations & SII value

The above figure shows mean SII (sound intelligibility index) values for 6 lighting configurations (including no lights) with H-B ceiling tiles at a ceiling height of 2.44m.

2.74 mX2.74 m workstations were constructed of 1.52 m high panels faced with 50 mm absorbing foam.

OS- over separating partitions, CW- centre of the workstation

Air Supply and Return Grilles

- Place ceiling-mounted air supply diffusers and return grilles carefully. Avoid placing diffusers and grilles directly over workstations or in areas where they are likely to reflect sound into neighbouring workstations.

Workstation Design and Orientation

- The workstation design in an open-plan office should screen occupants from noise sources (machinery, office equipment, corridor and other occupants etc).
- Use large workstations to increase speech privacy and reduce acoustical distractions especially if the partitions are low.
- Place workstation openings such as it avoid sound reflection paths.

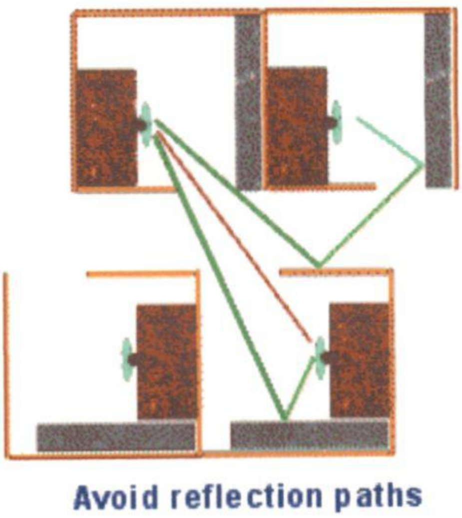


Figure 5.15: Sound Reflection Paths of Workstation

- Place occupants close to the partitions where absorbent is used, to reduce diffracted sound.

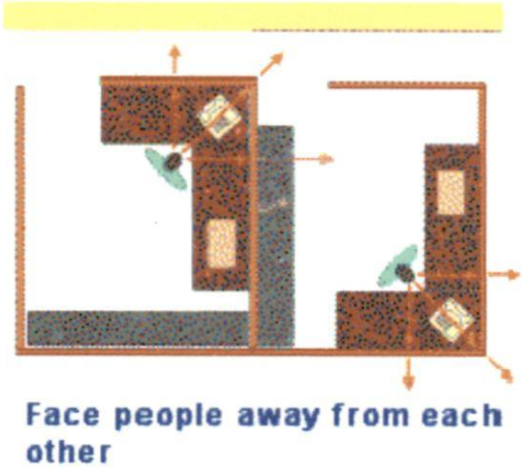


Figure 5.16: People Facing in Workstation

- Within workstations, orient occupants to face away from each other. Place computers and telephones in absorbent corners, away from neighbouring occupants.

- Do not use partition on window where it is extended into multiple workstations. Additional panels should block reflections bouncing off.

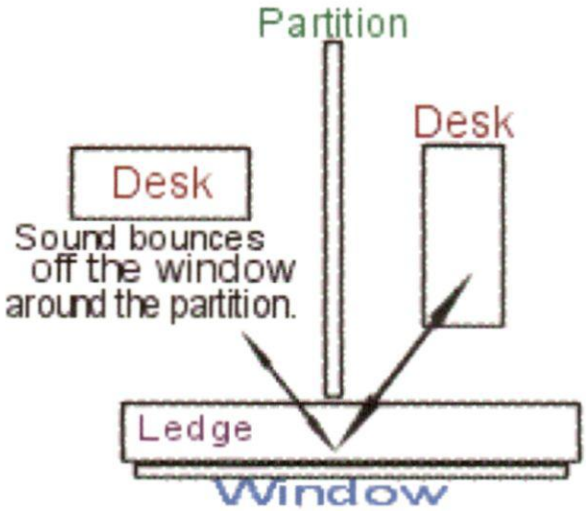


Figure 5.17: Sound Reflection through Window

Sound Masking System

- A sound masking system should be provided to create neutral background noise by adding simulated ventilation sound in the office where ever required.
- Once a sound masking system is installed, it should not be turned off during occupation /noise/silence.

5.3.2 Conference room / Meeting room

Size and background noise should be the first priority for designing these spaces.

- Recommended reverberation time is between 0.6 and 1 second.

