Speech and the Acoustic Design of Classrooms: A Case Study

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Abstract

In a classrom it is most importance to provide conditions so that it may be possible for the teacher to verbally communicate with his students. Volume, shape, materials, etc can adversely affect speech clarity; the consequent annoyance is not uncommon. Reverberation Time being the single most important factor in room acoustics, designers tend to compromise volume, shape, materials, etc in order to achieve good hearing conditions. Acoustical design by its very nature cannot be generalized in view of the widely varying parameters involved. The paper takes a close look at a particular classroom to examine the methodology that may be carried out wherever corrective measures are entailed.

Speech is one of the useful sounds as compared to disturbing acoustic sensations caused by traffic and machinery noise. Speech can, however, be a matter of considerable irritation depending on the intensity and content, or on the psychological condition of the recipient. Very loud or inaudible speech can be disturbing, as can be the boring or uninteresting talk. A listener may react to a speech depending on the state of his mind. Interesting or boring, the lecture in any classroom requires to be audible without distortion so that the entire class may be able to absorb its important contents.

In a room designed for speech it is obviously essential that every person in the room should clearly hear and understand the utterances. Moreover, the natural qualities of the speaker's voice should be preserved, meaning that the listener should recognise the owner of the voice.

The above may be achieved by

(a) making optimum use of the limited amount of acoustic power i.e. the intensity of the speaker's voice.
(b) ensuring that the background noise (which may mask the desired sounds) is at a level below 30 dBA.
(c) limiting the size and manipulating the shape of the room
(d) appropriate positioning of absorbing and reflecting surfaces
(e) maintaining the reverberation time of the space within a specified range.

The paper is based on an investigation prompted by observations, often bordering on complaints, that the lecture rooms in the Civil Engineering Building (of the Bangladesh University of Engineering

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References

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3. Moore, J.E., Design for Good Acoustics, 2nd Ed., Architectural Press, London, 1967, p 41
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6. Dept of Education and Science, Acoustics in Educational Buildings, HMSO, London, 1975, p 77
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and Technology, Dhaka) do not constitute acoustic conditions which may be termed as ideal for speech.

The experience of users of most classrooms of the Civil Building is that lectures are not clearly intelligible and words seem to be incomprehensible. The situation is most annoying in a situation where the speaker's intention is to transfer knowledge through verbal communication and the listener's occupation is to learn by hearing. The reasons for the disturbing situation could be as varied as the following possibilities

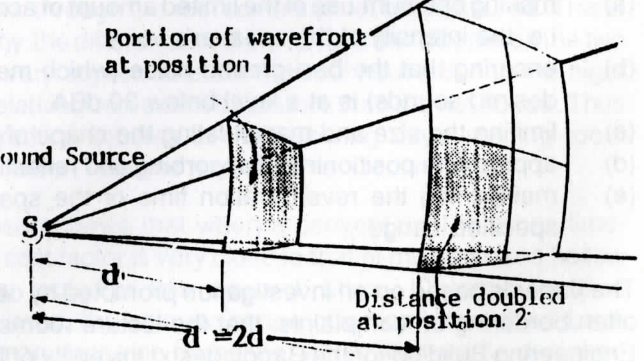
1. Weak voice of the speaker
2. Hearing problem of the listener
3. Room volume being in excess of 300,000 cft[1]
4. Room shape being conducive to acoustic problems
5. High reverberation time (RT) due to large volume and large areas of highly reflective surfaces.

Since the reported problem is of a general nature, possibilities 1 and 2 may be ruled out.

As a Case Study a typical room viz. Room 2004 of the Civil Building was selected.

The approximate dimensions of the room are 36.5 feet(length), 30 feet (breadth) and 12.25 feet (height). The calculated volume (V) of the room is 13,414 cft. This is very much within the limits of room volumes recommended for unaided voice.
Therefore, possibility 3 above can also be excluded.

Inverse Square law
Sound waves from a point source in the free-field are virtually spherical and expand outwards as shown below.



