

Sustainable Architecture
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Lecture – 20
Visual and Acoustic Comfort

Welcome back to this new lecture for the online course on Sustainable Architecture. Today's lecture is on Visual and Acoustic Comfort. When we are talking about sustainable buildings and then gradually as we are moving on towards green buildings because, we realize that environmental aspects, environmental parameters are the more tangible ones and hence it is easier to measure, monitor and verify them and also assess the performance of a building as far as the environmental parameters are concerned.

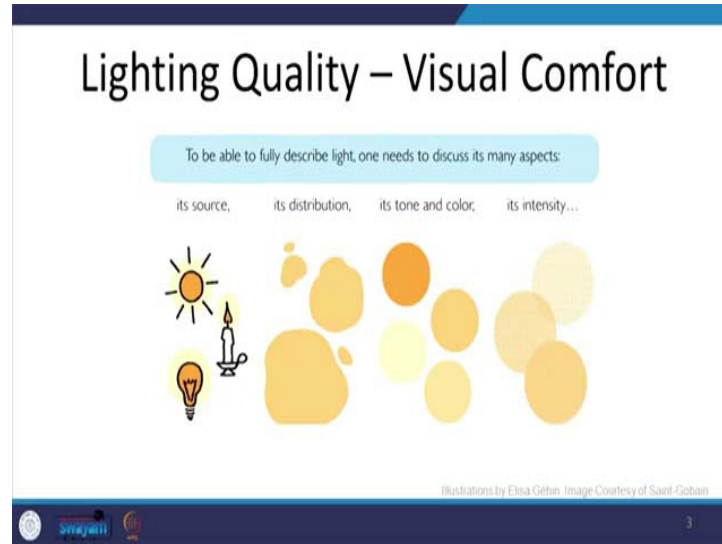
We largely are focusing towards the energy implications, the thermal comfort, how the building performs for a given climate. However, there is an important aspect of it which is the visual and acoustic comfort which also needs to be taken care when we are designing buildings and since we started talking about the sustainability in buildings.

We have discussed that human beings, the occupants, the users are at the center of these buildings and these buildings have to be designed for the human beings keeping in mind the comfort of these occupants. So, only thermal comfort is not the one which should be considered or thought about while designing the buildings, it is also the visual and acoustic comfort.

Visual and acoustic comfort find mention both in our course like NBC and also in our green building rating programs the voluntary rating programs which are available. Let us quickly go over each of these and what are the related concepts and terminologies that we should be looking at.

I am sure most of you have already undergone the courses on lighting and acoustics as part of your curriculum, if you have not some of these concepts are briefly introduced here, but not in great detail. So, let us go over the visual comfort first.

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So, what is visual comfort and what comprises of visual comfort? So, there are many components to it. The first one which is essential for visual comfort is the source of light. So, what is the source of light? The other which contributes to it is how is it distributed. So, if it is distributed non-uniformly, so, in one place you have more light in the other place you have less of light then this varying distribution causes discomfort, what is the tone and color of the light that we are using.

So, earlier people were using candles or flames for lighting up the interiors, gradually we moved on to incandescent bulb and then we moved on to tube lights and now we are using CFLs and LEDs. As the technology has progressed the quality of light the tone of light has also changed.

So, earlier we were using yellow light where the color of the light was yellow the tone was such, and gradually we are moving to more sunlit kind of light the light white light that we received from direct sun. It is very similar to what we are able to produce using the artificial light as well.

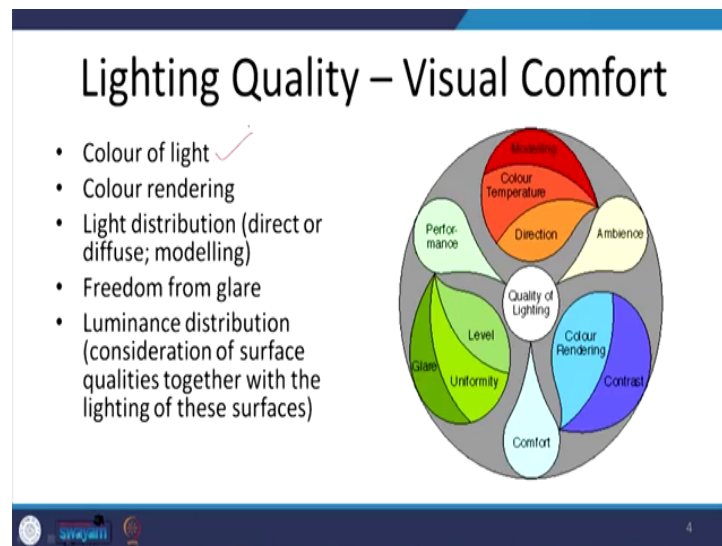
So, where there is a wide spectrum of colors available where it is a white light or combination results in a white light is what a good color or tone of the light is. Wherever there is a different tone or color which is there in the light, it is not usually comfortable when we are talking about long working hours.

So, suppose assume yourself working in a space which has only red colored lights all around you. You will not feel comfortable for long sitting in that space. The last one is its intensity. So, we need intensity sufficient enough to perform a task. Now that varies from activity to activity space to space, depending upon the activity and the space the intensity has to be there.

Together all these 4 parameters define what visual comfort is. Visual comfort is defined as the ability to fully describe light and understand the space as it should be perceived or as it is. So, it is the absence of discomfort because of its source, distribution, the tone and color and its intensity and the absence of this discomfort is called as the visual comfort.

So, when we are talking about visual ~~comfort~~comfort, we are talking about 2 aspects the quality, as well as the quantity. So, of these 4 parameters 2 are used to define the quality of it.

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First is the color of light as I just said, that color of light defines how comfortably things can be seen in the given light. Preferably the light's color should be close to what the color of direct sunlight is which is white. We should comprise of all the colors equally and we should be able to perceive the color of any given object as its original color and that is what the color rendering is. So, here we are looking at the light distribution also which is direct or diffuse.

Now, suppose I have a lamp right on top of my head, so, there is direct light there. While if I have a in case of artificial light I am saying in case, of a bulb where I have a diffuser where I have a reflector which reflects it to the ceiling and then I get to diffused light, where I do not get any shadows, I do not get glare, same for artificial as well as natural lighting. So, what kind of light distribution is there, whether it is the direct or diffuse?

In some easescases, direct light is required. For example, for a doctor who is performing a critical operation in the operation theater, there he may want to have there, we may want to have direct light focused onto the operation area where the doctor is able to clearly see things because he is going to perform a critical operation there.

Unlike when we are working or when we are reading in a classroom, there I might not require direct light falling onto my book, onto my notebook. I would prefer diffused light. Because, I have to sit looking at my book for long hours and there, diffused light would help keep stress of my eyes.

Another thing that we require here is freedom from glare. We will come to glare what glare is in subsequent slides, but glare is that pinching light directly falling onto your eyes. It is not necessarily that direct light, but it is when there is a great difference between what my eyes are used to and suddenly when I go into a bright light or there is a bright light coming from somewhere.


We are also looking at the luminanceous distribution, how the luminance is distributed throughout the work surface. So, these are the qualitative aspects of visual comfort.

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Lighting Quantity – Visual Comfort

- Visual comfort and efficiency can be ensured by the control of luminance distribution within the visual field.

Both too little and too much light can cause visual discomfort. Important changes in light levels or sharp contrast (which is perceived as glare) can cause stress and fatigue as the human eye is permanently adapting to light levels.




We are also looking at the quantitative aspects of these visual comforts. Some of these qualitative aspects can be converted into quantities. SoSo, first of all we are looking at the illumination, how much of the light the intensity is going to be there. So, when we are talking about illumination we are talking in the units of lux and for different types of tasks from casual seeing to exceptionally severe task with minute detail as I was talking about the operation theater the illumination level goes on increasing.

