Engineering Physics 1

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Module-02
Lecture-05
Acoustics of Buildings - Part II

Okay. This is the first lecture of this 5 lecture series on Acoustics.

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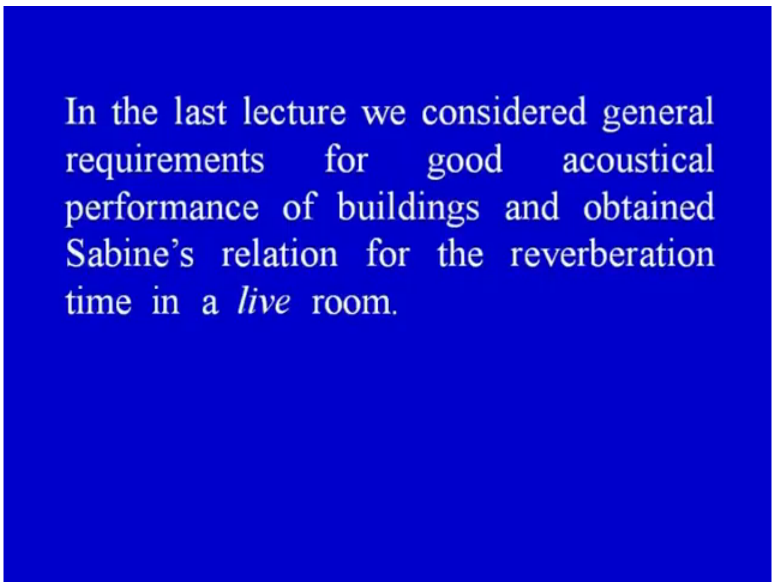

In the last lecture, we considered general requirements for a good acoustical performance of buildings and obtained a Sabine's relation for the reverberation time in a live room.

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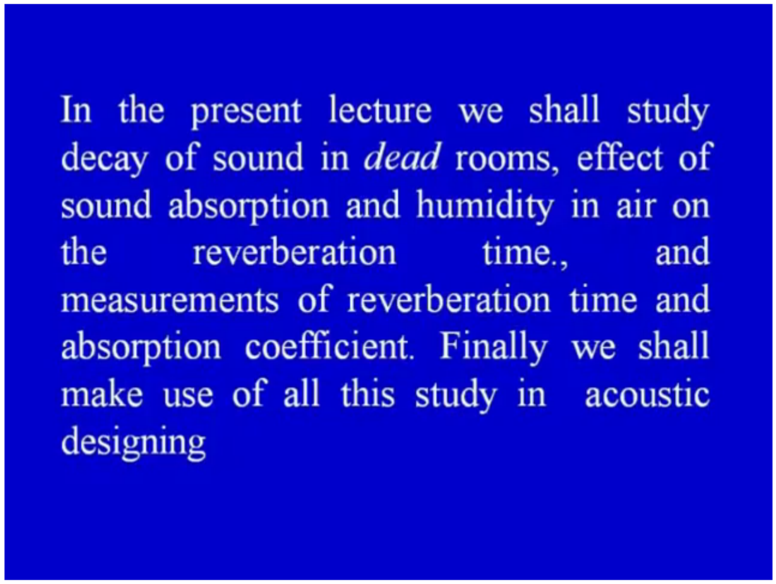

Now, in the present lecture we shall study decay of sound in dead rooms, effect of sound absorption and humidity in air on the reverberation time and measurements of reverberation time and absorption coefficient. Finally, we shall make use of all this study in acoustic designing.

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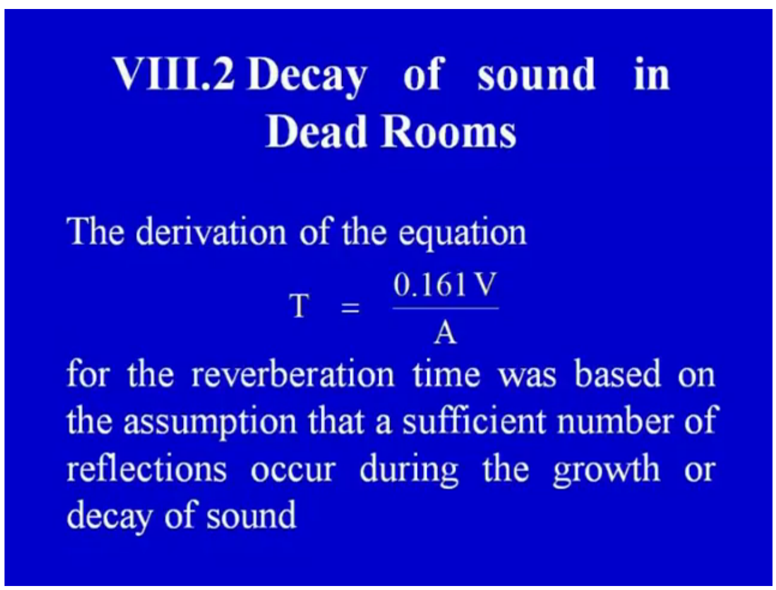

Now, the derivation of the equation t = 0.161 V by A for the reverberation time was based on the assumption that a sufficient number of reflections occur during the growth or decay of sound.

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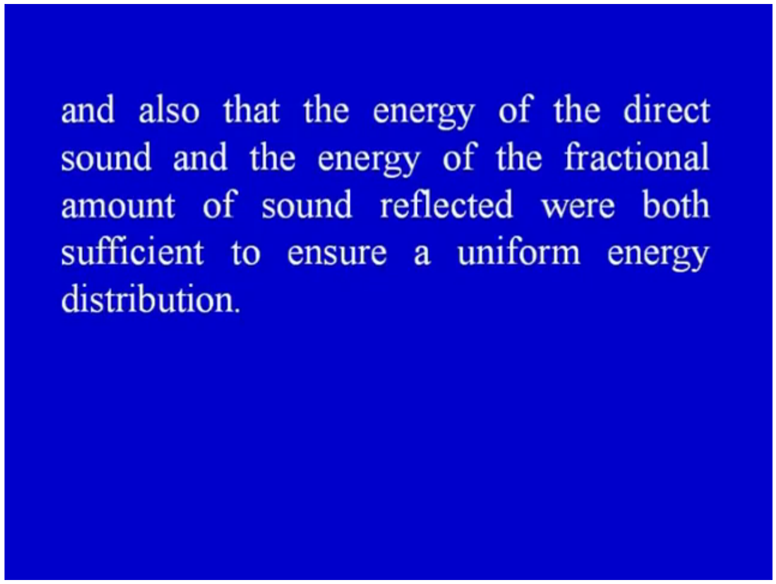

And also that the energy of the direct sound and the energy of the fractional amount of sound reflected were both sufficient to ensure a uniform energy distribution;

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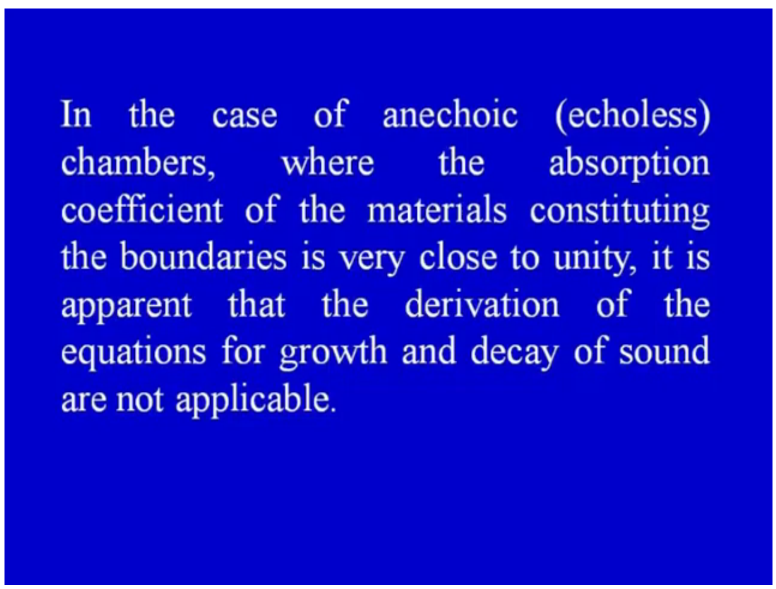

In the case of anechoic that is echoless chambers, where the absorption coefficient of the materials constituting the boundaries is very close to unity very good absorbers it is apparent that the derivation of the equation for growth and decay of sound. They are not applicable.

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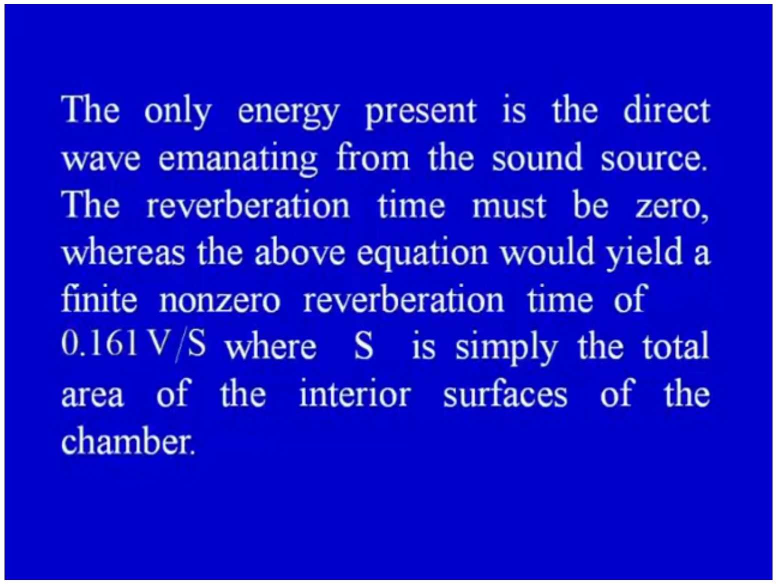

The only energy present is the direct wave emanating from the sound source. The reverberation time must be 0 whereas the above equation would yield a finite nonzero reverberation time of 0.161 V by S where S is simply the total area of the interior surfaces of the chamber.

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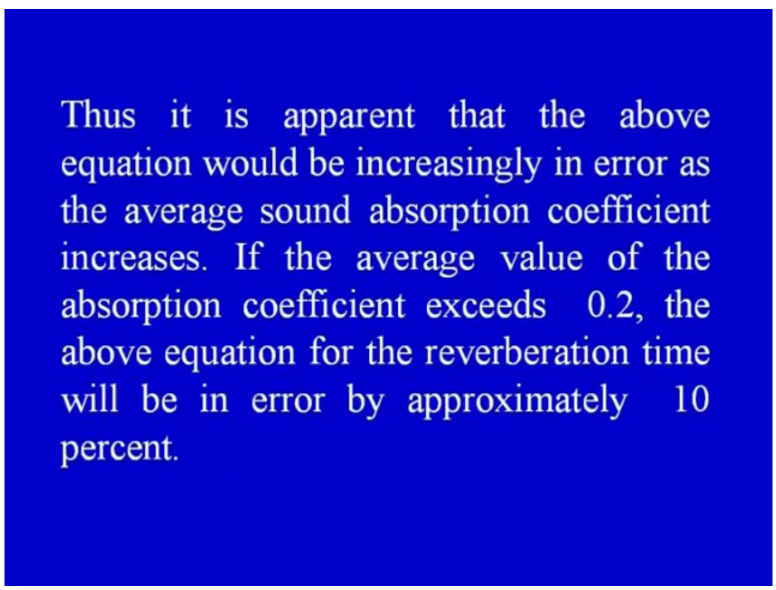

Thus it is apparent that the above equation would be increasingly in error as the average sound absorption coefficient increases if the average value of the absorption coefficient exceeds say 0.2 the above equation for the reverberation time will be an error by approximately 10 per cent.

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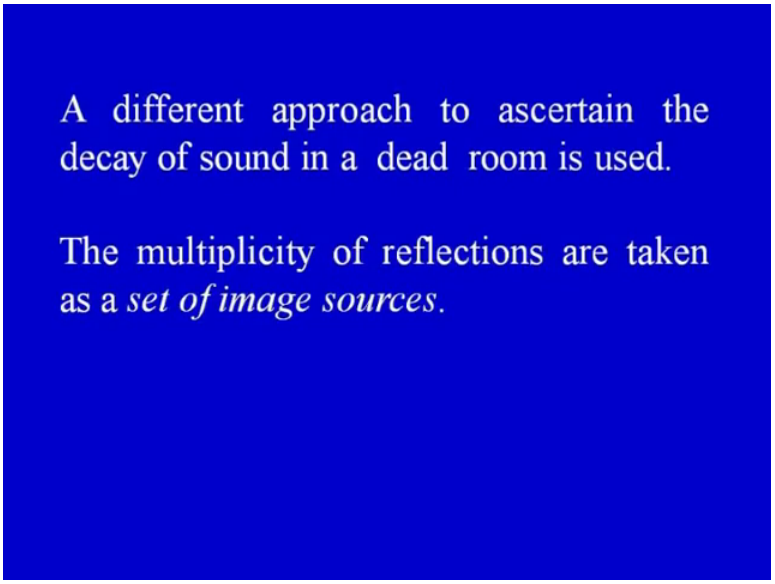

A different approach to ascertain the decay of sound in a dead room is used. The multiplicities of reflections are taken as a set of image sources.

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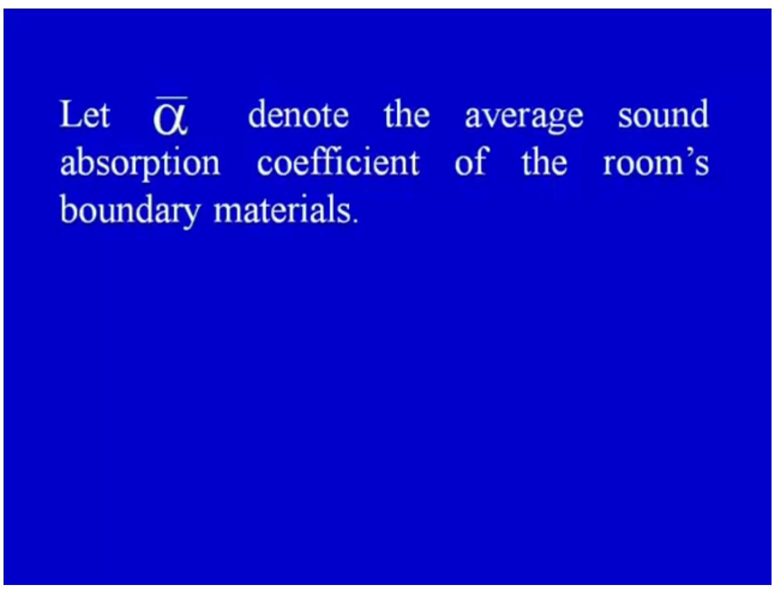

Le the alpha bar denotes the every sound absorption coefficient of the room's boundary materials.

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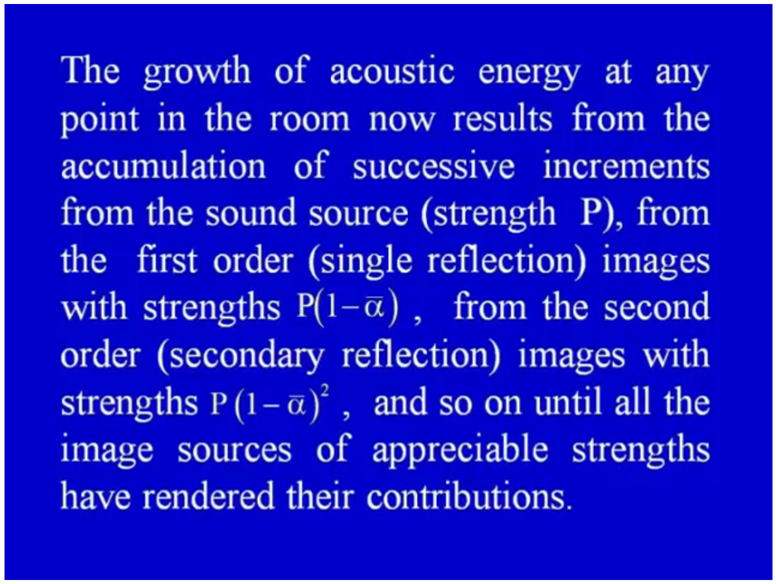

The growth of acoustic energy at any point in the room now results from the accumulation of successive increments from the sound source, say of strength P, from the first order that a single reflection images with the strength P into 1 - alpha bar, from the second order. That is secondary reflection images the distance P into the square of 1 - alpha bar and so on until all the mid sources of appreciable listings have rendered their contributions.

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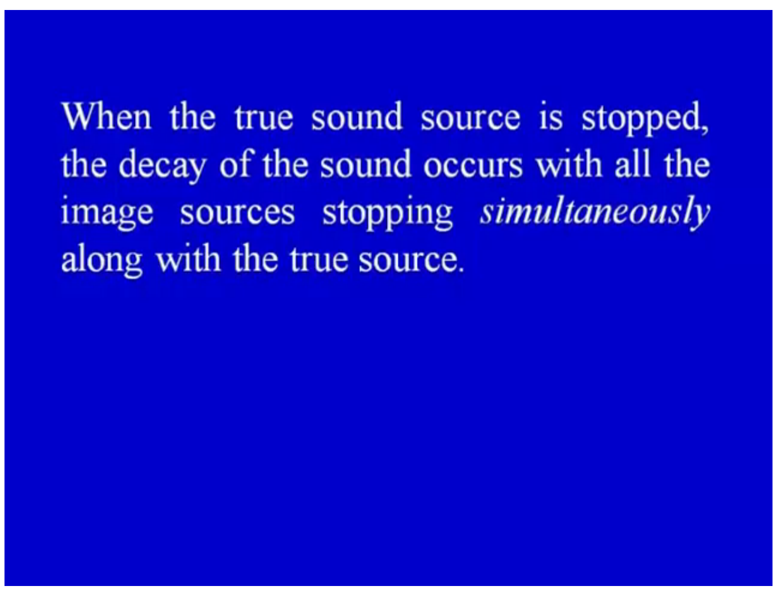

When the two sound sources stopped, the decay of the sound occurs, with all the image sources stopping simultaneously along with the true source.

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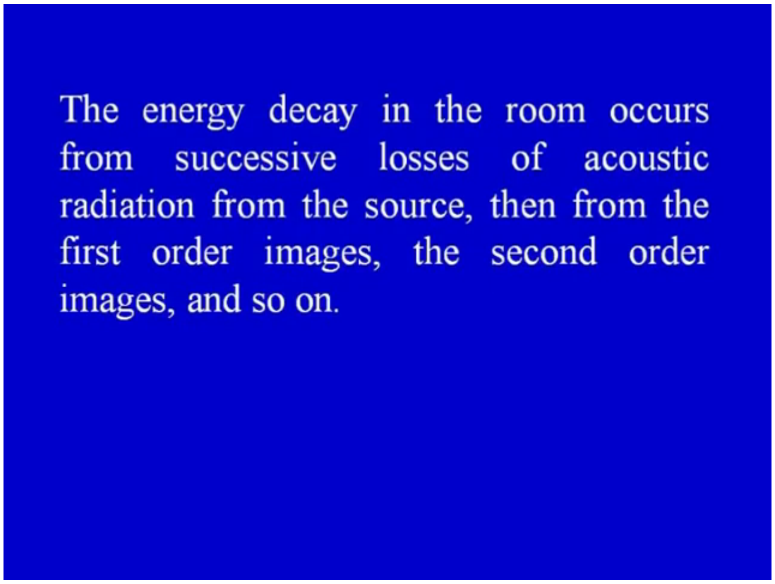

The energy decay in the room occurs from successive losses of acoustic radiation from the source and then from the first order images, second order images and so on.