From Inverse Square law[2], it is known that sound weakens with distance and, therefore, rooms for unaided speech as in the Case Study should adopt square rather than linear plane proportions. Configurations of 36.5 and 30 feet demarcate a plainly square plan. The seating arrangement in the Case Study also satisfies the criteria that listeners (students) ought to be within an angle of about 140° subtended at the position of the speaker (teacher) because, speech being directional, the power of the higher frequencies falls off rapidly outside this angle.

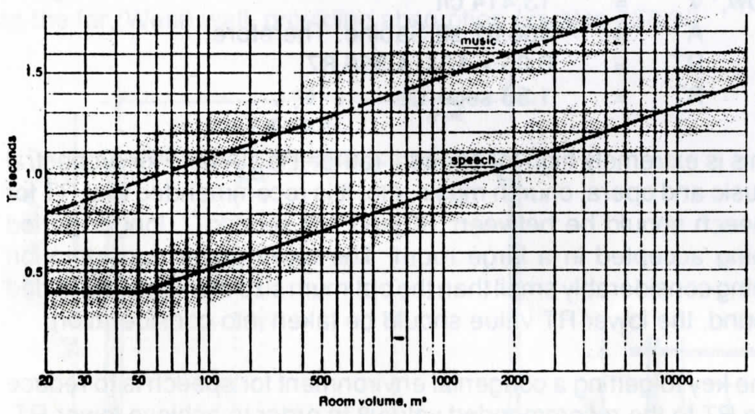
Echoes can occur if a reflected sound arrives .05 of a second after the original sound. This means that with reference to a point in the space the reflected sound has traveled about 50-60 feet more than the direct sound path.[3] In order for sound to be reverberant, the wave energy needs to be reflected as many times as possible by the bounding surfaces. Therefore, it is best to place the absorbents on surfaces that are likely to give rise to undesirable echoes and on those that may be conducive to multiple reflections, i.e. the further away form the speaker, the better.

Reflectors, on the other hand, should be near the speaker such that near-reflections may reinforce the direct sound without causing echoes.

Reverberation Time is the principal acoustical factor in the design of rooms. It is defined as the time taken for a sound to decay by 60 dBA after the source has stopped generating the sound.[4]

Excessive Reverberation Time (RT) reduces the clarity of speech by filling in the gaps between syllables.[5] Under situations of long reverberation time, the syllables (or sound) delivered earlier remain suspended long enough to blend with consecutive sounds causing a blurring effect. High RT occurs in a room because of

a. large room volume being disproportionate with absorption
b. highly reflective surfaces
c. lack of absorption



Optimum reverberation times at 500 Hz for speech and music related to volume

The optimum value of reverberation time can be a matter of debate. However, there is complete agreement that RT should be as short as possible for speech. Factors such as frequency and room volume give widely varying RT values for the same room use.[6] Generally, small rooms such as Room 2004 should be at the lower extreme of the RT range.

In order to calculate RT for Room 2004, it is necessary to find out the total absorption (A) of the room.

Surface	Finish Material	Area(Sft.) (rounded up)	Absorption Co-efficient	Absorption sft Sabine
Ceiling	plaster	1080	0.05	54.00
Floor	cement	602	0.05	30.10
Table	wood	305	0.10	30.50
Walls:				
North	open	108	1.00	108.00
	plaster	339	0.05	16.95
South	glass	72	0.05	3.60
	plaster	316	0.05	15.80
	wood	59	0.10	5.90
East	plaster	279	0.05	13.95
	blackboard	88	0.10	8.80
West	plaster	367	0.05	18.35
Air		$124m^3$	0.02	4.92
People		90 persons	0.40	36.00
Total Absorption, A				366.87

Existing Reverberation Time calculation

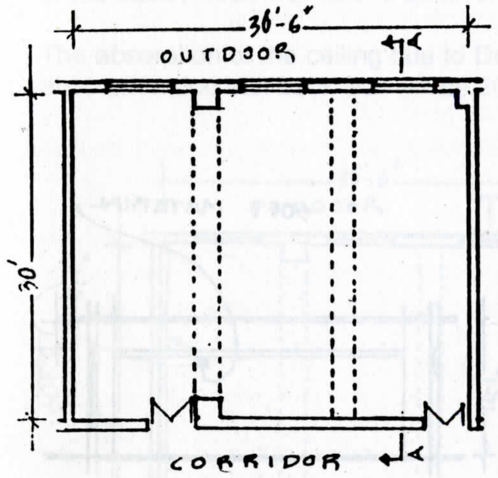
Now, V = 13,414 cft
A = 366.87 sft Sabine. Therefore,
RT = 0.05 × 13414/366.87
RT = 1.83 seconds