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Recommended Illumination

visual task	illumination lux	glare index
Casual seeing	100	28
Rough task with large detail	200	25–28
Ordinary task, medium detail	400	25
Fairly severe task, small detail (e.g. drawing office, sewing)	600	19–22
Severe, prolonged task, small detail (e.g. fine assembly, hand tailoring)	900	16–22
Very severe, prolonged task, very small detail (e.g. gem cutting, hosiery mending, gauging very small parts)	1300–2000	13–16
Exceptionally severe task, with minute detail (e.g. watch and instrument making)	2000–3000	10

Recommended illumination and limiting glare index (based on IES Code, 1968)

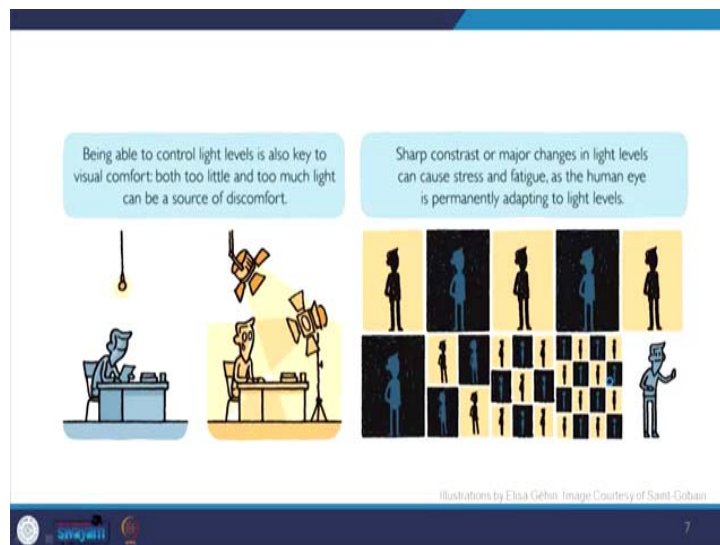


So, if we are casually walking around seeing things a ~~100-lux~~100-lux illumination is sufficient enough and of glare index as high as 28 is also fine because, we are casually seeing around things. However, when we go high on the intensity of the visual tasks for example, we look at the ordinary task or medium detailed task which is where our classrooms and offices come in.

We look at ~~a-an~~ illumination level of around 400 lux, 400 to 500 lux is what we would want in our offices and classrooms and a glare index of around 25. We will come to what glare index is. If we look at where is severe or prolonged tasks which require minute detail for example gem cutting there the lux levels are quite high, but though the lux levels are high we are not promoting a very high, we are not accepting a very high glare index, the glare has to be less.

So, the entire workspace has to be highly lit along with the task table, along with the task work plane. And the maximum it goes up to 2000 to 3000 lux which is in case of operation theaters or instrument making, watch making which is very minute very small parts go in and the glare is further reduced.

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If I look at beyond the quantity quantitative aspects of visual comfort in general, the ability to control the light levels by the occupant is key to this satisfaction. So, suppose I am in an office area where I cannot control the illumination around, today I might ~~to~~ be

feeling a little low and I might require more light to perform a task the same task as compared to some other days where I might want to work with less of the light depending upon my mood, depending upon my comfort that ability that flexibility in the built environment is also a key to satisfaction.

So, it is both for thermal comfort, for visual comfort equally. If I am able to control my thermal environment and, if I am able to control my visual environment, the researchers have proven that the occupant is more likely to feel comfortable be at comfort.


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Glare

- Glare is a subjective human sensation that describes 'light within the field of vision that is brighter than the brightness to which the eyes are adapted' (HarperCollins 2002).

Effects of glare :

- injures the eye
- disturbs the nervous system
- causes annoyance, discomfort & fatigue
- reduces efficiency of work
- interferes with clear vision
- risk of accident increases



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Now, we come to glare. So, glare as defined is a subjective human sensation that describes light within the field of vision that is brighter than the brightness to which the eyes are adapted. Now, this brightness to which the eyes are adapted is the overall brightness of the place, the general illumination level luminance of the place and the light within the field of vision.

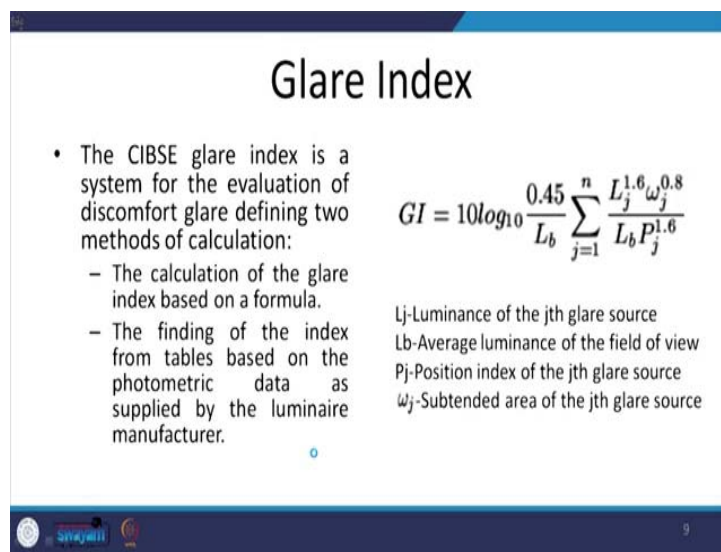
So, suppose I am sitting here if you look at this picture, so, if somebody who is sitting here is usually looking at this wall this is the work side, this is the work desk and this side is where the bright light comes in. So, the difference between the brightness coming from this side versus the brightness which is prevailing in this larger area this room is what is perceived as glare and there are quantified formula to define what glare is, but glare is often harmful.

Because, it injures the eye, it disturbs the nervous system and at times it when we are talking about injuring the eye it almost blinds a person you cannot see. It is a cause of annoyance, discomfort and fatigue. So, if you are constantly, for example, if you are driving during the night and there are vehicles coming from the opposite direction, so, your eyes are used to a much lower level of brightness because it is night and suddenly when the light from the vehicle which is coming from opposite side hits your eyes that is what causes a discomfort because of glare.

Now, constant exposure to this glare causes fatigue; it is mental fatigue, it is fatigue to eyes, it is fatigue to body. So, ~~itsit~~ reduces the efficiency of work and it interferes with a clear vision which is what I say that people are almost blinded when there is glare when there is high glare and thereby increasing the risk of accidents.

So, a lot of accidents happen because of this glare on highways. So, I am giving example of glare from highways, but when we are talk about the ~~buildingsbuildings~~, we experience a lot of glare coming because of surrounding buildings. So, suppose I have a window and there is a reflection coming from the building which is adjacent because of the ~~light-coloredlight-colored~~ finish of that building a lot of reflection of light is coming onto my window and onto my eyes. So, that is how the glare inside a building often comes in.

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Glare Index

- The CIBSE glare index is a system for the evaluation of discomfort glare defining two methods of calculation:
 - The calculation of the glare index based on a formula.
 - The finding of the index from tables based on the photometric data as supplied by the luminaire manufacturer.

$$GI = 10 \log_{10} \frac{0.45}{L_b} \sum_{j=1}^n \frac{L_j^{1.6} \omega_j^{0.8}}{L_b P_j^{1.6}}$$

L_j-Luminance of the jth glare source
L_b-Average luminance of the field of view
P_j-Position index of the jth glare source
ω_j-Subtended area of the jth glare source

o

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So, to define glare the glare index has been defined which is what we just saw when we were defining the illumination level and the glare indices. So, the formula incorporates largely the luminance of the glare source which is under question, the average luminance of the field of view to which the eyes have adjusted, the position index of the glare source how far or how close it is to the object to the area under study subject under study and the subtended area of the glare source.

