RESOURCE MATERIAL FOR ACOUSTICAL TREATMENT OF AUDIOLOGICAL TEST ROOMS : MATERIALS AVAILABLE IN INDIA

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INDEPENDENT PROJECT SUBMITTED AS PART FULFILMENT FOR THE FIRST YEAR
M.Sc. (Speech and Hearing)

All India Institute of Speech and Hearing
Mysore

May 1999

Dedicated to

my

family

Certificate

This is to Certify that this Independent Project entitled **"RESOURCE MATERIAL FOR ACOUSTICAL TREATMENT OF AUDIOLOGICAL TEST ROOMS : MATERIALS AVAILABLE IN** INDIA" *is the bonafied work in part fulfilment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M. 9820.*

Mysore
May, 1999

Dr. S. Nikam
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Certificate

This is to Certify that this Independent Project entitled **"RESOURCE MATERIAL FOR ACOUSTICAL TREATMENT OF AUDIOLOGICAL TEST ROOMS : MATERIALS AVAILABLE IN** INDIA" *has been prepared under my supervision and guidance.*

Mysore
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DECLARATION

This Independent Project entitled ***"RESOURCE MATERIAL FOR ACOUSTICAL TREATMENT OF AUDIOLOGICAL TEST ROOMS : MATERIALS AVAILABLE IN INDIA"*** *is the result of my own study under the guidance of* ***Dr. Asha Yathiraj,*** *Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other diploma or degree.*

Mysore
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Reg. No. M 9820

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INTRODUCTION

Acoustics is the science of sound, which includes its production, transmission and other properties (Suri, 1996). The physical principles of this science are utilized in architecture to attain distinct hearing conditions in enclosed spaces.

Acoustical environment plays an important role in the field of Audiology and Speech Pathology especially in conducting hearing activity tests. Several tests used to assess hearing status are carried out in audiological test rooms. A few of these tests include pure-tone audiometry, speech audiometry, central auditory processing disorders tests, otoacoustic emissions. Reliable measures of hearing sensitivity requires that ambient background noise levels in the test environment be sufficiently low to avoid interference with the measurements,. If the audiological tests are conducted without considering the ambient noise conditions inside and outside the room, there is every possibility of getting audiological results that are not valid. Also, for comparing the audiological results taken at different centers and at different times at the same center, it is essential that the ambient noise levels meet specific standards.

ANSI S3.1 - 1991 provides criteria for permissible ambient noise during audiometric testing. Table 1 gives the values of the acceptable noise level in the audiometric test rooms which should not be exceeded when one wishes to test to levels as low as 0 dBHL. Table 2 compares the values of acceptable noise levels of ANSI standards (S3.1 - 1991) and ISO standards (8253 - Partl, 1989) in audiometric test rooms when testing is expected to reach '0' dBHL for uncovered ears. There is very little difference between the acceptable noise levels of the two standards. Difference ranges from 0.5 to 4.5 dB. The ambient level in the test room is checked by using a sound level meter (SLM) that is sensitive enough to allow testing to levels as low as 8 dBSPL (Wilber, 1994).

Frequency (Hz)	Under Earphones Only (in dBSPL)	Sound Field or Bone Conduction (in dBSPL)
125	34.0	28.0
250	22.5	18.5
500	19.5	14.5
1000	26.5	14.0
2000	28.5	8.5
4000	34.5	9.0
8000	43.5	20.5

Table 1: Acceptable Noise Levels (in dBSPL for octave bands) in Audiometric test rooms when testing is expected to reach "O" dBHL (ANSI, 1991).

Frequency (Hz)	ANSI S3.1-1991	ISO 8253-Partl, 1989 (Assumes testing starts at 125 Hz)	Difference between the ANSI and ISO Standards (dB)
125	23.0	20.0	3
250	13.5	13.0	0.5
500	9.5	8.0	1.5
1000	9.0	7.0	2.0
2000	3.5	8.0	4.5
4000	4.0	2.0	2.0
8000	15.5	15.0	0.5

Table 2 : Comparison of Acceptable Noise Levels (in dBSPL for One Third Octave Bands) for ANSI and ISO Standards in Audiometric Test Rooms when testing is expected to reach 'O' dBHL for uncovered ears (eg. Bone Conduction or Sound Field).

To keep the levels of background noises within the maximum permissible sound pressure levels in audiometric test rooms various sound absorbing and sound insulating materials are used.

Sound Absorptive Materials :

Sound absorptive materials are used to reduce the noise levels within a room. Nabelek and Nabelek (1978) noted that when noise wave strikes the surface material, part of the energy is reflected back into the room. The remaining energy penetrates into the material where it is either converted into heat or passes to the space at the other side of the material. The greater the absorption, the larger the amount of the sound energy which is eliminated from the room.

Sound absorptive materials in rooms serve two purposes:

1. They reduce reverberation time and

2. They reduce the level of the background noise.

The sound absoptive coefficient is a measure of a given material. This coefficient is defined as the ratio of unreflected to incident energy and it can have values between 0 and 1. Materials having appreciable sound absorption coefficients (Usually greater than about 0.20) are referred to as sound absorbing. The absorptive coefficient for most materials varies with frequency Absorptive materials are usually soft and porous.

Sound Insulating Materials:

Nabelek and Nabelek (1978) noted that sound insulation material results in only a part of the incident acoustic energy striking a partition (eg. A door or a wall) passing through it to the other side. The rest is reflected back or dissipated in the partition as heat. So, these materials prevent external noises from entering in the room. The insulating properties of a material are expressed as Transmission loss (TL). The transmission loss is given by the difference between the SPL in air (air borne sound) at the sound source side of the partition and the SPL in air at the receiver side of the partition. Transmission loss is usually expressed in decibels (dB). The transmission loss of the partition depends on the material, thickness and number of layers of the partition, and the frequency of the sound and other factors. The insulation of a partition is determined by that part of it which has the smallest transmission loss.

Need for the study:

Knowledge about the audiometric rooms construction that meet the specifications of standards (ANSI S3.1 -1991 ; ISO 8253 - Partl, 1989) for ambient noise levels is limited. Though, several sound treated rooms have been constructed in India, majority of them do not meet the specifications given by the standards. Hence, there is a need to provide information about construction of audiological test rooms. Information is also required about the various indigeneously available acoustical materials which can be used in the construction. So, this present study is undertaken to provide information on sound treatment of audiological test rooms.

Aim of the study :

Aim of this project is to collect the following information for the sound treatment of audiological test rooms:

1. Information about the location and dimension of audiometric rooms.

2. Construction details of acoustical wall, floor, ceiling, doors observation windows, electrical connections for equipments, lighting and ventilation of the audiometric rooms and the materials needed for it.

3. Information on vibration isolation in audiological test rooms.

4. Different sound absorptive and sound insulating materials available in India.

5. Comparison of noise reduction coefficient of different sound absorbing materials. Calculated using either standing wave tube method / Reverberation chamber method, as reported by the manufacturer and / or research institutes ,and

6. Comparison of transmission loss of materials as reported by the manufacturer and / or research institutes.

REVIEW

1. ***LOCATION :***

Generally a sound treated room will be constructed in an ordinary room of a building. This particular room should be selected in such a way that it is away from heavy traffic or any other noise source in the vicinity (Murthy and Jacob, 1971). Frequently, a proposed space does not meet noise-level requirements, and modification of the area is necessary. Noise reduction is expensive, but in audiometry it can neither be dispensed with nor delayed. If large noise reductions are needed at the location chosen for testing, it may be necessary to consider an alternate location, or even to relocate the source of the noise. The inconvenience and expense of using an alternate location or relocating the noise source, must be balanced against the cost of reducing the noise level of the chosen environment (Snow, 1965).

2.DIMENSIONS:-

In designing the audiometric test room, consideration must be given to equating the area available with the equipment to be included and with the comfort of the person using the room (Snow, 1965). The overall size and dimensions of the sound treated room depends on the requirements, i.e., the various tests to be carried out, eg., puretone audiometry, speech audiometry, free-field tests, central auditory processing test (carried out using both live and recorded voice), otoacoustic emissions, brainstem evoked audiometry etc. If only one person is to be tested at one time, a relatively small room can be selected. In addition to the sound treated experimental room, a control room of proper dimension should be provided in case of two room situation (Murthy and Jacob, 1971).

Murthy and Jacob (1971), suggested an experimental room of the size of 10' 8' 8' for conducting all the tests. If the test is to be administered to a group (group audiometry), the dimension for work area will differ (Snow, 1965).

Dimensions of single rooms and double rooms as recommended by IAC Bulletin 5 0003 5, (1993) for audiological reasons are given in Table 2.1 and Table 2.2 respectively. Table 2.3 gives the dimensions of audiological test rooms suggested by other experts (Murthy and Jacob, 197 l;Bhattacharya, Tripathi and Chatterjee,1983; Murthy, Murthy and Ramanjaneyulu 1977).

Dimensions (Ft - in)

Inside			
Sl. No.	**Width**	**Length**	**Height**
1	3' - 4"	3'-0"	6' - 6"
2	4' -_0"	3'-4"	6'-6"
3	6'-4"	6' - 0"	6'-6"
4	7-4"	7'-0"	6' - 6"
5	9'-0"	8' - 4"	6' - 6"
6	10' - 0"	9' - 4"	6'-6"

Table 2.1 : Single room dimensions recommended by IAC Bulletin 5.0003.5 (1993).

From the above data it can be concluded that audiometric rooms of single room situations can be constructed with an inside dimension as small as 3'-4" x 3'-0" 6'-6" and an inside dimension as large as 10'-9"x 9'-4"x 6'-6" as per IAC Bulletin 5. 0003.5 (1993).

Dimensions (Ft - in)

	Control Room			Experimental Room		
Sl. No.	**Width**	**Length**	**Height**	**Width**	**Length**	**Height**
1	4'-0"	6'-4"	6' - 6"	6'-0"	6'-4"	6'-6"
2	5'-4"	7'-0"	6'-6"	7-4"	7' - 0"	6'-6"
3	7'-0"	8'-4"	6'-6"	9' - 0"	8'-4"	6' - 6"
4	8'-0"	9' - 4"	6'-6"	10" - 0"	9'.. 4"	6'-6"
5	6' - 0"	7' - 4"	7'-9"	6' - 4"	6'-0" 1	6' - 6"
6	7'-0"	8'-4"	7' -.9"	7'-4"	7'-0"	6'-6"
7	7'-8"	9'-8"	7'-9"	9'-0"	8' - 4" 1	6'-6"
8	8'-8"	10' - 8"	7' - 9"	10' - 0"	9'-4"	6'-6"

Table 2.2 : Shows the dimensions of two suit audiometric rooms, as given in IAC Bulletin 5.0005.5 (1993).

Sl.No.	Source/Audiological Test centers	DIMENSIONS	
		Experimental Room	**Control Room**
1	Murthy and Jacob0971), AIISH	51/2'x5'x7'	51/2'x5'x7'
2	Bhattacharya, Tripathi and Chatterjee(1983), Ahmedabad	3.58mx3.33mx2.92m	2.08mx1.80mx2.90m
3	Murthy, Murthy and Ramaanjaneyulu (1976) ,Manipal	9'x12	10'x9'

Table 2.3 - Dimensions of audiological test rooms in different centers in India.

From the above tables it can be concluded that for two suit audiometric rooms, an experimental room can be constructed with dimensions as small as 6'-0"x6'-4"x6'-6" (recommended by IAC bulletin 5.0003.5,1993) and as large as 11'x10'x9' (given by Bhattacharya, Tripathi and Chatterjee,1983)and also an control room can be constructed with dimensions as small as 4'-0"x6'-4"x6'-6" (IAC Bulletin 5.0003.5 1993) and as large as 8'-8"x10'-8"x6'-6" (IAC Bulletin 5 0003 5,1993).

To conclude, dimensions of an audiometric room should be decided with respect to the space available, money, number of equipments to be placed, furnitures to be kept in it and also the number of persons who will be present inside the room while testing a patient.

3. WALLS :

Walls are the most commonly employed sound barrier systems. The noise reduction or the transmission loss of the walls will vary depending upon the physical acoustical properties of the wall.

Kind of Wall :

Depending on the required sound insulation single, double, composite wall or metal stud wall can be constructed (Suri, 1966; Murthy and Jacob, 1971 ; Cook and Chrzanowski, 1956)

(a) Single Wall *:*

Single wall is the simplest kind of wall. According to Miller and Montone (1978) factors which influence the sound transmission loss characteristics of a single wall are following

(i)Mass

(ii) Stiffness

(iii) Resonances

(iv) Damping

(v) Coincidence effect

(i)Mass :

Cook and Chrzanowski (1956) denoted that the transmission loss of a single wall increases with increase in the mass. Suri (1966), Cook and Chrzanowski (1956), Egan (1972) and Miller and Montone (1978) noted that in order to increase the sound insulation of a wall by about 4 to 5 dB, the mass must be doubled. This is known as the empirical mass law.

(ii) Stiffness :

Cook and Chrzanowski 1956, noted that transmission loss at low frequencies increases with increase in stiffness of the wall.

(Hi) Resonances :

Cook and Chrzanowski 1956, reported that when the sound incident on a wall is of the same frequency as one of the natural frequencies of the wall, the wall will resonate and vibrate at much larger amplitude than at other frequencies. To avoid the effect of resonance it is desirable to have a low natural frequency of the wall. This can be obtained by increasing the mass of the wall.

(iv) Damping Effects :

Cook and Chrzanowski 1956, noted that damping has a strong effect on the transmission loss. It is observed that a wall with small damping, when struck, vibrates at a natural frequency for a longer time as compared to a highly damped wall. Thus, to increase the transmission loss, the damping should be increased

(v) Coincidence Effect:

Cook and Chrzanowski (1956), and Miller and Montone (1978) described the coincidence effect as the effect which occurs at frequencies greater than a certain critical frequency (fc) , which is the frequency where the wavelength of sound in a panel is the same as that in air. At these frequencies the phases of incident sound waves will coincide with the phases of vibration of the wall and result in a marked reduction in sound insulation.However, Cook and Chrzanowski 1956, noted that this effect can usually be neglected as the influence of coincident effect reduces in building because of studing, discontinuities, damping in walls and also the sound waves in rooms are usually more or less random.

Fig 3.1 shows the transmission loss curve which is generally seen for most of the single walls (Egan,1972) . This figure shows that the transmission loss curve of single walls consists of the following three basic parts or regions.

(1) Low frequency mass controlled region at 6dB/octave slope
(2) Constant plateau of Transmission Loss (TL) region, which depends on bending stiffness and internal damping.
(3) Mass controlled region above plateau at 10 dB/octave slope.

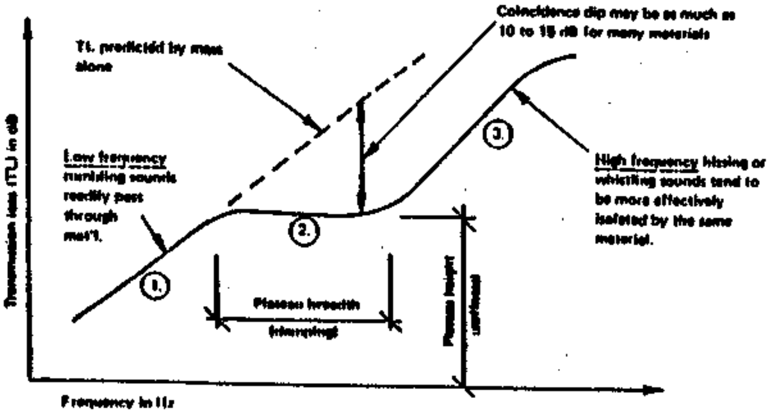


Fig 3.1: Typical transmission loss curve for most single walls (Egan, 1972)

Thus, for a single wall construction to have maximum transmission loss it should have more mass, high stiffness, high internal damping and low resonance frequency. Suri (1956) noted that a transmission loss up to 50 dB can be obtained by a single wall constructed using homogeneous material and for this purpose 9" to 13" bricks can be employed.

In Table 3.1 specifications for single leaf walls or partitions given by Bhandari, Srivastava and Dhabal 1985, (Central building research institute, Roorkee) is given. From the above table it can be concluded that a 38 cm thick dense concrete wall has the highest average transmission loss followed by a 35 cm thick brick wall (with modular brick).