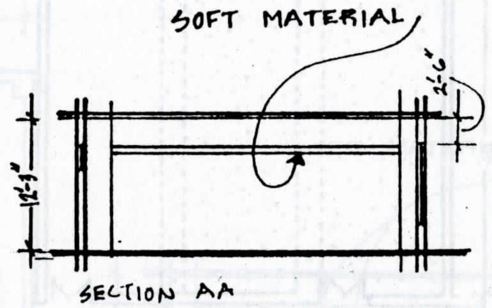
This is extremely high for speech, rather it is suitable for orchestral music and opera, church music, etc. It is recommended that RT for speech should be between .80 and 1.0 second[7], longer period being accepted in a large room. The room under consideration being considerably small than the optimum size allowed for unaided sound, the lower RT value should be taken into consideration.

The key to getting a congenial environment for speech is to reduce the RT to the recommended value.[8] In order to achieve lower RT, it is necessary to reduce the volume and also increase the absorption in the room.

Acoustic design is perfected by a trial and error method. It is, however, possible to design to the nearest recommended value and then put the theoretical to test. In the design of Room 2004, the following variations may be tested :

Design a: A suspended ceiling of a soft material (perforated partex board, gypsum board, etc.) is considered just below the beam bottom, i.e. 9.5. feet.

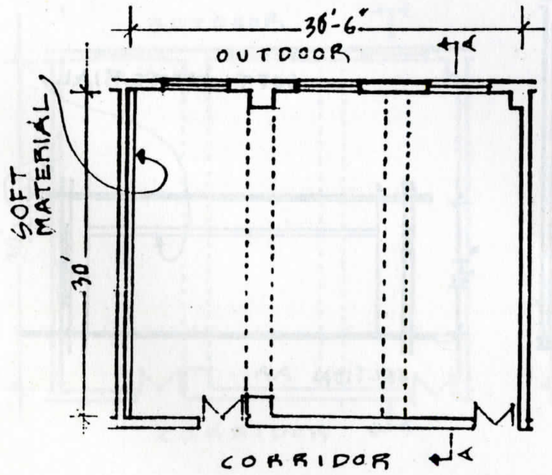


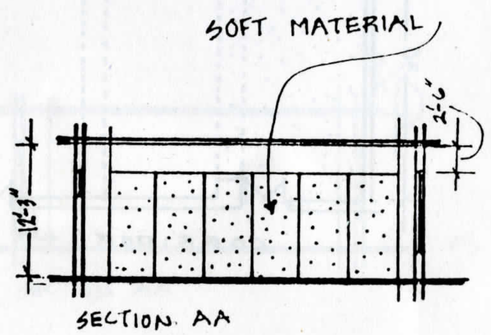


Volume will be reduced to Va = 10260 cft
Absorption due to soft ceiling is 1080×0.70 = 756
Therefore, total absorption Aa = 366.87 + 756—54
= 1068.87 sft. Sabine
Now, RTa = 0.05×10,260/1068.87
RTa = 0.48 second

Thus, it is not advisable to reduce the volume and apply a soft material on a suspended ceiling to the extent discussed.

Design b: If the volume is not reduced, but a soft material is applied on the far (West) wall, providing absorption equal to 256.90.