Put together in a formula it gives us the glare index. With the help of this glare index as we have already seen we can define how much of glare is ok. So, up to 25 is maximum that can be seen that can be accommodated this is as per CIBSE glare index, but there is a new glare rating which is unified glare rating or UGR.

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Unified Glare Rating

- Unified Glare Rating or UGR method** is an international index presented by CIE (International Commission on Illumination) and is used to evaluate and limit the psychological impact of direct glare from luminaries.

$$UGR = 8 \log \left[\frac{0.25}{L_b} \sum \left(\frac{L^2 \omega}{p^2} \right) \right]$$

* Gives UGR numbers which vary up to a range from about 1 to 30






The sum of the ratios of the luminance of the source to the background luminance

The solid angle of the source seen from the observer's position

The glare index gives higher the better the luminance is from the line of sight of the observer

The glare index gives higher the better the luminance is from the line of sight of the observer

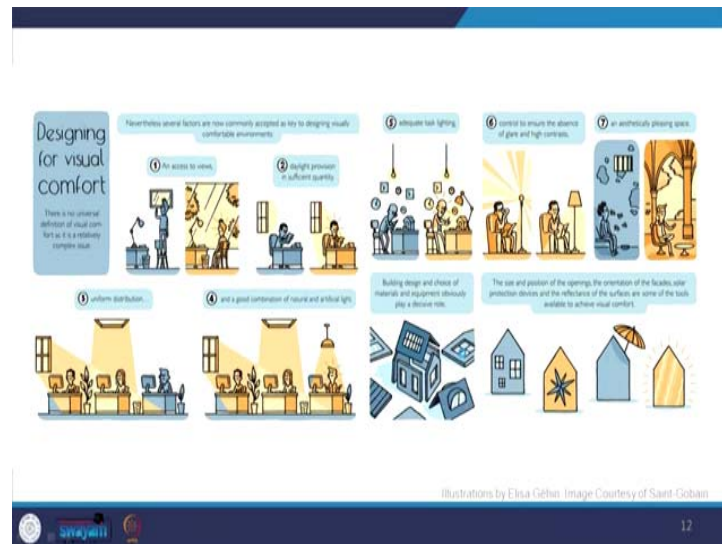
The glare index gives higher the better the luminance is from the line of sight of the observer

COMMON UGR 25	COMMON UGR 22	COMMON UGR 19	UGR 16	UGR 13
				
Not Comfortable	Just feel it	Can live with it	Good	Excellent

And it is defined by this formula again where we are taking into account the background luminance, we are taking into account the luminance of the source and the luminary, and putting together in an formal in a formula to get the UGR as per the UGR we are looking at a limit of UGR 16 which is good enough for the human eyes beyond 16 it is not advisable to have the glare. Now when we have talked about the illumination level the luminance and the glare index always whenever we are talking about visual comfort, we are talking about 2 things.

We have to look at strategies to control glare and to allow for this minimum illumination which is desirable besides these 2 the qualitative parameters where we were talking about the color of light and we are talking about the uniform distribution the tone of the light, the tone color and uniform distribution also comes into a picture and one more thing which is the direct access to views. So, how much can we view.

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So, this is a beautiful illustration which is put up by Elisa Gehin and it is available in public domain at the Saint Gobain website. So, there are 6, 7 strategies or indicators to assess visual comfort. First of [aHall](#), which we of a neglect is an access to views this is very well taken care in green buildings in sustainable building where each workplace should have an access to views.

If every workplace cannot be connected to the outdoors outside the building, punctures or green areas natural areas within the building have to be created in order to provide for these views. The next is provision of sufficient day light every workplace should be day lit as much as possible. Though we may have sufficient light available artificially yet the provision of daylight has a lot of impact now we may not be able to perceive that immediately.

But if human beings are continuously exposed to controlled environments where they cannot see the daylight there are psychological changes which start to happen which are

visible and a lot of medical research has proved that. So, direct provision of daylight in sufficient quantity is required for visual comfort. The next is uniform distribution of that we cannot have some workplaces with limited daylight availability and others with less of that.

If it is a uniform distribution that is what will lead towards the visual comfort then we are looking at a good combination of natural and artificial light for some for the entire year for all the working hours it is very difficult almost impossible to provide for provision of day light to all the workspaces. So, we have to have a good combination of artificial and natural light preferably day lit areas which are which are receiving good amount of diffused light daylight, day lit combined with provision of artificial light in addition to that we should have adequate task lighting.

So, there may be general lighting in a space and then specific task lighting depending upon an individual's need which also fulfills the need of an individual to control his own environment. Maybe I need more light to work and there is someone who prefers low levels of light to work. So, that personalization of a space giving individual controls is what can be fulfilled through provision of adequate task lighting.

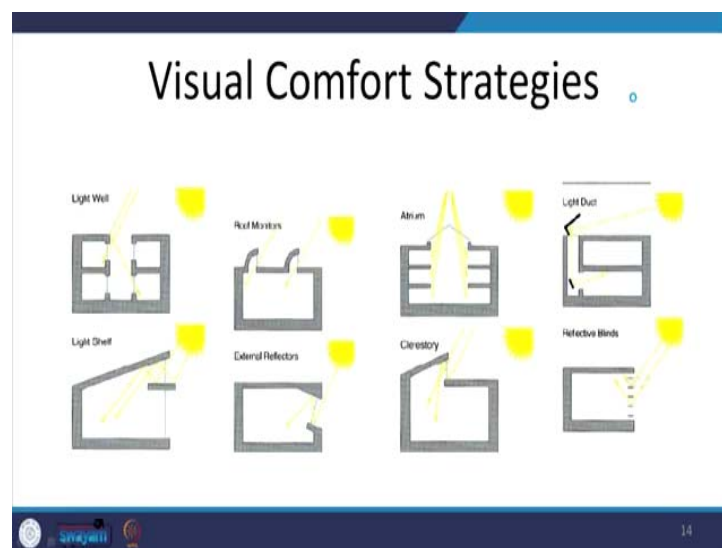
The next is the ability to ensure the absence of glare and high contrast. So, we should use such fixtures such luminaries where we are able to control the glare the next is an aesthetically pleasing space this is a very qualitative aspect, but any space which is if esthetically pleasing, beautifully designed interiors and environments enhance the productivity of people they become they feel more energetic they feel more activated to work. So, these are few parameters which we can keep while designing any space for visual comfort.

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And this is based upon a lot of socio psychological research where it has been established that good visual comfort, good amount of light, but type of light, quality of light, amount and intensity of it. Actually, has a significant effect on how we feel how we experience in a space and in time both consciously and subconsciously. So, we have to provide for good visual comfort now some of the visual comfort strategies which can be employed to bring in visual comfort passively are shown here on this slide.

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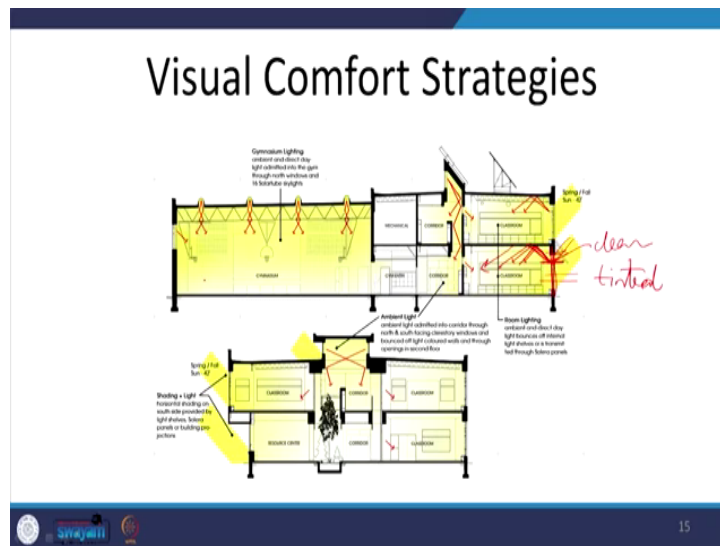


So, we can use light well we can use roof monitors and atriums where a lot of daylight can be brought into the atrium the courtyards actually served such a purpose there are light ducts. So, this is the reflective side of the material where the light is actually reflected it is mirror and if you remember, if you have seen some of the old photos and traditional buildings, mirrors were used to bring in light to the deep corridors to the deep areas inside the buildings.