- The NC level should not exceed 25 to 35 dB. Although specifying a lower number will ensure minimal background noise, it might be cost prohibitive to achieve.
- Electronic masking system should be used for better acoustics.
- To ensure confidentiality, the wall must be extended to the ceiling.
- Absorptive materials are necessary for the ceiling. The perimeter of ceiling is absorptive and the area above the conference table is kept reflective for better sound intelligibility.
- Acoustic Fabrics and Acoustical Ceiling Tile are suitable for such areas.

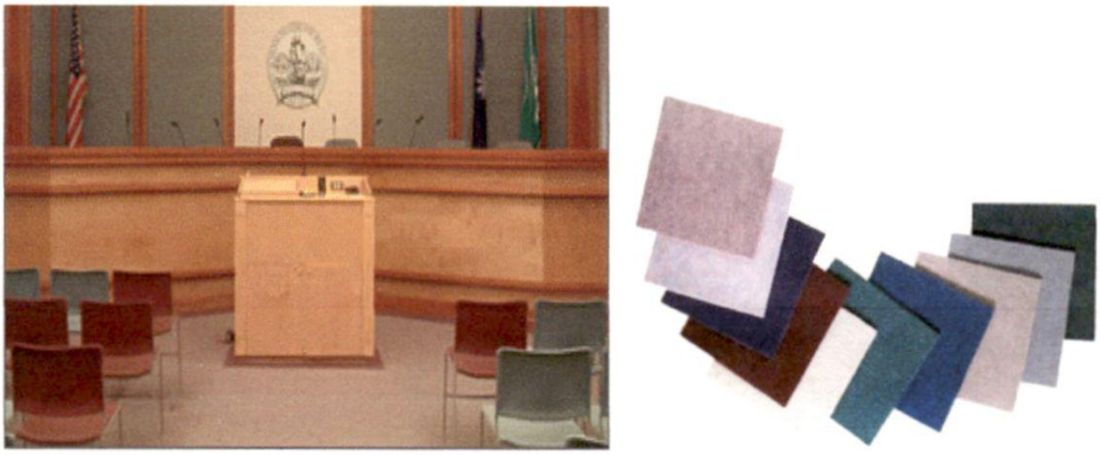


Figure 5.18: Acoustical Fabric

- Sound diffusers should be used for better sound intelligibility.

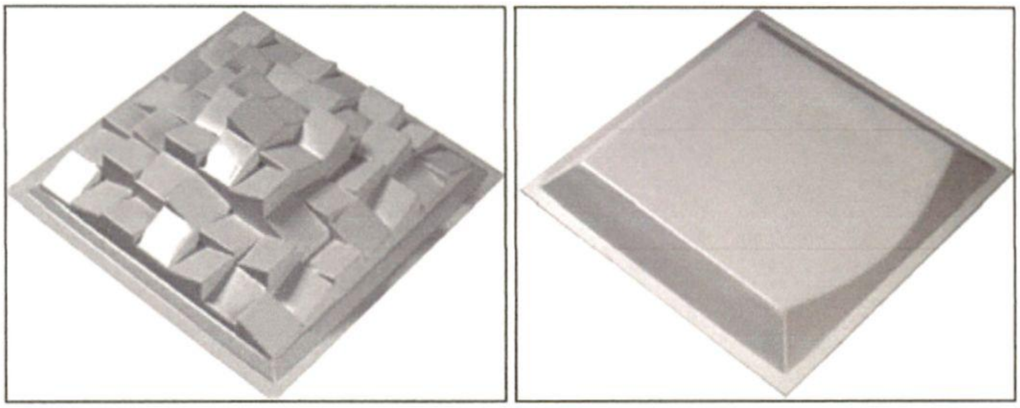


Figure 5.19: Sound Diffusers

5.3.3 Cafeteria/Lounge

Because of the size and materials typically used in this type of space, a cafeteria can become very reverberant, causing a tremendous build up of noise.

- Echo and reverberation which cause poor acoustics in cafeteria and lounge area are best reduced by installing sound absorbing materials.
- Cafeteria- As usage of carpet is not possible in this area, ceiling and wall treatments are necessary.
- Lounge - Carpet can be used in this area but it will not be that much effective (carpet is only about 20-35% absorptive). So ceiling and wall treatments with absorbing material are necessary.