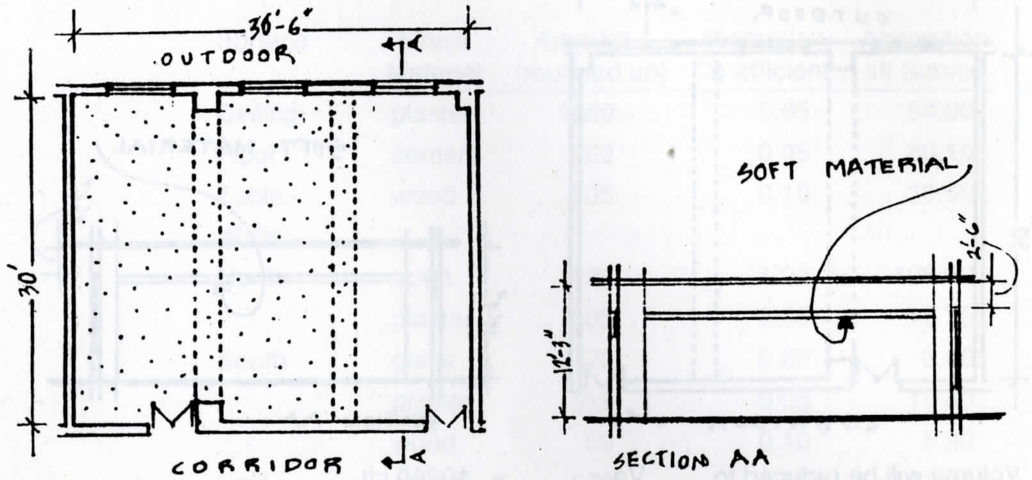
The total absorption becomes

Ab=366.87 + 256.90—18.35=605.42 sft Sabine

Now, RTb=0.05 × 13,414/605.42

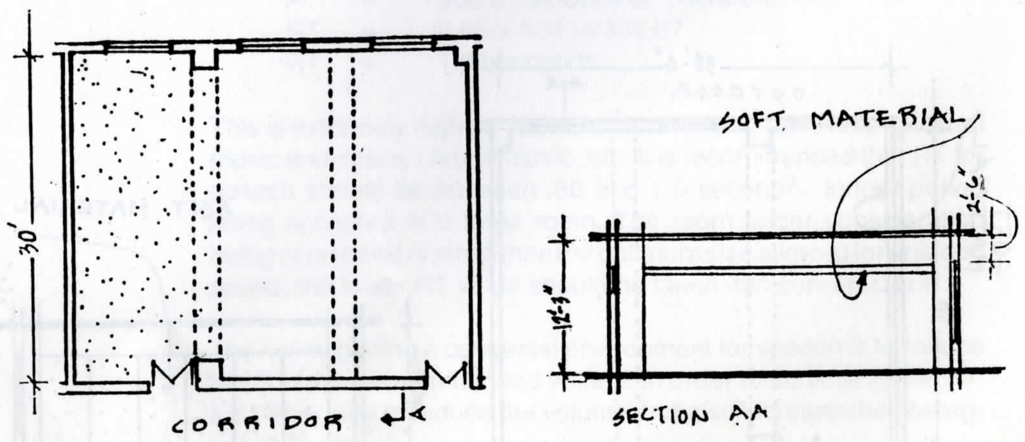
RTb=1.11 second

Design c: With 1/3 of the ceiling kept untreated, the absorption is 18 and 2/3 being treated with suspended ceiling of soft material, the absorption is 504. Thus, combined absorption of the ceiling is 522.



The volume is reduced to	Vc	=	1150 cft
The total absorption becomes	Ac	=	366.87 + 522 - 54
		=	834.87 sft Sabine
	Now, RTc	=	0.05×11,250/834.87
	RTc	=	0.67 second