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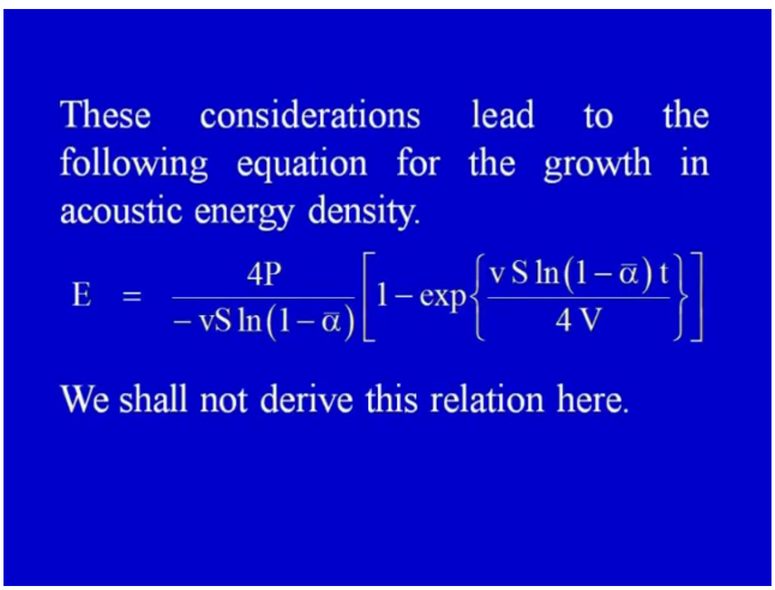

These considerations lead to the following equation for the growth in acoustic energy density. E is given by 4P divided by - v into v S log of 1 - alpha bar times 1 - exponential of vS log of 1 - alpha bar divided by 4V times t. We shall not derive this relation here.

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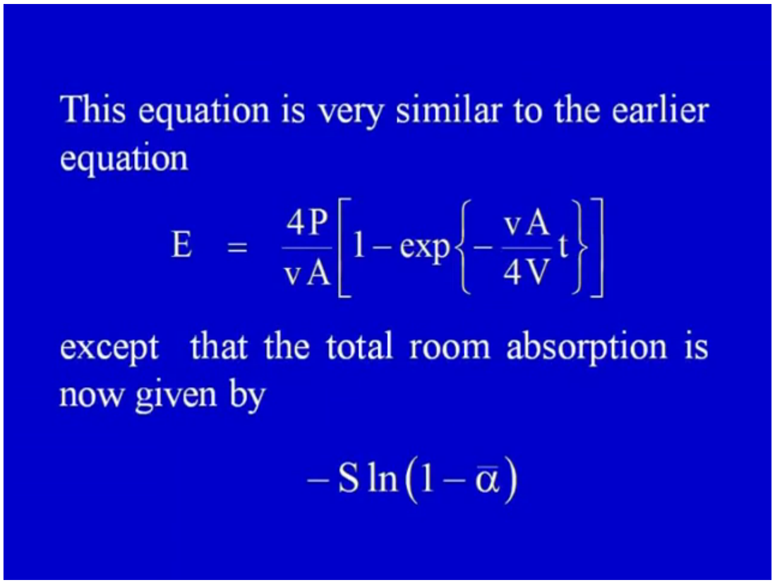

And this equation is very similar to the earlier equation which was E is = 4 P upon v A times 1 - E raised to the power - v A upon 4 V times t except that the total room absorption is now given here by - S log of 1 - alpha bar.

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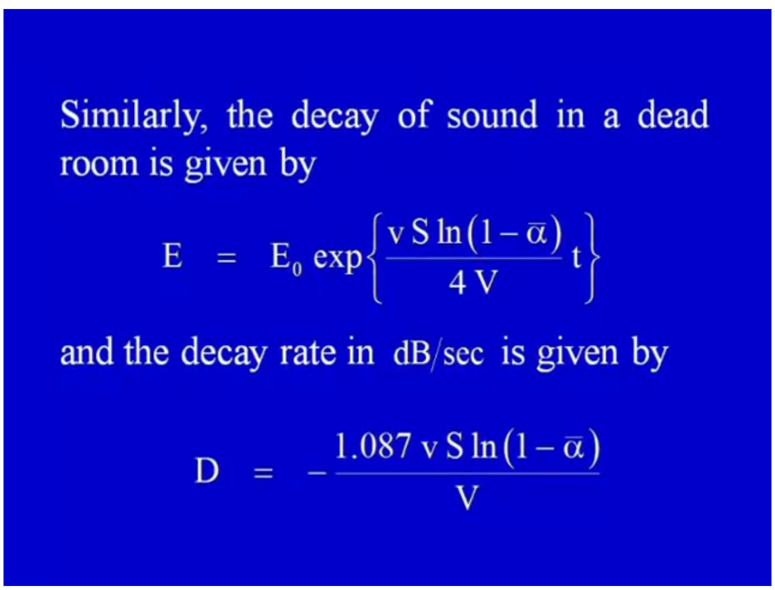

Similarly, the decay of sound in a dead room is given by E is = E naught E raised to the power vS log of 1 - alpha bar divided by 4V times t and the decay rate in decibels per second is given by D is = - 1.087 times v times S times log of 1 - alpha bar times by capital V.

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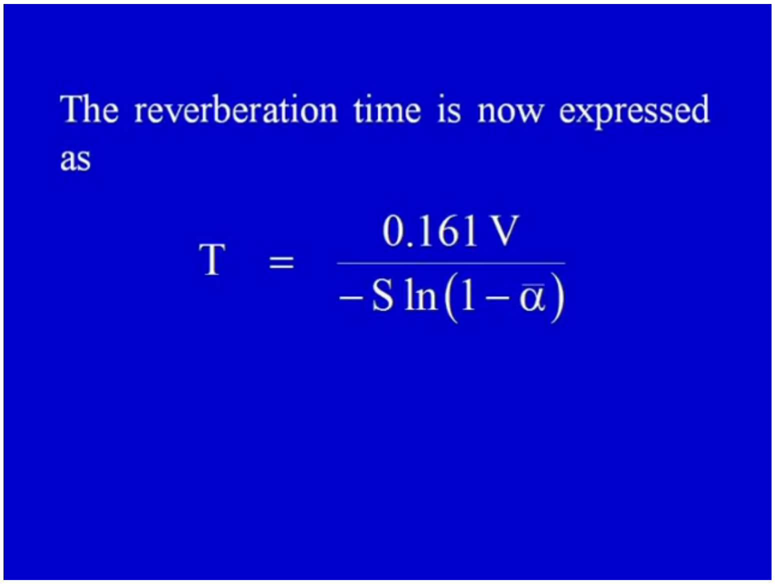

The reverberation time is now expressed as capital T = 0.161 times V divided by - S log of 1 - alpha bar.

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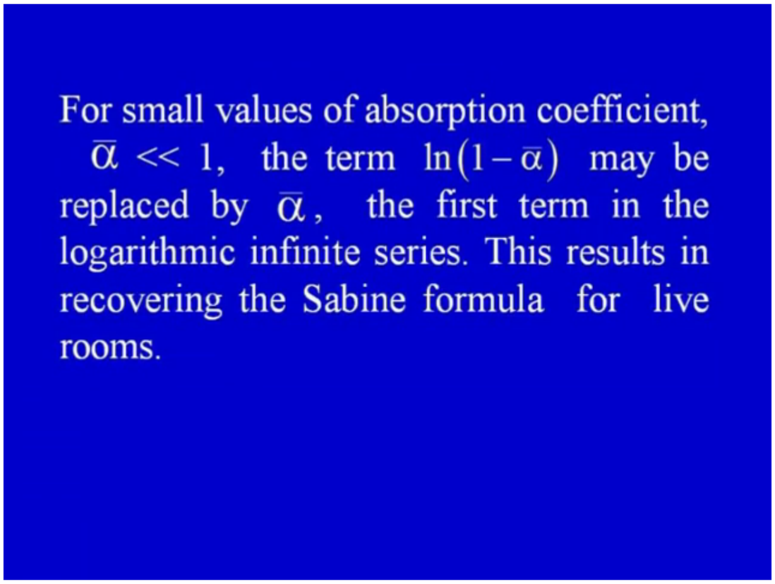

For small values of absorption coefficient, alpha bar is very, very smaller than 1. The term log of 1 - alpha bar may be replaced by alpha bar, the first term in the logarithmic infinite series. This results in recovering the Sabine formula for live rooms.

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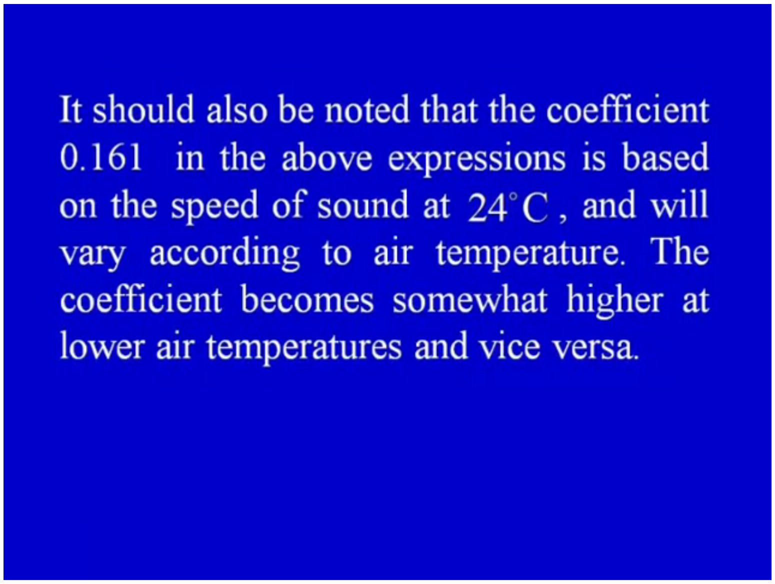

It should also be noted that the coefficient 1.161 one appearing in the above expressions is based on the speed of sound at 24 degree centigrade naturally will vary according to air temperature. The coefficient becomes somewhat higher at lower air temperatures and vice versa.

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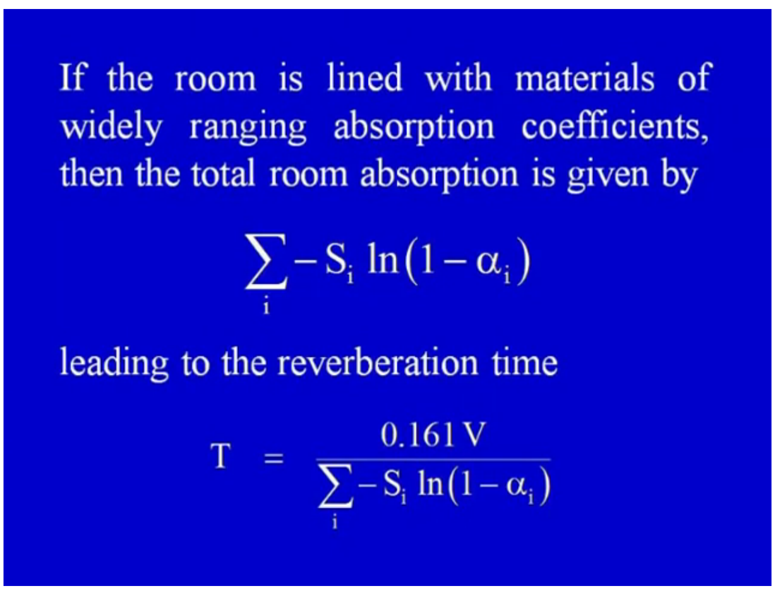

If the room was lined with materials of widely ranging absorption coefficients and the total room absorption is given by summation over individual contribution, summation over i - Si log of 1 - alpha i leading to the reverberation time now which is given by capital T = 0.161 V divided by summation over i - Si log of 1 - alpha i.

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Now, let us consider the effect on the reverberation time of the humidity in air and sound absorption in air. The effect of absorption of sound and humidity in air on the reverberation time needs to be considered.

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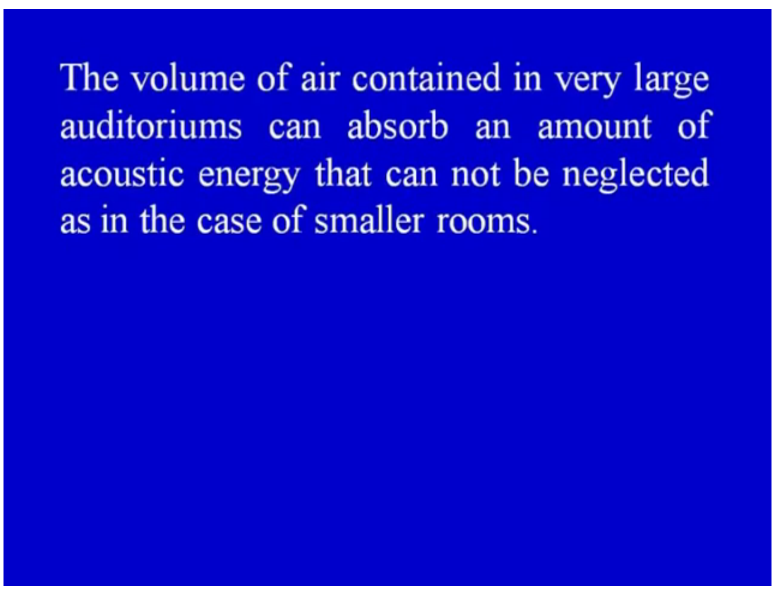

Sometimes you see the volume of air contained in very large auditoriums can absorb an amount of acoustic energy that cannot be neglected as in the case of smaller rooms.

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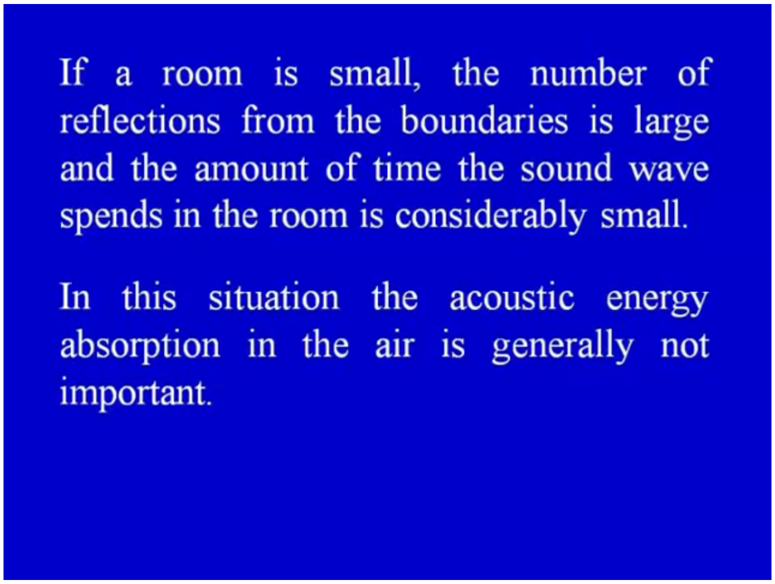

If a room is small the number of reflections from the boundaries is large and the amount of the time the sound wave spends in the room is considerably small. In this situation, the acoustic energy absorption in the air is generally not important.

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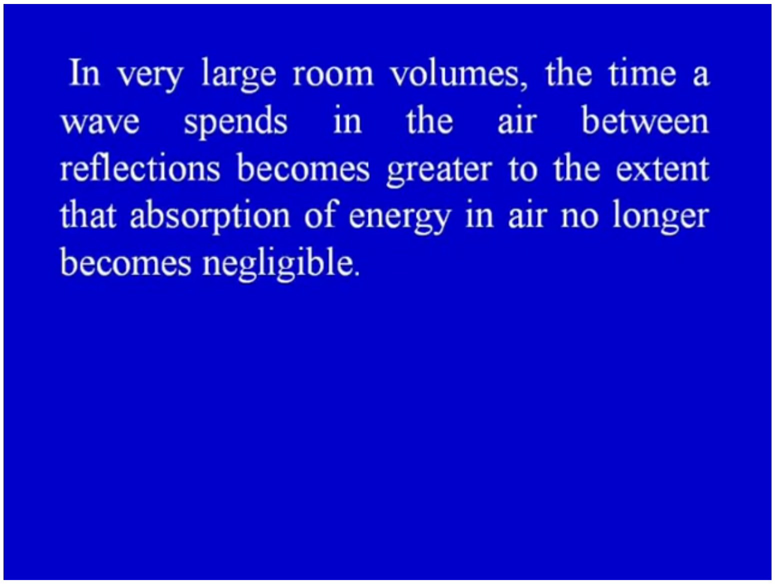

In very large volumes, big halls, the time wave spends in the air between reflections becomes greater to the extent that absorption of energy in air no longer becomes negligible.

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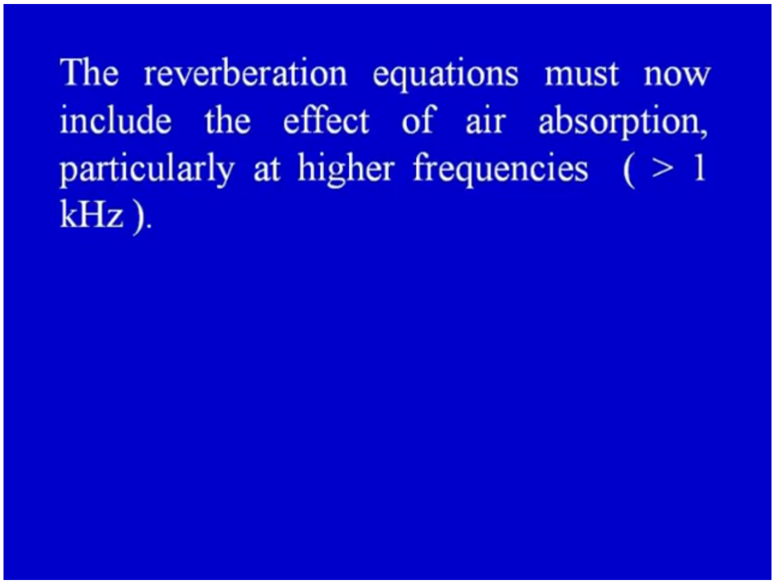

The reverberation equation must now include the effect of air absorption particularly at high frequencies higher than 1 kilohertz.