Sound absorbing materials which are suitable for such areas are:-

Soft Sound Acoustic Panels

Soft Sound Anechoic Studio Foam

Echo Absorber Acoustic Panels

Quiet Board Acoustic Panels

Echo Absorber Hanging Baffle

Soft Sound Class Anechoic Hanging Baffles and Banners

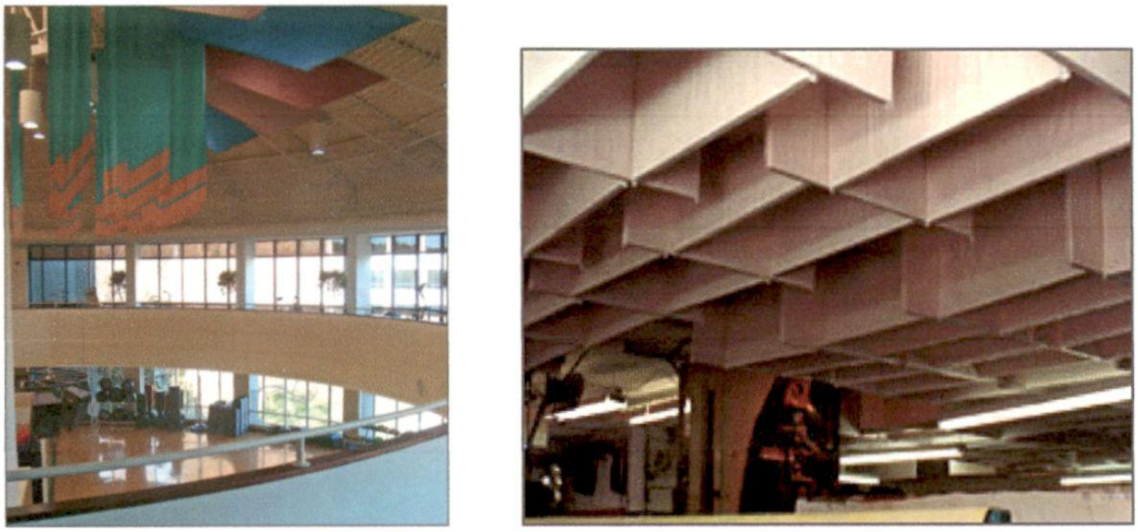
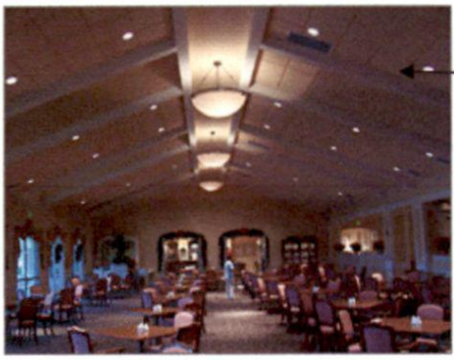


Figure 5.20: Acoustical hanging Baffles and Banners



Acoustical Ceiling Tile

Figure 5.21: Acoustical Ceiling Tile

5.3.4 Library

Main aim is to limit noise levels, thus allowing users to read and contemplate without distractions.

- Recommended reverberation time is 0.8 to 1 second.
- The NC level should not exceed 30 to 40dB.
- High density absorptive materials should be used to reduce the reverberation time.
- If domes or other concave surfaces are used, they must be treated with absorptive materials (like- acoustic fabric etc) as it reduces unwanted reflections.
- Place machinery equipment causing noise in remote area.

5.3.5 Gymnasium

Main goal is to properly absorb excessive noise in this naturally loud environment to protect the users and minimize distractions and help to ensure the audibility of the PA (power amplifier) system.

- Absorptive materials in the ceiling and wall are necessary to control reverberation time.
- Reverberation time should be less than 2 seconds.
- Acoustic materials are based on type of equipment & activity like noisy electronic equipment etc.
- Noise from the gymnasium could potentially impact the surrounding spaces. So avoid placement of gymnasium next to quiet spaces e.g. library, conference room etc.

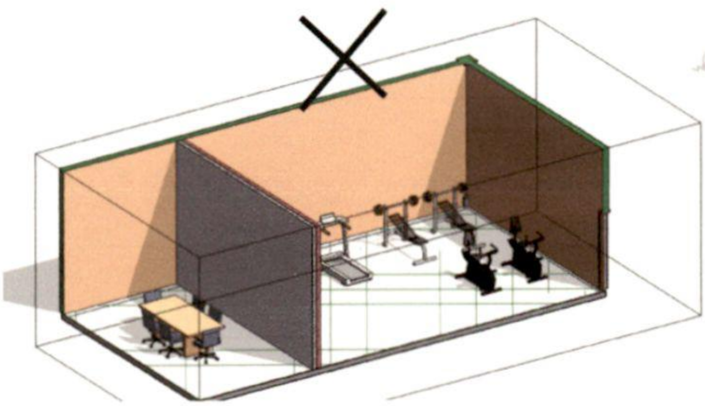


Figure 5.22: Gymnasium & Conference room Position

- Even if everything else is controlled perfectly, the space might be negatively impacted, if the background noise (like HVAC system noise) is too loud. So the NC level should not exceed 35 to 45dB.