Sl.No.	Single leaf walls or partitions	Weight Kg/m^2	Average transmission loss (dB)
1	22.8 cm brick wall	488	50
2	30.48 cm brick wall (with modular bricks)	590	53
3	35 cm brick wall (with modular bricks)	707	53
4	25.4 cm dense concrete (used in the reduction of high intensity noise)	634	52
5	38 cm dense concrete	927	55
6	11.4 cm brick wall with 1.25 cm plaster on both sides	268.4	45
7	20 cm hollow dense concrete block with 1.25 cm plaster on both sides	244	45
8	7.6 cm hollow clay block with 1.25 cm plaster on both sides	108-122	36-39
9	7.6 cm clinker block with 1.25 cm plaster on one side	108-122	36-39
10	5 cm clinker block with 1.25 cm plaster on both sides	108-122	36-39

Table 3.1: Specifications for single leaf partitions or walls given by Srivastava, Bhandari and Dhabal (1985).

(b) Double Walls *:*

Miller and Montone (1978), described double wall as an acoustical barrier constructed of two panels separated by an air space. The two walls are tied together by means of ties of corrosion proof metal, brick or concrete blocks. These experts noted that the sound transmission toss, of a double wall for mid frequencies is approximately equal to the TL of a single wall equal in weight to the two walls plus an air space correction factor.

Cammer and Durhammer (1934) proposed that with increase in the width of the air gap generally gives an increase in the TL of the wall is observed . But there is an optimum size for the air gap at which maximum transmission loss can be obtained. This optimum value for air gap is about 10 cm and further increase after 10 cm decreases theTL.

Transmission loss for double wall decreases for air gaps of 10 to 20 cm and further increase in air gaps again increases the TL. The TL decreases for air gaps of 10 to 20 cm due to resonances caused by the standing wave between the two leaves of the wall (Utley and Mulholland ,1968).They found that the mean transmission loss of a double wall is only 5-6 dB above that for a single wall when the air gap is reduced to a minimum. Also,by placing sound absorbent around the edges of the air space the mean transmission loss can be raised by about 6dB.

Turner and Robinson (1967) introduced a urea-formaldehyde foam known as "U Foam" in to the cavity of a 2" gap and an improvement of 3dB was seen in the foam-filled wall for frequencies above 400 Hz as against an unfilled cavity wall.

When air cavities are employed with cross connections between the two partitions, these cross connections should be kept as few as possible and made preferably of a flexible material or wire (Suri,1966)

Thus for a double wall construction to have maximum transmission loss it should have more mass, high internal damping, high stiffness, an air space up to 10 cm or above 20 cm, fewer cross connections between the partitions in case of semi-discontinuous construction and introduction of an absorbent material in the cavity.

In Table 3.2 specifications for double walls given by Srivastava, Bhandari and Dhabal, CBRI (1985) is given From this table it can be concluded that a two 11.4 cm brick leaves with 5 cm cavity have the maximum average transmission loss. However, use of double 10 cm clinker block with 5 cm cavity, thin wire ties, 1.25 cm plaster on both sides leads to only marginal reduction in average transmission loss.

Note : For detailed information on cavity wall construction refer to notes published by CBRI on thin cavity walls.

Sl.No.	Double wall	Weight Kg/m^2	Average transmission loss (dB)
1	Two 11.4 cm brick leaves with 5 cm cavity (wire ties)	488	50-53
2	Double 10 cm clinker block with 5 cm cavity, thin wire ties, 1.25 cm plaster on both sides	312	50
3	Double 5 cm clinker block with 5 cm cavity, thin wire ties, 1.25 cm plaster on both sides	185	47
4	Double 7.6 cm clinker block with 5 cm cavity, thin wire ties, 1.25 cm plaster on both sides	244	49
5	Double 5 cm wool slab with 5 cm cavity, thin wire ties, 1.25 cm plaster on both sides	97.6	42

Table 3.2: Specifications for double or cavity walls given by Bhandari, Srivastava and Dhabol (1985).

(c) Composite Wall :

Suri, 1966 reported that , a composite wall can be constructed using the principles and methods involved in single and double walls construction to obtain any sound insulation desired .Maximum value is obtained when all the layers of alternate. Porous and rigid materials are separated by an air space. The value, then, approaches approximately the sum of the values of individual units. Construction of a composite wall occupies more space and also is more expensive. Table 3.3 gives the specifications for composite walls as given by Bhandari, Srivastava and Dhabal, 1985. It is observed that an average TL of about 50 dB can be obtained by using composite walls.

Sl.No.	Composite wall	Average TL (in dB)
1	Basic wall masonry weighing at least 107 kg/m2. On one side of basic wall an additional leaf consisting of 1.25 cm gypsum lath mounted with resilient clips, 2 cm sanded gypsum plaster	50 dB and more
2	Composite wall as in 1, except gypsum lath supported on wood furring	45to49dB

Table 3.3 : Specifications for composite wall given by Bhandari, Srivastava and Dhabal, 1985.

(d) Metal lath partitions :

Metal lath partitions constructed are of various types (Suri ,1966).They are constructed around single panels or two separate panels. The partitions thus constructed are either solid, hollow or double wall construction with and without cross ties. These partitions are light in weight. Efficiency of a double metal lath and plaster partition varies according to the manner in which the assembly is insulated form the surrounding construction.

Very frequently pre fabricated metal studs are used, either staggered or erected in two rows. Although the effectiveness of a partitions as a barrier to the transmission of sounds, is not dependent upon their rigidity, it is important that the panel faces be constructed in such a manner that they will be sufficiently stiff to resist impact and other lateral forces (Suri, 1956).

Suri 1956, reported that air space can be filled with homogeneous cellular type material (eg. mineral wool quilt or an insulation board) to improve the transmission loss. Non-cellular type filler material should be avoided in the air space as they tend to form a bridge across the two partitions and reduce the insulation considerably.

Green and Cameron (1982) studied the effect of following parameters on acoustical behaviours of unfilled steel stud partitions.

(1) Surface density : With increase in surface density the transmission also increases. Fig 3.2 depicts the effect of surface density on the sound transmission loss (STL) and sound transmission class (STC) for various stud sizes at different frequencies.

(2) Mass of the partition (the panel thickness): Both STC and STL increases with increasing mass and also a shift is seen in the location of coincidence dip to a lower frequency due to the increased wall stiffness.

(3) Stud size(Panel separation) : STC and STL increases with increasing stud size and the increase with increasing stud size is greatest between the 2 1/2" and 1 5/8". steel stud partitions.

(4) The methods of attaching the gypsum board to the studs can have a significant effect on STL. Gluing the board to the studs with a rigidly curing adhesive, rather than using screws, significantly lowers the STL for multilayer partition. The method of attaching the second layer of board to the first also effects the STL. It is found that if the second sheet is attached to first with screws alone, the STC is increased at most frequencies as compared to use of rigidly curing adhesive.

Green and Sherry (1982) found that adding glass fiber batts to the cavity space increases the STC by 5 to 8 points. The largest benefit occurs at the low and mid frequency bands but the exact increase depends also on the partition stiffness. The heavier and stiffer the wall the less the sound transmission loss increase when the glass fiber is added. They also found that the increase in the stud size from 2 ½″ to 3 5/8" does not significantly increase either the sound transmission loss or the sound transmission class of filled steel stud partitions.

Green and Sherry (1982), studied the sound transmission loss of partitions constructed using gypsum wall board and 2"x 4" . wood studs with or without glass fiber batts in the cavity spaces. Fig 3.2 shows the sound transmission of this partition. It is seen that transmission loss is maximum with frequencies 1K Hz and 2K Hz and also transmission loss increases with increase in surface density of materials.

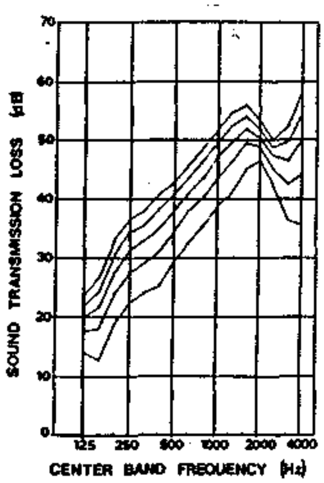


Fig 3.2 : Sound transmission loss of wood stud partition with second layers of gypsum wallboard attached with adhesive, first layers screw attached (no cavity filler ,stud 16" o.c.); the curves (from lowest to highest) correspond to surface densities of 4, 6, 8, 10 and 12 lb/ft^2 and STCs 32, 37,41,43, and 46, respectively (Green and Sherry,1982).

Green and Sherry (1982) found that for multilayer wood stud partitions gluing second board to the first is preferable to attaching the board with screws, especially for high density walls. They found that a slight increase in STC can be obtained by increasing the stud spacing from 16 to 24-in. on centers. They suggest an addition of a resilient channel to one side of the filled wood studs to increase the sound transmission class.

Wong and Qiang (1982) studied the effects of resilient pad strip attached on both sides of the stud and found an improvement in transmission loss for double panel structures by 8 dB for wood stud partitions and by 4 dB for metal stud partitions.

Table 3.4 and Table 3.5 gives the transmission loss for different metal stud walls as given by Bhandari, Srivastava, Dhabal (1985) and India Gypsum Company (1993) respectively. It is seen that gypboard metal stud separating wall [Gypboard fixed horizantally and outer layer of 12.5 mm, gypboard fixed vertically to the outside faces of two 48 mm metal frames (48s.53) which are braced at mid height 25 mm glass wool mat in cavity studs at 600 mm centers] have the maximum sound insulation among all the metal stud walls.

Sl.No.	Metal Stud Wall	Weight Kg/m^2	Average transmission loss (dB)
1	Stud wall -5 by 10cm studs. On each face 1.25 cm gypsum lath mounted with resilient clips, 1.25 cm gypsum plaster, paper wrapped mineral or glass wool batts between studs	—	50 dBand more
2	Staggered stud wall-5 x 7.6 cm studs at 40.6 cm centers on (a) Gypsum plaster 2 cm on expanded metal lath on opposite sides staggered 5 10 cm wood studs 40.6 cm P.C. (b) 1.25 cm lath and 1.25 cm sanded gypsum plaster on opposite sides of staggered 5 x 7.5 cm studs at 40.6 cm O.C on 5 x 15 cm plate; paper wrapped mineral wool batts between one set of studs.	—	50 dBand more 50 dB and more
3	Staggered stud walls (a) Gypsum wall board 1.25 cm on opposite sides of staggered 5 x 10 cm wood studs 40.6 cm O.C, wood-fiber blanket 2.28 cm thick stapled to studs in one set (b) Staggered 5 x 10 cm wood studs each set 40.6 cm O.C, and spaced 20.3 cm O.C with 1.25 cm offset from the other set. On each side 0.95 cm plain gypsum lath 1.25 cm gypsum vermiculite plaster; air space filled with vermiculate fill of 100 Kg/m3	67 63	45 47

(Table contd.)

	density.		
4	Stud wall-5 x 7.6 or 5 x 10 studs, 0.95 cm gypsum lath and 1.25 cm sanded gypsum plaster.		35-40 dB

Table 3.4:- Transmission loss for different metal stud walls, given by Bhandari, Srivastava, and Dhabal (1985).

Table 3.5 : Specifications of metal stud wall or partitions of India Gypsum Co., tested at AIR, 1993.

In Table 3.6 comparison on walls of a few of the audiological test rooms of different centers is made on the following factors :

(a) Kind of walls

(b) Thickness of each wall

(c) Air gap through walls

(d) Depth of air gap into floor

(e) Air space between the experimental and control room

(f) Number of bricks in each wall

(g) Materials of walls construction

(h) Material placed on the inner, surface of wall

Table 3.5 : Transmission loss of metal studs wall or partitions of Indian Gypsum Co., tested at AIR, 1993

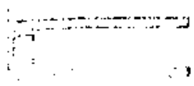
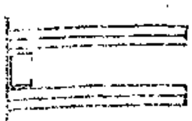
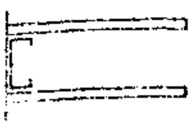
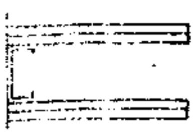
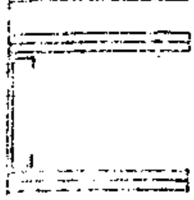
Detail	Construction	Nominal thickness (mm)	Approx. weight (kg/w')	Average transmissioi loss (dB)
	Gypboard single studs partitions 12.5mm Gypboard each side of 48mm studs	75		37
	As above with 25mm minimum glass fibre mat in cavity	75		41
	15mm Gypboard each side of 48mm studs	80	28	39
	As above with 25mm minimum fibre glass mat in cavity	80	28	45
	Two layers of 12.5mm Gypboard each side of 48mm studs	100	43	45
	As above with 25mm minimum glass fibre mat in cavity	100	43	51
	Two layers of 15mm Gypboard each side of 48mm studs	110	55	49
	12.5mm Gypboard each side of 70mm studs	97	22	39
	As above with 25mm minimum glass fibre mat in cavity	97	22	44
	15 mm Gypboard each side of 70mm studs	102	28	41
	As above with 25mm minimum glass fibre mat in cavity	102	28	45
	Two layer of 12.5mm Gypboard each side of 70mm studs	122	43	49
	As above with 25mm minimum glass fibre mat in cavity	122	43	53
	Two layer of 15mm Gypboard each side of 70mm studs	132	55	51

Table Contd..

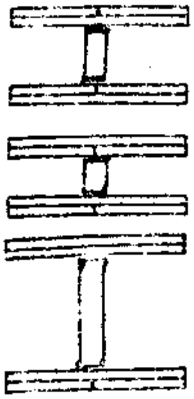
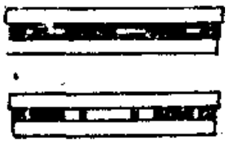
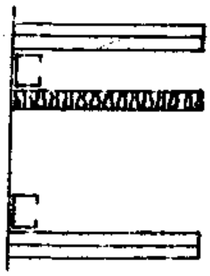
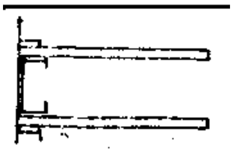
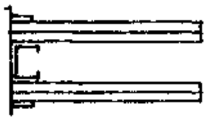
	Two layer of 12.5mm Gypboard each side of 146mm studs	198	43	53
	As above with 25mm minimum glass fibre mat in cavity	198	43	54
	Two layer of 15mm Gypboard each side of 146mm studs	208	55	53
	Two layer of 12.5mm Gypboard each side of 48mm boxed studs	100	43	44
	Two layer of 12.5mm Gypboard each side of 70mm boxed stud	124	43	46
	Two layer of 12.5mm Gypboard each side of 146mm boxed stud	200	43	52
	Gypboard Demountable Partition 12.5mm Gypboard each side of studs 70mm alternate stud boxed	98	22	39
	As above with 25mm minimum fibre glass mat in cavity	98	22	44
	Two layer of 12.5mm Gypboard each side of •r«48mm stud alternate studs boxed	100	43	47
	As above with 25mm minimum fibre glass mat in cavity	100	43	51
	**Gypboard Metal Stud Separating wall** Gypboard metal stud separating wall inner layer of 23mm	200	57	61
	Gypboard fixed horizontally and outer layer of 12.5mm Gypboard fixed vertically to the out side faces of two 48mm metal stud frames (48s.55) which are braced at mid height 25mm glass wool mat in cavity studs at 610mm centres	300	57	62

Table Contd..