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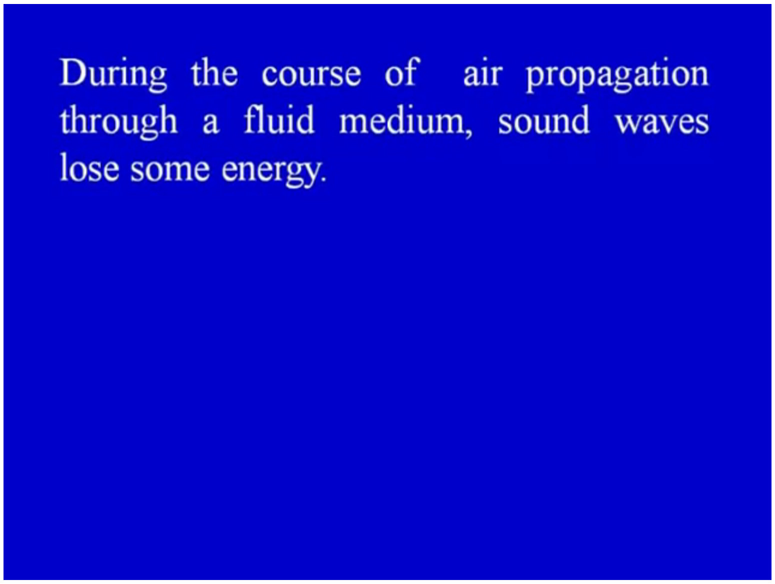

Now, during the course of an air publication through a fluid medium, through air, Sound waves will lose some energy.

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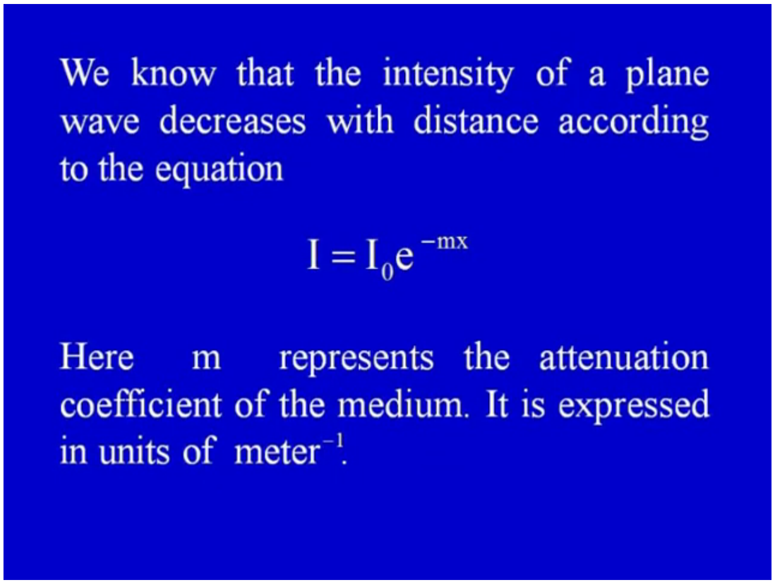

We know that the intensity of a plane wave decreases with distance according to the equation I = I naught e raised to the power - mx. Here m represents the attenuation coefficient of the medium expressed in units of meter inverse.

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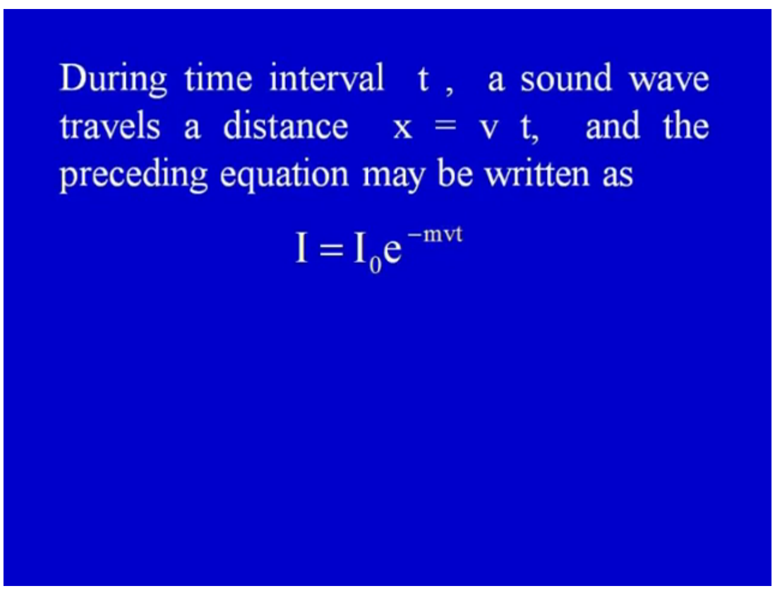

During the time interval t, a sound wave travels a distance x given by v into t and the preceding equation may now be written as I = I naught e raise to the power - mvt.

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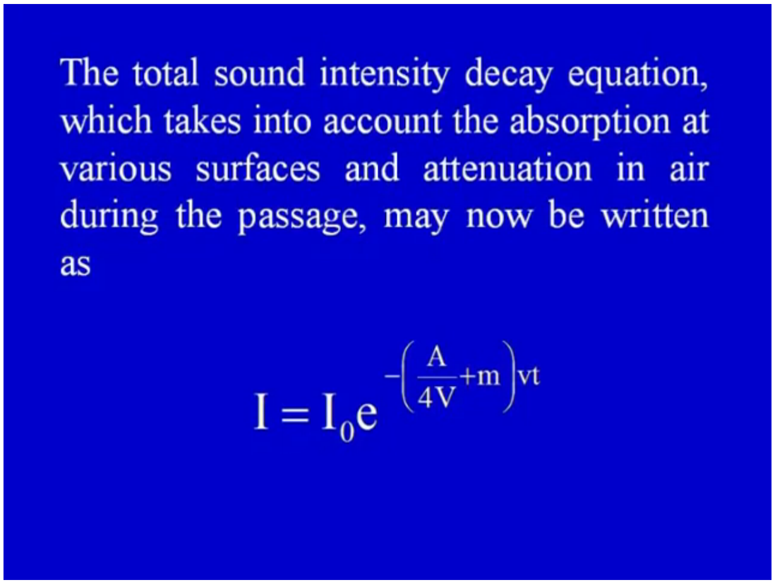

The total sound intensity decay equation, it takes into account the absorption at various surfaces and also the attenuation in air during the passage may now be written as I = I naught e raised to the power A upon 4 V + m and all of this multiplied by v into t. You see, the modification in this term containing m.

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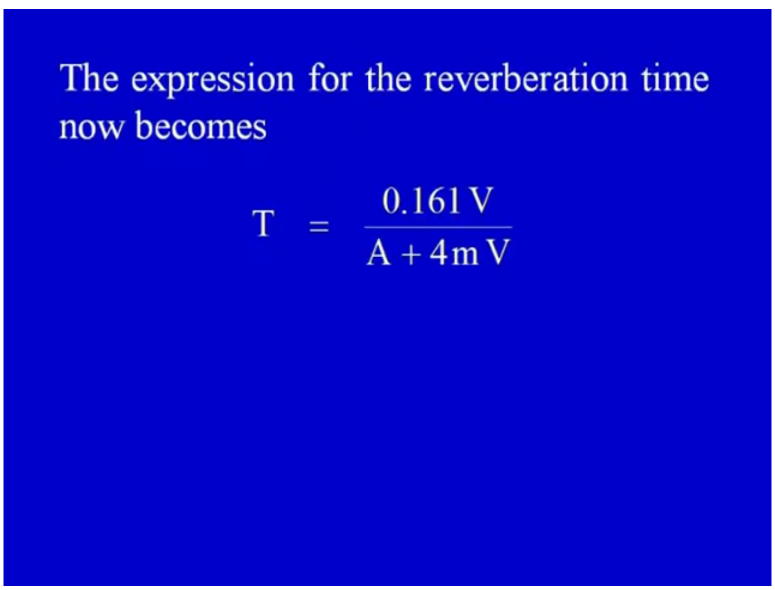

The expression for the reverberation time now becomes T is = 0.16 1 times V divided by A + 4mV.

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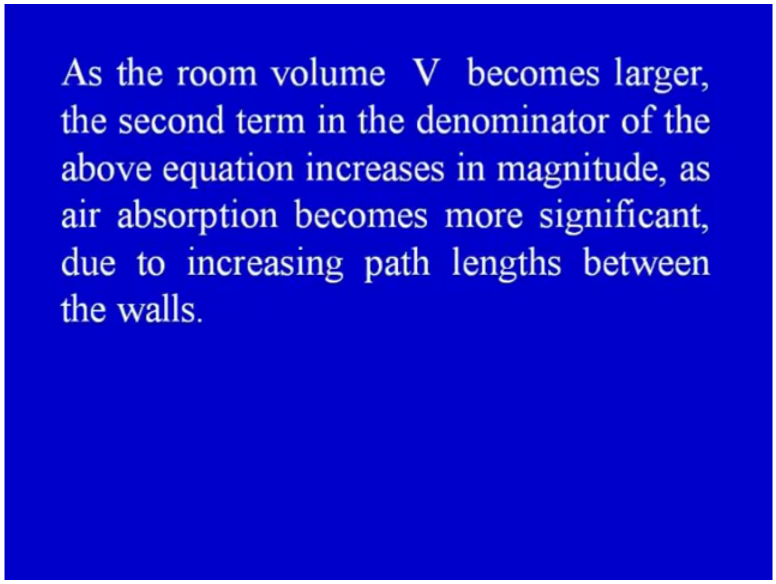

As the room volume V becomes larger, the second term in the denominator of the above equation increases in magnitude naturally as air absorption becomes more significant due to the increasing path lengths between the walls.

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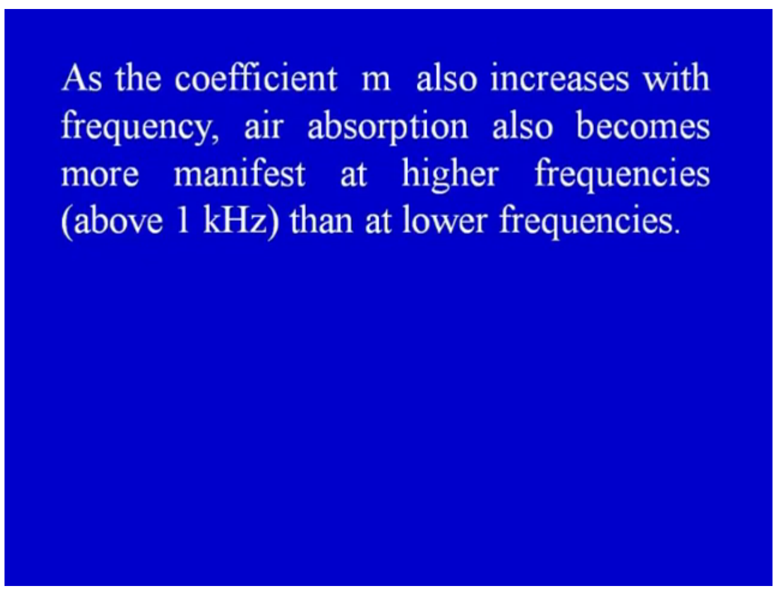

As the coefficient m also included with frequency air absorption also becomes more manifest at higher frequencies above about 1 kilo Hertz than at lower frequencies.

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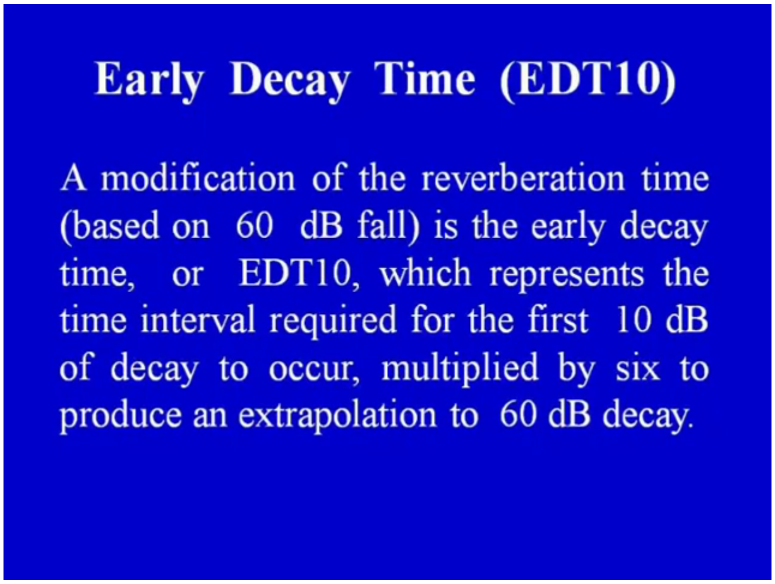

Early decay time a modification of the reverberation time based on the Sabine's definition of 60 decibel fall is the only detail, only decay time EDT10, which represents the time interval required for the first just 10 decibels of decay to occur first 10 out of the 16 multiplied by 6 to produce an extrapolation to 60 decibel decay.

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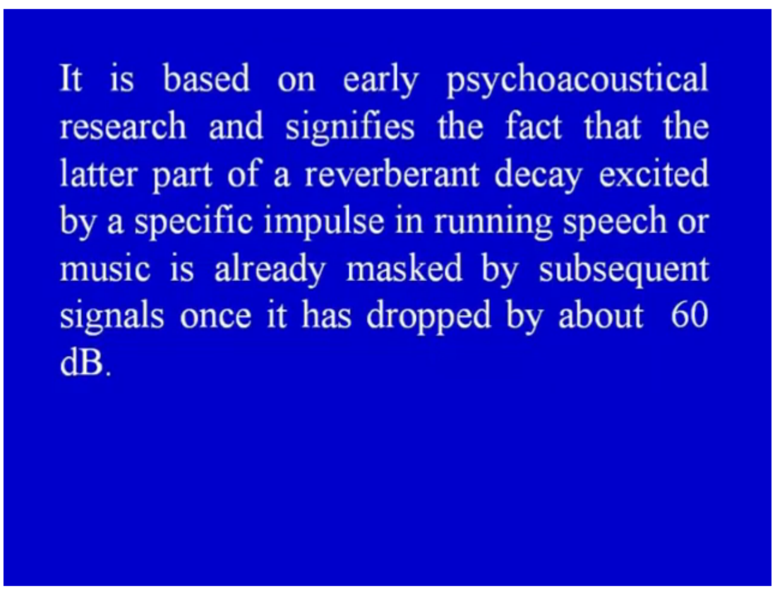

You see, this is based on early cycle acoustical research and signifies the fact that the later part of a reverberant decay excited by a specific impulse in running a speech our music is already masked by subsequent signals once it has dropped by about 60 decibels.

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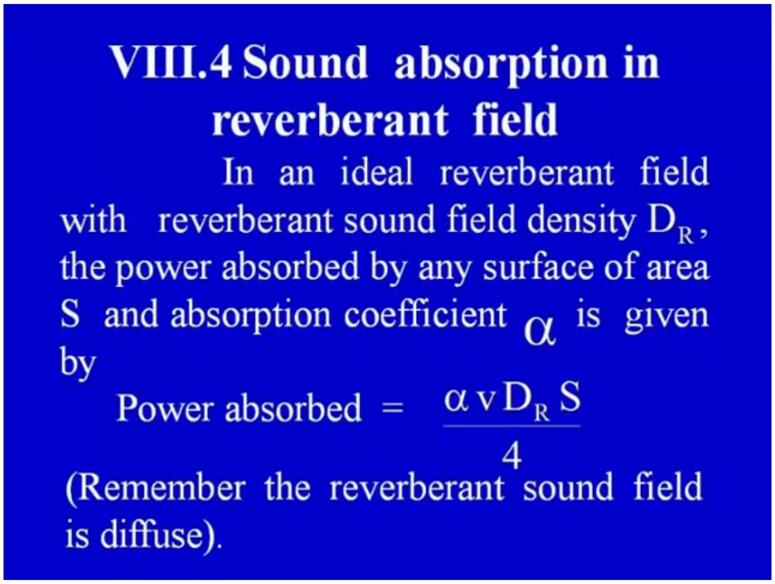

Let us now consider Sound absorption in reverberant field. In an ideal reverberant field with the reverberant sound field in density DR, the power absorbed by any surface of area has absorption coefficient alpha is given by the power absorbed is given by alpha into v into DR times S divided by 4. Remember, the reverberant sound field is the diffuse phase.

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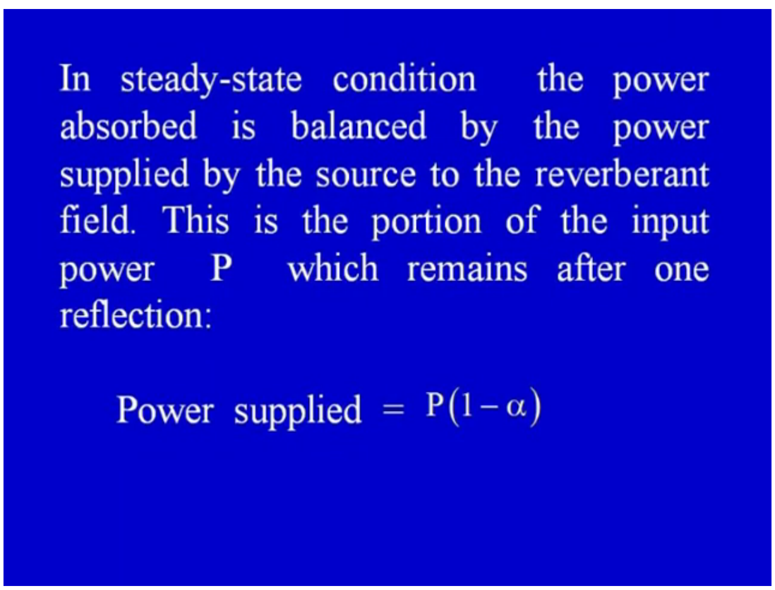

In a steady state condition the power absorbed is balanced by the power supplied by the source to the reverberant field. This is the portion of the input power which remains after one reflection and this is given by P into 1 - alpha.

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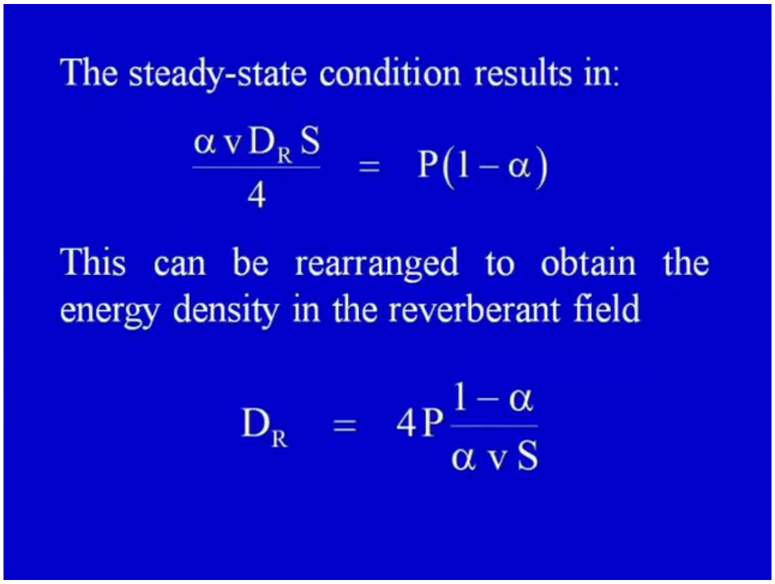

The steady state condition results in let us equate these. Alpha into v DR into s divided by 4 = P into 1 - alpha. This can be rearranged to obtain the energy density in the reverberant field. D of R is given by 4P times 1 - alpha divided by alpha vS.