5.3.6 Corridor / Common Area

Main aim is to prevent noise from travelling through the corridors and/or hallways.

If surfaces are left untreated, a corridor can act as a megaphone, transmitting conversations into nearby spaces.

- Be cautious with curved surfaces, as they can compound this megaphone effect.
- The noise criteria for background noise (HVAC) should not exceed NC 35-40dB.
- Acoustic Foam should be used in such areas, as it is a good sound absorber as well as less expensive and available in variety of colours.

Figure 5.23: Acoustic Foam

5.3.7 Electrical room & HVAC room

These type of equipments should be placed either inside basement of the building or isolated properly.

- Mechanical equipments should not be in direct contact with the ground. Use shock absorber and vibration isolator at the base.

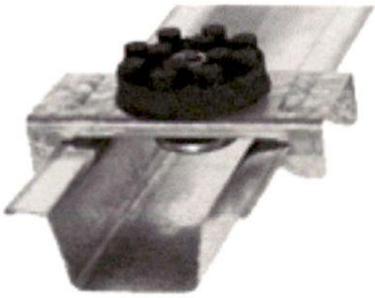


Figure 5.24: Vibration Isolator

- Use sound enclosure system with acoustic door to reduce the noise.

Figure 5.25: Sound Enclosure System for HVAC and Power Generators

- In HVAC system, low frequency noise is transferred in different spaces through the duct and pipes used. Pipe and duct wrap is the solution for that which not only improves the sound proofing performance of the noise barrier but also provides sound absorption and thermal insulation to the pipe or ductwork.

Figure 5.26: Pipe &Duct Wrap

- Duct should not be in direct contact with false ceiling.

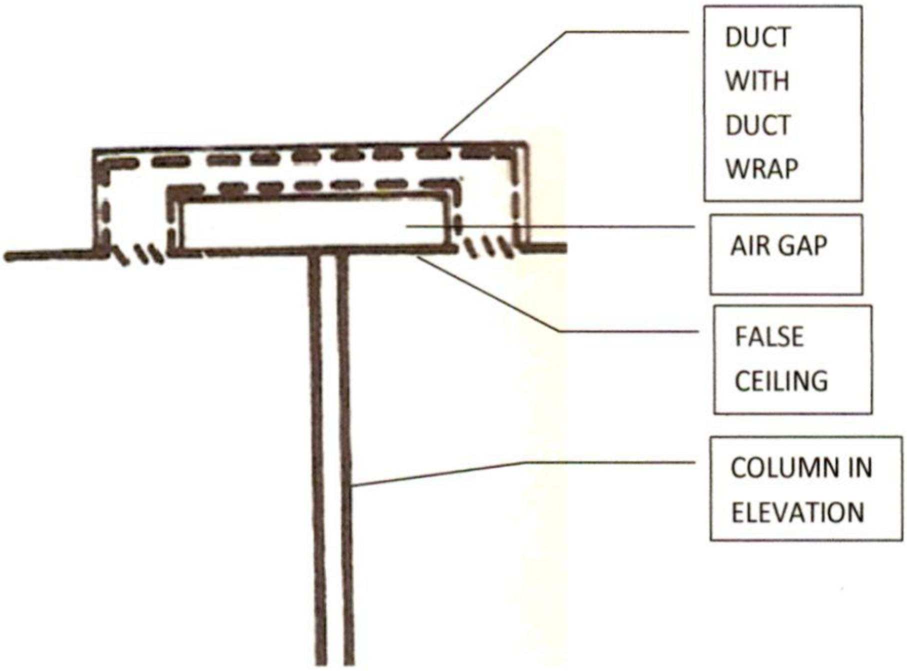


Figure 5.27: False Ceiling & Ducting System sectional Elevation

5.3.7 Staircase & lift

Staircase and lift well are the easy paths through which unwanted sound travels; it should not be located near the areas of prime importance.