	Gypboard Jumbo Metal Stud Separatin Walls Inner layer of 23mm Gypboard fixed horizontally and outer layer of 12.5mm Gypboard fixed vertically on each side of 146mm studs (146s.55) at 610mm centre with 25mm glass wool mat in cavity	211	55	57
	Timber and partition 12.5mm Gypboard each side of (50x50mm) timber stud	75	-	36
	Gypboard Compact Wall Two layer of 23mm Gypboard on metal angle	50	60	34
	23mm Gypboard on each side of 23mm Gypboard strip	75	70	34

Tiible 3.6: Comparison of walls of a few of t ie audiolo;;ical test rooms of diffent: c e n t r e

S. No.	Source/ Audiological , Test Centre	Kind of Walls	Thickness of each wall	Airgap between walls	Depth of air gap into floor	Air space between Expt. & control	No. of bricks in each wall	Material of walls construction	Material on inner surfac of wall
1.	Murthy and Jacob AIISH(1971)	Double. walls	114.75mm **(41/2) with** 8.4mm (1/3") plaster on outer side	76mm **(3")**	32cm		Single	Brick with cement motar plaster	.Randomly perforated acoustic tiles on wooden frames
2.	Bhattacharya, Tripathi and Chatterjee (1983) Ahmedabad	Double walls	Inner room - 115mm Outer room - 270mm	125mm				Brick	**Inner Room**: 20 mm thick Jute Bartex Board on the inner surface of it a lattice made of 35mm thick and 100mm wide wood bars forming 200mm square caviters. Cavities are fitted with foam wedges **Outer Room**: 20mm thick jute bartex board and on its inner surface is 10mm thick plastic rartex sheets
3.	IAC Bulletin 5.0003.5,1993	Double walls Single wall	102mm (4") 102mm (4")	102mm (4")		102mm (4")		Exterior surfaces Cold rolled textured steel Interior surfaces Perforated galvanized textured steel	
4.	Murthy, Murthy and. Ramanjaneyulu (!976)Manipal	Double walls	344mm and 229mm	127.5mm (5")		-	1.5 and single	Cement marter &38mm(lW) thick rough cement plaster	2" thick glass wool and acoustic tiles placed on 3/4" wide, 1/4" • thick teakwood reapers.

Thus, for the audiometric test rooms, different kinds of walls such as single wall, double wall, metal stud wall and composite walls can be constructed. It is observed that metal stud walls can provide the highest average transmission loss (62 dB). All the types of walls discussed earlier are capable of producing an average transmission loss of about SO dB. However the weight of the single walls has to be relatively much higher than other walls to have an equivalent transmission loss. Though the double walls may weigh relatively less, they would occupy more space. It is observed that among all types walls, the metal stud walls occupy minimum space (about 10 cm to provide TL above 50 dB), but it may not be cost effective. Thus, depending on available space for the walls construction, materials available for it cost and the desired weight, a person can choose any of the walls among single wall, double wall, metal stud walls and composite walls for the constructed of walls.

4. CEILINGS :

Ceiling constitute the overhead surface in a room . Through the ceiling, both the air borne and structure-borne sound can be transmitted .To provide adequate insulation for sounds and vibrations special kinds of ceilings are required.

Types of Ceiling :

The two kinds of ceiling construction which will increase the sound insulation are false ceilings and the suspended ceilings. These ceilings reduce the noise level in the room where they are used by decreasing the radiation from the ceiling treated. These ceilings improve the insulation for both impact sounds and air-borne sounds (Harris and Ingerslev, 1956).

(a) Fake Ceilings :

False ceilings are ceilings which are independent of the floor-ceiling structure (Harris and Ingerslev, 1956). For double wall construction, the outer wall should carry the concrete slab and the inner walls should support the false ceiling.

(b) Suspended Ceiling :

Suspended ceilings are ceilings which are hung from the structural floor-ceiling combination by wire suspension or resilient hangers (Harris and Ingerslev, 1956). The extent of improvement of both air-borne and structure-borne sounds depends on the weight of the ceiling, as well as on the structural rigidity with which it is connected to structural floor ceiling construction. The best results are obtained if the points of contacts with the structural floor are as few as possible (Suri, 1966).

Fig-4.1 shows the floor-ceiling constructions for impact isolation and Fig-4.2 shows sound absorbing ceiling arrangements. It is observed in the Fig-4.1 that a ceiling with a floated slab plus a suspended ceiling has the maximum sound insulation. From Fig-4.2 we can conclude that an "egg-crate" sound sound absorbing ceiling arrangement provides maximum sound absorption.

Surface Material ofthe Outer Ceiling :

Outer ceiling should be made of higher density materials such as reinforced cement concrete (Murthy and Jacob, 1971).

Surface Material of Inner Ceiling :

To reduce the reverberation in a room, sound absorbing materials are placed on the inner ceiling. The surface material of the inner ceiling should be made of wooden frames, particle boards or hardboard etc. to support the sound absorbing material.

Filler Material between the Inner and Outer Ceilings :

Murthy and Jacob (1971), noted that an air gap between the two ceiling surfaces improve the insulation properties of the ceiling. Further improvement in attenuation of noise levels can be achieved by placement of sound-absorbing material in this air gap.

Mohanan (1987) studied the effect of different locations of a damping layer in a false ceiling on the absorption characteristics of perforated panels such as aluminium sheet, particle board and hard board. Absorption coefficient across 100Hz to 4000Hz were calculated using the reverberation chamber method for glass wool. Glass wool was kept at different positions namely (i) Top (glass wool kept in contact with the perforated panel) (ii) Middle (glass wool kept at half the distance between the

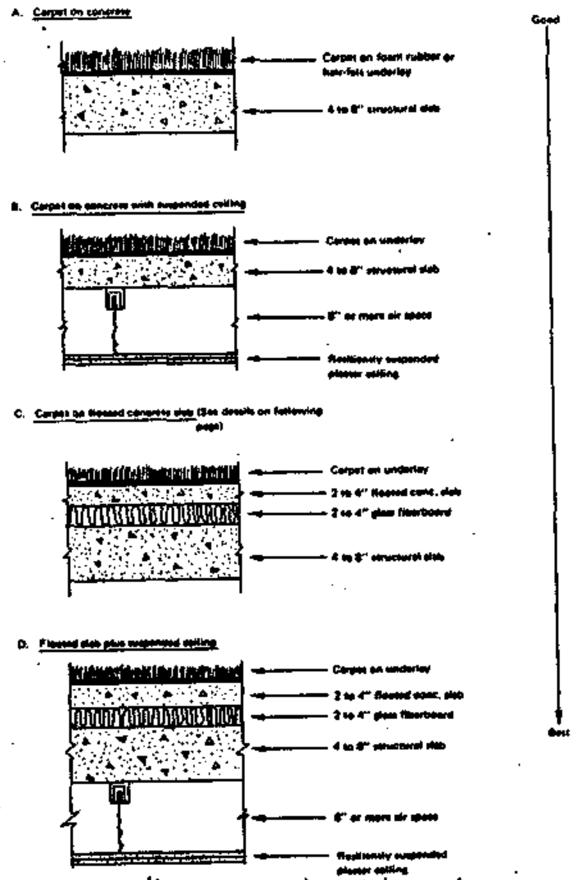


Fig 4.1 : Floor ceiling construction for impact insolation (Egan, 1972)

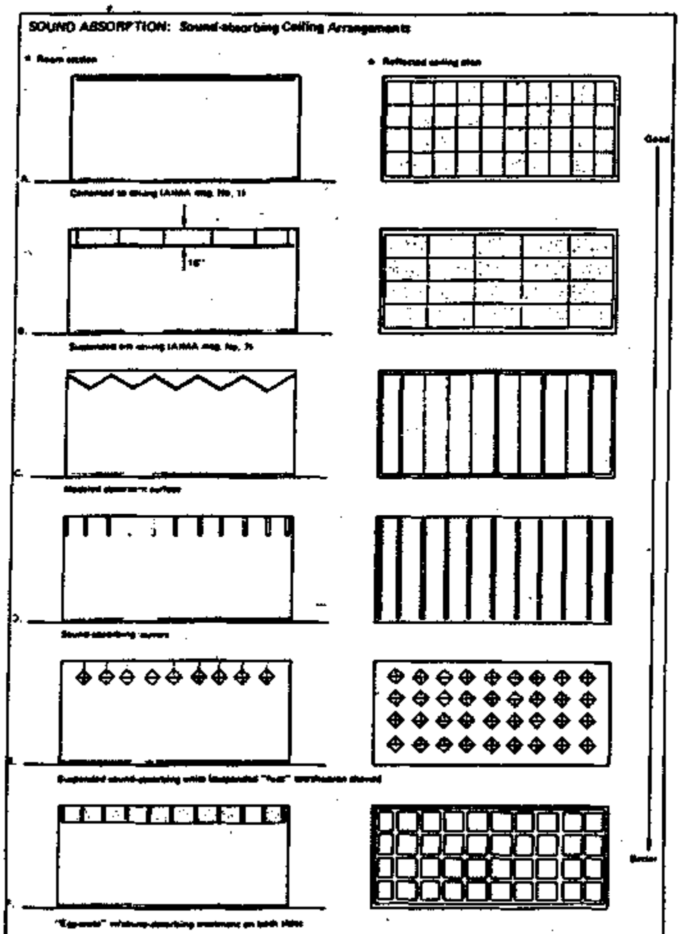


Fig 4.2 : Sound absorbing ceiling arrangements (Egan, 1972)

perforated panel and test surface) (iii) Bottom (glass wool laid on the test surface) and (iv) Slanting (glass wool kept at an angle). He found that in all cases i.e., aluminium sheet, particle board and hard board the top position showed maximum absorption over the wide range of frequencies.

Materials Placed on the Inner Ceiling :

Sound absorption material is placed on the inner ceiling which in turn reduces the noise level (Murthy and Jacob, 1971). Fig 4.3 shows the absorption coefficient of a fiber glass wool ceiling tile (UP. Twiga Fiber Glass Limited) with a protection covering of tissue paper with / without paint coating. An air gap of SO mm is kept between tissue paper (the protection covering) and the ceiling tile. It is seen that paint coating affects the absorptive properties of ceiling tiles.

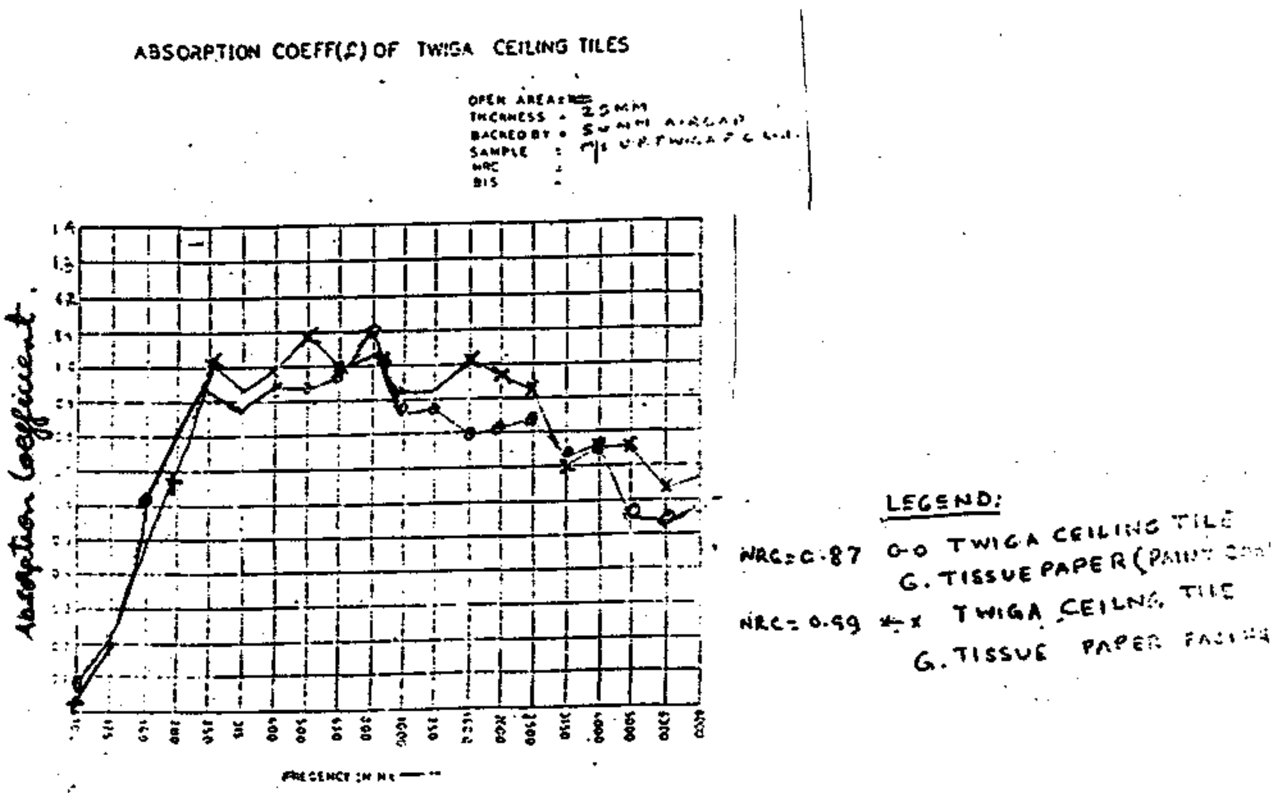


Fig 4.3 : Absorption coefficient of fiber glass wool ceiling tile at different frequencies

Table 4.1 gives the transmission loss for some of the roofs as given by Egan (1972). It is seen that a 3 x 8 wood beams 32" o.c with 2 x 6 T&G planks, asphalt felt built up roofing and ground topping with 2 x 4 & 16" o.c. between beams with 1/2" gypsum board supported by metal channels on ceiling side, and 4" glass fiber batt insulation in cavity has the maximum sound transmission class rating (53).

Building Construction-Roofs	Transmission Loss indB						
	125 Hz	250 Hz	500 Hz	Ik Hz	2k Hz	4k Hz	STC Rating
3 x 8 wood beams 32''. o.c. with 2 x 6 T&G planks, asphalt felt built-up roofing and gravel topping	29	33	37	44	55	63	43
Construction with 2 x 4s 16" o.c. between beams with *V2 "* Gypsum board supported by metal channels on ceiling side, and 4". Glass-fiber batt insulation in cavity	35	42	49	62	67	79	53
Corrugated steel, 24-guage with 1 3/8" sprayed cellulose insulation on ceiling side (1.8 psf)	17	22	26	30	35	41	30
2 1/2" sand gravel concrete (148 psf) on 28 guage corrugated steel supported by 14". Steel bar joists, with 1/2"gypsum plaster on metal lath and 3/4". Metal furring channels 13 1/2" o,c, on ceiling side (41 psf)	32	46	45	50	57	61	49

Table=4.1 : Transmission loss for different roofs at different frequencies

A comparison of ceilings constructed in different audiological test centers is depicted in Table 4.2. The comparison is done for the following factors:

(a) Kind of ceilings

(b) Air gap

(c) Surface material of outer ceiling

(d) Surface material of inner ceiling

(e) Filler material

(f) Material placed on inner ceiling

It is observed that usually false or suspended ceilings are constructed for the audiology test rooms .An air gap is provided between the inner and outer ceilings with sound absorbing material placed in between and over the inner ceiling.

Table 4.2 Comparison of ceilings of audiological rooms of different centers

Sl.No.	Source/Audiological Test centers	Kind of ceilings	Air gap	Surface material of outer ceiling	Surface material of inner ceiling	Filler material	Material placed on inner ceiling
1.	Murthy and Jacob, (1971),AIISH	False ceiling	30cm (12")	Tin sheets fixed on wooden raftors	Wooden frame	River sand 76mm (3") thick	Perforated acoustic tiles
2	Bhattacbarya, Tripathi and Chatterjee, (1983) Ahmedabad	Two suspended ceiling	70cm between the concrete ceiling and suspended ceiling and 60cm between the two suspended ceiling	Concrete ceiling and Jute bartex Board	Wood particle board (12mm thick)		Foam wedges fitted in a wooden frame work with 78 square cavities
3	IAC Bulletin (5.0003.5,1993)	Single wall or Double wall constructed of 4-in. (102mm) thick modular panels .	10cm (4-in.) air gap for double wall construction	Cold rolled textured steel	Galvanized perforated textured steel	Acoustic infill	
4	Murthy, Murthy and Ramanjaneyulu (1976), Manipal	False ceiling	13cm (5")	Concrete ceiling	Teakswood frame with reapers		Layer of wire gauze, 5cm (2") glass/wool and acoustic tiles and a lining on the acoustic tiles

From the above mentioned information on ceilings of audiological test rooms it can be concluded that most of the experts opt for a false or suspended ceilings. Different kinds of arrangements of sound absorbing material such as between the inner and outer ceiling and on the inner surface of inner ceilings can be made to provide sound insulation from air-borne sounds and structure-borne sounds.