Light shelves we have discussed again this top surface of the light shelf is a reflective surface and it reflects and this light which has received indoors is actually a diffused light similar to light shelf we have a shelf here. So, it is slightly different from this light shelf, but serves the same purpose of reflecting the light and then diffusing it.

We have clear story again reflective surface here direct as well as diffused penetrates inside and we have reflective blinds here which are serving similar purpose as the light shelves smaller light shelves as we can see here. Another very interesting strategy which is utilized in case none of these is working is to divide the window in such a manner.

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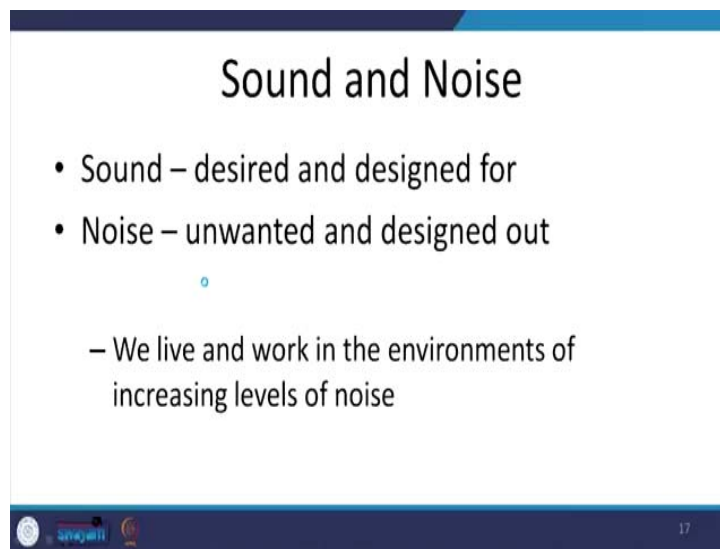


That a large window where we have a large window we can divide it the portion above the visual part of the window is where the clear glass is used and that part is used to reflect the light to bring in light and penetrated deeper while this part of the window we will use a tinted glass now this will help in cutting down the glare. So, there will be no

direct light falling onto the eyes of the occupants and there is; however, there is sufficient light which is brought in through the clear glass which is above.

So, the window very clearly can be divided into 2 parts and just by choice of the color of glass interesting combinations and overall a uniform distribution of light can be achieved. So, this particular case study shows how different day lighting strategies have been used to day lit almost the entire school. So, this is the case study of a school where different strategies have been used to bring in diffused daylight into the habitable rooms.

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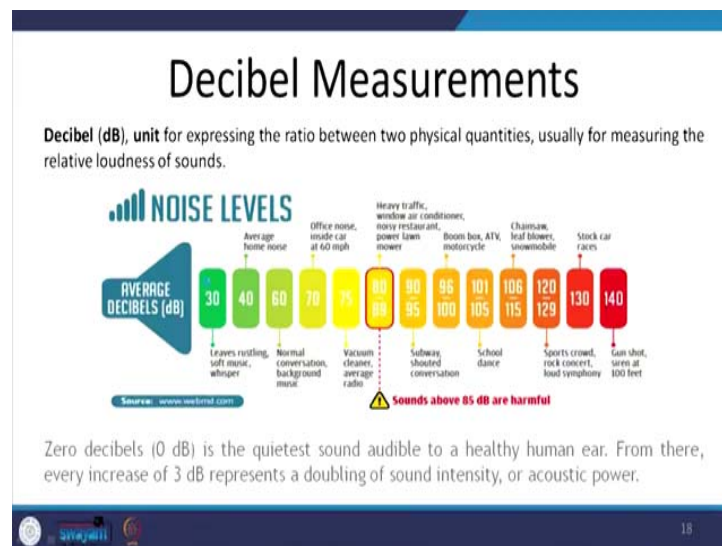
NextNext, we have acoustic comfort. Now when we are talking about acoustic comfortcomfort, we must very clearly understand the difference between sound and noise. So, sound is what we have desired and we have designed for while noise is something which is unwanted and we have to design out. For example, I often take this example of a classroom. So, when as a teacher I am in the classroom what I am saying the lecture that I am delivering and what my students are able to hear is what the sound is.

I should be hear able to hear what my students have to say they have to ask and the students should be able to hear me what I am delivering. While noise is something which is what we do not desire in this space for example, somebody walking in the corridor

outside my classroom, a vehicle going by the side of the classroom on the road. So, all these noises are unwanted.

So, we want to hear each other clearly while in a classroom, but we do not, do not want any of the noises coming from outdoors to inside of this room that is nice for me. Now how do we know how much of the sound is available or should be allowed? How much of the noise should be cut?

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So, first of all we have to measure I am sure you have already read the course on acoustics where you know how we measure. So, we measure using decibels. So, Decibel is the unit for expressing the ratio between the 2 physical quantities for measuring the relative loudness of sounds. If you look at the average decibels which are required in an office and in a classroom around 60 decibels is what we would normally require that is, that is what should be maintained extremely low decibels spaces which are too quiet are also not comfortable we might be comfortable in those spaces for a very short while.

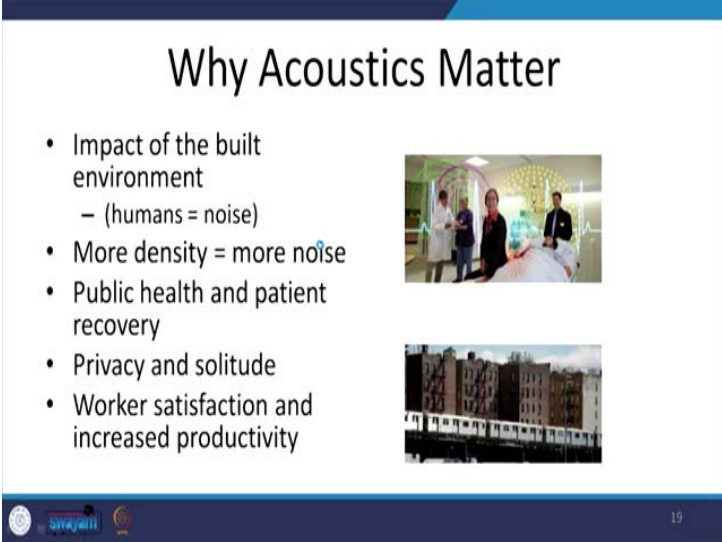
So, there was an experiment which was conducted and one of the universities in a United States where they were able to bring down the decibels in a space down to 0. So, an absolutely quiet space and at 0 decibels the human beings we can hear our own blood flowing through our body and it is quite disturbing. So, we need a little sound around us

which is around 30 decibels is good. 30 decibels is where you have the leaves rustling, you have the sounds of the nature, little bit of whisper and it is quite comfortable.

If we look at 40 decibels this is what we require for sleeping. So, around 30 to 40 decibel we can comfortably sleep. 60 is what we would look at what we want in the classrooms slightly higher than that is what we would look at of we would be comfortable when we are in an office space where people are moving, people are talking.