- Use acoustical door for separation of staircase & lift lobby area from prime areas.
- Use acoustical tiles for staircase/s are for absorption of noise.

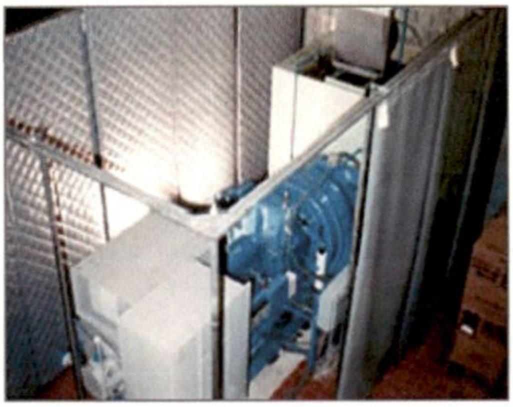


Figure 5.28: Sound Curtain for Lift Machine Room

- Shock absorber and sound curtains should be used for lifting machine in machine room.

CONCLUSION

&

FUTURE SCOPE FOR STUDY

CHAPTER-6

CONCLUSION

Like lighting, air quality, furniture, cleanliness, maintenance etc, acoustic also play an important role for better working environment. In contemporary office culture, profit is the main concern. Appropriate acoustics environment cannot be achieved without considering indoor acoustics. To create an efficient and healthy work environment architect should consider acoustics at initial stages.

Architects and Interior designers have a responsibility to design functional and safe environment. Acoustics is essential for the functioning of almost every type of building e.g. open office & worship center etc. Environment can even become dangerously loud and unsafe for the occupants. In present scenario of corporate office building, the enormous increase of noise levels and noise sources affect the acoustical performance of a building. Acoustic affects the occupant's health and overall performance.

Speech intelligibility, speech privacy and low noise level are prime concern for indoor work environment. After extensive literature study and case studies, inferences shows that external factors e.g. site selection, building layout, circulation, orientation etc and internal factors e.g. shape, size, internal landscaping, materials etc affects indoor acoustical environment.

Optimum level is difficult but standard level can be achieved by considering external and internal factors in different stages of construction. In contemporary office, different types of spaces found which have different acoustic demand. The design guidelines will be helpful for architects in order to design spaces with better acoustics quality which in turn will result in efficient working environment.

FUTURE SCOPE FOR STUDY

Demand for office building is increasing rapidly due to corporate culture and on the other hand sound pollution too. Office building demands good working environment which can't be achieved without considering acoustics. Guidelines are prepared after extensive literature study and case studies which will help to make better indoor acoustical environment. Due to the advancement in construction and technology new methods and products are available in practice which helps to achieve goal. To get precise result, different softwares are available to get desired results and graphs. Softwares are also helpful to get pre-design and post-design evaluations. But softwares have limitations.

Softwares available:-

ODEON-

This software is used for modeling room acoustics. Its calculation methods combine the best features of both ray-tracing and image source methods with the aim of achieving maximum accuracy in predictions of reverberation, energy parameters and reflectograms with only modest calculation times. But the limitation of this software is that it requires a completely enclosed space. It is also not possible to model noise transmitted through structures.

COPE-Calc (Acoustics)-

COPE-Calc is an acoustics design program that can model the propagation of speech from one cubicle to another. It accounts for cubicle geometry, acoustical properties of materials and sound levels of background noise and speech. One can compare alternative workstation designs. The results can be displayed graphically and one can also listen to the results.

These type of study can be done for the other type of buildings also.

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APPENDIX

IMPORTANT DEFINITIONS /TERMS

Sound power

Sound power or acoustic power of a source is the rate at which it emits Sound energy. This power may be;

The total power radiated by the source over its entire frequency range;

The power radiated between limited frequencies ranges;

The power radiated in each of the series of frequency bands.

Inverse square law

Under free field conditions of sound radiation, sound intensity is reduced by $1/4^{th}$ each time the distance from the source is doubled.

Intensity and loudness

Intensity of sound is defined as the amount or flow of wave energy crossing per unit time through a unit area taken perpendicular to the direction of propagation.

Intensity is proportional to its amplitude square.

Loudness of a sound corresponds to the degree of sensation depending on the Intensity of sound and the sensitivity of eardrums. It does not increase proportionally with increase of its intensity but more nearly to its logarithm. **Phon** is the unit of loudness level.