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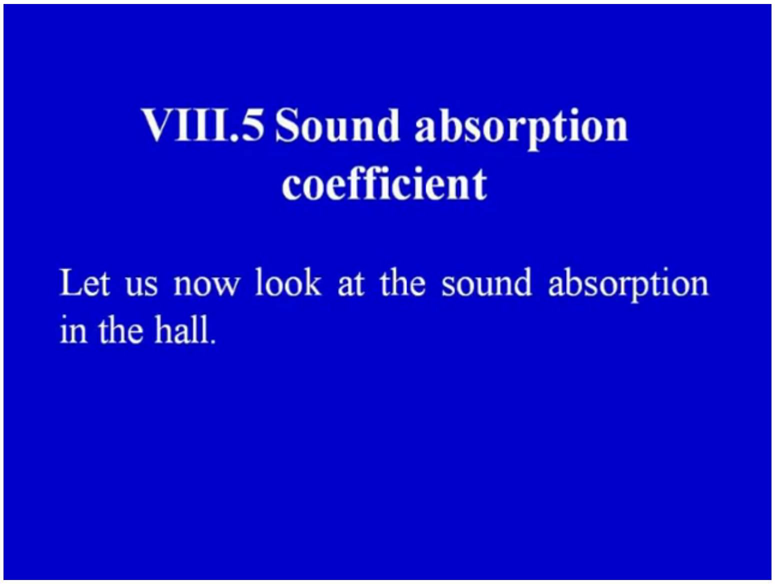

Now, let us consider the Sound absorption coefficient. We have been talking about absorption all this time. Let us spend some time on absorption coefficients.

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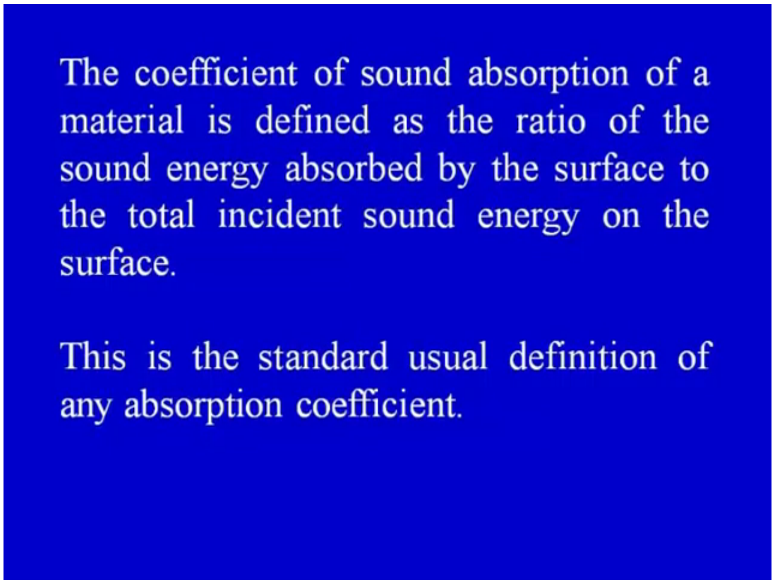

The coefficient of sound absorption of a material is defined as the ratio of the sound energy absorbed by the surface to the total incident sound energy on surface. This is a standard definition of any absorption coefficient.

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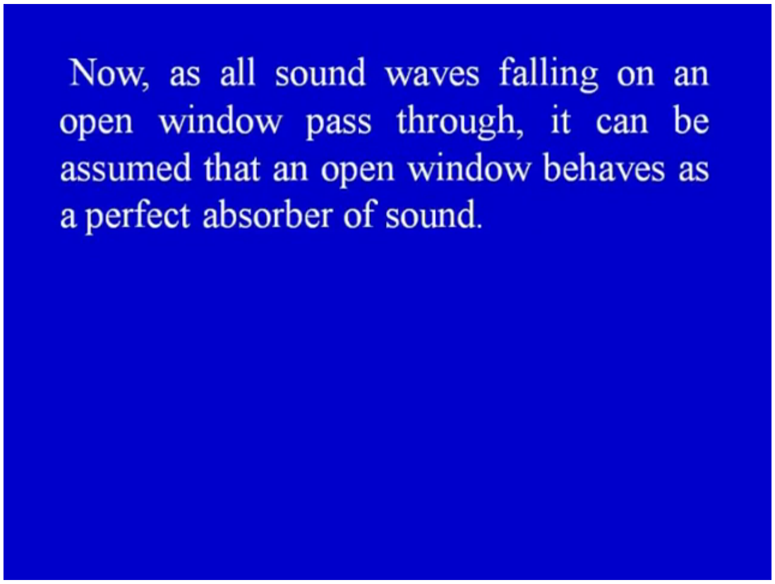

Now, as all sound waves falling on an open window pass through it, it can be assumed that an open window behaves like a perfect absorber of sound.

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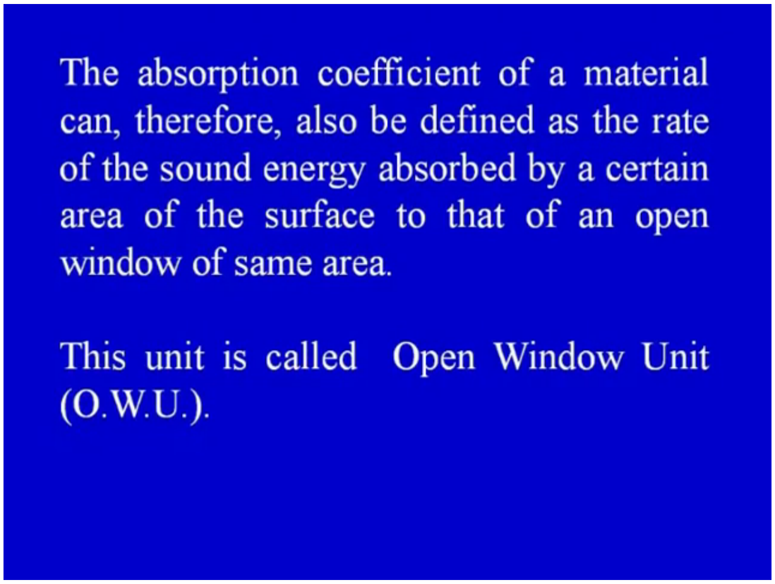

The absorption coefficient of a material can therefore, also be defined as the rate of sound energy absorbed by a certain area of the surface to that of an open window of the same area. This unit is called Open window unit OWU.

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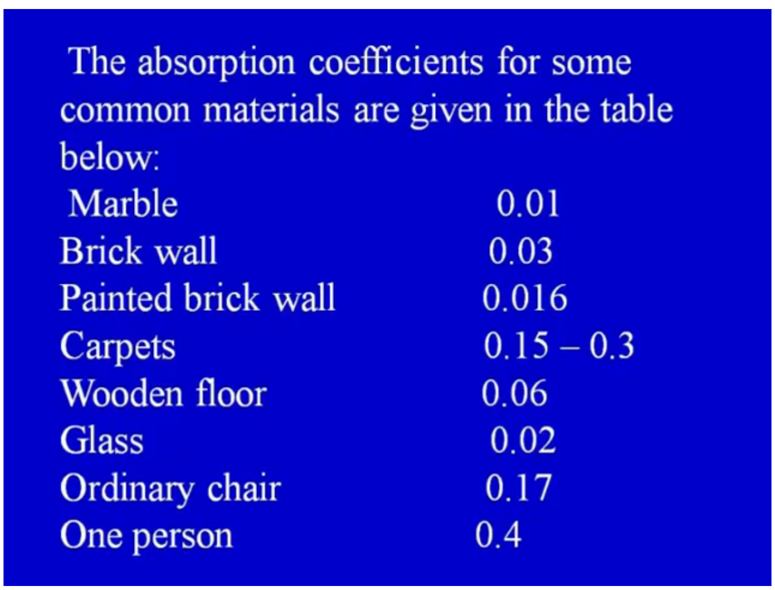

The absorption coefficients for some common materials are given in this table. These are for marble, for brick walls or painted brick balls, for carpets, wooden floor, for glass, or ordinary chair and also the audience for the single person.

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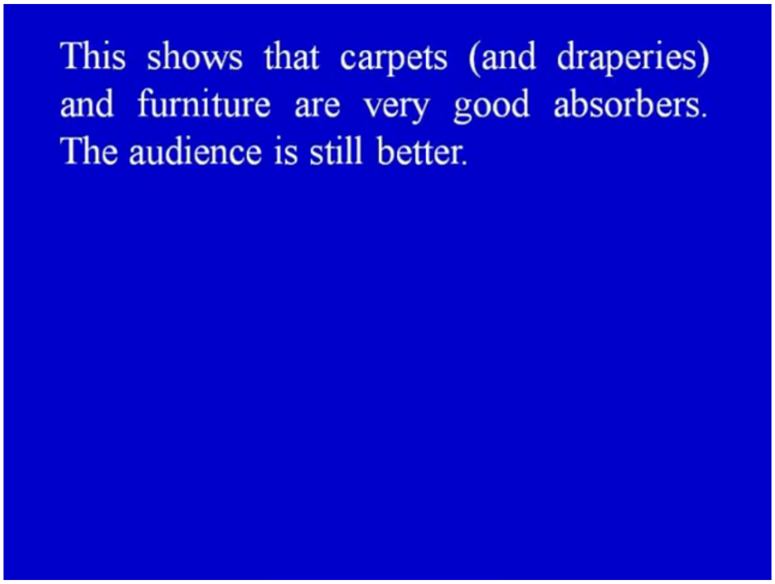

This table shows that the carpets and draperies and furniture are very good absorbers. The presence of audience is still better now. Let us consider the measurements: Measurement of reverberation time and the measurement of absorption coefficients later on.

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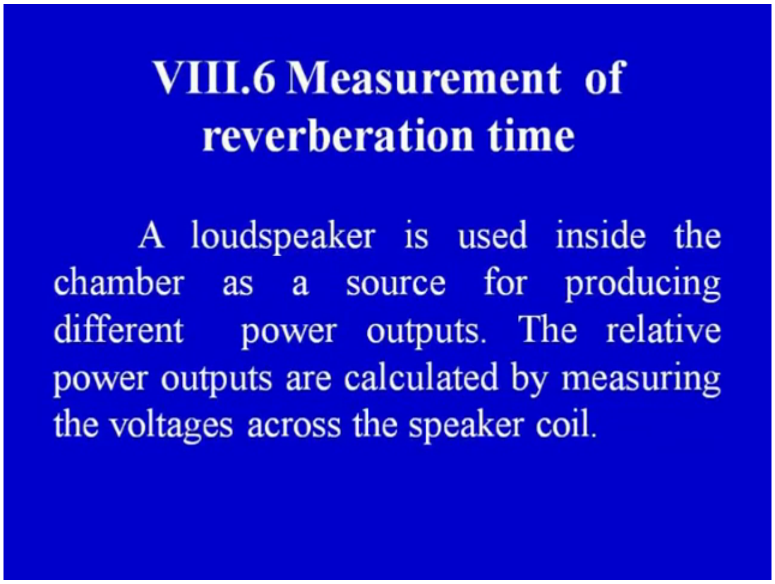

The Method is works like this. A loudspeaker is used inside the chamber as a source for producing different power outputs. The relative power outputs are calculated by measuring the voltages across the speaker coil.

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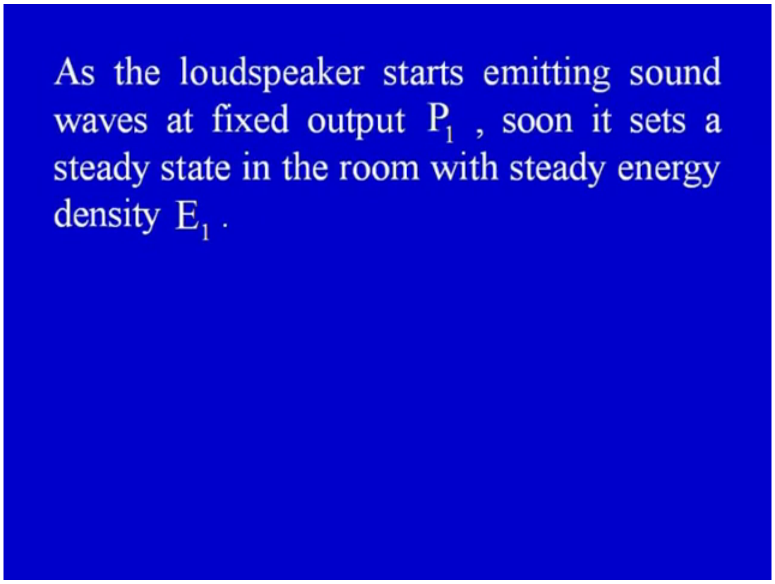

As the speak loudspeakers thoughts emitting sound waves at some fixed output say P1 soon it sets a steady state in the room the steady state energy density E1.

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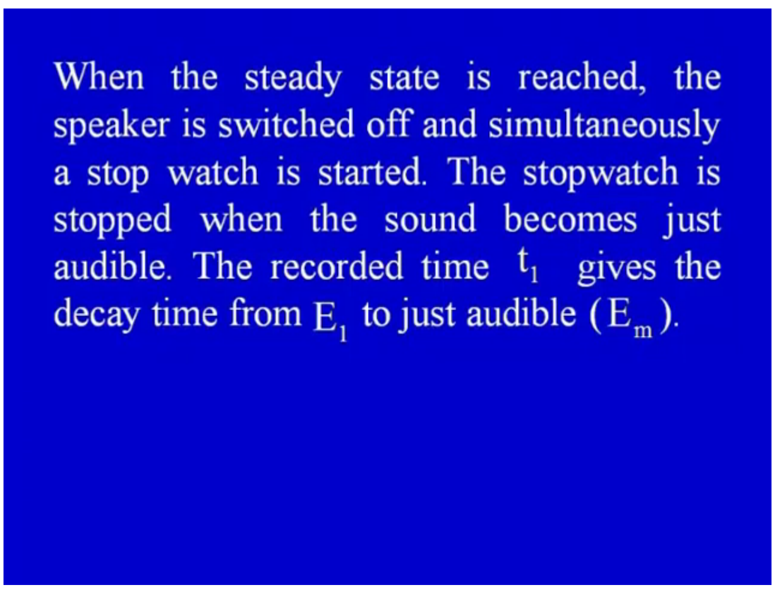

When the steady state is reached, the speaker is switched off and simultaneously a stop watch is started. The stopwatch is stopped when the sound becomes just audible. The recorded time t1 gives the decay time from the energy density E1 to just audible Em.

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The experiment is repeated for another power output P_2 leading to steady state energy density E_2 . Now

$$E_1 \exp\left(-\frac{vA}{4V}t_1\right) = E_2 \exp\left(-\frac{vA}{4V}t_2\right) = E_m$$

The experiment is then repeated for another power output P2 leading to the steady state energy E2 and time 2 is obtained for the decay, to the energy density Em. Equating these, we get a relation, which is connecting E1 t1 and E2 t2 to the energy Em.

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$$\text{or} \quad \frac{E_1}{E_2} = \exp\left(\frac{vA}{4V}(t_1 - t_2)\right)$$

$$\text{or} \quad \frac{4V}{vA} = \frac{(t_1 - t_2)}{\ln(E_1/E_2)}$$

$$\text{or} \quad T = 6 \times 2.3026 \times \frac{4V}{vA}$$

$$= 6 \times \frac{(t_1 - t_2)}{\log(E_1/E_2)}$$

This can be solved the E1upon E2 is given by the exponential of vA upon 4V times t1 - t2 that gives me 4V upon vA is given by t1 - t2 divided by log off E1 upon E2 and one can now have the standard definition of T, we know, 6 into 2.0326 into 4V upon vA substituting its value from the above equation, the result is T is given by t1 - t2 divided by log of E1 upon E2.

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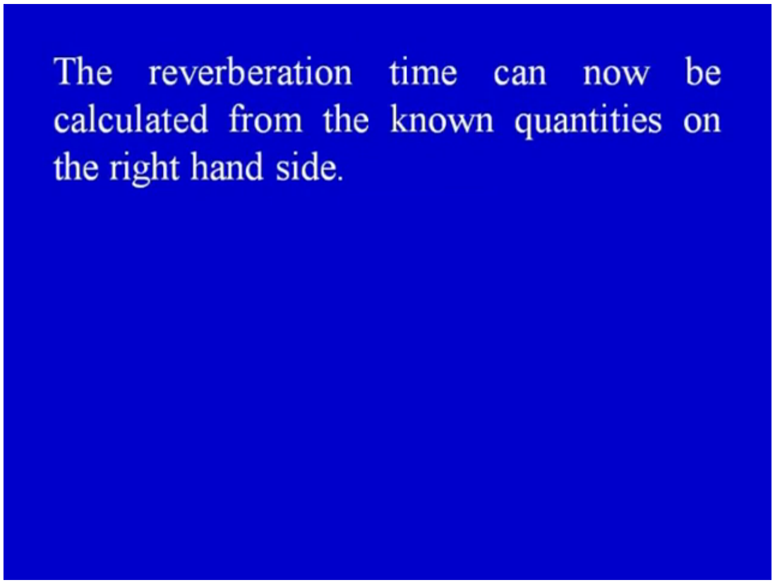

The reverberation time cannot be calculated from the known quantities on the right hand side of this expression.

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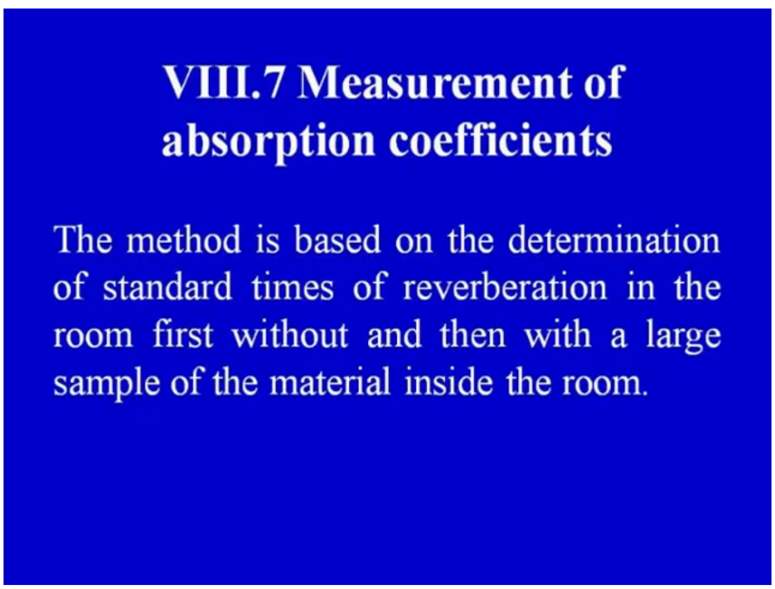

A measurement of absorption coefficients, the method is based on the determination of standard times of reverberation in the room first without and then with a large sample of the material experimental material inside the room.