There are little discussions going on. When we have a-somesome average radio being played little bit of music, vacuum cleaner and all that is around 75 decibels. Now 80, 85 is the limit beyond this it is harmful for the ears. So, any sound above 80, 85 decibels is noise, -beneath this also depending upon the space it is it may be qualifying as noise above this it is definitely harmful and noise.

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Why Acoustics Matter

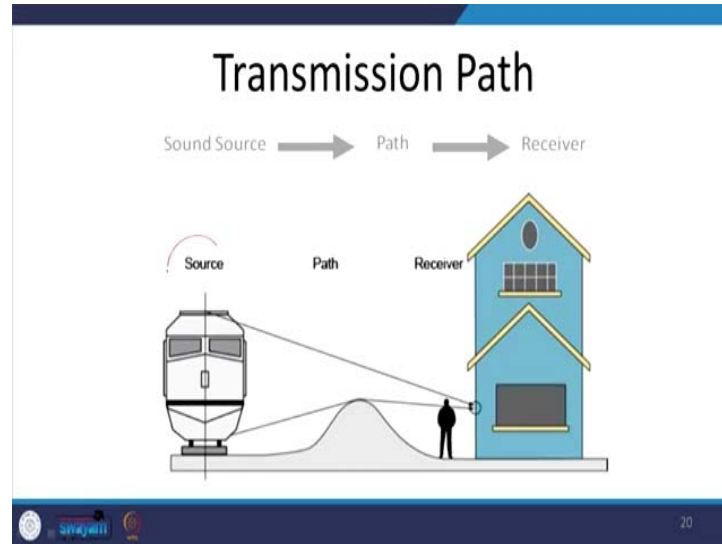
- Impact of the built environment
 - (humans = noise)
- More density = more noise
- Public health and patient recovery
- Privacy and solitude
- Worker satisfaction and increased productivity

The slide features two images: the top one shows a person in a hospital room, and the bottom one shows a multi-story urban building.

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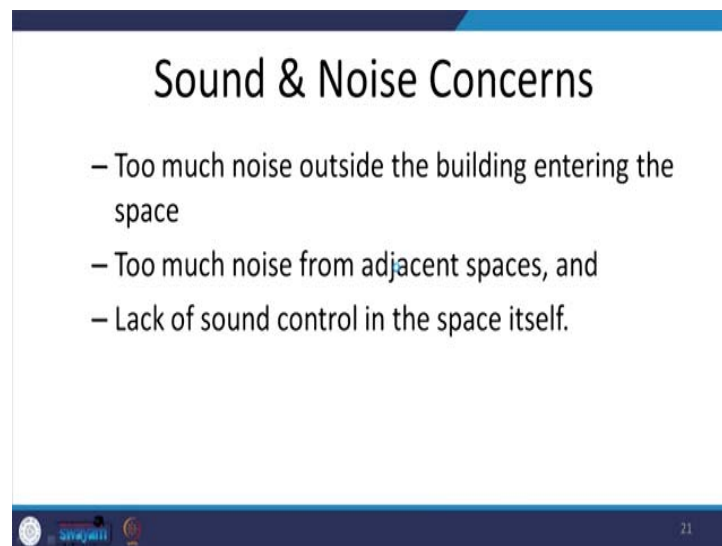
So, depending upon the quietness that you require or the amount of sound that you require the space has to be designed it will impact the health of the occupants the amount of sound which is present amount of noise which is present it depends upon waiting levels of privacy. So, in areas which are more private suppose I want to have a private discussion in a conference room even when I am in an office such areas would require more acoustic treatment.

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For example, the theaters they require more sound acoustic treatment to provide for the sound quality. So, when we are looking at the design of buildings for acoustic ~~comfort~~ comfort, we should look at the transmission path we should identify the source, we should identify the receiver and we should look at how what the path of this sound travel is from source to the receiver.

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Based upon this we have to identify the strategies we have to look at these strategies for designing these buildings. The impact of this environmental noise can be direct as well

as indirect on human health and wellbeing people ~~expe~~experienced~~diency~~ sleep disturbances, speech interferences and annoyance.

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Environmental Noise Impacts

- Sleep disturbance
- Speech interference
- Occupant annoyance
- Reduced worker productivity
- Prolonged patient recovery




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Because of the environmental noise there is a reduced productivity and there is a prolonged patient recovery that is why in all the hospitals where patients are, people are there with illnesses, sicknesses. The hospitals are supposed to be maintained quiet. Since it reduces the retention, concentration of occupants those classrooms and work areas like offices are also required to be maintained at low decibel levels.

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Architectural Acoustic Concerns

- Environmental Noise
- Mechanical/Equipment Noise
- Structural Vibration
- Speech Privacy
- Room Acoustics
- Sound Isolation



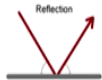
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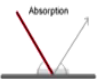
When we are talking about buildings, we are talking about many concerns, we are looking at environmental noise; we are looking at mechanical and equipment noise which is often a very high noises a major concern. We have HVAC systems, we have air conditioners, on our windows and inside our rooms we have water coolers, we have fans, we have different equipment which is there.

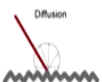
So, a lot of noise is because of these mechanical or other equipments we also have structural vibrations which are passing from the; which are passing through the structure of the building into the space. We have concerns for speech privacy as I would just mentioning for conference rooms, meeting rooms we have requirements for room acoustics and sound isolation is what we require we need to isolate the source where the sound is coming from the noise is coming from.

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Absorption Coefficient

Reflection

Reflection
 Sound is bounced off a surface. This usually occurs on flat, rigid surfaces like concrete or brick walls. The sound bouncing back off the surface creates an echo.

Absorption

Absorption
 When a sound wave hits the surface, the kinetic energy is converted into a small amount of heat energy which dissipates causing it to decay faster. Soft material like Ekigs, foam and rubber are absorbent. How well a material absorbs sound depends on a number of different factors, including material density.

Diffusion

Diffusion
 When a sound wave hits an irregular surface the vibration breaks up and travels along many much smaller paths. This divides the energy of the wave, sending it in many different directions which depletes its energy faster.

Absorption Co-efficient

$$a = \frac{\text{Energy of Sound absorbed by the surface}}{\text{Total sound energy incident on the surface}}$$

- Effective absorbing area (A) = a.S
 (S = Total Area of Reflecting Surface)
- For Multiple Reflecting Surfaces

$$A = a_1 S_1 + a_2 S_2 + a_3 S_3 + \dots$$

For doing that we have to understand very quickly some of the phenomena some of the quantities parameters that we use one most important is absorption coefficient. Now what is the absorption coefficient very simply if I put it is the proportion percentage of the not percentage. It is the proportion of the sound which is absorbed by a surface versus its total incident sound energy which is incident on the surface. So, the more amount of sound which is absorbed by it out of the incident sound is what its absorption coefficient is higher is that amount, higher is the absorption coefficient.


Maximum it can be 1 because 100 percent of the sound is absorbed and least would be 0 where all the sound is transmitted. For example, an open window so, an open window ~~have~~, will have all the sound transmitted through it. So, that is where the comparison would be just as we have light, we have the phenomena for sound. So, the sound is reflected from the surface the harder the surface is the more is the sound which is reflected then we have absorption by the surface. So, the more porous the material is the more is the amount of sound it absorbs.

So, a material such as wool ~~voile~~ or fabric because it is porous absorbs more amount of sound and then there is diffused. So, based upon the shape of the; shape of the material the amount the sound when it is incident on this it is diffused. So, it is broken into sound of reduced intensity, but it is there it is still there it is reflected that is what diffusion is the next concept that we have to keep into mind is reverberation.

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Reverberation:

- This prolongation of the sound in the room caused by continued multiple reflections is called reverberation.
- When room surfaces are highly reflective, sound continues to reflect or reverberate.
- A high reverberation time will cause a build-up of the noise level in a space.