5. *FLOORS*

In most of the buildings the floor construction is of solid structure, like cement concrete. These floors have sufficient weight and rigidity to provide adequate insulation for air-borne sounds but rather offer poor insulation for structure borne or impact sound. For construction - audiological test rooms it is necessary to increase the insulation against both air- borne sounds and structure- borne sounds.

According to Suri (1956), the special kind of floors which can be constructed for the sound treated rooms are following;-

1) Resilient floor finish on concrete floors, and

2) Floating floor construction.

a) concrete floors.

b) wood floors.

1) Resilient floors finish on concrete floors ;- Harris and Ingerslev (1956) noted that a resilient floor finish laid in the floors increases the effectiveness of a concrete floor in isolating noise in buildings, linoleum, rubber tile, cork tile, asphalt and carpet are some of the materials usually employed. Softer and thicker the material used, greater will be the improvement.

In Fig-5.1 the typical Sound Transmission Class (STC) and Impact Insulation Class (IIC) values provided by various floor finished laid on concrete self is given (Magrab, 1975). From the Fig 5.I discussed above it can be conclude that a floor with 25 mm glass wool, 19 mm tongue and groove wood floor 38 x 50 mm steeper, 150 mm concrete slab and 13 mm plaster has the maximum Sound Transmission Class (STC) rating and the floor with 13 mm oak floor, 10mm carpet, 6mm form, rubber pad and 100

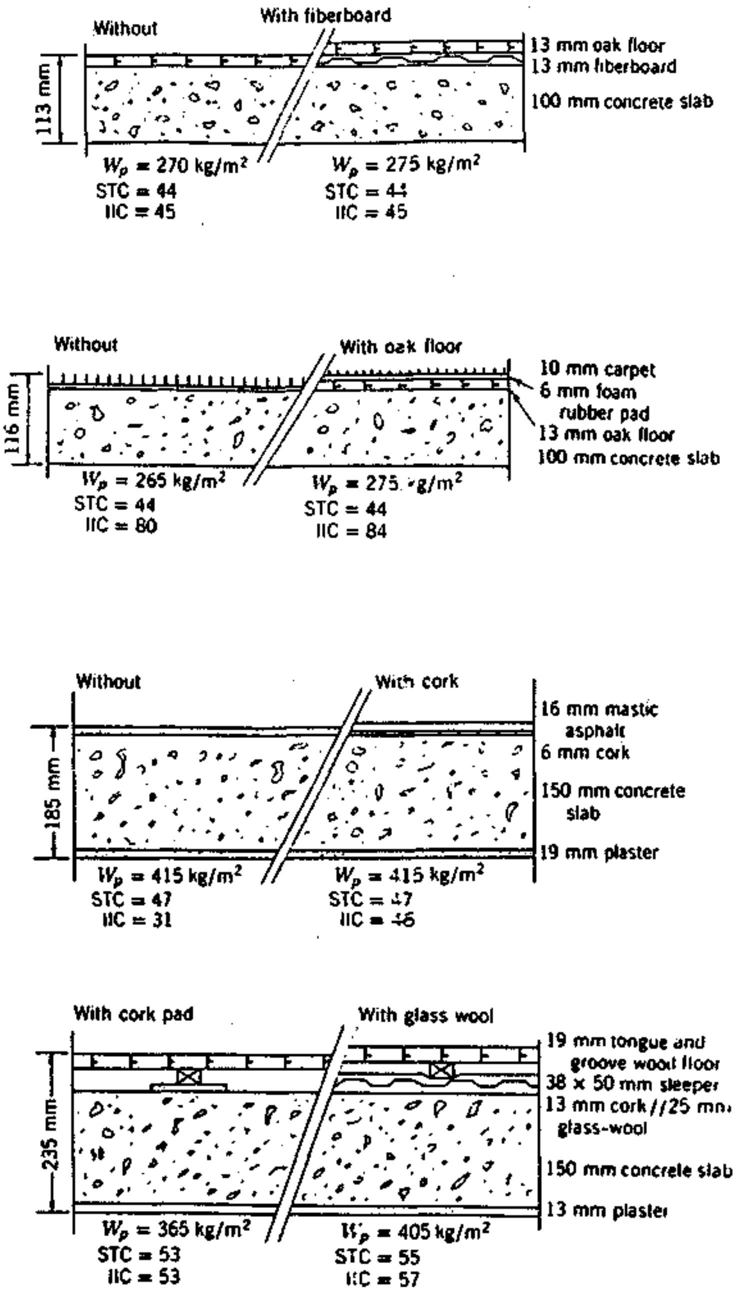


Fig 5.1 Sketches of concrete slab floor with resilient floor finish, Dolle (1972)

mm concrete slab has the maximum Impact Insulation Class (IIC) rating. Ingerslev and Harris (1956), gave the average values of impact sound insulation provided by various floor finished laid on a bare concrete (Table 5.1). It is observed that 3/8" wilton carpet provides the maximum impact sound insulation among all the materials cited in table 5.1.

Table 5.1 : Average values of Impact sound insulation provided by various floor finishes laid on bare concrete (Harris and Ingerslev, 1956).

S.No.	Floor Finish	Impact-sound Insulation dB
1	Linoleum, 1/8"	3
2	Rubber Tile, 1/8"	5
3	Asphalt, 7/8"	5-7
4	Parquet flooring on battens	7
5	Cork tile, 5/16"	10
6	Witton carpet, 3/8"	24
7	5/32" linoleum on 1/4" hard cork tile	6
8	5/32" linoleum on 1/4" soft cork tile	14
9	5/32" linoleum 1/2" soft cork tile	16
10	5/32" linoleum on 1/2" soft fiber board	18

Table 5.1 : Average values of inpact sound insulation provided by various floor finishes laid on bare concrete (Harris and Ingerslev, 1956)

Suri (1966) described a floating floor as one which rests on the structural floor but is separated from it by an insulating layer of mineral wool, resilient quilt, or other materials which provide insulation. The floating floor therefore, provides useful improvement in the insulation of air- borne sounds and does not allow the impacts and consequent vibrations to be transmitted to the room.

It is important in any floating floor construction that the resilient element / insulating material used be nowhere shorted by a rigid mechanical connection. Particular attention should be paid to electric ducts, service pipes, and skirting to avoid a solid connection between the structural floor and the floating floor. Floating floors can be constructed either of a concrete or of wood (Suri, 1966)

a. Concrete floors

Ingerslev and Harris 1956, reported that floating floors constructed using concrete screeds are highly effective in insulating impact noises, The construction consists of a layer of resilient material laid out on the bare structural floor. It is covered with a layer of water-proofing material such as a thin alkathene sheet to prevent wet concrete running through it. A wire reinforcement is provided on the floating screen laid directly on the water proofing sheet

Apart from reducing the risk of cracks developing on the screed the wire netting protects the water- proofing material and the resilient quilt from mechanical damage during construction. The floor is then finished with cement concrete of appropriate thickness. The resilient layer must be turned up along the walls to prevent contact between screed and walls. A typical floating floor is shown in Fig 5.2 given by Egan, 1972. Suri, 1966 reported that after the construction of such floors, the skirting at the top should be filled with any soft type of sealant. This should never be filled with cement concrete otherwise, there would be a direct contact between the upper floor finish and structural floor which may lead to the transmission of sound.

Table 5.2 gives Impact Noise Rating (INR) of sandwiched resilient materials as described by Srivastava, Dhabal , Bhandari (1985). An impact noise rating of zero indicates satisfactory performance of a floor. A rating of 'plus' or minus sign indicates better or worse performance of a floor respectively. It is observed from the table 5.2 that bare concrete results in maximum negative impact noise rating, while certain verities of asbestos results in the maximum positive INR. Egan (1972) opined that resilient layer of precompressed glass fibre, cork or neoprene can be used for the floated floors.

Material	Thickness cm.	Impact Noice Rating (NR) According to Indian Standard	
		Laboratory	Field
Bare Concrete	"	-16	-13
Bartex	2.00	-1	+3
Kurlon	4.00	+ 12	-
Fibreglass	5.00	1.27	+5*
Spintex	2.50	+7	-
Thermocole	2.50	-5	-
Linoleum	0.42	-7	-
Hollow-pan units	6.00	-	-8
Asbestos	1.27	+5 to +15.	-
Mineral wool	2.50	+ 10	-

* Thickness of fibreglass in the field test was 4.0 cm (unloaded).
• The variation in rating of asbestos is due to the different qualities tested

Table5.2;- Impact noise rating of sandwiched resilient materials, given by Srivastava, Dhabal and Bhandari (1985).

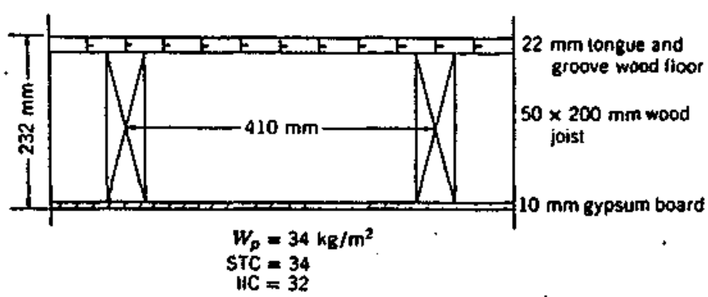
(c) **Wood floors floating on concrete structural floors**

Suri1966 noted that, the effectiveness of a concrete floor in insulating noise can be improved by wood flooring laid on the concrete . Further improvement in insulating noisecan be obtained if the wood floor rests (floats) on blankets , strips, or pads of a resilient material, such as mineral wool laid on the bare concrete structural floor.

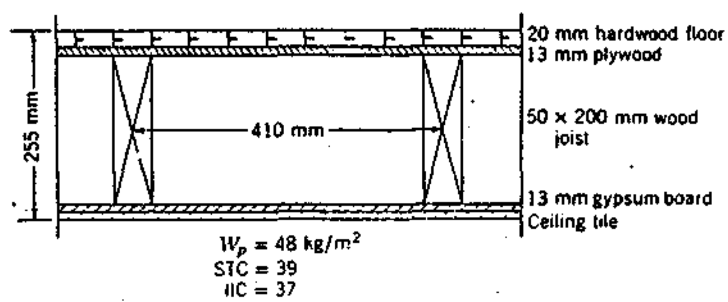
Suri 1966 suggested that additional increase in insulation can be obtained by placing of sand on the structural concrete floor between the battens which carry the floating floor. The thickness of the sand should be less than the height of the battens

Floating wood-joist floors:-

In wood joist floors, a wood beam provides direct support for the floor board. Transmission of air-borne and impact sounds can take place easily in these floors. So, for insulation purpose floating wood joist floors are constructed in which fiber board or mineral wool quilt are employed (Suri ,1966) fig (a) to (i) gives sketches of varying types of wood joist floors. The number of layers on the wood joist floor may vary from one to six. Among these floors, it is observed that [fig 5.3] a 50 x 25, 5 mm wood joist floor with 1.5 kg/m2 carpet, 1.35 kg/m2 hair felt fad , 20 mm oak floor, building paper, 13 mm plywood, 75 mm isolation blanket resilient bar 61 cm in centre and 16 mm gypsum board has the highest STC (50) and IIC(70) rating values among all the wood joist floors.



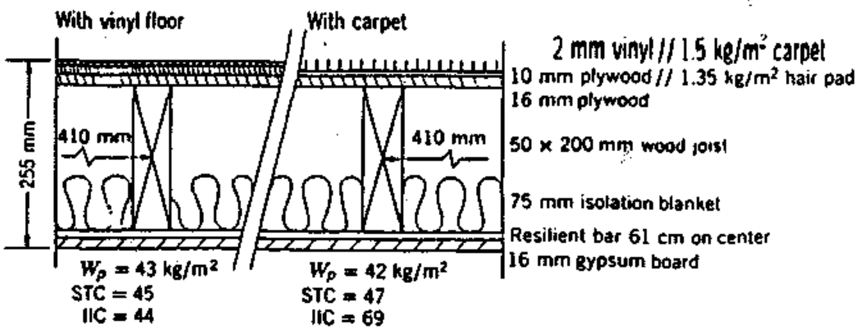
Wood joist—50 × 200 mm.



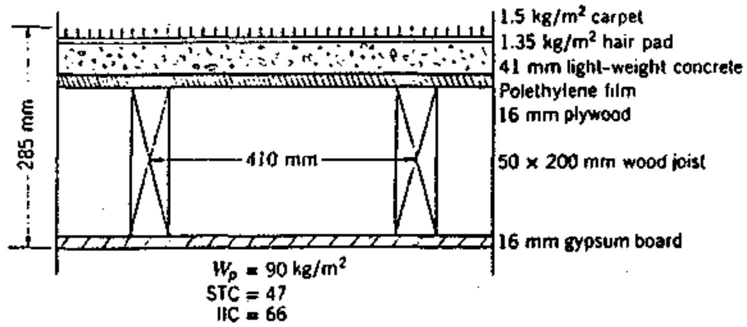
Wood joist—50 X 200 mm.

Fig 5.3;-Sketches of wood joist floors with their transmission (STC) and impact insulation class rating (IIC) values (Doelle, 1972)

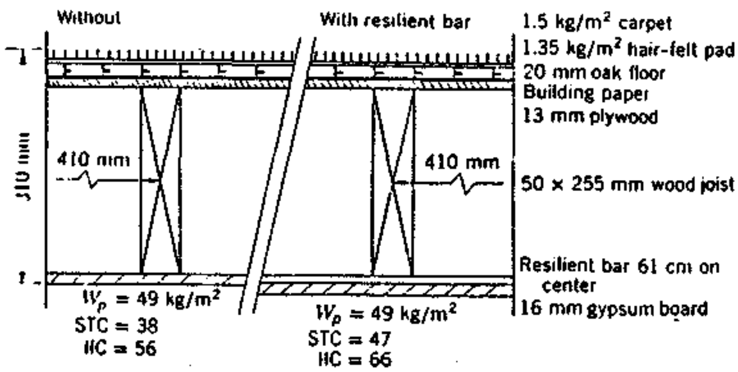
(Continued......)



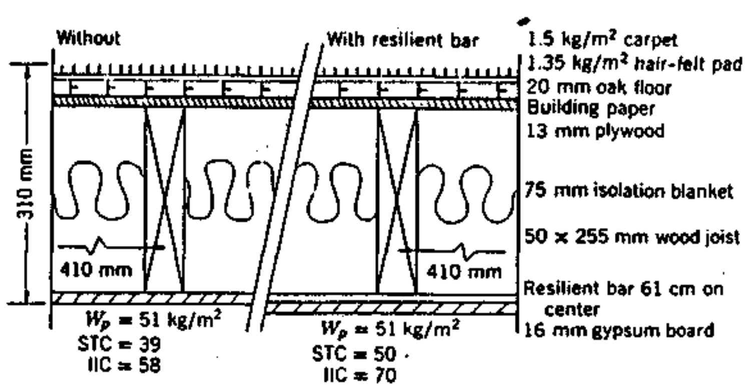
Wood joist—50 × 200 mm.



Wood joist—50 × 200 mm.

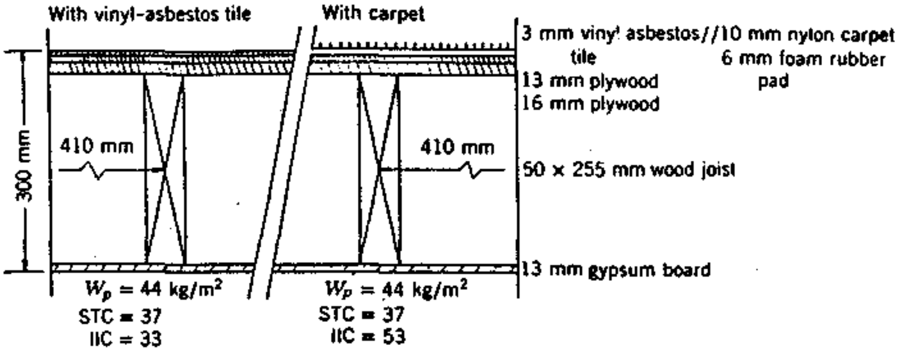


Wood joist—50 × 255 mm.