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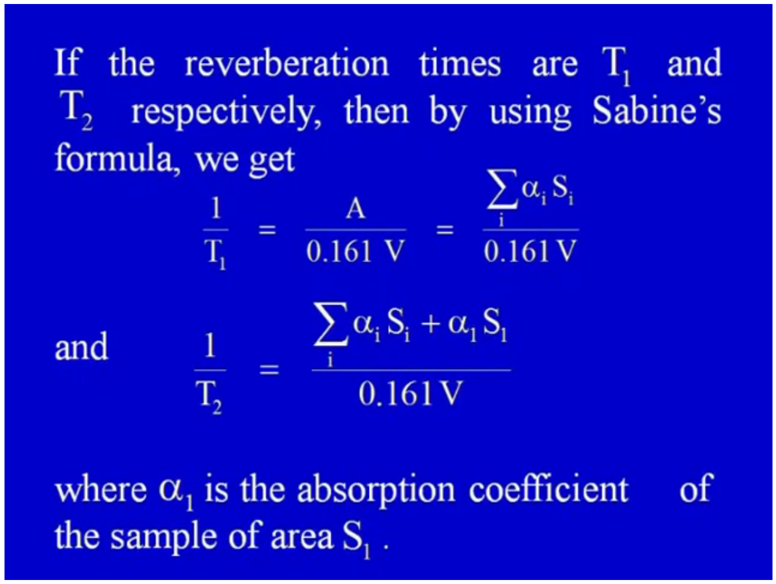

If the reverberation times are T1 and T2 respectively then by using Sabine's formula we get 1 upon capital T1 that is really related to summation over l Phi Si divided by 0.161 times V and the other result 1 upon T2 it is L Phi Si that is the original contribution + alpha 1 S1 that corresponds to the sample divided by 0.16 1 times V alpha 1 is the absorption coefficient of the sample of area S1.

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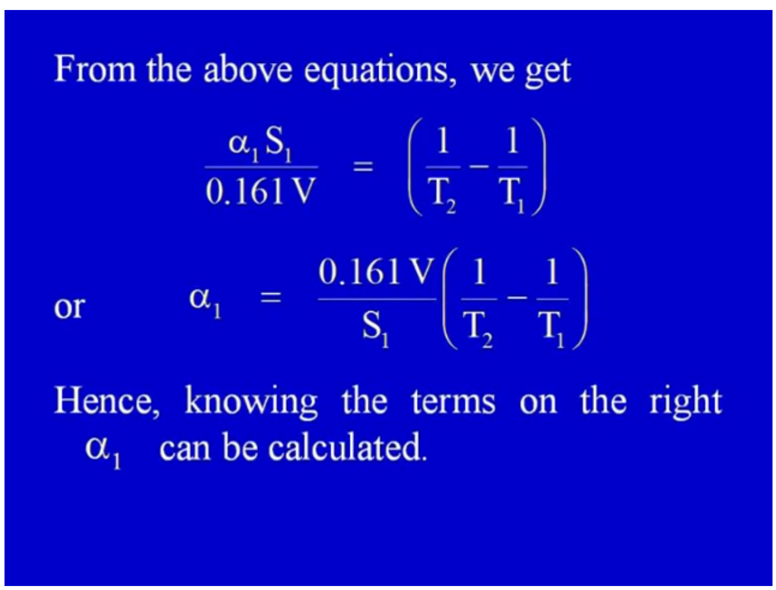

From the above equations, we get, we solve these equations, basically the result is, we get, alpha 1 is = 0.16 1 v upon S1 multiplied by 1 upon T2 - 1 upon T1. Hence knowing the terms on the right hand side alpha 1 can be calculated.

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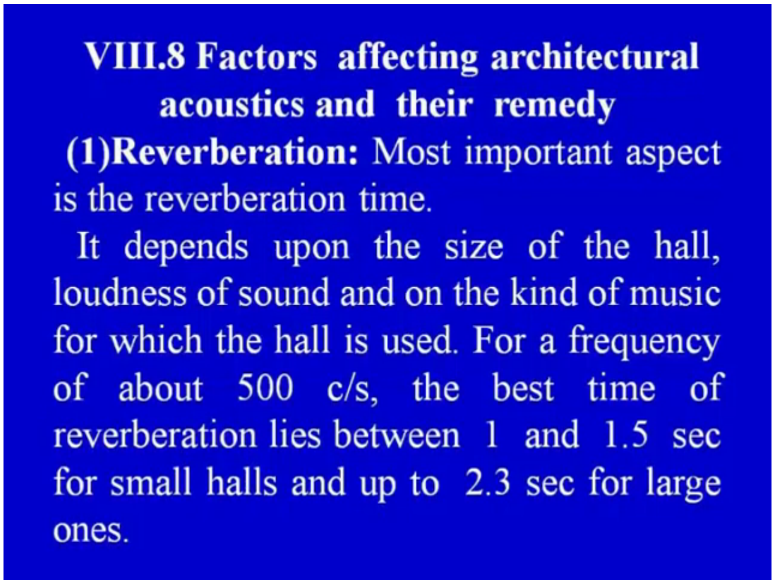

Now the factors affecting architectural acoustics and remedy: Number 1: We have been talking about evaporation all the time. Most important aspect is the reverberation time. As we have seen it, depends upon the size of the Hall, loudness of the sound and on the kind of music for which the hall is used for a frequency of about 500 cycles per second the best times as we have said that about between 1 to 1.5 seconds for small halls and it can go up to 2.3 seconds for large ones.

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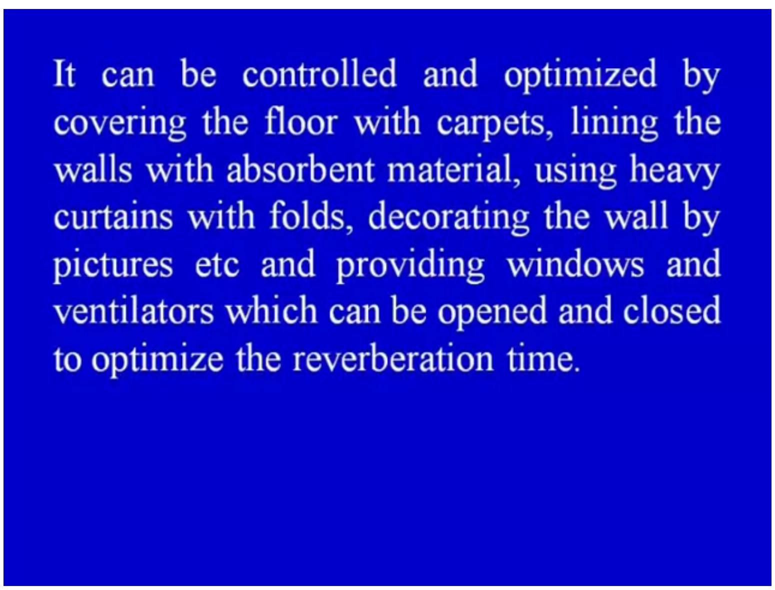

It can be controlled and optimized by covering floor with carpets, lining the walls with absorbent material, using heavy curtains with folds, decorating the walls by pictures etcetera and providing windows and ventilators which can be opened and closed to optimize the reverberation time.

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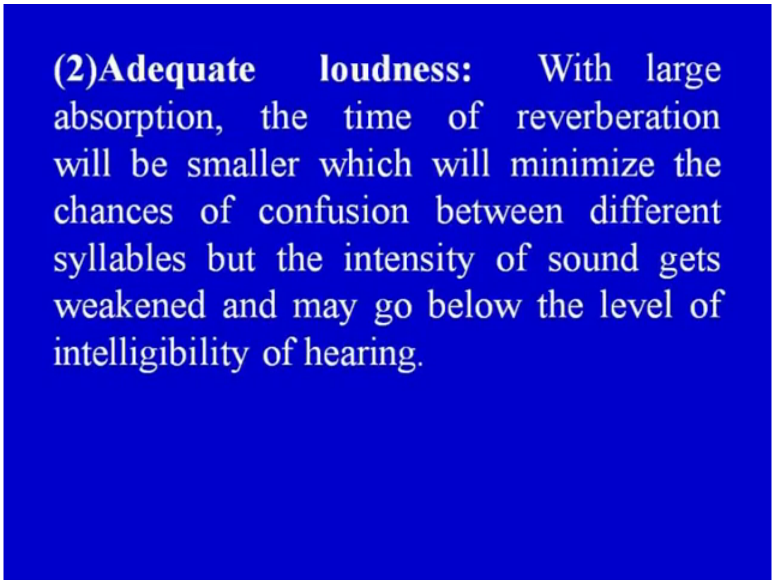

Number 2: Adequate loudness: Large absorption the time of reverberation will be smaller which will minimize the chances of confusion between different syllables but the intensity of sound gets weakened and may go below the level of intelligibility of hearing.

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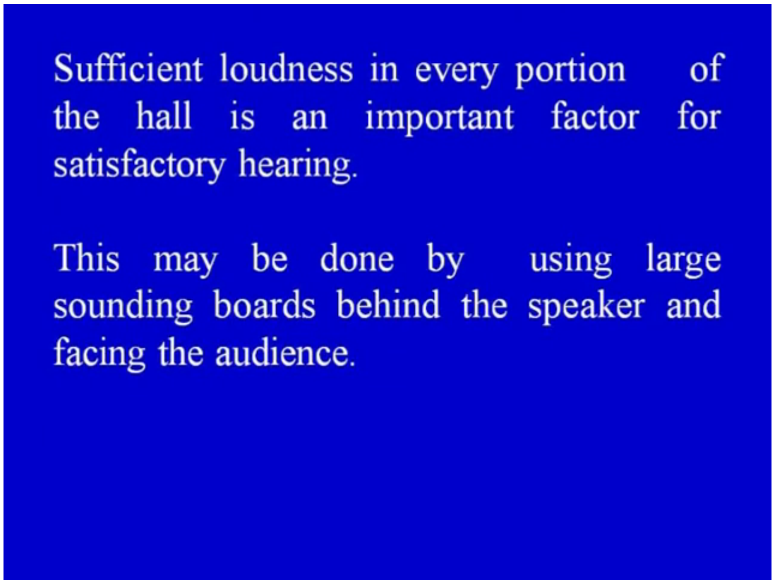

Sufficient loudness at every portion of the hall is an important factor for satisfactory hearing. This may be done by using large sounding boards behind the speaker and facing the audience.

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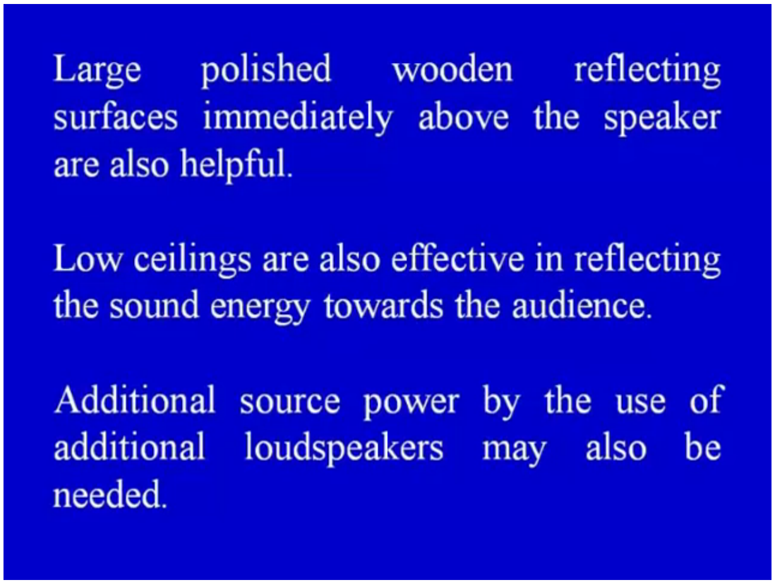

Large polished wooden reflecting surfaces immediately of the speaker are also helpful. Low ceilings are also effective in reflecting the sound energy towards the audience. Additional source power by the use of additional loudspeakers may also be needed.

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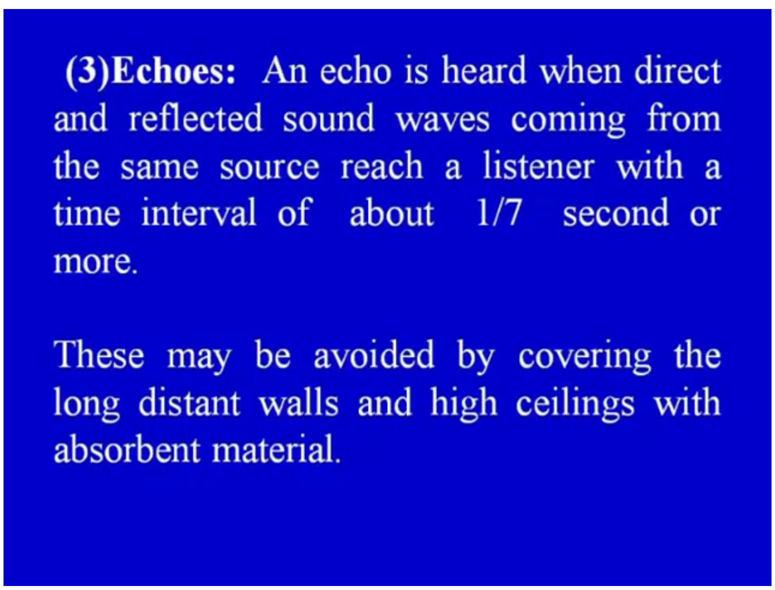

Number three: Echoes: An echo is heard when direct and reflected sound waves they, coming from the same source reach a listener with the time interval about 1 by 7 seconds or more. This may be avoided by covering the long distance wall, distant walls and high ceilings with absorbent material.

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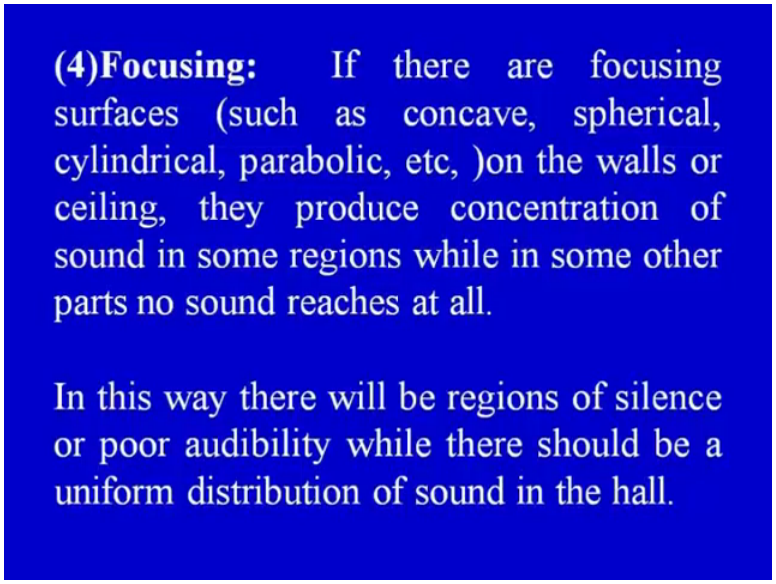

Number four: Focusing: Even there are focusing surfaces such as concave, spherical, cylindrical or parabolic etcetera on the walls or on the ceilings. They produce concentration of sound in some regions while in some other parts no sound reaches at all. In this way, there will be regions of silence or poor audibility while there should be uniform distribution of sound in the hall.

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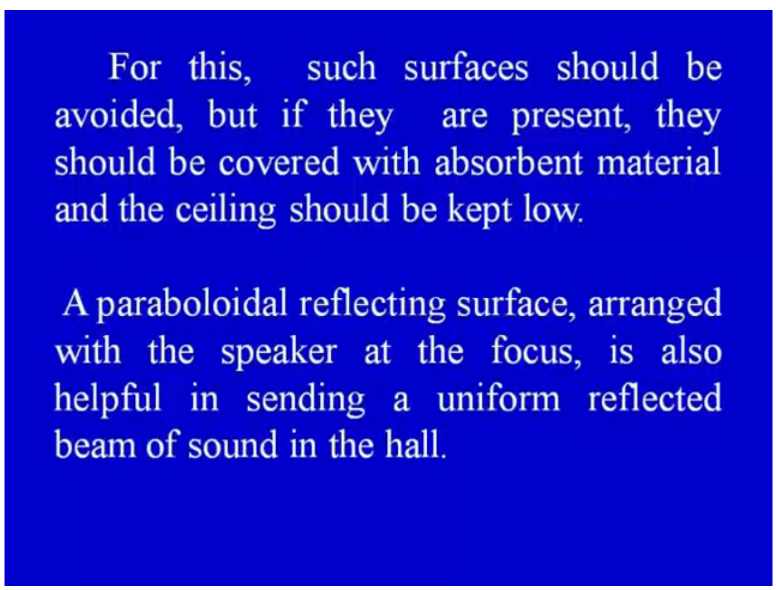

For this, such surfaces should be avoided but if they are present they should be covered with absorbent material and the ceiling should be kept low. A paraboloidal reflecting surface arranged with the speaker at the focus, is also helpful, in sending a uniform reflected beam of sound in the hall.

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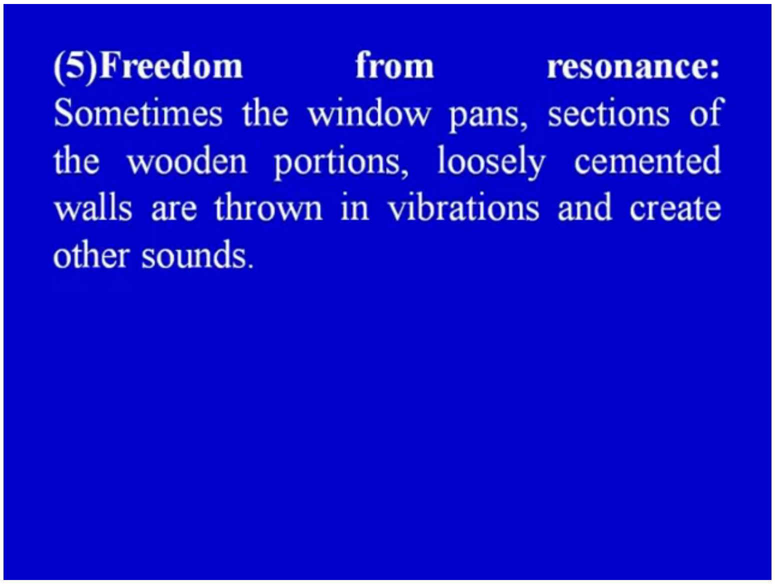

Number five: Freedom from resonance: Sometimes the window pans, sections of the wooden portions, loosely cemented walls are thrown in vibrations and create other sounds.