The diagram shows a simple room outline with a person standing in the center. Arrows point from the person towards the walls, ceiling, and floor, and then reflect back towards the person, illustrating the concept of sound reverberation.

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So, reverberation is prolongation of the sound in the room caused by continued multiple reflections which is what we would see in case of different shapes. So, it gets reflected from one surface goes onto the other surface and then further reflected and comes back. So, it will happen only when we have hard surfaces and there are multiple reflective surfaces present in any room.

That is what will also cause the echo now based on reverberation and the formula we can calculate the reverberation time.

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Reverberation Time

A reverberation time that is optimum for a music program could be disastrous to the intelligibility of the spoken word. Conversely, a reverberation time that is excellent for speech can cause music to sound dry and flat.

Highly reflective surfaces lengthen the reverberation time.

Absorbing surfaces shorten the reverberation time.

8.5 s Notre Dame. Dramatic for the big pipe organ, but don't make a speech.

5.5 s "Muddy", severe loss of articulation, can't understand speech.

3.5 s Fuller, richer musical sound. The organist would like it. Some loss of articulation, more difficulty understanding speech.

1.5 to 2.5 seconds For a general purpose auditorium for both speech and music:

1 s Clearer articulation of speech. Desirable for lecture halls, speech only.

0.5 s "Dead" sound, difficulty hearing in back, loss of bass in back.

0 s No reverberation gives pure inverse square law behavior.

$$RT_{60} = (0.16 \text{ s/m}) \frac{V}{S_e} = (0.049 \text{ s/ft}) \frac{V}{S_e}$$

for dimensions in meters for dimensions in feet

The **reverberation time** of a room or space is defined as the **time** it takes for sound to decay by 60dB.

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Now this reverberation time decides for how long the sound is going to be present in that space for any ~~general purpose~~ general-purpose auditorium which is both for speech and music now there are different reverberation times which are proposed good for music and separately for speech. So, for any music to be enjoyed for a theater where musical performances are going to be a reverberation time of around 2.5, 3.5 is good. So, when we have a reverberation or time of 3.5.

Because, there are different types, different intensities, different notes, different musical waves which are hitting our ears that is where the musical sound will sound fuller, richer, if we have less reverberation time less than 1 it will it will be perceived as a very dead space it will be perceived as a very dead sound while it may be good for speech. So, around 1.5 seconds of reverberation is good for speech it is a little bit of hard surfaces should also be there that is when it sounds good.

Now that is this reverberation time is calculated on the basis of the total surface area equivalent and surface area which takes into account the absorptivity, the absorption coefficient of the surface and the surface area. All the different surfaces and


~~there~~their absorption coefficients put together and also the volume of the space so together these 2 result in a reverberation time.

So, whenever we are designing for auditoriums, theaters reverberation time becomes very important, but often we forget about it when we are designing classrooms when we ~~are~~we designing offices, but we should take into account take care of the kind of surfaces which are being used. Here we are also talking about reflections.

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Reflections

- Reflected sound strikes a surface or several surfaces before reaching the receiver.
- These reflections can have unwanted or even disastrous consequences.
- Domes and concave surfaces cause reflections to be focused rather than dispersed which can cause annoying sound reflections.
- Absorptive surface treatments can help to eliminate both reverberation and reflection problems.



The diagram shows a person standing in a room with a gabled roof. Lines represent sound waves reflecting off the walls and ceiling, illustrating the concept of sound reflections. A red checkmark is visible above the diagram.

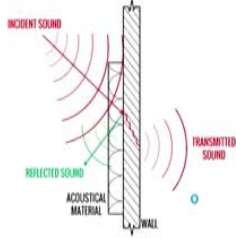
27

Now, reflection results in reverberation. So, how the sound is going to be reflected? So, it depends upon the material as well as design. So, how the sound is going to be reflected? How many times will it be reflected will result in reverberations. So, for any good classroom or office a reverberation time of around 1.5 is a good reverberation time and we should choose materials effectively.

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Noise Reduction Coefficient (NRC)

- The Noise Reduction Coefficient (NRC) is a single-number index for rating how absorptive a particular material is.
- It is simply the average of the mid-frequency sound absorption coefficients (250, 500, 1000 and 2000 Hertz rounded to the nearest 5%).
- The NRC gives no information as to how absorptive a material is in the low and high frequencies, nor does it have anything to do with the material's barrier effect (STC).




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Here we are also talking about noise reduction coefficient this is an, this is a measure of the material individual material where we know how much of the sound can be absorbed by the material. So, on higher number of noise reduction coefficient implies that larger is the amount which can be absorbed or diffused by the material. Lower is that number, lower is the amount of sound which can be reduced the reduction of the sound. So, of the incident sound which is their how much is transmitted to the other side ~~other side~~ is the measure of NRC noise reduction coefficient.

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Sound Transmission Class (STC)

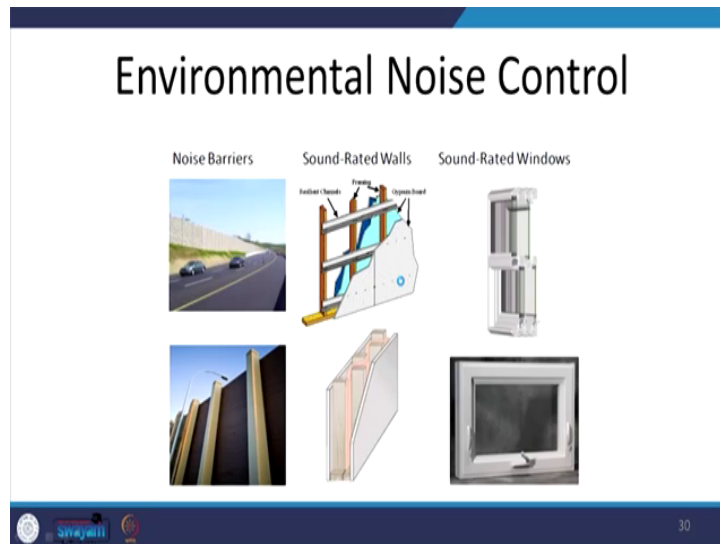
- The Sound Transmission Class (STC) is a single-number rating of a material's or assembly's barrier effect.
- Higher STC values are more efficient for reducing sound transmission.
- For example, loud speech can be understood fairly well through an STC 30 wall but should not be audible through an STC 60 wall.



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Lower is that number the better is this material for sound insulation the same is further taken to understand or classify the materials in different classes. So, there are, there are sound transmission class STC. So, higher this STC values are the more efficient is the material for reducing sound transmission. So, it is an inverse of NRC in a way.

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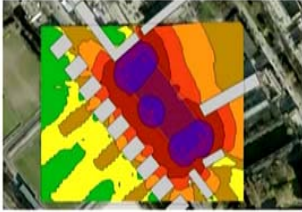
Once we understand what these materials are and what our requirements from design isis, we can look at the different strategies for sound barriers we can use the sound rated walls which are STC and we can look at these windows which are also sound rated windows.

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Acoustic Measures

Site Selection:

- Understanding Outdoor activities
- Avoid sites in high noise areas
- Ensure compatibility with existing facilities
 - Eg: do not site a school in an industrial area.
- Determine the future use of surroundings.
 - if future buildings are acoustically incompatible with yours, significant remediation measures may be necessary to return the interior sound environment to an acceptable level.



Source: www.wbdg.org & www.pbsionthenet.net

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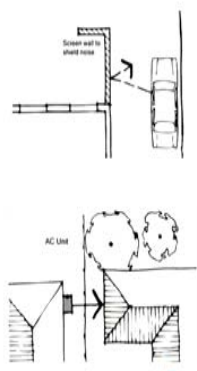
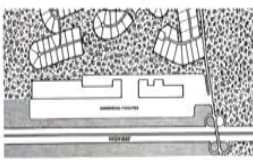
There are design measures which we can use for example, the selection of site. So, understanding from where the sound comes to a site organizing activities in such a manner that noisy activities which can be performed with high noise amount placed in the high noise areas and the quieter activities are placed in the quieter areas.