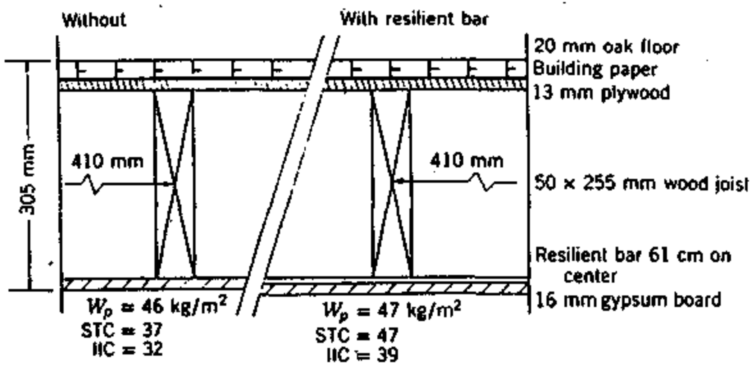


Wood joist—50 × 255 mm.

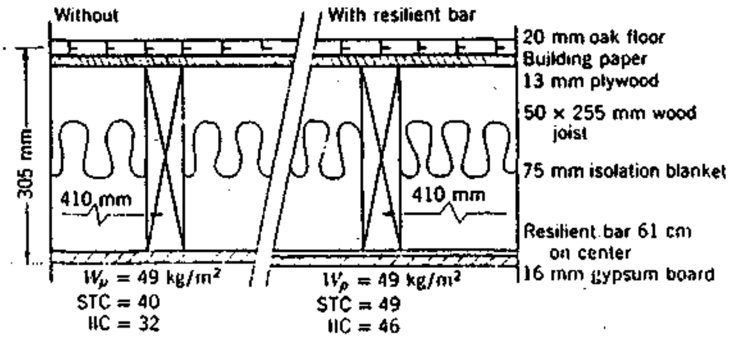
– Fig 5·3 contd



Wood joist—50 × 255 mm.



Wood joist—50 × 255 mm.



Wood joist—50 × 255 mm.

Suri (1966) reported that the floating floor should not be allowed to have any solid contact with the main supporting structure, joists or the sub floor, by nailing or otherwise as this will reduce the effect of insulation. The floating floors remain quite steady even without nailing.

To improve the insulation of wood floors Ingerslev and Harris (1956) suggested use of a puffing or deadening material in the air-space between the wood joists. Either sound absorbent type materials like mineral wool, or other materials, like sand could be used, but the latter are found to be more effective because of the fact that efficiency of 'pugging' depends on the weight of the material used. These wood joist floors should be finally concerned with floor finish materials such as linoleum, cork tile, vinyl tile or carpet (Egan, 1972). Table 5.3 lists the IIC improvement and STC improvement values for the floors. It is seen that carpet on foam rubber under lay provides the maximum IIC improvement. All the materials tested are found to have similar STC improvement value.

In Table 5.4 - comparison of floors used in the audiological test rooms of a few centers is made. The comparison is made on the following factors;-

a) Air gap width between the walls and floors.

b) Depth of the air gap between wall and floor.

c) Surface material of outer layer.

d) Surface material of inner layer.

e) Materials filled in air gap.

f) Sound absorbing materials above outer layer and

g) Inner layer of floor.

From the above review, it can be noted that special kinds of floors such as, those with

Table 5.3: List of IIC improvement and STC improvement with floor finish materials

S.No.	Floor-Finish materials	Typical IIC Improvement	Typical STC Improvement
1	Vinyl tile	0	0
2	3/32 in linoleum	4	0
3	1/4 in cork tile	12	0
4	Carpet on foam rubber underlay	10-25	0

Table 5.4 : Comparision of floors used in the audiologica! test rooms of defferent centre

Sl. No.	Source / Audiological	Air gap width between walls	Depth of air gap between wall & floor	Surface material of outer layer	Surface material of inner layer	Material Tilled in air gap & between outer and inner layer	Sound-absorbing material above outer layer	Covering of floor
1	2	3	4	5	6	7	8	9
1.	Murthy and Jacob (1971) A11SH	3"	1"	Cement Concrete				Coir matting & thick carpet
2.	Bhattacharya Tripathi & Chatterjee (1983) Ahmedabad	-		50mm thick precast RCC slabs	Concrete Platform	Fiber glass (25mm) covered with polythene sheet and layer of sand (200mm)	Polyethene Foam (10cm)	Jute Mat (10cm)
3.	IAC Bulletin -5.0003.5(1993)	-		Hot rolled steel (3.04mm)	Cold rolled steel (1.52mm)	Acoustic infill		Carpet
4.	Murthy, Murthy and Ramanjaneyulu (1997)Manipal	4"	12"	Wood floor	Cement concrete	Glasswool and hard board sheet and water proof paper	Linoleum	1/2" thick coir matting and 1" thick carpet
5.	Pancholy, Chhapgar and Mohanan (1980) National Physical Laboratory			RCC Slabs (300 mm)	Cement concrete	Special and bed		

resilient material in top or a floating floor of concrete or wooden type can be constructed. However, it is preferable to constructed a floating floor of concrete slab as it is more effective and long lasting. Wooden floating floors are also equally effective but are not very durable. It is seen that the transmission loss values of these floors can be increased by using combination of resilient materials

6.AC0USTICAL DOOR

A door is basically an operable partition used for privacy and security purposes. Acoustically, it is primarily a noise barrier. Doors are often the "weakest link" in acoustical isolation for building. An efficient acoustical door unit should have sound attenuating properties approximating those of the wall into which the door is installed (Purcell, 1981).

According to Suri 1966 the commonly used wooden type of doors provide only about 20-30 dB of sound insulation, while sound proof doors need to provide about 40-50 dB of sound insulation. Such a requirement calls for special design and construction.

Kind of door :

Both a single or double doors can be used. But it is preferable to have double doors. The double doors should be fixed in such a way that one opens into the room and the other opens outwards (Murthy and Jacob, 1971).Ginn (1978) noted if the two doors are separated by a short passageway, application of sound absorptive material to the walls and ceilings in the passageway will improve further the insulation. He reported that for double doors separated by atleast 8 cms the average insulation is estimated to be atleast 5 db greater than the mass law value based on a mass equal to the sum of the masses of the two doors

Dimensions:

The door usually occupies a small area of the wall. The dimensions of the door is decided based on the total area of the room and need of the users such as number of equipment to be placed inside, size of the equipment, number of persons who will be present inside the room while testing etc.

According to Suri 1966, depending on the proportionate area it covers, it is possible to have the door with a Transmission Loss (TL) lower than that of a wall without appreciably affecting the overall sound insulation. It is observed that doors with smaller dimensions can have their transmission much lesser as compared to the loss of the wall (eg. 10 db lower if the door occupies 5% of wall area) and doors with larger dimensions cannot have their transmission loss much lesser than TL of a wall (eg. 2 db lower if door occupies 25% of wall area)

The dimensions of smallest and largest doors used in audiological rooms are 0.61m 1.68m (IAC Bulletin 5.0702.5, 1995) and 1.35m 2.06m (Bhattacharya, Tripathi, and Chatterjee, 1983) respectively.

Materials used for construction of doors :

According to Purcell (1981),the outer surface materials used for door construction varies from simple wood doors to doors of steel composite construction. It is preferable to have metal doors for better sound insulation, but they are relatively high-priced. (Merritt, 1994).

Structure of sound proof doors :

Sound proof doors are usually, multilayered "sandwich" structures. Layers of different materials such as foam, rubber sheet, thermocoele, lead sheet can be placed between the outer surface materials of the door (Bhattacharya, Tripathi and Chatterjee, 1983). For further improvement in sound insulation an airgap can be provided between the layers.

The air gap may be kept hollow or filled with sound-absorbing materials such as glass wool, fine river sand, hydrous calcium silicate, polyurethane foam or polystrene foam (Murthy, Jacob, 1971 ;Merritt 1994;Purcell,1981).

Frame :

The surface material of the door is mounted on the frame. The frame should be fixed tightly because even a slight opening as small as 1/32" . around a door will cause noticeable degradation of a noise reduction structure(Miller and Montone,1978).

Materials on the inner surface of door :

The inner surface of the door (within the audiology test room) can be covered with sound-absorbing materials. This improves the attenuation characteristics of the door.

Seals :

A tight, perfect closure is necessary to insure an effective sound barrier. Even the best rated door panel can be by-passed and its effectiveness as a sound barrier cancelled out by poorly fitted and adjusted seals. So ,careful attention should be paid to the perimeter seals (Purcell, 1981) Ginn(1978) suggested use of covered key holes and compression gaskets to achieve a proper seal.

According to Murthy and Jacob (1971), to achieve effective closing of the door without any air gap a lining is provided along the edges of the door. eg. a thick rubber lining. Miller and Montone (1978), noted that porous materials and open cell foams should not be used for acoustical seals since they offer very low sound transmission loss characteristic. Various seals and sealing techniques are available/These include pressure sensitive, magnetic, spring loaded or contact type door seals (Purcell, 1981). Fig 6.1 shows some examples of acoustical seals for doors (Miller and Montone, 1978).

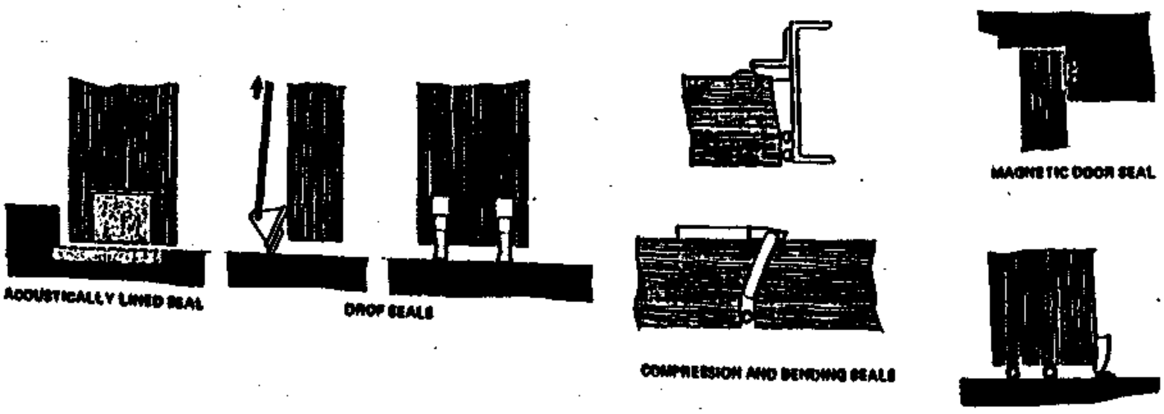


Fig. 6.1:Examples of acoustical seals for doors. (Miller & Montone, 1978).

Hinges :

The swinging part of the door turns over the hinges attached to it. It is preferable to use compression type of gaskets to prevent air leakage through the sides of hinges. (Purcell, 1981). Fig 6.2 : shows a diagram of a hinge used in a audiometric room recommended by Trac6ustics,U.S.A.(1982).

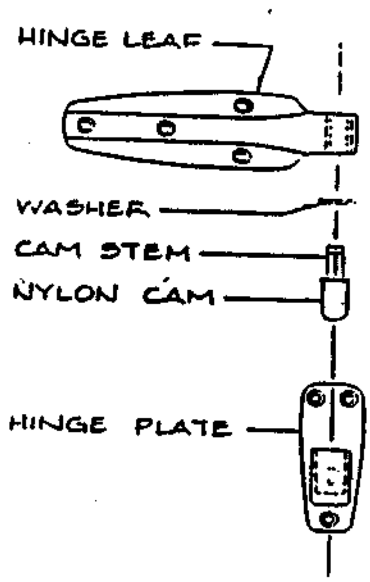


Fig 6.2 Diagram of a hinge used in audiometric rooms (Tracoustics, 1982).

Handle :

According to Bhattacharya, Tripathi and Chatterjee (1983), handle should be welded to the door from both inside and outside of the door. They possibly suggested . welding as use of nails and screws for fixing the handle could cause transmission of structure borne noise through the door.

Latches :

Locking arrangement is not required in doors to achieve adequate insulation in case of doors with magnetic seals. Locking arrangement may be required from outside the door (IAC Bulletin 5.0003.5, 1993) for security reasons.

Table 6. 1 shows the transmission loss characteristics of different doors across frequencies. (Egan, 1972)

Doors	Transmission Loss in dB						
	125 Hz	250 Hz	500 Hz	Ik Hz	2k Hz	4k Hz	STC Rating
Louvered door, 25 to 30% open area	10	12	12	12	12	11	12
1 3/4" hollow wood core door, no gaskets or closure, 1/4″ air gap at still	14	19	23	18	17	21	19
Construction as above, with gaskets and drop seal	19	22	25	19	20	29	21
1 3/4" solid wood core door with gasket sand drop seal (4.3psf)	29	31	31	31	39	43	34
1 3/4" hollow 16-gauge steel door, glass fiber filled core with gaskets and drop seal (6.8psf)	23	28	36	41	39	44	38

Table 6.1: Transmission loss characteristics of some of the doors at various frequencies (Egan, 1972).

Table 6. 1 shows the transmission loss characteristics of different doors across frequencies. (Egan, 1972) . From the above table given by Egan (1972), it is observed that a 13/4" steel door filled with glass fibre inside and having a gasket and drop seal provides maximum transmission loss in the frequencies above 500 Hz.

In table 6. 2 a comparison of acoustical doors used in a few audiological centers, is made. The comparison is done for the following factors:

(a) Kind of door
(b) Dimensions
(c) Surface materials
(d) Filler material in cavity area
(e) Window frame
(f) Materials on inner surface
(g) Hinges
(h) Seals
(i) Latches / Handles

It is observed from the table 6.2 that most of the doors are muiltilayered sandwich structures .A rubber lining is provided generally along the edges of these doors.

From the above mentioned information it can be concluded that most of the audiological centers have a single door or double acoustical doors. The acoustical door of the desired dimension can be constructed from different materials such as steel or wood with a cavity area inside. Sound absorbing materials can be placed in the cavity area. Also, for an effective seal, suitable hinges, handle, latches are required for these doors.

Table-6'2:Comparison of acoustical doors of audiological test rooms of different centers

Sl.NO.	Source/Audiological Test center	Kind of door	[Dimension	Surface material	Filler material in cavity area	Frame	Lining along the edges	Materials on inner surface	Hinges	Seals	Latches / Handles
1	Murthy and Jacob(1971), AIISH	Double doors	.74 x 1.97m (2[1]-3"x 6')	Plywood planks 3.2mm (l/8" thick	Fiber glass	Wooden frame	Thick rubber lining	-		-	
2	Bhattacharya, Tripathiand . Chatterjee Ahmedabad	Single door	1.35m wide 2.06m high	Galvanised aluminium sheets (3mm Thick)	Sandwkich of two 12mm thick layers of thermocolle with 2mm sheet in between	Wooden frame embedded with sound insulating material	Rubber gasket(2mm thick)	Foam rubber sheet (10cm thick)	-		Handle and locking arrangements are present on both the sides
3	IAC Bulletin 5.0104.2, 1998 5.0703.0,1997 5.0102.4, 1993 5.0702.5, 1995	Single door	.84 x 1.87m (33" wide 731/2" . high) .91 x 142m(36") . x 56 .61 x 1.85m (24"; 731/2" .61 x 1.68m (24") x 66-i(	Cold rolled textured steel (1.52mm)	Acoustic Infill				Cam lift butt type	Magnetic - on seals. Gravity activated seal	Latches not required

4.	Murthy, Murthy and Ramaanjanevulu (1976). Manipal	Two shutters and two frames	2.13 x .98m (61/2X3')	Plywood sheets	Glass wool .076m (3") thick	Teak wood frame with thick d glass wool and drill cloth in its edges	Rubber lining 6.35mm (1/4") thick	Acousti< tiles	-	Hvdraulic closure	
5	M PL.(1978). Panccholy Chhap82 & Monanan.			Heavy steel Jead sand which construction			Rubber lined metal frame	Wedge			

7.OBSERVATION WINDOWS

Observation windows are built on the wall separating the control room and experimental room. Windows are generally weakest in sound insulation in the design of buildings. To have an adequate sound insulation, special attention is required in design and construction of observation windows.

Kind of window :

To reduce the transmission of sounds across the observation window, double or triple glass partitions with air space should be designed. Renault (1939) studied the insulation of windows with different constituents at various frequencies. He found that at lower frequencies, the attenuation of sound of a double glass partition is equivalent to that of a single glass having mass equal to the two glasses taken together. According to Renault (1939), double glass partitions are advantageous for attenuating medium and high frequency sounds but have no advantage for low frequency sounds attenuation.