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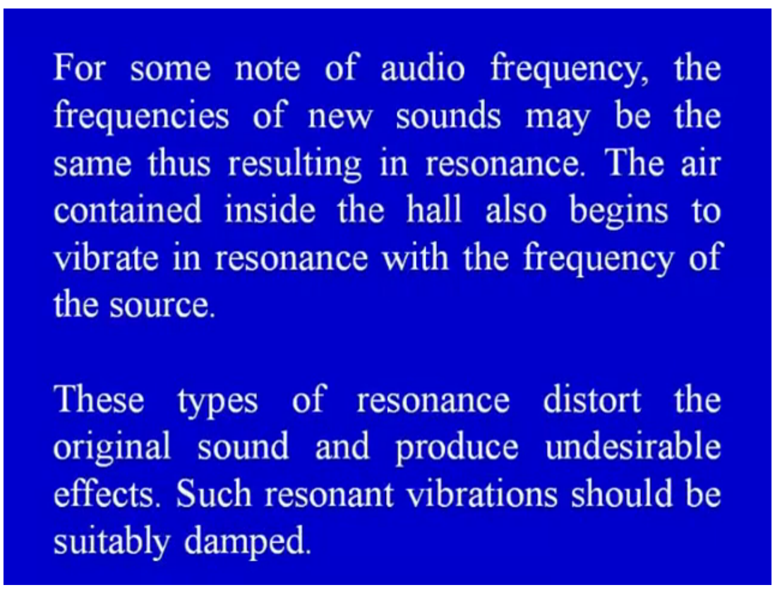

For some notes of audio frequency, the frequencies of new sounds may be the same and those resulting in resonance. The air contained inside the hall also begins to vibrate at resonance with the frequency of the source. These types of resonance distort the original sound and produce undesirable effects. Such resonant vibrations should be suitably damped.

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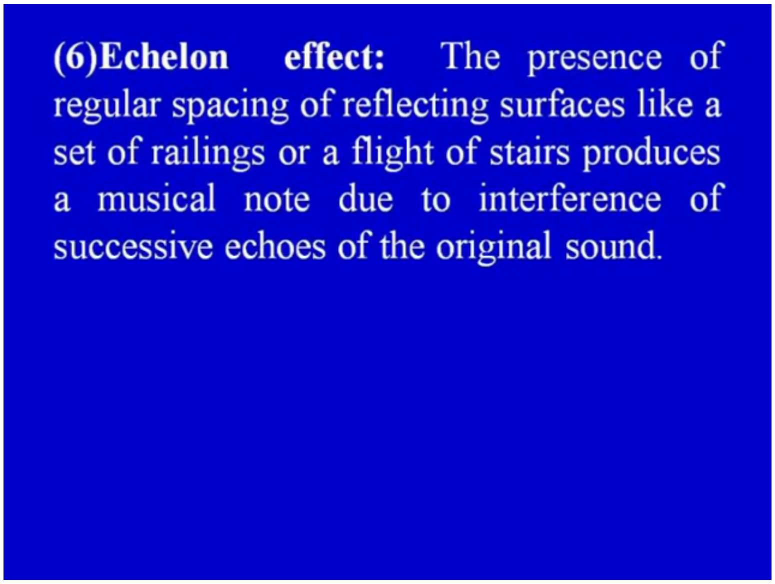

Number 6: Echelon effects: Now, the presence of regularly spacing of reflecting surfaces like a set of railings on a flight of stairs produces a musical note due to the interference of successive echoes of the original sound. This is called a echelon.

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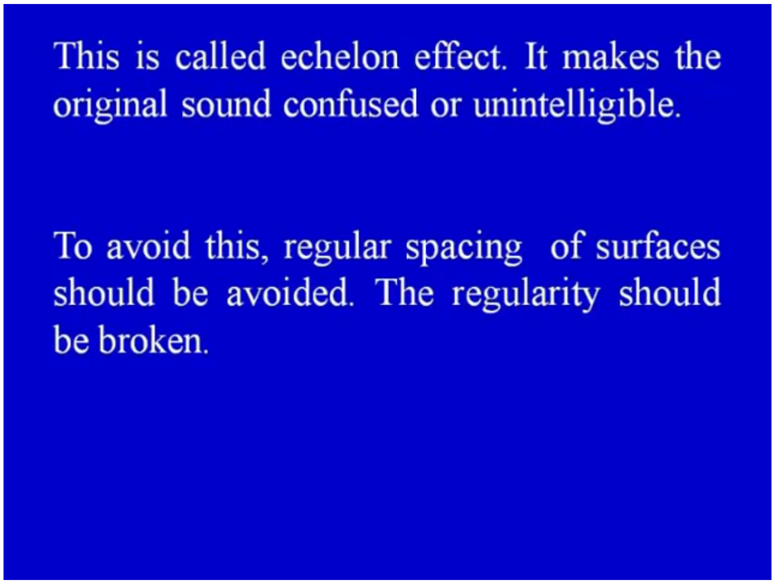

It makes the original sound confused or unintelligible. To avoid them, regular spacing of surfaces should be avoided. I mean, the point is that the regularity should be broken.

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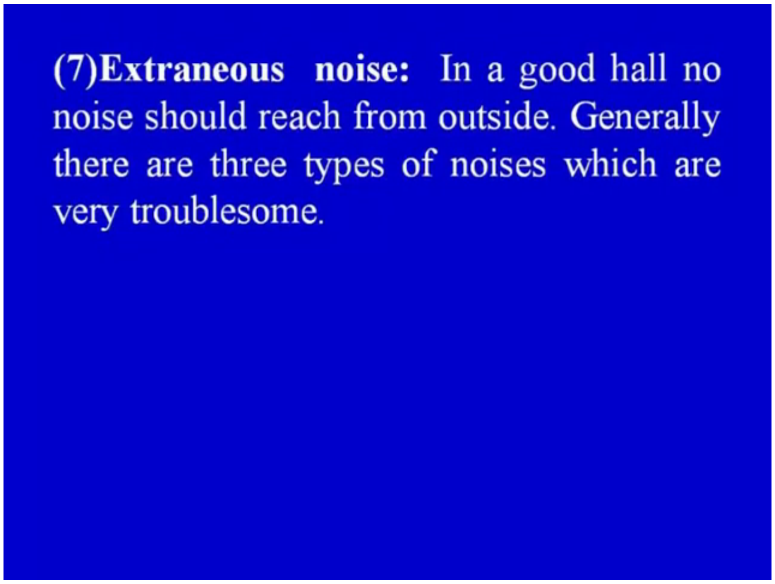

Number 7: Extraneous noise: In a good hall no noise should reach from outside. Generally there are three types of noises which are very troublesome.

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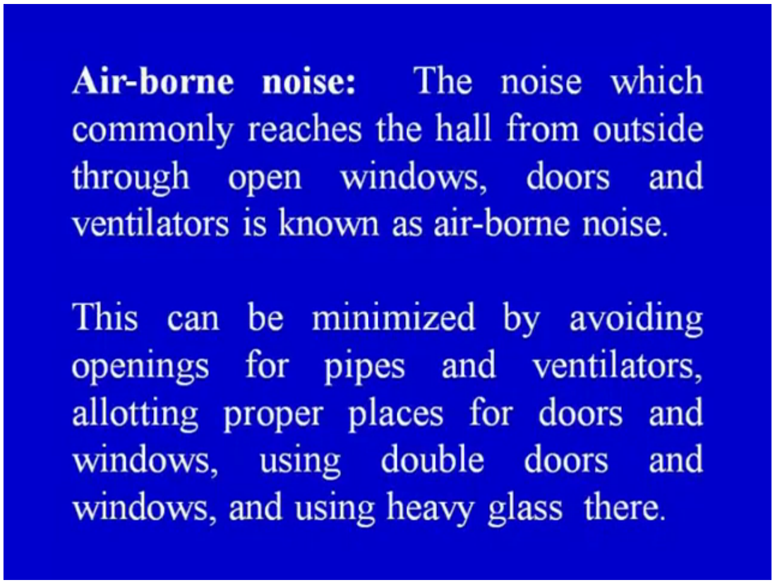

Airborne noise the noise which commonly reaches the hall from outside through open windows, doors and ventilators is known as airborne noise. This can be minimized by avoiding openings for pipes and ventilators allotting, proper places for doors and windows, using double doors and windows and using heavy glass there.

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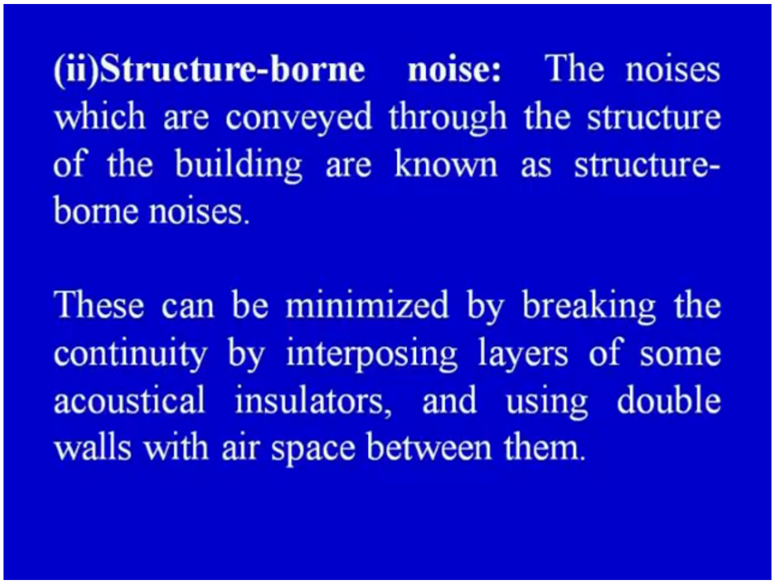

Structure borne noise: The noises which are conveyed through structure of the building are known as a structure borne noise. These can be minimized by breaking the continuity by interposing layers of some acoustical insulators and using double walls with air space between them.

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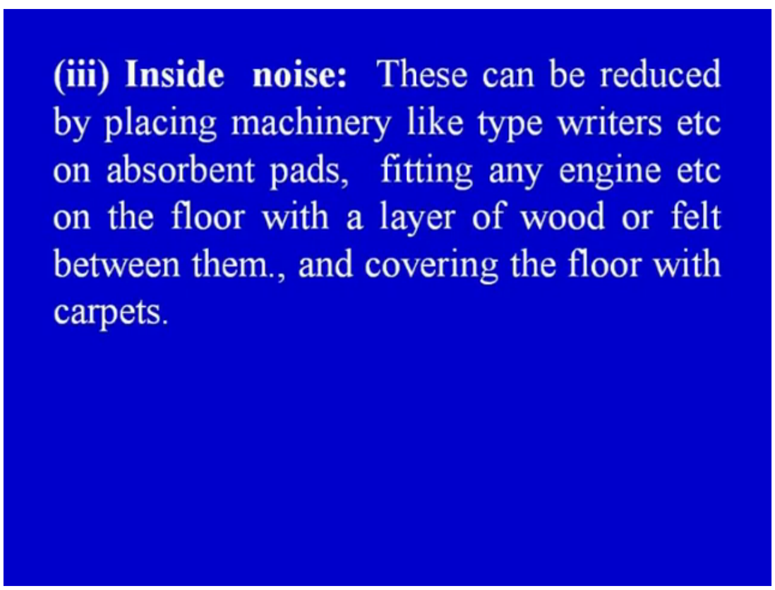

Inside noise this can be reduced by placing machinery like typewriters etcetera on absorbing pads, fitting an engine on the floor with a layer of wood or felt between them and covering the floor with carpets. This is reasonably easy.

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Now, we come to the acoustic designing. We shall now take up designing considerations to optimize performance of the buildings from acoustic point of view. This will naturally depend on the purpose for which the building is to be used. We shall consider some typical examples.

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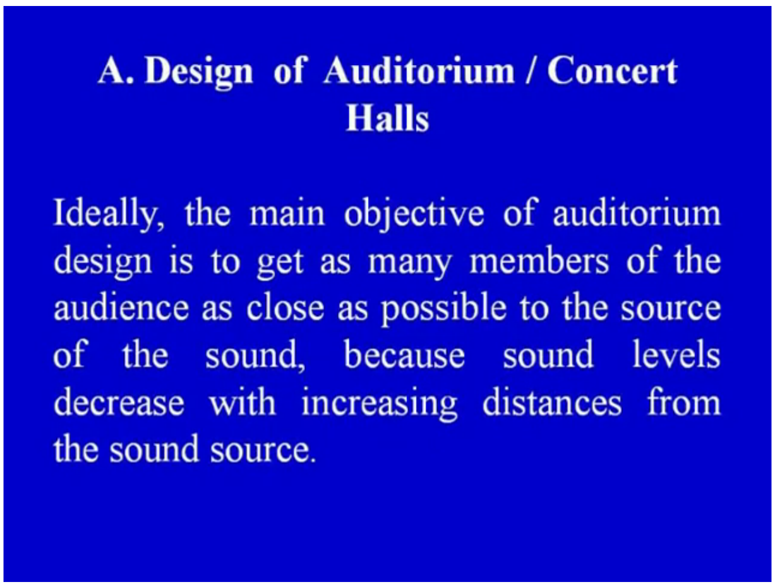

Number 1: Design of auditorium or Concert halls: Ideally the main objective of auditorium design is to get as many members of the audience as close as possible to the source of sound, because some levels decrease with increasing distances from the sound source.

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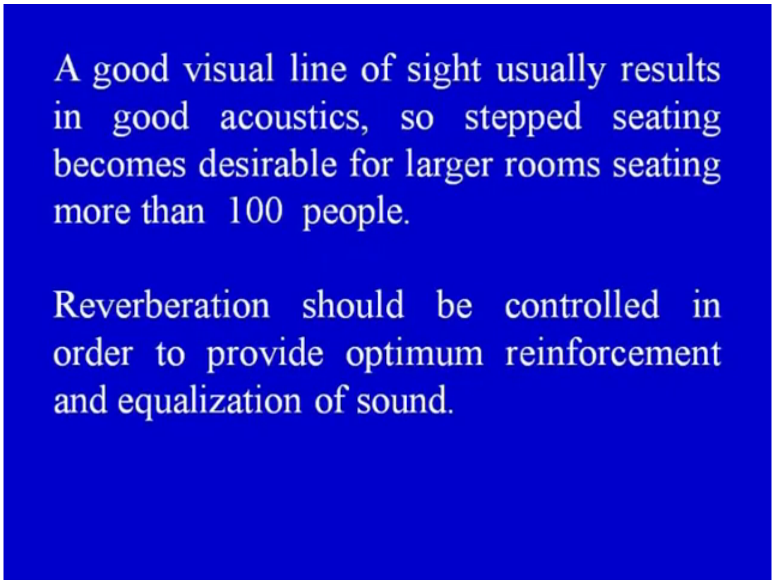

A good visual line of sight literally results in good acoustics. So, stepped seating becomes a desirable for large rooms seating more than 100 people. Reverberation should be controlled in order to provide optimum reinforcement and equalization of sound. We should be assured of adequate loudness in all parts of the hall.

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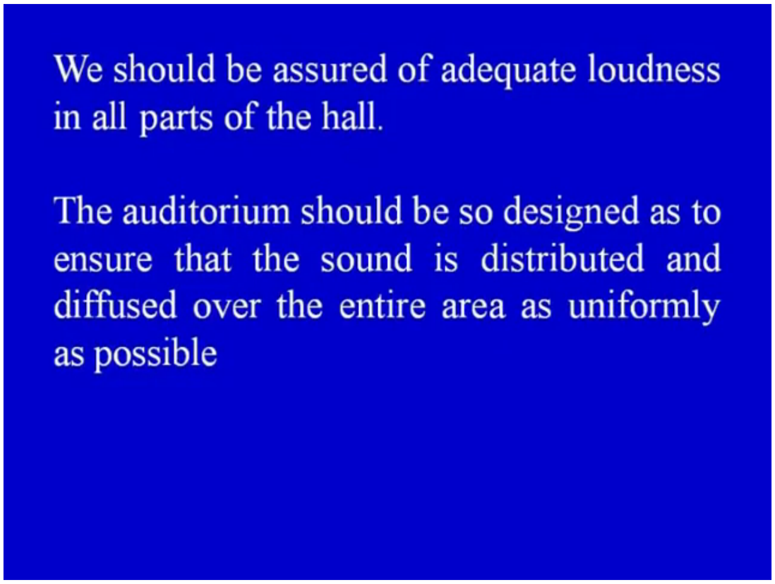

The auditorium should be so designed as to ensure that the sound is distributed and diffused over the entire area as uniformly as possible.

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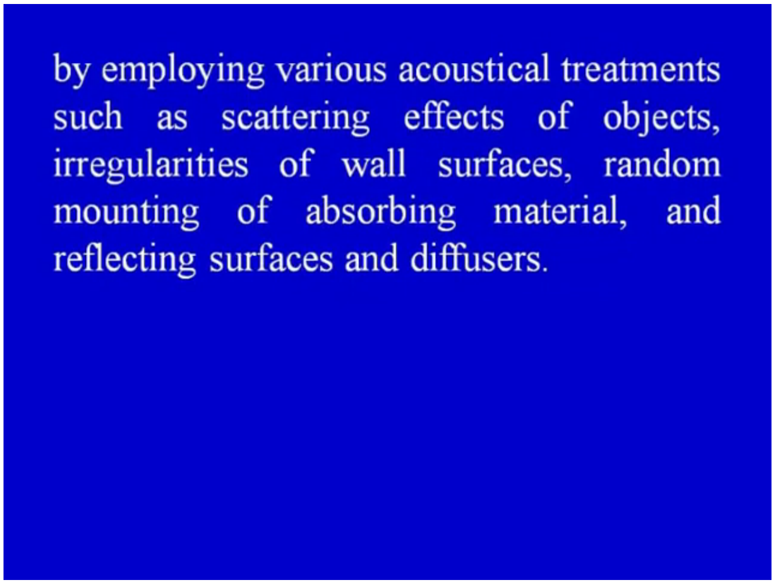

By employing various acoustical treatments such as, scattering of effects of objects, irregularities of wall surfaces, random mounting of absorbing material and reflecting surfaces and diffusers;

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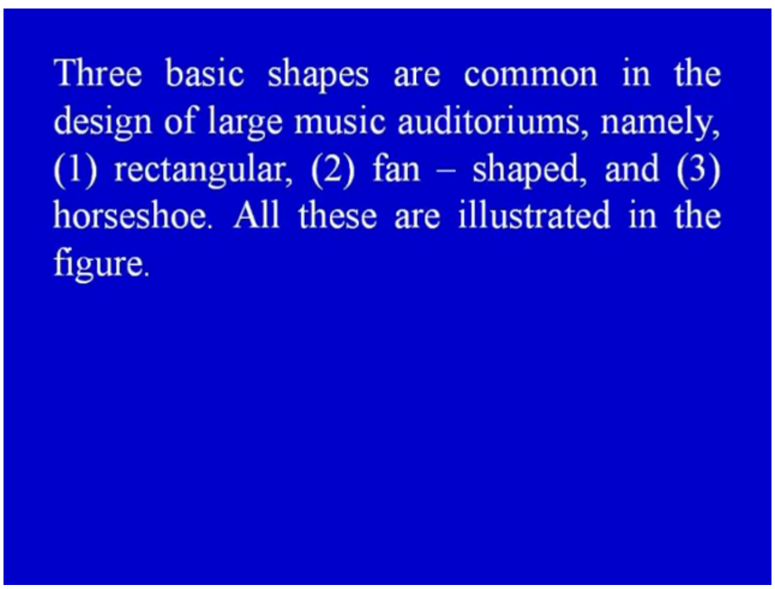

Three basic shapes are quite common in design of large music auditoriums, namely, rectangular or fan shaped or horseshoe shaped. All these are illustrated in the figure.