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Acoustic Measures

Site Planning:

- Setting up Distance
- Non-residential elements as buffers
- Buildings acting as shields
- Building orientation away from noise



Source: www.wbdg.org

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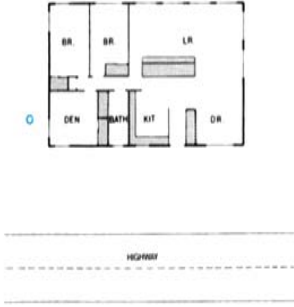
We can look at the distance of the site we can look at different elements non residential elements for example, commercial facilities. So, this is a highway going and this is the residential area. So, between the highway and the residential area a huge commercial

facility has been developed where it acts as a barrier of sound to the residential area. So, this is building acting as shields and also orienting the building away from the noise. So, we can orient the building in such a manner that the noise is cut away.

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Acoustic Measures

- Room arrangement
 - lay out the building so that restrooms, mechanical and electrical equipment rooms, and other less noise-sensitive spaces are adjacent to the roadway.



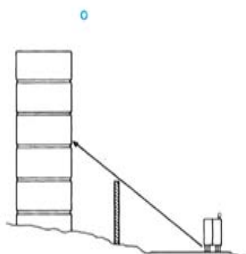
33

We can also look at the internal arrangements now bedrooms are the quieter areas where people sleep during night. So, they can be kept away from the noise creating side the source of the noise. So, more active areas for example, the drawing rooms, and kitchens and bath areas they can be used as a buffer as an acoustic buffer and the bedrooms can be at towards the quieter side.

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Acoustic Measures

- **Use of Solid Walls**
- The use of solid walls means, to use a wall with fewer openings.
- Having an opening in walls will reduce its efficiency in noise control. The openings in the forms of windows or doors that are facing directly towards the noise, would welcome noise into the building.







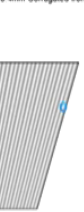
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There are multiple other measures for example, using walls, solid walls as acoustic measures. So, this is a highway going and this actually acts as an acoustic measure besides trees can also act as acoustic measure.

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Acoustic Measures

When constructing an acoustic wall to eliminate highway noise, the height, width and location of the noise barrier wall, dictates the size and shape of your noise shadow.

1.0m Gabion	200mm Solid Block	75mm Brick	20mm Timber	0.4mm Corrugated Iron
				
60db	50db	40db	25db	17db

Noise from heavy trucks is around 85db. The denser the wall the more noise it stops, a 100% solid timber fence will only stop 25db of noise, the remaining sounds passes through. The gabion noise barrier wall stops the most direct road noise.

Source: <https://i.pinimg.com>

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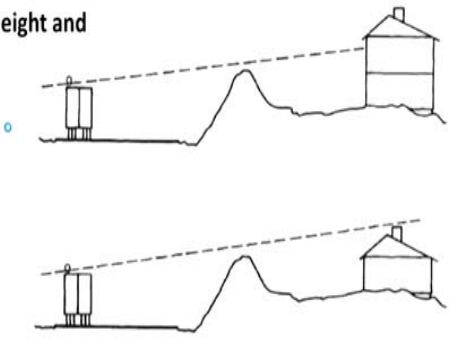
If you are looking at ~~materials~~ materials, we should understand the difference between each material and the amount of sound reduction, insulation that each of these materials provide. So, the walls the regular walls provide around 40 Decibel of a sound insulation

difference from the source to the sink side. If you want around 60 Decibel around 1 meter of Gabion is a useful strategy or useful material.

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Acoustic Measures

- **Building Height and Massing**



The diagram consists of two line drawings. The top drawing shows a building on a hill. A dashed line starts from a source on the left, goes up to the roof of the building, and then reflects back down towards the source. The bottom drawing shows a building on a lower slope. A dashed line starts from a source on the left, goes up to the roof of the building, and then reflects away from the source towards the right.

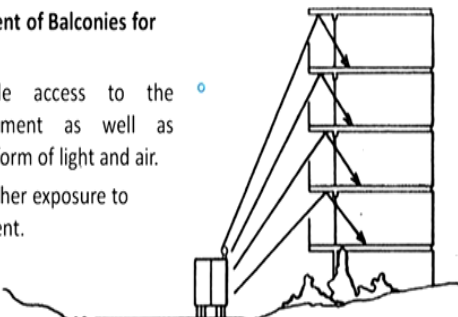
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But it is a very thick wall and we should also see that it is porous and that is what causes a lot of sound reduction to happen through this wall. There are other design measures for example, adjusting the building height depending upon the topography and the site features which are available.

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Acoustic Measures

- **Proper Arrangement of Balconies for Noise Control**
- Balconies provide access to the external environment as well as ventilation in the form of light and air.
- Balconies have higher exposure to outside environment.



The diagram shows a cross-section of a multi-story building with balconies on each floor. Arrows point from the balconies outwards, indicating sound waves reflecting away from the building. The building is situated on a slight slope.

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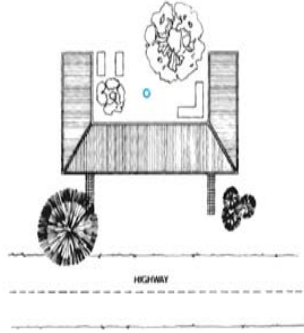
For exampleexample, designing the balconies such a way that is known direct noises hitting into the space it is coming into the space.

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Acoustic Measures

Having Courtyards for Noise Control

- Having courtyards helps in reduction noise control in buildings.
- They provide an acoustical privacy through shielding effect .



The diagram shows a cross-section of a building with a central courtyard. To the right of the building, a highway is indicated by a dashed line. The building's design includes balconies and a courtyard that is oriented away from the highway. A tree is shown in the courtyard, and a small figure is visible on a balcony. The highway is labeled 'HIGHWAY'.

Having courtyards for noise control, so, for example, in this building the courtyard is facing away from the highway and this side would be a blocked side. So, the sound because its travels straight. So, there will be less of sound which will be available in this courtyard.

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ABC of Acoustics

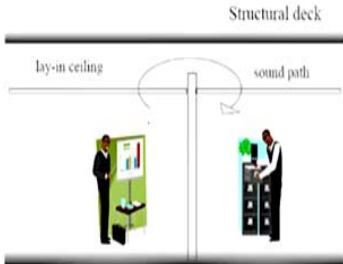
Absorb Capture reflected sound	A	Block Stop sound travelling	B	Cover Mask unwanted sound	C
The use of products to absorb the sound energy that hits them and reduce unwanted, reflected sound energy from hard surfaces such as glass and concrete.		The introduction of vertical barriers between the noise source and listener that blocks sound travelling from one to the other. The higher the barrier, the more effective the result.		Computer generated random sound that covers or masks unwanted noise and makes conversation and noise more difficult to hear and comprehend.	

To conclude it all we can say there are 3 fundamental ways in which acoustics of a place of a space can be designed that is ABC absorb, block and cover. So, first is to capture the reflected sound by using appropriate material absorptive material. Second is to block the sound from traveling by introducing the vertical barriers the barriers to this sound which can be possibly disturbing and. The third is to cover the unwanted sound to mask that sound by providing certain covers.