Dimension :

Dimension of the observation window should be such that the tester can observe all the reactions and responses of the patient properly. Different experts have suggested different dimensions for the observation window (Table 7.4). From the available data on dimensions of observation window, we can conclude that dimensions of the smallest and largest observation window used in audiological test rooms are 0.46m x 0.3m (Murthy and Jacob, 1971) and 0.82m x 0.66m (Murthy , Murthy and Ramanjaneyulu, 1977) respectively. The most common dimension used for observation windows is 0.61m x 0.76m (IAC Bulletin 5.0003.5,1993)

Thickness of glass panes:-

The usual thickness used for double or triple glass windows are 3/8", 5/8" or 1/4". Cops and Soubrier (1988) measured the sound transmission loss (STL) of three glass panels with the same dimension but different thickness and found that sound transmission loss increased with increase in thickness. Table 7.1 gives the sound transmission loss through double glass units with varying glass thickness.lt is observed that adouble glass unit with 1/4" and 1/2" thicknesses of its glass results in maximum transmission loss across most of the frequencies tested. Between frequencies 160 Hz to 400 Hz the transmission loss was more in unit with 1/4" and 3/4" thick glasses or 1/4" and 3/8" thick glasses.

	Sound Transmission Loss		
Frequency (Hz)	1/4" glass 2" air space 3/16" glass	1/4" glass 2" air space 3/8" glass	1/4" glass 2" air space 1/2" glass
100	25	25	33
125	31	32	36
160	33	33	29
200	36	33	34
250	38	38	38
315	40	40	36
400	43	43	42
500	45	45	46
630	48	46	50
800	48	45	51
1000	48	44	50
1250	46	45	50
1600	45	46	51
2000	46	46	46
2500	47	47	48
3150	50	51	51
4000	. 52	54	54
5000	54	56	55

Table 7.1: Sound Transmission Loss Through Double Glass Units with Varying Glass Thickness.

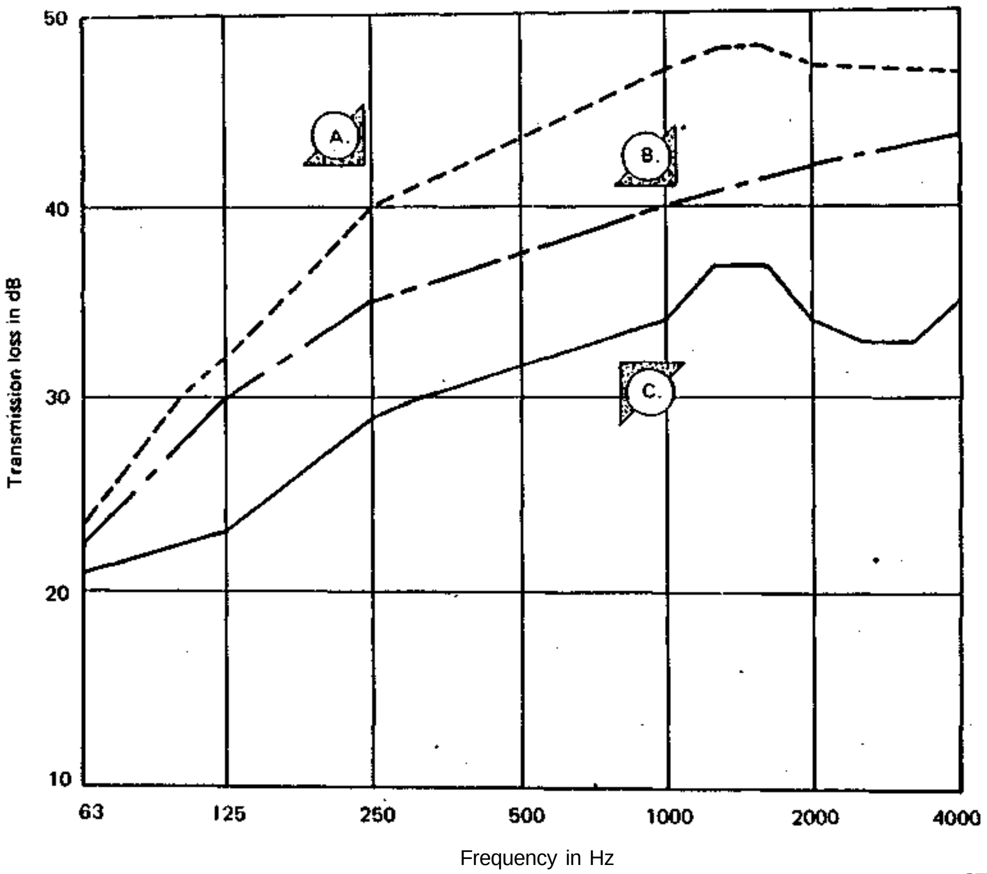
To improve the transmission loss of windows Egan (1972) recommended .

(1) Increase thickness of single panel upto 1/4"

(2) Use laminated glass

(3) Use double window construction with air space and panel of different thickness to avoid resonance effects.

SOUND ISOLATION: Transmission Lpss of Glass



		STC Rating
A.	1/4"	43
B. Same as A but w/2"" air space		39
C. 1/4" plate-glass window set in caulking		33

Fig 7.1. Transmission loss of glass at each frequency (Egan, 1972)

Fig 7.1. Gives the transmission loss of glass at each frequency and Table 7.2 gives data on transmission loss and STC rating for windows as given by Egan 1972.

Glass	Transmission Loss indB						
	125	250	500	Ik	2k	4k	STC Rating
1/8" single plate-glass pane	18	21	26	31	33	22	26
1/4 "single plate-glass pane with rubber gasket	25	28	30	34	24	35	29
9/32" laminated glass pane (i.e., viscoelastic layer sandwiched between glass layers)	26	29	33	36	35	39	36
1/4 + 1/8" double plate-glass window with 2-in. air space	18	31	35	42	44	44	39
Construction with 4 air space	21	32	42	48	48	44	43

Table7.2 : Transmission loss of glass at different frequencies (Egan ,1972).

From the Table7.2 and Fig7.1 it can be concluded that double plate glass windows with 4" air space between them, provide more transmission loss compared to others.

Air Space :

An air space of 4" has been found to be adequate for insulation at medium and high frequencies but greater spacing is desirable for low frequencies. Table7.3 gives the sound transmission loss through double glass units with varying air space (Suri,1966).

Shenoda (1979) measured the sound insulation of double and triple glass layer window using reverberation method and found that for small air space between the glass layers of a window, double-glass layer window has higher sound insulation than triple one having the same mass and air space. For large air space between the glass layers, triple-glass layer windows are more efficient.

Sound Transmission Loss				
Frequency (Hz)	1/4" glass 1" air space	2" air space	3" air space	4" air space
100	23	22	21	20
125	23	29	30	31
160	27	30	32	31
200	26	29	32	33
250	31	34	35	35
315	31	35	37	38
400	36	39	41	42
500	37	40	44	45
630	40	42	47	48
800	41	46	48	50
1000	43	47	49	51
1250	44	48	50	52
1600	41	45	46	48
2000	. 35	37	40	42
2500	37	39	42	44
3150	42	45	47	46
4000	46	48	49	51
5000	47	49	53	52

Table 7.3 : Sound Transmission Loss Through Double Glass Units with Varying Air Space

Height from the ground :

Height of the observation window should be such that the tester can see the subject easily to note reactions and signals and the subject can see the tester (if necessary). Under no circumstances however, should the subject be able to observe the tester's manipulation of the audiometer (Snow, 1965).

Inclination :

One of the glass sheet should be tilted a little inward for good visibility and to reduce the mass volume resonances (Murthy & Jacob, 1971). Suri (1966) noted that inclination of glass sheets helps in avoiding glare to the tester or patient sitting on either side.

Window Mounting :

According to Suri (1966) the mounting of the glass panels is very important. The glass panels are mounted in a frame which should be massive and discontinous to avoid the transmission of sound. It may not be possible to have a massive frame but it is not difficult to make the frame discontinous at the comers. Plenty of felts should be used to avoid all structural and rigid contacts. The glass should be clamped and the frame should neither be fixed too tightly nor too loosely because the frame itself may transmit sound or cause the glass panels to vibrate.

Utley and Flecture (1969) studied the effects of different frames on their transmission loss. The following four types of frames were used, Fig 7.2 :

(a) Neoprene gasket
(b) Metal frame with glass bedded in a ferromastic putty
(c) Wood frame with a wash leather strip round the glass
(d) Concrete frame and putty

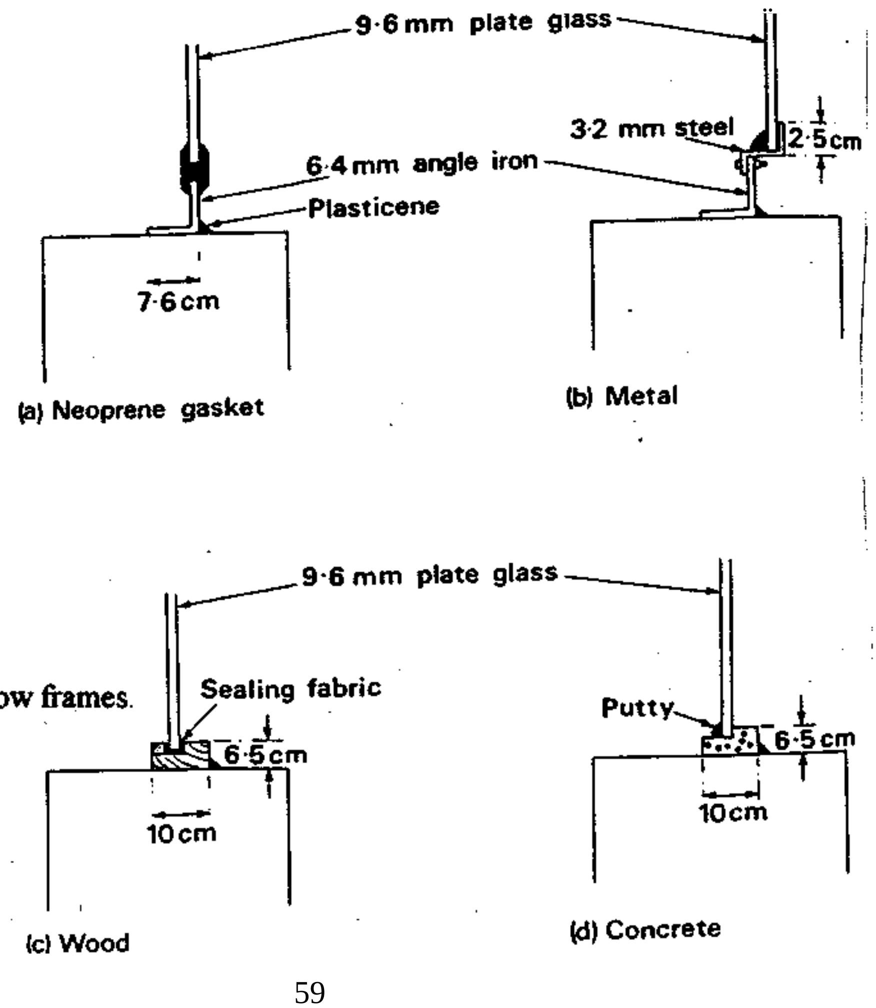


Fig 7.2 Window frames.

They found that neoprene gasket gave highest transmission loss among all the types of window mounting used. The measured value of sound transmission loss all shown in Fig-7.3.

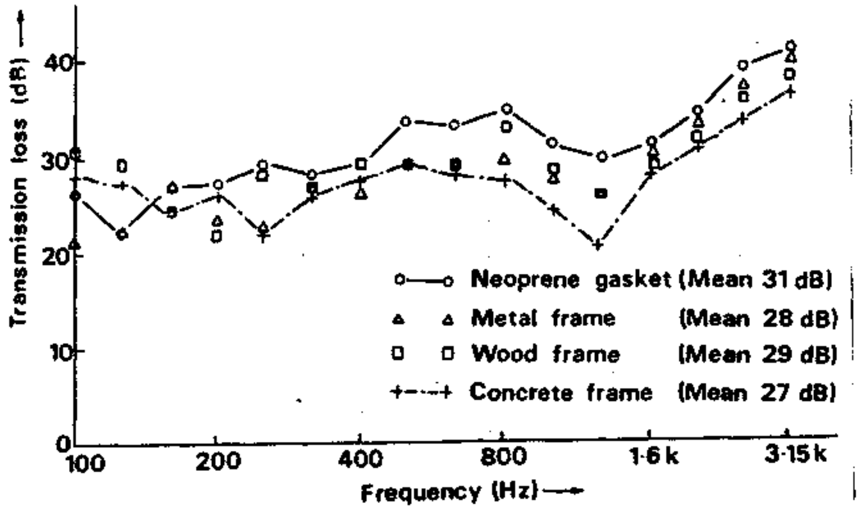


Fig 7.3:Transmission loss of windows in different frames. (Utley & Fletcher, 1969).

Cops and Soubrier (1988) measured the sound transmission loss of glass panels of the same thickness inserted into three different frames of PVC, aluminium and wood. They found that at mid and higher frequencies the different windows gave approximately the same results, were as at low frequencies some small discrepancies occur between the results of sound transmission loss for different windows as shown in Fig-7.4.

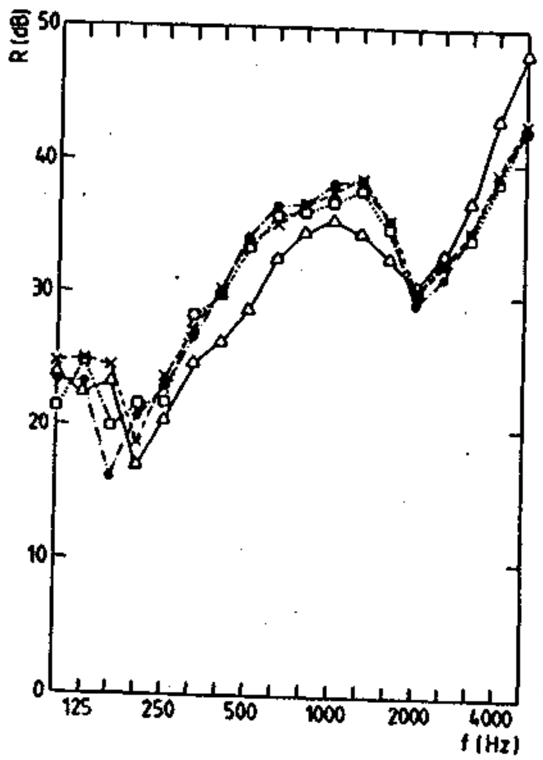


Fig 7.4. Sound transmisson loss of the double glass panel with thickness (6-12-6)mm compared with the results on PVC , wooden and aluminium frames:(A - A)glass panel;(X - X) PVC frames; (• - •) wooden frames;(• - •) aluminum frames

To prevent the leakage of sound waves ,lining along the edges of the glass sheets with a suitable sound absorbing material such as sponge or glass wool should be provided. (Murthy & Jacob, 1971).

In Table-7.4 comparison of the observation windows of audiological test rooms of different centers is done on the following factors :

(a) Kind of windows
(b) Dimensions
(c) Air space
(d) Thickness
(e) Height above the floor
(f) Inclination
(g) Window mounting

It is seen that generally double glass windows are provided as observation windows with an air space between them. These glasses are inclined to each other at an angle of 10 usually.

Table7.2:Comparison of observation windows of the audilogical test rooms

SI. No.	Source/Audiological Test centers	Kind of windows	Dimensions	Air space	Thickness	Height above the floor	Inclination	Window mounting
1	Murthy and Jacob (1971), AIISH	Double glass	.46 x .3m (18"x12")	Max. available space	6.35mm (1/4")	-	Inner glass sheet is tiled slightly	Teak .wood frames, Glass wool
2	Bhattacharya, Tripathi and Chatterjee,(l983) Ahmedabad	Double glass	.64m x .66m	300mm	5mm	-	10^0 to each other	Wooden frame and 2mm thick rubber gasket, Fiberglass
3	IAC Bulletin 5.0104.21,1995 5.0703.0,1997 5.0102.4,1993	Double glass	.61 x .76m (24"x30") .53 x .64m (21"x25")/. 41 x .61m (16" x 24")	-	6.35mm (1/4") 6mm (1/4") 6.35mm (1/4")	.98m (3^1)	-	"Pressure Sealed" Aluminium trim frame
4	Murthy, Murthy Ramaajaneyulu, (1976), Manipa]	Double glass	.82 x .66m (21/2' x 2')	203mm (8")	6.35mm (1/4")	.66m (2') above the floor	Inner glass sheet tilted by 10" on the top side	76mm (3") square teak wood frame and rubber gasket, Glass wool

From the above information on observation window it may be concluded that majority of experts suggest construction of observation window with double or triple glass partitions of different thickness. These glass partitions are placed with an air space between them and inclined to each other. Window should be suitably mounted on the wall separating the patients room and control room.