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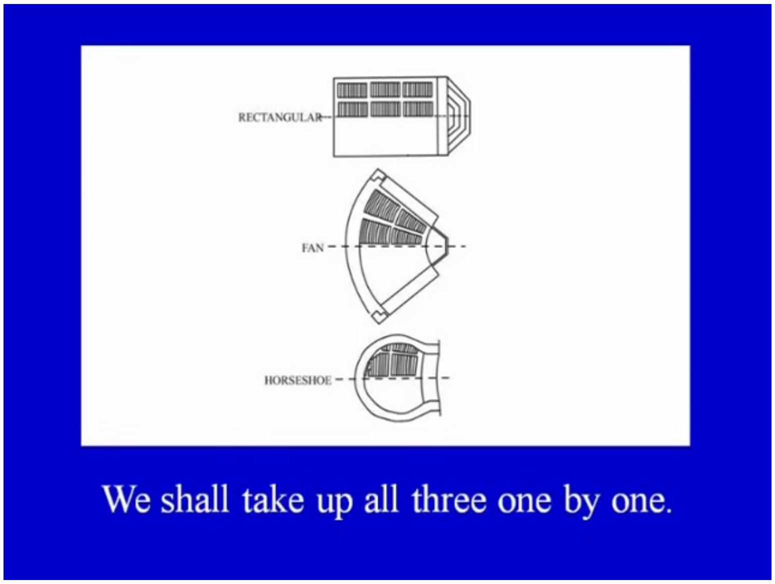

We shall take up all three one by one. A rectangular hall is quite traditional and is built to accommodate both small and large audiences.

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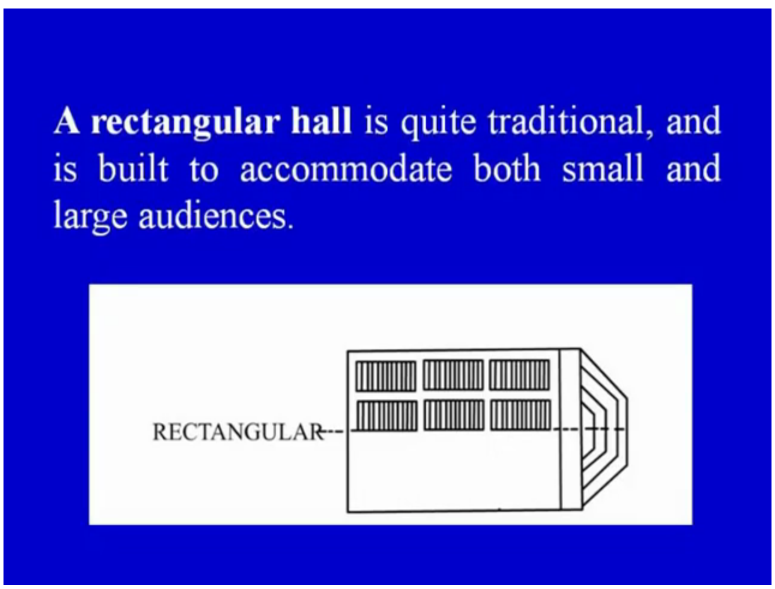

But these halls will always generate cross reflections flutter echoes between parallel walls.

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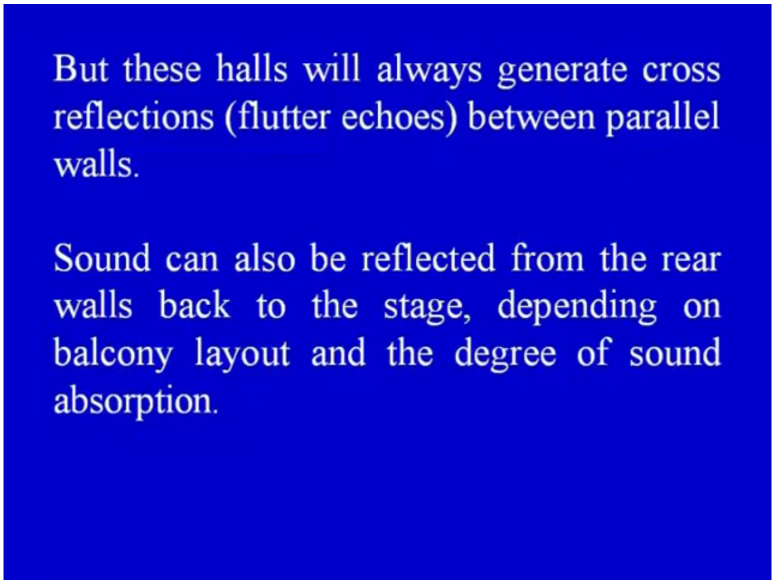

Sound can also be reflected from the rear walls back to the stage, depending on balcony layout and the degree of sound absorption.

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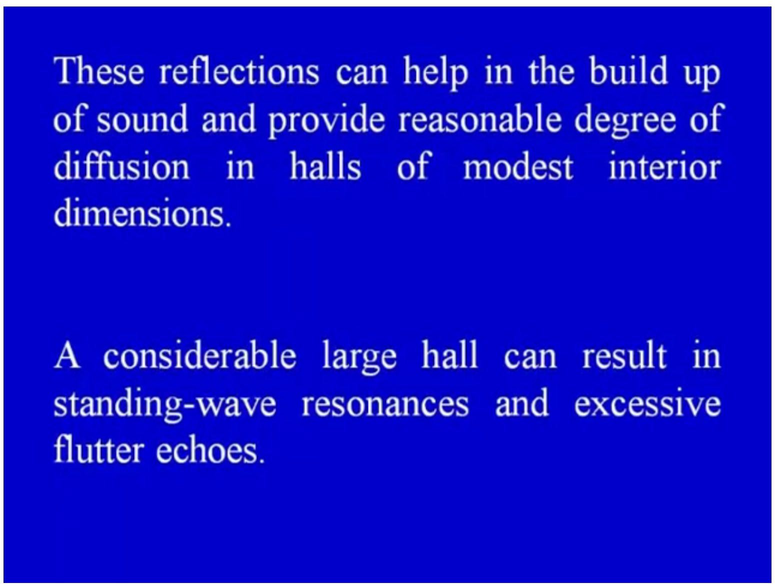

These reflections can help in the build-up of sound and provide reasonable degree of diffusion in halls of modest, interior dimensions. The considerable large hall can result in standing wave resonances and excessive flutter echoes.

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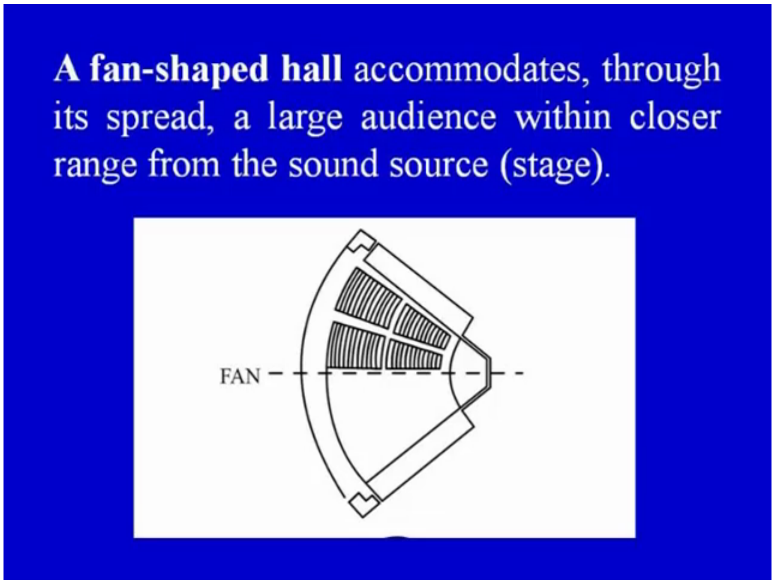

A fan shaped hall accommodates through its spread a large audience within closer range from the sound source from the stage.

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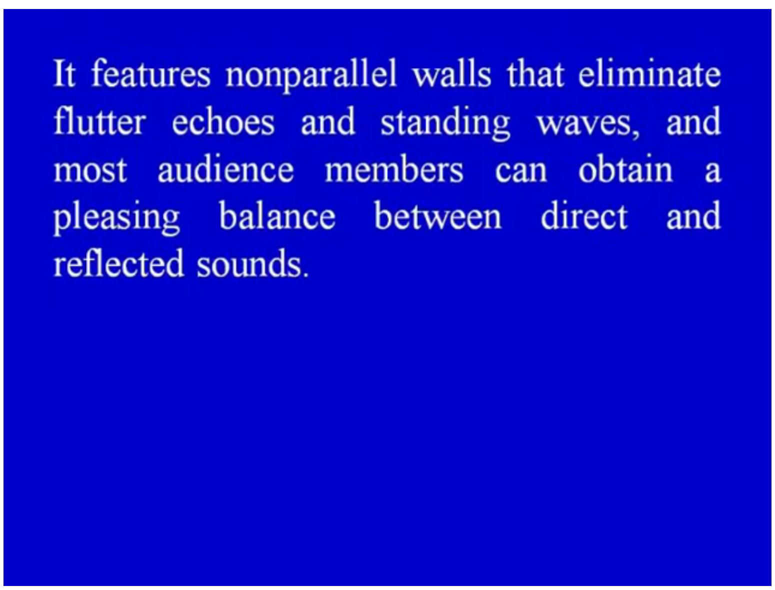

It features non parallel walls that eliminate flutter echoes and standing waves and the most audience members can obtain a pleasing balance between direct sound and reflected sounds.

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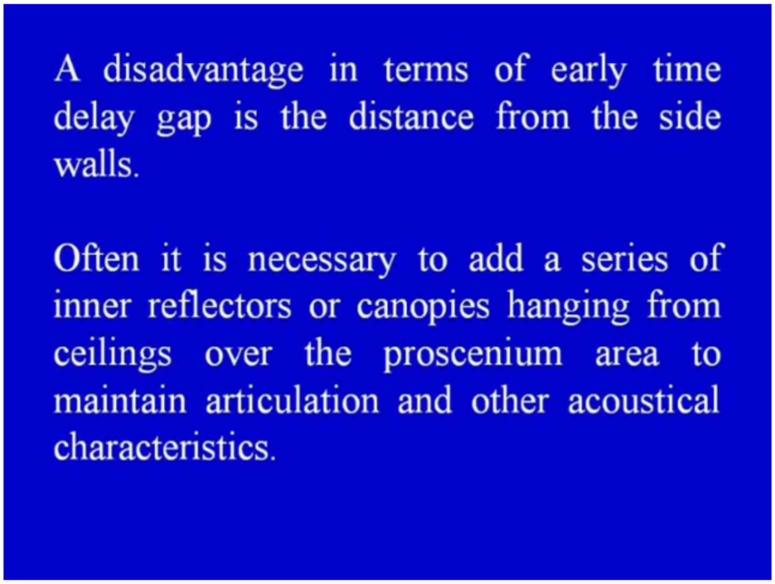

The disadvantage in terms of early time delay gab is the distance from the sidewalls. Often it is necessary to add a series of inner reflectors or canopies hanging from the ceilings over the proscenium area to maintain articulation and other acoustical characteristics.

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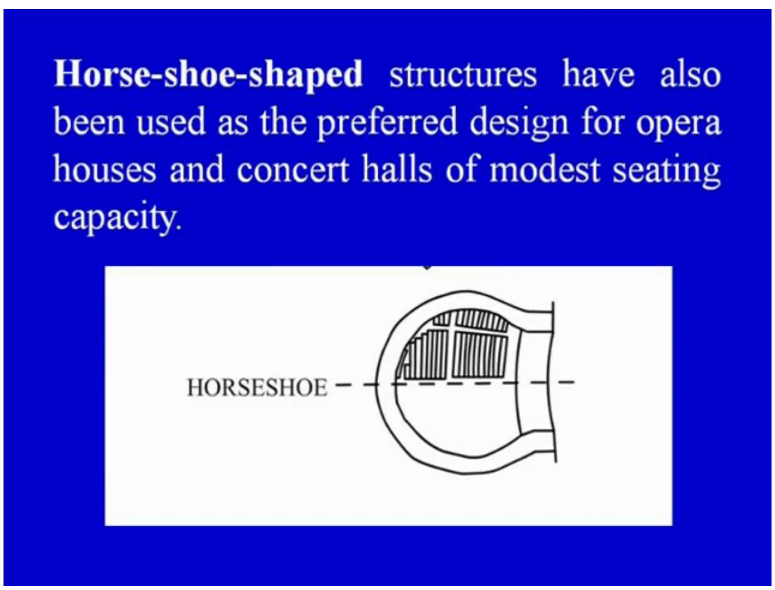

Horseshoe shaped structures have also been used as beautiful design for opera houses and concert halls of modest seating capacity.

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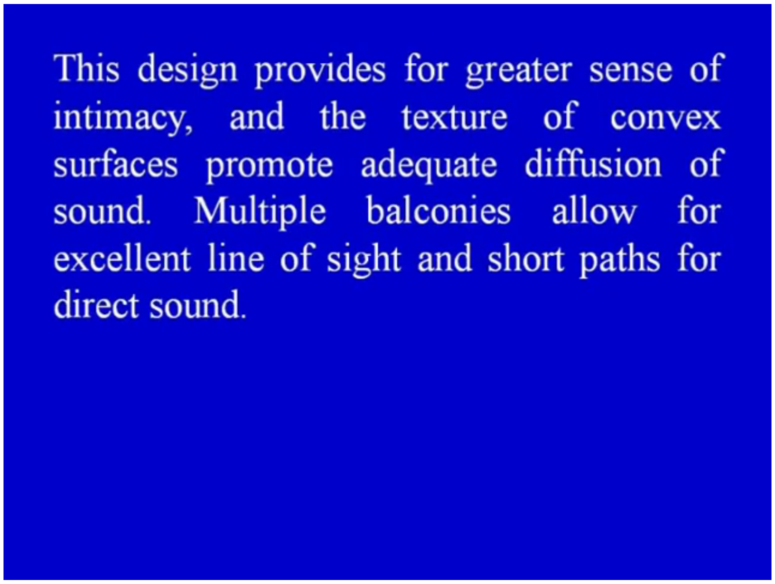

This design provides for greater sense of intimacy and the texture of convex surfaces promote adequate diffusion of sound. Multiple balconies allow for excellent line-of-sight and short paths for direct sound.

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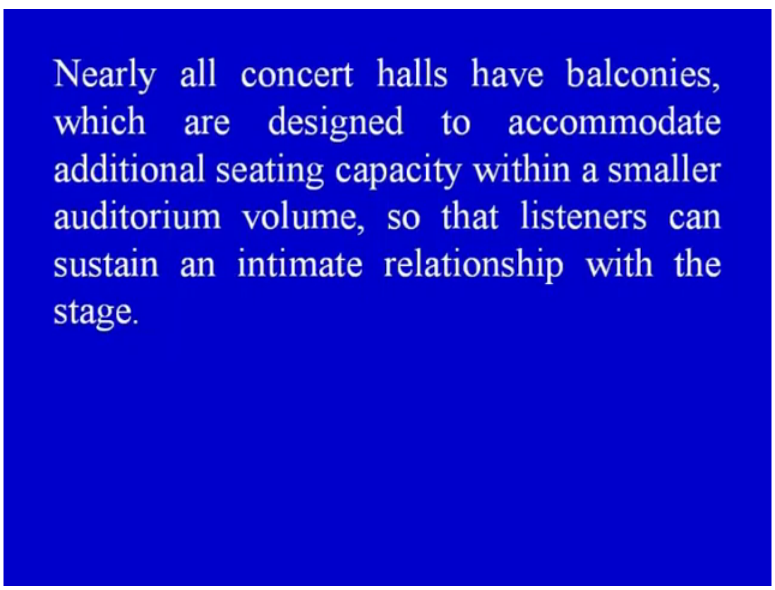

Nearly all concert halls have balconies which are designed to accommodate additional seating capacity within a smaller auditorium volume so that the listeners can sustain an intimate relationship they stage.

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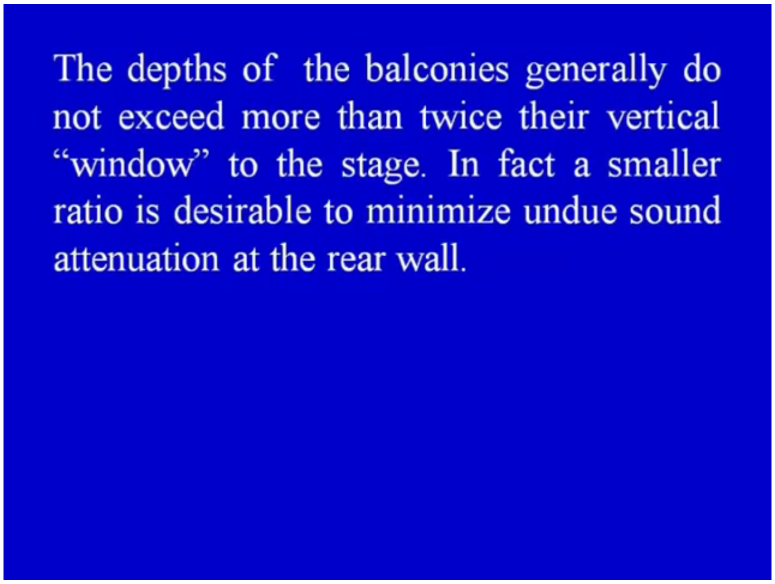

The depths of the balconies generally do not exceed more than twice their vertical window to the stage. In fact a smaller ratio is desirable to minimize undue sound attenuation at the rear wall of balcony.

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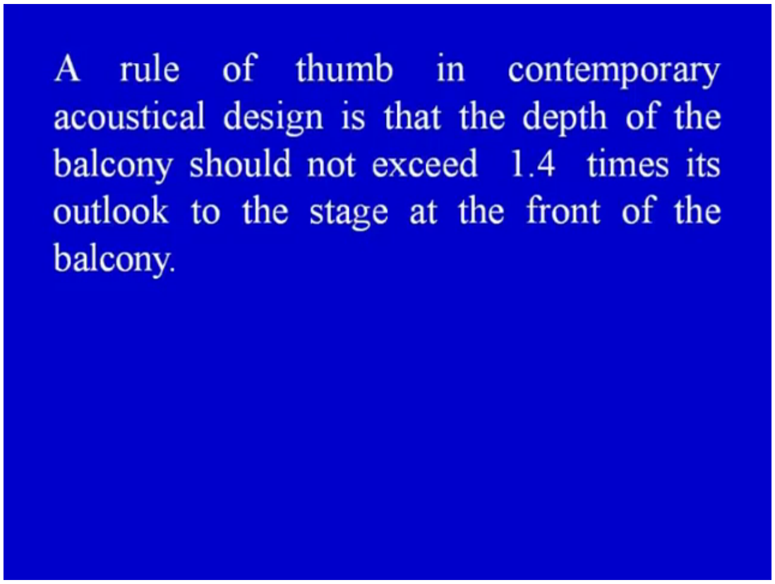

A rule of thumb contemporary the acoustical design is that the depth of the balcony should not exceed 1.4 times its outlook to the stage at the front of the balcony.