If I0 and I represent the intensities of two sound of particular frequency, and L0and L be their corresponding measures of loudness, then

$L = k\ 10\log I$

$L0=k\ 10\log I0$

The difference in loudness of the two, technically known as intensity level L between them.

Octave bands

For convenience, the audible frequency range (20Hz-20000Hz) is divided into octave bands, each band having range of one octave. The upper frequency limit is therefore twice the value of lower limit.

A large % of total speech intelligibility is provided by the fifth, sixth, seventh bands.

Magnitude of sound

Intensity or magnitude of acoustical energy contained in the sound wave. Sound intensity is proportional to the amplitude of the pressure disturbance above and below the undisturbed atmospheric pressure.

Wavelength

The distance a sound wave travels during each complete cycle of vibration, that is, the distance between the layers of compression is called wavelength.

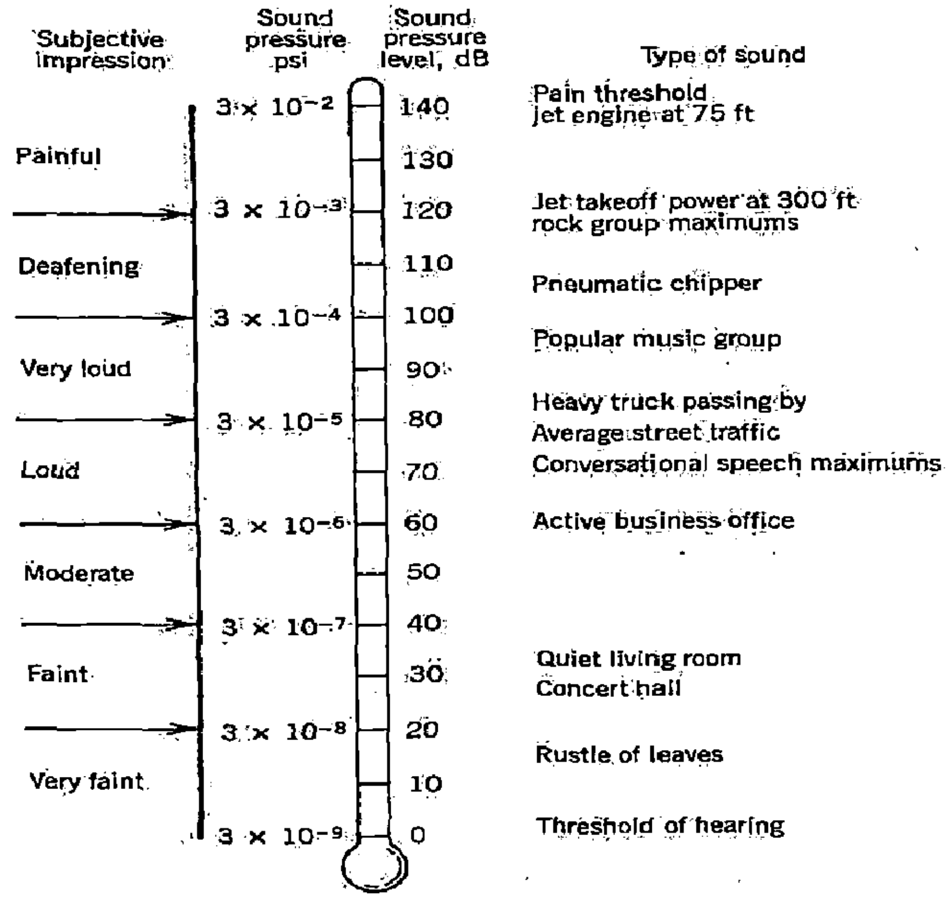
WAVELENGTH = SPEED OF SOUND/FREQUENCY

Articulation class (AC) – Rating system used to evaluate open office acoustical ceilings based on speech privacy. Values range from 100 to 250, with higher meaning better performance.

Articulation index (AI) – Measurement of speech privacy between open office plan workstations. It is performed with a speaker reciting meaningless words while someone in the neighboring workstation writes down the intelligible content. Values range from one to zero, with lower meaning better performance.

Sound pressure (SP)

The average variation in atmospheric pressure above or below the static Pressure due to a sound wave is called the sound pressure. The unit of SP is the **microbar**, which is the pressure of 1 **dyne/sq cm** or approx. one millionth of the normal atmospheric pressure.



It does not take into account the fact that the ear does not respond equally to the changes of sound pressures at all levels of intensity. For these reasons, sound pressures are measured on a logarithmic scale, called decibel scale.