8. ***SOUND INSULATING MATERIALS***

Sound insulation is the term which describe the reduction of sound which passes between two spaces separated by a dividing element. The insulating properties of a material are expressed as transmission loss. The insulation of a partition is determined by that part of it which has the smallest transmission loss (Na"be'lek and Na'be'lek, 1978).

Method to measure transmission loss :

Suri, (1966), reported that transmission loss tests of a wall or partition are carried out by various laboratories using the reverberant sound field method. The test panel is inserted in an opening provided in the common wall between two rooms-the transmission (or source) room and the receiving room. Sound levels are measured in both the source and receiving rooms. The transmission loss in decibels is given by:

$$TL = L1 - L2 - 10 \log A/S$$

Where L1 = Average sound level, in dB, in source room

L2 = Average sound level, in dB, in receiving room

S = Total area of the test panel in Sq. Ft.

A = Total absorption in receiving room in Sabins.

Measurements of average sound level are made at a number of microphone positions (Suri, 1966). This is normally at one-third octave intervals in the range 100-3150 Hz which encompasses most of everyday sounds, India Gypsum Co. Ltd. (1993).

Properties of materials influencing Transmission Loss :

As per Na'be'lek and Na'be'lek's (1978), finding sound insulation of a material depends on the, thickness number of layers of the partition, the frequency of the sound and other factors. Suri (1966) noted that sound insulating efficiency of a partition depends on its mass, internal damping and stiffness. Greater the mass per unit area, higher is the sound insulation obtained. Suri (1966) described that the natural or resonant frequencies of walls or partitions employed in normal construction falls below 100 Hz and so their internal damping is higher. It is observed that low frequency sound attenuation of a wall depends on the stiffness of the partition and for frequencies higher than 100 Hz sound attenuation depends on the mass. Sound insulating properties of non-porous and porous materials is discussed below.

(a) ***Non-porous rigid materials :***

Suri, (1966) reported that for non porous, homogeneous and rigid construction such as solid masonry of bricks or concrete, the sound insulation varies as the logarithm of the mass per unit varies. It is seen that, if the mass is doubled, the insulation of materials increases by about 4 to 5 dB (Suri, 1966; Cook & Chrzanowski, 1956).

Suri, (1966) reported that the attenuation of sound increases with the increase in frequency. The resonant frequency of the material should be as low as possible so as to minimize the structural vibration. It is observed that if the natural frequency of a vibrating diaphragm is less than that of the incident sound, it is the mass of the material which controls the transmission loss property. But if, the natural frequency is higher than the incident sound, it is the stiffness and the fixture that affects its behavior.

(b) Non -porous flexible materials such as lead :

Suri, (1966), described that these materials possess high density and low rigidity and are able to provide good insulation (eg. lead). He noted that transmission of existing partitions can be significantly increased by adding a layer of lead as thin as 1/8". This increases the weight of the partition without significantly increasing its stiffness. For this purpose leaded cloth or leaded vinyl has been used as wall paper on existing partition walls. Also, soft leaded plastics are being used increasingly in noise control since their density and flexibility make them almost perfect barriers. Its observed that the transmission loss of these partitions increases with frequency upto 55-60 dB there after a plateau is reached. Beyond this plateau again the transmission loss increases with frequency (Fig 8.1)

(c) Rigid porous materials:

Suri (1966), noted that sound insulation of porous type materials like porous concrete masonry , cinder, concrete, increases by 10 percent of weight, when mass of the material is increased. This is because of their sound absorption properties. However, Suri, (1966) suggested that for best insulation from these materials, it is essential that the partition be plastered atleast from one side if not on both the sides. These materials are commonly employed for hollow materials.

(d) Porous non-rigid/flexible materials :

Sound insulation provided by flexible porous materials like felt or glass silk is mainly due to their absorption of the sound incident on it. Here, the sound insulation is approximately proportional to the thickness of the material. Doubling the thickness may also double its insulation value in dB (Suri, 1966).

In Fig 8.1 transmission loss for some homogeneous materials is shown as given by Egan (1972). It is observed that lead has the maximum transmission loss characteristics.

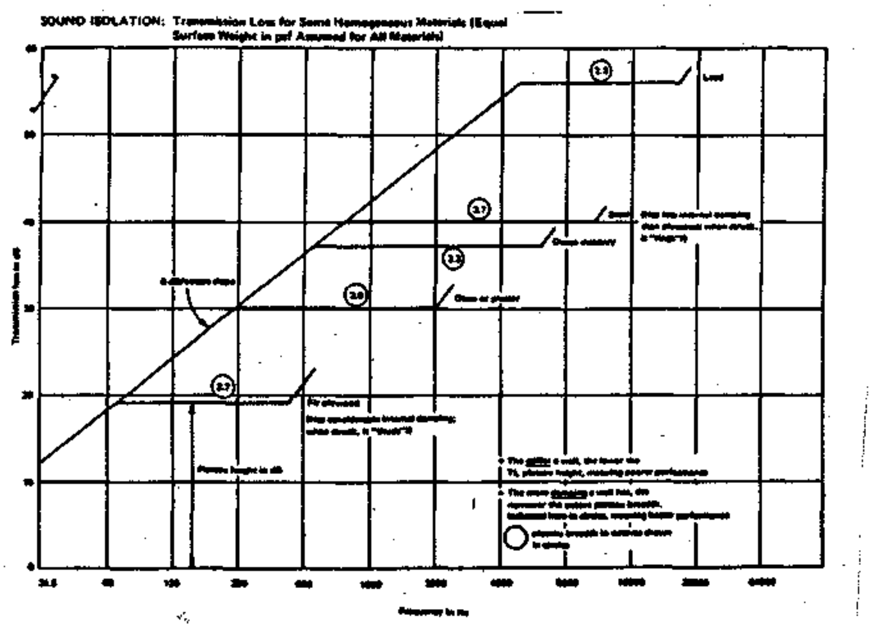


Fig 8.1: Transmission loss for some homogeneous materials (Equal Surface Weight in psf Assumed for All Materials). Egan, 1972.

Table 8.1 gives the sound transmission loss characteristics of some of the indigeniously available materials. It is seen that two layers (12.5 mm) gypboard present on both the sides of G.I frame work (70 mm) with (25 mm) mineral wool in between has the maximum average transmission loss (47 dB) among all the materials, listed in the table.

Table 8.1: Sound transmission loss characteristics of indigenously available materials

S. No	Material	Manu-facturer	Place and year of testing	Bulk density (kg/m^3)	Thick-ness mm	Sound Insulation (dB) at frequencies of						Average trans-mission in loss(AB)
						125	250	500	1000	2000	4000Hz	
1	2.	3	4	5	6	7	8	9	10	11	12	13
1.	Wood particle board	-	NPL 1982	800	19mm	22	18	22	24	23	27	23
2.	Wood particle board	-	NPL 1982	800	25mm	23	20	22	23	25	27	23
3.	Wood particle board composite panel of two layers of material with air gap between	-	NPL 1982	800	12mm each, 60mm total	25	24	28	31	37	32	24
4.	PVC sheet, composite panel of two years of material with air gap between	-	NPL 1982	1200	lmm each, 20mm total	19	16	19	21	19	23	20
5.	Cement asbestos sheet	-	NPL 1982	1600	4mm	11	10	13	19	21	22	17
6.	Asbestos millboard	-	NPL 1982	1300	5mm	14	14	19	25	28	27	21
7.	Calcium silicate slab	-	NPL 1982	275	40mm	19	20	25	29	26	29	25
8.	Composite panel plyboard sheets with foamed polyurethane between	-	NPL 1982	110	3mm each, 46mm total	12	15	18	21	23	29	20
9.	Vinyl rubber sheet	-	NPL 1982	648	1.10mm	4	6	8	10	16	19	11
10.	Vinyl rubber sheet	-	NPL 1982	2730	0.80mm	7	10	12	16	21	23	14
11.	Babmoo chicks partition across full width of the room	-	CBRI 1997									4

Table Contd..

12.	Two layers 12.5mm Gypboard either side of 70mm G.I. frame work with 25mm mineral wool in between	India Gypsum Ltd.815 Tolystoy House, Tolstoy Marg, New Delhi	AIR 1993		122mm							47
13.	Single layer 12.5mm Gypboard either side of 50mm G.I. frame work with 25mm Hysil in between	-do-	AIR 1993		75mm							45
14.	Two layers 12.5mm Gypboard either side of 50mm frame work with 25mm Hysil in between	-do-	CBRI 1977		12.5mm							42.5
15.	Plywood screens	-	CBRI 1997		12.5mm							5
16.	Timber partitions	-	CBRI 1997		40mm							6
17.	Thick timber partition across full width of the room	-	CBRI 1997									10
18.	ARISBR class division unit	-	CBRI 1997									6
19.	ARISBR science storage unit	-	CBRI 1997									8
20.	Masonry wall across full width of the room	-	CBRI 1997		10mm							8
21.	Masonry wall across full width of the room	-	CBRI 1997		—							18
22.	Partitions of perforatedacoustical wards	-	CBRI 1997									6
23.	Partition made of fibre glass packed between two tapestry cloth	-	CBRI 1997									7

From the survey of the Indian market it is evident that several sound insulating materials are available that brings about considerable transmission loss. These materials include porous / non-porous, rigid or flexible material based on required insulation, cost method of application of materials any one or combinations of the materials can be chosen for sound insulation.

9. ACOUSTICAL MATERIALS:

Any natural or synthetic materials which absorb sound are called as acoustical materials. Acoustical materials are available in a wide variety of environmental coordinated systems. Sound inside a room can usually be controlled by sound absorbing material and outside noise can be controlled only by proper construction of partition (Hornbostel,1978). Information about the desirable properties of acoustical materials, different types of materials and is protective covering (material facings) is disscused in this section.

Desirable properties of acoustical materials :

(1) Acoustical efficiency:

Suri (1966), described acoustical efficiency as the most important factor which determines the choice of a suitable material. It is not only important that the material should have requisite absorption coefficient, but also that every unit should offer uniform absorption, which should be as close to the test figures.

(2) Durability of material:

The sound absorbent materials used in the audiological test rooms should be long lasting. Most of the soft acoustical materials are found to have limited life as they get easily damaged. The semi-hard and hard acoustical materials such as perforated panels or tiles are found to be more rigid and durable. This can be observed from Table 9.5 given by Hornbostel (1978).

(3) Maintainance:

In order to maintain a clean appearance and to retain the same light reflection properties, the material would need to be cleaned, washed or renovated in due course of time. In some cases special vacuum cleaners would do the job, but ultimately the surfaces would become soiled unsightly and might require painting (Suri,1996).

Price and Mulholland (1967) studied the effect of paint finishes on the sound absorbing materials and found that the more porous materials suffer most from the application of paint due to the blocking of the "access passages" in to the material. They suggested that if painting of the surface is essential then only thin paint should be used and these should be applied by means of spray-gun.

According to Price and Mullholland (1967) for materials like felt and polyurethane foam, the only way to obtain a desirable surface finish is to cover the surface with a perforated paneling of the Helmholtz resonator type. This panel can now be painted any number of times, and provided the holes are not blocked, it will not be affected by the paint.

(4) Vermin and Rot proof:

It is necessary that the Acoustical materials selected should be proof against the attacks of Vermin and insects, rats and mice, termite and dry rot etc., so that it can last for many years (Suri, 1966).

(5) Resistance to moisture :

Suri, (1966), noted that the extent of resistance offered to moisture varies from one material to another, therefore it is necessary to check up if the selected material would stand the humid conditions prevalent in the room where it will be used. Effect of humidity can be checked using an airtight box containing appropriate saturated solutions (Ando and Kosaka, 1969). This box is kept at a constant temperature of 26 ± 3°C during the measurements. Measurements are made as soon as the material is removed from the box using standing wave tube or reverberation tube method.

Ando and Kosaka (1969) studied the effect of humidity on sound absorbing materials. They measured reflection coefficient of wood felt, ' rock-wool ' board and glass fibre and found that for wood felt reflection coefficient increased as humidity increased and for rock-wool board and glass fiber decreased considerably.

(6) Incombustibility :

According to Bhatnagar (1991), for ensuring fire safety in the rooms, only those materials should be used which do not contribute significantly to the growth of a fire inside the room.

Table 9.1 gives the non combustibility test results for materials, where the maximum rise in temperatures recorded by the furnance, surface- and the center-thermocouples, duration of flaming and percent weight loss are tabulated for each material it is reported whether it is non-combustible or combustible (Bhatnagar, 1991). It is evident from the table-1 that mineral fiber (Resin bended) with the density of 50-140 kg /mm is the only non-combustible material.

Suri, (1966) reported that it is necessary to use fire proof material to fix the acoustic materials. In case wooden strips are used to fix the acoustic material, they should be made fire proof by chemical treatment.

Material	Thickness mm	Density Kg/ cu.m	Maximum rise in temperature			Sustained flaming*s	Mass Loss %	Design ation
			Furnace deg. c	Surf-ace deg.c	Centre deg.c			
Calcium silicate sheet	6	900-1100	55-80	65-100	80-180	Nil	13-20	C
Calcium silicate sheet	6	1600	60	60	30	Nil	15	C
Calcium silicate block	50	300	50-70	35-105	20	Nil	15	C
Mineral fibre, resin bonded	25-50	50-140	2-5	7-22	10	Nil	3-5	NC
Mineral fibre, resin bonded	25-50	30-90	20-47	58-100	35-150	Nil	2-6	C
Mineral fibre, resin bonded	50	170	-	133	55	Nil	2	C
Mineral fibre, resin bonded	50	380	35	-	57	Nil	11	C
Mineral fibre, resin bonded	50	555	60	137	-	Nil	13	C
Timber, kailwood	12	500	390	325	180	350	98	C
Plywood	3	660	200	200	135	520	86	C
Particle board	12	400	230	215	140	220	97	C
Fibre board	12	250	225	190	125	230	99	C
Decorative laminate	2-3	1400-1600	150-325	190-310	150-445	636-850	55-80	C
Polyurethane foam, rigid	25	55	140	155	165	60	98	C
Polyurethane foam, flexible	50	100	175	190	170	180	83	C
Phenol formaldehyde foam	25	55	140	155	80	80	100	C
Rubberised coir	50	60	105	118	105	80	94	C
Expanded polystyrene	25	-	120	125	112	27	100	C
Composite panel, gypsum Plaster core, Paper surfaces	12-15	1100 WPA	65-110	-	160-240	Nil	25	C

(Table contd...)

Composite panel,polyurethane foam, paper surfaces	25	1.4 WPA	100	125	100	42	96	C
Phenol formaldehyde foam, Laminated	48	3WPA	170	185	130	120	99	C

Table 9.1 : Representative Values of the Non-combustibility Test Results for lining materials, Bhatnagar (1991).

WPA - Weight per Unit area, Kg/Sq.m ; C - Combustible; NC - Non-Combustible.

(7) Fire propagation Index of lining materials :

Bhatnagar and Yadav (1991) noted that once the lining materials are ignited, they can continue to burn and contribute to the growth of fire. The rate at which the fire build up takes place in an enclosure is dependent upon the behavior of these materials apart from its design, ventilation available and thermal characteristics of its construction materials. So, a proper selection of lining materials, therefore, is of utmost importance in order to maintain a desired level of fire safety in buildings. In Table 9.2, the fire propagation Index of common materials is given. Three sub-indices i_1, i_2 and i_3 are computed and the index of overall performance is the sum of the three sub-indices (ie. Fire propagation Index, $I = i_1 + i_2 + i_3$).