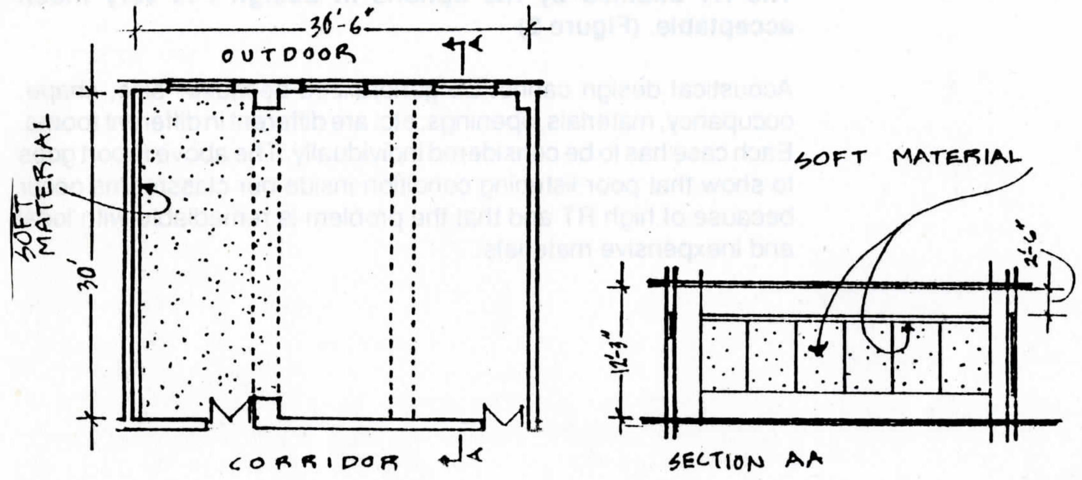
Design d: If the situation is reversed, ie 1/3 of the ceiling is treated with a suspended soft material providing absorption of 252; and 2/3 of the ceiling is kept as it is with absorption of 36, the absorption due to the ceiling will be 288.



The volume is reduced to	Vd	=	12240 cft
The total absorption becomes	Ad	=	366.87 + 288 - 54
		=	600.87 sft Sabine
	Now, RTd	=	0.05×12,240/600.87
	RTd	=	1.02 second

Design e: It Design d is repeated along with a soft treatment for part of the back (West) wall above sill level to protect form damage,

The absorption of the ceiling due to Design d will be 288 and the absorption due soft back wall will be 204.



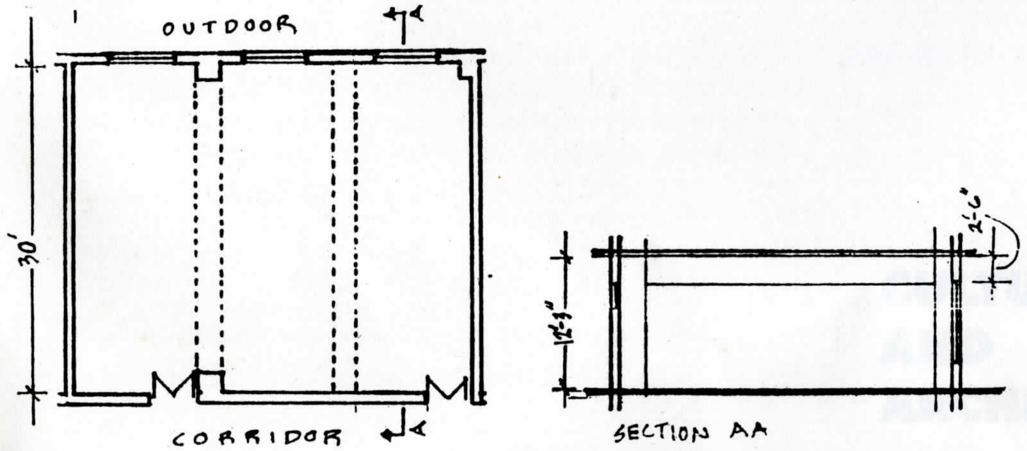
The total absorption becomes Ae = 366.87 + 288 + 204-54

=18.35+3.75=790.27 sft Sabine

The volume is as in Design d, ie Ve = 12240 cft

Now, RTe =0.05×12240/790.27 sft Sabine

RTe = 0.77 second



Design f: Gypsum Board being expensive, it may be advisable to apply locally available Partex on a suspended ceiling, the rear wall and the wall opposite to the windows. The absorption will be $\{(1080+292.5) * 0.25\} = 343.13$

The total absorption becomes

$$A_f = 366.87 + 343.13 - 54 - 18.35 + 3.75 = 641.40 \text{ sft Sabine}$$

The volume becomes $V_f = 10260$ cft

Now, $RT_f = 0.05 \times 10260 / 641.40$

$RT_f = 0.80$ second

The RT attained by the options in Design f is very much acceptable. (Figure 2)

Acoustical design cannot be generalized because size, shape, occupancy, materials, openings, etc. are different in different rooms. Each case has to be considered individually. The above report goes to show that poor listening condition inside our classrooms occur because of high RT and that the problem is remediable with local and inexpensive materials.