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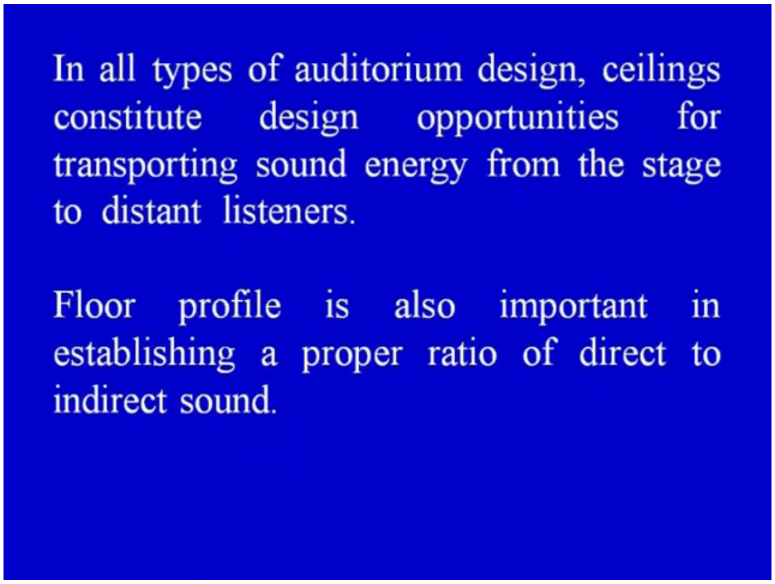

In all types of auditorium design, ceilings constitute design opportunities for transporting sound energy from the stage to distant listeners. Floor profile is also important in establishing a proper ratio of direct to indirect sound.

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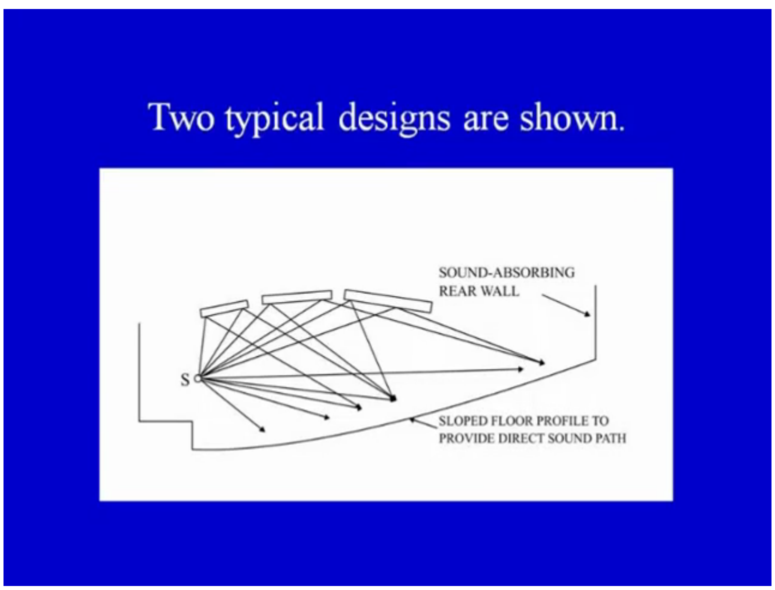

Two Typical designs are shown for the floor profiling and for the design of the ceiling.

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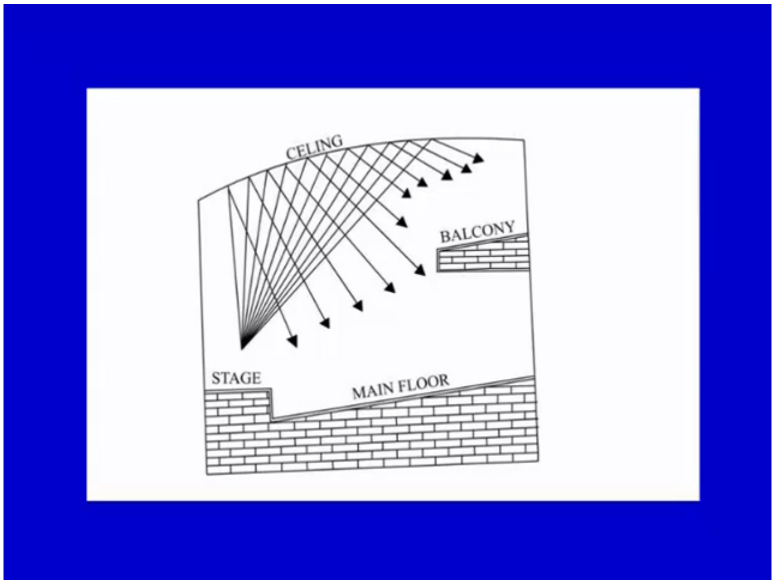

A balcony is also shown in this figure.

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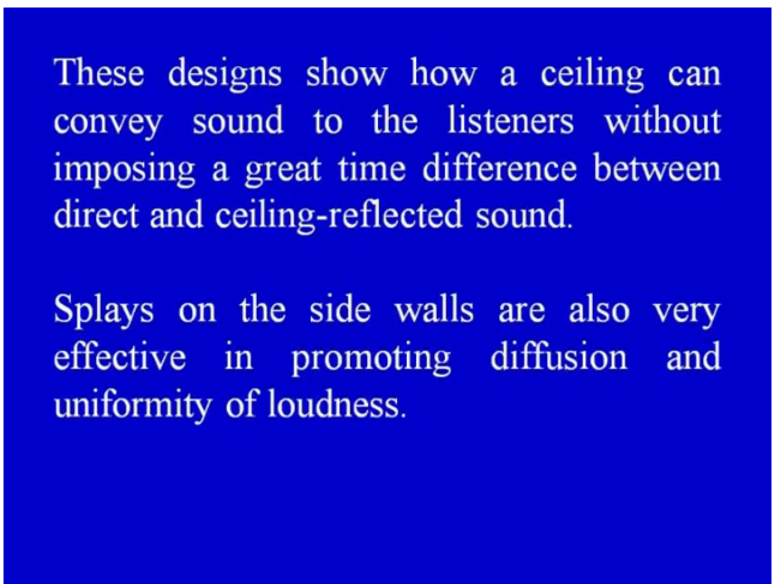

These designs show how a ceiling can convey a sound to the listeners without imposing a great time difference between direct and ceiling reflected sound. This splays on the side walls are also very effective in promoting diffusion and uniformity of loudness.

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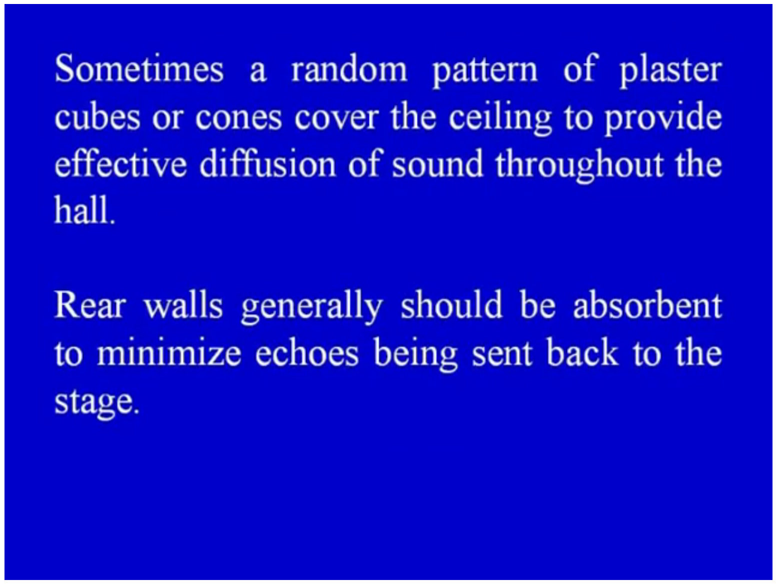

Sometimes random pattern of plaster cubes or cones cover the ceilings to provide effective diffusion of sound throughout the hall. Rear walls generally should be absorbent to minimize the echoes being sent back to the stage. Let us now consider the studio design.

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A broadcast studio must fulfill two major requirements: A good acoustic link between the microphone and the source and exclusion of noise and extraneous sound.

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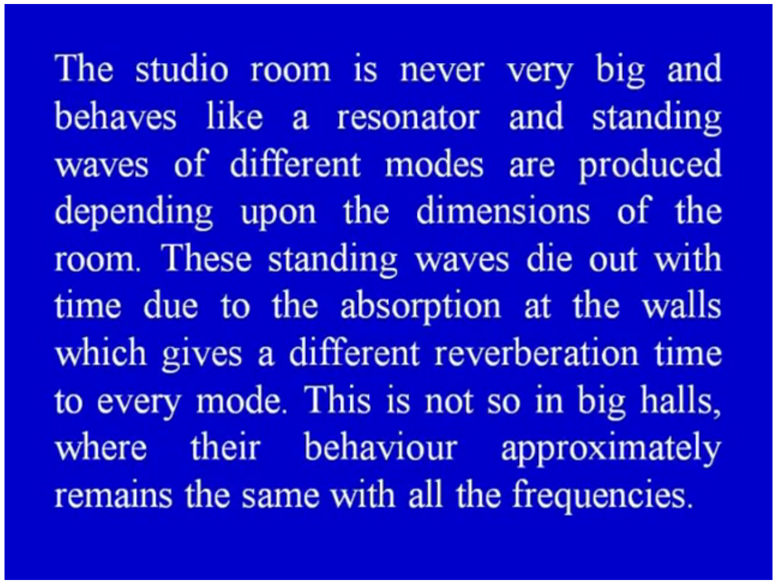

The studio room is never very big and behaves like a resonator and standing waves of different modes are produced depending upon the dimensions of the room. These standing waves die out with time due to the adoption at the walls which gives different reverberation time to every mode. You see, this is not so in big halls, where their behavior approximately remains the same with all the frequencies.

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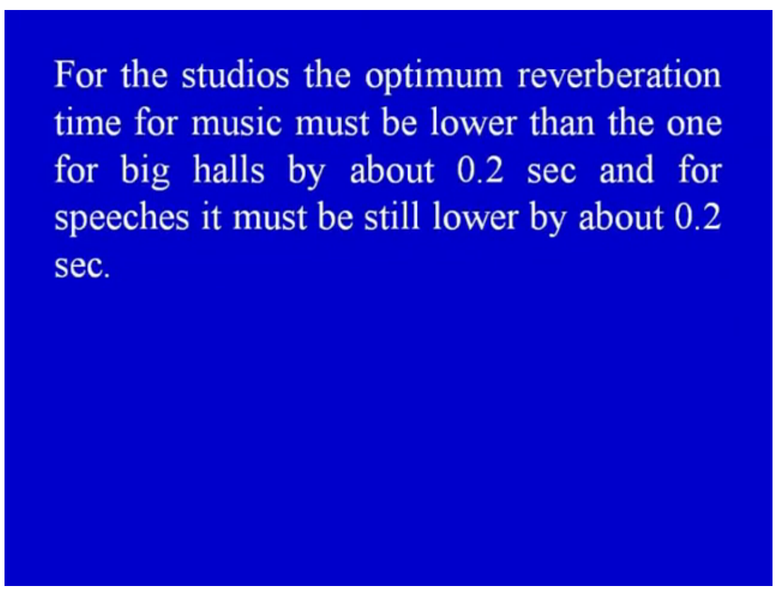

But the studio the optimum reverberation time, but music must be lower than the one for big halls by about 0.2 seconds and for the speeches it must be still lower, by another 0.2 seconds.

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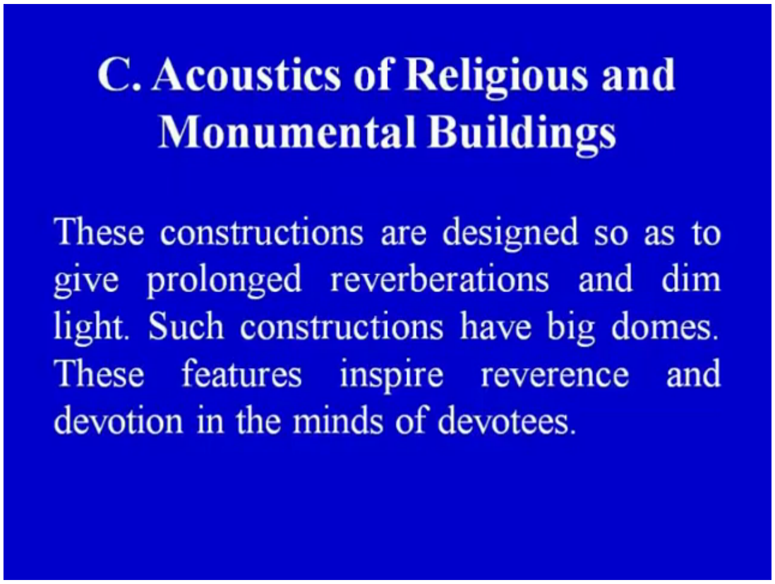

Acoustics of religious and monumental buildings: These constructions are designed so as to give prolonged reverberations and dim light. Such constructions have big domes. These features inspire however reverence and devotion in the minds of devotees. Such buildings are not good for speeches etcetera.

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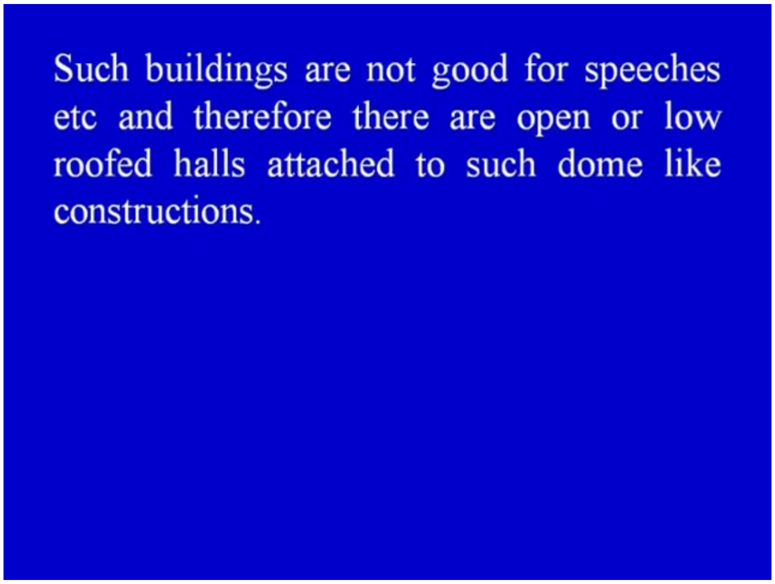

And therefore they are open or low-roofed halls attached to such dome like constructions. Let us see the acoustics of factory buildings.

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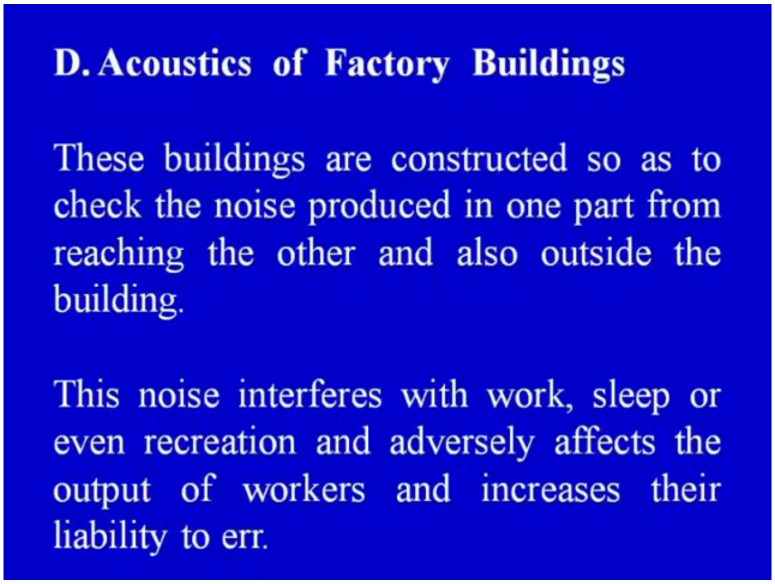

These buildings are constructed so as to check the noise produced in one part from reaching the other part and also outside the building. This noise interfere should work, sleep or even recreation and adversely effects the output of workers and increases their liability to err.

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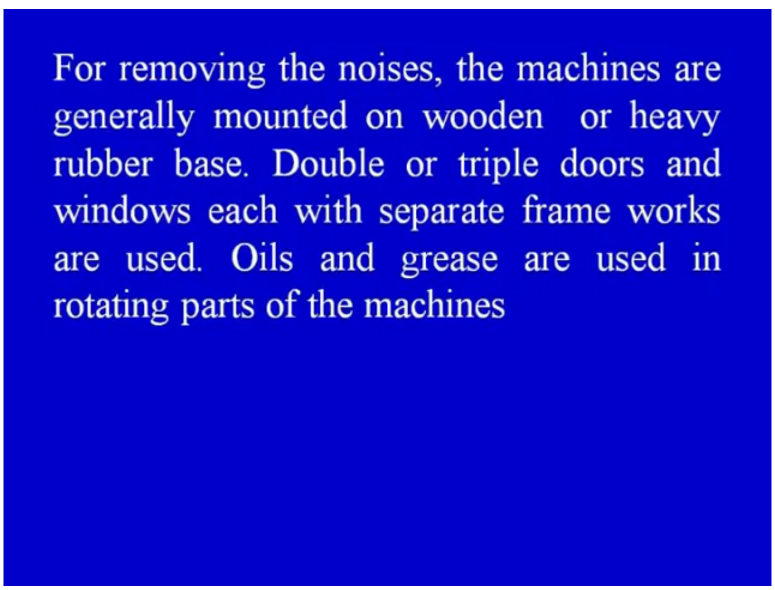

For removing the noises, the machines are generally mounted on wooden or heavy rubber base. Double or triple doors and windows each with separate frameworks are used. Oils and grease are used in rotating parts of the machines.

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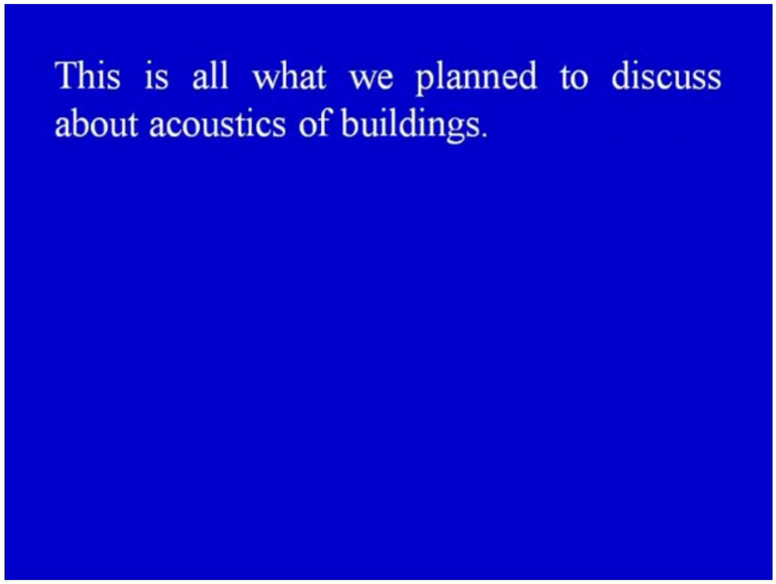

Ok and this is all what we planned to discuss your Acoustics of buildings. And with this we have come to the end of this lecture series and Acoustics. We have considered almost all aspects which need be covered. I hope we enjoyed these lectures. Thank you for listening and watching.