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Office

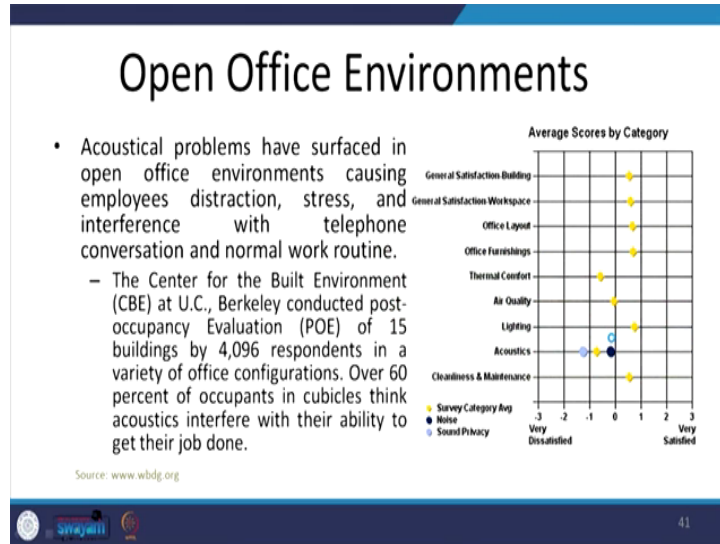
- Common problems
 - inability to have private discussions
 - can hear sounds through partitions
 - too noisy in room
 - can hear sounds from air return registers



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So, which is what we see in our buildings happening very quickly going over the kind of problems that we have we often see in our offices and our classrooms is we have a lot of noise traveling through the ceiling, through the ducted area there is inability to have private discussions and ~~we can~~ the partitions are so thin that we can hear through the partitions and there is no privacy and it also becomes noisy. So, if there is a n lot of noise happening in this area the area which is supposed to be quiet also receives a lot of noise.

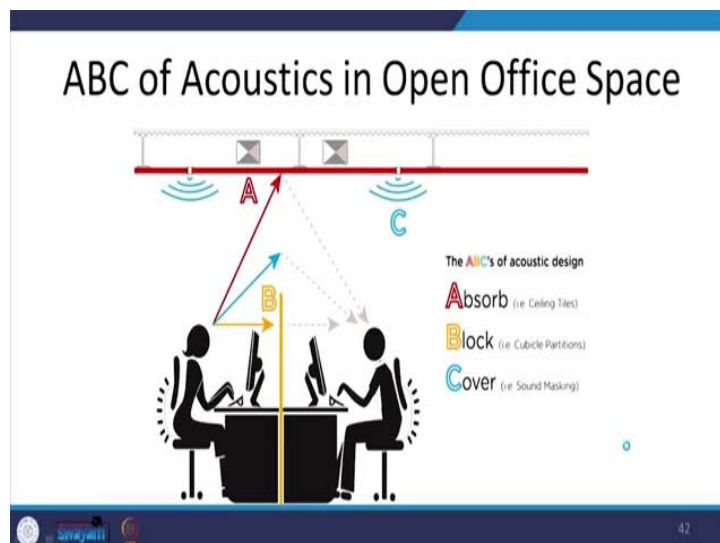
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So, these are some common problems which are there in the office environments and there was a research conducted by center for built environment at UC Berkeley and there people felt dissatisfied, uncomfortable only because the acoustics was not good for everything else they were quite comfortable satisfied, but because of acoustics because this was. So, noisy in an open plan office.

So, this research was largely on open plan office environments and people felt dissatisfied simply because the acoustics was not comfortable.

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So, when we are looking at strategies in an open office space we are again looking at the ABC we are looking at the ceiling material which is reflect, which is absorptive we are looking at the partitions which block, we are looking at the masking of the sound through provisions of absorptive material here.


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Office

- Solutions
 - Extend walls from floor to structural deck above.
 - Insulate partition cavity/increase partition sound transmission class (STC).
 - Specify NRC of 0.75 for ceiling tiles.
 - Employ ducted air return system.
 - Do not locate mechanical equipment rooms next to offices and conference rooms.



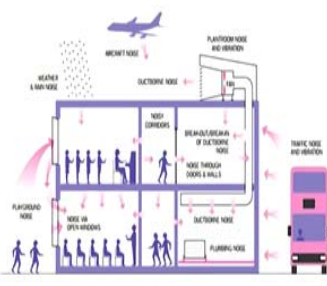
High definition acoustic camera shows noise reflecting off a low NRC 0.60 acoustic ceiling (yellow) and being absorbed by a high NRC 0.95 stone wool acoustic ceiling (blue).



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Classrooms

- Typical Problems
 - outside of the school (vehicular traffic and aircraft flyover)
 - the hallways (foot traffic and conversation)
 - other classrooms (amplified sound systems and inadequate partition sound transmission loss)
 - mechanical equipment (compressors, boilers, and ventilation systems), and
 - inside the classroom itself (reverberation).




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Similarly, we have problems for classrooms where there is outside sound maybe the noise of traffic or the noise of children playing in the playground, inside the room. So, one room might be noisy room while the other one might be a quieter room. So, how the

sound is transferred from one to the other noisy corridors? So, that is ~~the~~ of the usual acoustic problem inside a classroom.

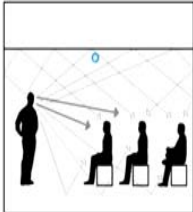
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Classrooms

- To reduce noise from adjoining classrooms, do not have doors adjacent to each other or have doors directly across from each other. Rather, offset the door locations to extend the sound travel path from one classroom to the next. This strategy works well with conference rooms and private offices as well.

LEED v4

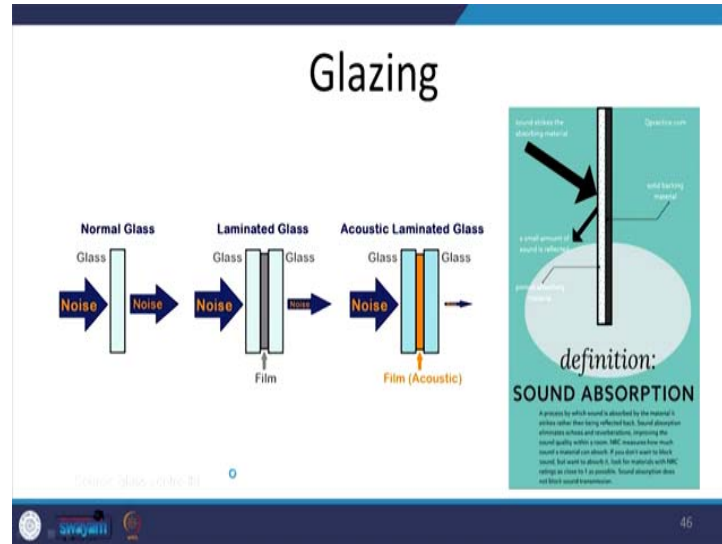
- HVAC Noise - 40 dBA (prereq), 35 dBA (credit)
- Reverb Time:
 - Option 1 – NRC of 0.70 for acoustical finishes
 - Option 2 – Calculate to meet ANSI S12.60
- Sound Transmission (Credit)
 - Interior Partitions
 - Exterior Windows



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And what we have to look at when we are looking at classroom is again the ABC we have to use the absorptive materials and if you look at the lead criteria, lead prescriptions it also prescribes the amount of HVAC noise which is the reverberation time for classrooms and also the sound transmission class of the material that should be used for interior partitions an exterior windows to ensure that all these different types of noises and sounds are not there inside the classrooms.

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Glazing, in today's times has ~~leapfrogged lead~~ (Refer Time: 46:05) there are different types of glazings which are available. So, we have acoustic laminated glass which is available where there is an acoustic film which is added and the 2 glass sheets, pins help to reduce the amount of sound which is transferred from one side to the other. So, with the choice of correct material with the correct selection of design strategy and special design of a building visual and acoustic comfort of a building a sustainable building is possible that is all for today's lecture. See you in the lecture next week.

Thank you.