Material	Thick Ness mm	Density Kg/ Cu.m	Sub-indices			Fire Propagation Index I*
			I_1 #	I_2	I_3	
Timber, Teakwood	12	550	13	17	4	34
Timber, Deodarwood	12	600	17	16	3	36
Timber, Sheeshamwood	12	700	8	16	4	28
Timber, Chirwood	12	650	20	17	4	41
Timber, Kailwood	12	500	17	20	5	42
Timber, Mangowood	12	600	15	18	5	38

Plywood, general purpose	**3-12**	**650-800**	**8-11**	**13-16**	**2-4**	**24-31**
Fibre Board	**12**	**300**	**26-34**	**18-20**	**3-5**	**48-53**
Fibre hard board	**6**	**960**	**8**	**14**	**5**	**27**
Particle board, insulation grade	**12**	**400**	**15-25**	**14-17**	**3-4**	**35-44**
Particle board, medium density	**18**	**830**	**13**	**15**	**4**	**32**
Wood wool building slab	**25**	**650**	**3**	**2**	**1**	**6**
Coir cement sheet	**10**	**1800**	**3**	**1**	**1**	**5**
Decorative laminates	**2-3**	**1500**	**3-8**	**6-10**	**2-3**	**10-20**
Expanded polystyrene	**25**	**15**	**7**	**2**	**1**	**10**
Rubberised coir	**25**	**145**	**25**	**16**	**2**	**43**
Phenol formaldehyde foam slab	**25**	**35**	**5**	**4**	**2**	**11**
Polyethylene foam	**10**	**60**	**6**	**5**	**1**	**12**
Polyurethene foam slab, rigid	**25**	**55**	**21**	**9**	**2**	**32**
Polyurethene foam slab, flexible	**50**	**85**	**21**	**12**	**1**	**34**

Table 9.2 : Representative Values of Fire Propagation Index of Materials (Bhatnagar and Yadav, 1991).

* Higher is the value of 1, more hazardous is the lining material
# Higher the value of I, of any lining material, more easily-ignitable and more rapid burning it would be.

Higher is the value of the "Fire Propagation Index", more hazardous the lining material is. Also, higher the value of sub-Indices (i_1), of any lining material, it is more easily-ignitable and it would burn more rapidly. From Table 9.2 it can be concluded that coir cement sheet and wood wool building slabs are least hazardous material.

(8) Smoke Generation By Lining Materials :

Bhatnagar, Sharma, and Singh (1991) has also highlighted that Smoke generated during fires has been identified to be a major factor responsible for hampering escape and impeding rescue operations. Smoke is generated by combustible lining material as they burn. Such lining materials, once involved in a fire, undergo thermal decomposition and generate smoke. The rate at which the smoke build up takes place in an enclosure of a building is dependent upon the behavior of these materials apart from other factors like the design of the enclosure, building and ventilation. Table 9.3 gives the specific optical density of smoke generated by different lining materials. A material of higher Maximum Specific Optical Density of smoke can be considered to generate more smoke during a fire and results in a greater reduction in the visibility than the one of lower value. It is observed in the above table that expanded polystyrene, Phenol formaldehyde foam slab and Polyisocyanurate foam are the less smoke generating lining materials.

Material	Thickness mm	Density Kg/ Cu.m	Max. Specific Optical Density	
			Non-flaming	Flaming
Timber, Kailwood	12	500	330	265
Plywood, general purpose	3	650	160	75
Fibre board, insulation grade	12	230	300	190
Particle board, insulation grade	12	400	410	250
Particle board, medium density	18	890	415	235
Wood wool building slab	25	515	15	25
Decorative laminate	1.6-3	1500	30-60	80-190
Expanded polystyrene	25	20	0	25
Rubberised coir	25	135	480	450
Phenol formaldehyde foam slab	25	35	4	80
Polyurethane foam slab, rigid	25	100-450	100-200	200-280
Polyisocyanurate foam	20	50	10	60
Mineral fibre marine board	25	85	30	6
Red mud PVC sheet	1.6	1740	200	310
PVC Calendered sheet	2	1450	170	510
Glass reinforced plastic sheet	3	1330	20	180
PMMA Sheet	3	1100	75	65

(Table contd...)

Table 9.3 : Representative values of Maximum Specific Optical Density of Smoke Generated by Lining Materials (Bhatnagar, Sharma, and Singh, 1991).

(9) Heat Insulation :

All the materials possess varying degree of heat insulation properties. It is observed that dense materials have high thermal conductivity (K) and are inefficient thermal insulants whereas light weight materials have low conductivity and are efficient thermal insulants. The lower the value of thermal conductivity better is its insulating efficiency. Suri (1966) opined that heat insulation is an important factor when the material is required to be used on the ceiling or on the walls which are exposed to the sun. Hence, an acoustical material with lower thermal conductivity should be selected for the sound treated rooms as it would cut down the initial cost on air conditioning as well as on winter heating. In Table 9.4 values of thermal conductivity of various materials tested at CBRI (cited by India Gypsum Co. (1993) is given.

Material	Density Kg/m^3	K-value (W/mK)
Gypboard	840	0.16
Rock wool (unbonded)	92.0	0.047
Resin bonded mineral wool	48.0	0.042
Resin bonded glass wool	24.0	0.036
Asbestos mill board	1397.0	0.249
Hard board	979.0	0.279
Straw board	310.0	0.057
Soft board	320.0	0.066
Particle board	750.0	0.098
Coir board	97.0	0.038
Flexo board	1.2	0.51
Fiber glass (crown)	24.0	0.020
Plywood	640.0	0.174

Table 9.4 : Thermal conductivity of (K-value) of various materials tested at CBRI given by India Gypsum Co. (1993).

From the above table it is evident that fiber glass, coir board, resin bonded mineral woof and resin bonded glass wool have low thermal conductivity (K-values).

(10) Weight :

Suri (1966) reported that the weight of an acoustical material would need consideration because it will affect the method of application, eg. a lighter tile would afford a greater safety factor for adhesive application. Again a light weight tile would enable a light weight suspension system being used for the ceiling. Suri (1966). Thus it is recommended to use a light weight acoustical material.

(11) Aesthetic Appearance :

Last, but not least desired property of an acoustical material is its aesthetic appearance. Suri, (1966) noted that the final finish and its light reflecting properties would affect the initial cost of the illumination required however, consideration of appearance should not be allowed to sacrifice the main function of the material, namely, sound absorption.

Table 9.5 gives general data on advantages, disadvantages and major uses of acoustical materials used for walls & ceiling of buildings (Given by Hornbostel, 1978).

From the Table-4 it can be concluded that asbestos (perforated), clay tile (structural perforated), concrete (lightweight), concrete block, paper (perforated), perforated tempered hardboard, and textiles can be used for the acoustic treatment of the walls. It is seen that textiles have the best acoustic value among these materials but it is relatively easily damaged and has limited life. The acoustic properties of other materials can be controlled by quantity and size of holes and sound absorption value of pads used behind it except for clay tile (structural, perforated), concrete (light weight) and paper which have limited acoustic values.

In Table 9.5 it is observed that for the acoustic treatment of ceilings aluminium (perforated), asbestos (perforated), concrete (light weight), glass fibers, mineral wool (sprayed), mineral wool tile, paper, paper(perforated), plastic foam, stainless steel (perforated) can be used. Its seen that among these materials, glass fibers, mineral wool (spayed) and plastic foam have good acoustic values but they can not withstand rough usage. The acoustic properties of most of the other materials discussed above can be controlled by quantity and size of holes and sound absorbing value of pads used behind them and also, most of these materials are rigid, durable, permanent and can withstand rough usage. For the acoustic treatment of floors materials like cork, textiles and carpet can be used.

Material	Advantages	Disadvantages	Major uses
Aluminum perforated*	Permanent, rigid, durable; acoustic properties can be controlled by quantity and sizes of holes and sound absorption value of pads used behind it; wide range of colors when porcelain enameled	Requires special supporting and attaching systems for ceilings; requires acoustic pads	Ceilings of buildings where acoustic control is important
Asbestos, perforated'	Permanent, rigid, durable; withstand rough usage; acoustic properties can be controlled by quantity and size of holes and sound absorption value of pads used behind it; easily painted; fire resistant	Available only in cement color, acoustic pads are required; fire resistance controlled by type of pad used and method of support	Walls and ceilings of buildings where acoustic control is important
Clay tile, structural, perforated	Permanent, durable; withstands rough usage; wide selection of colors; fire resistant; load bearing	Limited acoustic value; can be used only for walls; acoustic pad within structural tile becomes permanent	Walls of buildings where acoustic treatment is important, generally corridors

(Table contd...)

		part of building	
Concrete, lightweight	Permanent, durable, roof or floor decking gives ceilings with acoustic value; fire resistant	Limited acoustic value; cannot be painted and repainted; can be used only for ceilings; no color selection	Ceilings of buildings where some acoustic treatment is important
Concrete block	Permanent, durable; withstands rough usage; fire resistant; load bearing	Can be used only for walls; acoustic pads, when used become permanent part ot building	Walls and partitions of building where acoustic treatment is important; corridors, side walls, auditoriums, theaters, etc.
Cork	Limited acoustic value; easily installed; flame resistant	As acoustic values increase it becomes softer, for, ceiling tile the cork is granular in form with binders and other materials; limited color selection	Flooring; bulletin; tack and similar boards; ceilings (when in tile form)
Glass fibers	Good acoustic value; available with finery perforated plastic coating flame resistant; easilly installed	Soft; will not withstand rough usage	Ceilings of buildings where acoustic treatment is relatively important
Mineral wool sprayed	Good acoustic value; relatively easy to install by spraying on surface; fire resistant	Very soft; will not withstand rough usage; cannot be painted and repainted; no color selection	Ceilings of buildings where acoustic control is impotant
Mineral wool tile"	Limited acoustic value; easily installed; flame resistant	Soft, will not withstand rough usage' cannot be painted and repainted; limited color selection	Ceilings of buildings, where acoustic treatment is relatively important.
Paper"	Limited acoustic value; easily installed; flame resistant	Soft, will not withstand rough usage; cannot be painted and repainted; limited color selection	Ceilings of buildings, where acoustic treatment is relatively imoortant.
Paper, perforated"	Double, thin; withstands relatively rough usage; acoustic properties can be controlled by quantity and size of holes and acoustic value of pads behind it; easily painted; available in prefinished baked enamel in a wide range of colors;	Acoustic pads are necessary, requires careful support as it will sag and buckle	Walls and ceilings of buildings where acoustic control is important

(Table contd...)

	flame resistant		
Perforated tempered hardboard"	Permanent; rigid; double; acoustic properties can be controlled by quantity and sizes of holes and sound absorption value of pads used	Requires special supporting and attaching systems for both walls and ceilings; fire resistant depending on pads and supporting systems	walls requiring acoustic treatment
Plastic foam	Good acoustic value; easily installed; flame resistant	Soft, will not withstand rough usage; cannot be painted and repainted; limited color selection	Ceilings of buildings, where acoustic treatment is relatively important
Stainless steel, perforated	Permanent; double; acoustic properties can be controlled by quantity and sizes of holes and acoustic value of pad behind it	Requires special supporting and attaching systems; requires acoustic pads; fire resistance controlled by type of pad used and method of support; no color selection	Ceiling of buildings where acoustic control is important
Steel, perforated"	Permanent, durable, rigid; acoustic properties can be controlled by quantity and size of holes and acoustic value of pads behind it; easily painted; wide selection of colors in porcelain enamel type	Requires special supporting and *attaching systems;* requires acoustic pads; fire resistance controlled by type of pad used and method of support	Ceiling of buildings where acoustic control is important
Textiles	Good acoustical value when draped; available perforated to be applied over padding; flame resistant	Require periodic cleaning; relatively easily damaged ; have limited life	Walls of buildings where acoustic treatment and control IIVI11IIIVIH nl^T WHRIVA are important
Textiles, carpet	Good acoustic properties; easily installed; can be used on floors, walls, or ceilings; flame resistant; wide variety of colors, textures designs, and thickness	Required periodic cleaning; have limited life	Floors, not only for acoustic treatment but also for comfort and decorative purposes; on walls and ceilings for special types of acoustic treatment

Table 9.5 : Typical acoustical materials used for walls and ceilings of buildings given by Hornbostel(1978).

SOUND ABSORBING MATERIALS

Hornbostel (1978) , classified acoustical materials in to following three categories:

(1) Fabrics and Textiles
(2) Rigid, hard materials with holes, slots or perforations of various types, backed with a soft sound absorbing material and
(3) Artificial or natural materials with soft or porous surfaces. These materials can be pre-fabricated in to tile, sheets and other easily handled forms, or they may be installed on the job.

Following are the commonly used sound absorbing materials for acoustic treatment in rooms:

(a) Porous absorbents :

Magrab (1975), described porous materials absorb by reason of their porosity, whereby sound entering the inter connecting pores is dissipated in to heat by the action of viscous and thermal process. Some porous materials are of solid type such as acoustic plaster or wood-wool board. Others are fibrous, such as acoustic felt, mineral wool or sprayed asbestos, and the vibration of the fibrous material may contribute to the acoustic absorption. Porous absorbents are more efficient at high than at low frequencies, so when these materials are employed for acoustic correction it is important to use an adequate thickness to cover a wide frequency range of absorption (Magrab, 1975 ; Egan, 1972 ; Mohanan, Sharma and Chhapgar, 1983 ; and Moreland, 1981). Fig 9.1 shows absorption characteristics of porous materials with different thickness as cited by Magrab, (1975). Magrab, (1975) reported that mounting the material on battens to give an air space behind it acts in the same manner as an increase of thickness.

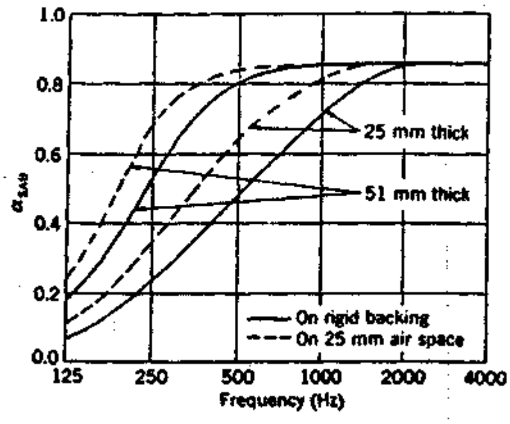


Fig 9.1 : Absorption coefficient for 25 and 51 mm thick mineral wool slabs, each on a rigid backing and on 25 mm battens by Magrab, 1975.

Magrab, (1975) opined that absorptive properties of porous absorbent are dependent on the surface treatment. Acoustic plasters require care in decoration and loose their efficiency if the surface is sealed by pointing. Sprayed asbestos can be given various surface finishes. Mineral wool is often covered by a thin muslin. Acoustic felts can be covered with muslin that is painted and later pin-pricked. Porous materials are frequently covered with thin perforated sheet metal. Detailed information is discussed in later section. Mirowska (1979), investigated the influence of the structural properties of inorganic fibrous materials (mineral wool, glass wool) and found that the material with smaller thickness of fibers, less shot content, weak connections of fibres, flexible connections have better sound absorption properties.

Rao and Reddy (1983) compared the sound absorption coefficient at different frequencies for glass wool, sponge and wood fiber of thickness 5.1 cm, 4 cm and 5.4 cm respectively and found that glass wool was the best among them.

(b) Unperforated panel absorbents :

According to Magrab (1975), in non-porous panel absorbents, the principle mechanism of absorption is by vibration of the panel. Unperforated absorbent materials like ply-board panels, plastic sheets etc. are usually mounted on a frame work to leave an air gap behind it [Mohanan, Sharma and Chhapgar (1983); Magrab (1975)]. Panel absorbents are usually designed for the low frequency region and the absorption is in a relatively narrow range about the resonance frequency. The absorption and the bandwidth are increased by the use of porous absorbent behind the panel (Magrab, 1975). Uniform absorption over a wider frequency range may be obtained by a combination of panels with different resonance frequencies (Magrab, 1975).

(c) Perforated tiles and boards :

Magrab, (1975) described perforated tiles and boards as having the following features : Made of porous material , usually fiber board and asbestos, and they may have a hard or non-porous face. The front surface is perforated with holes that penetrate in to the porous interior. The sound absorbing properties are mainly due to the holes, and where these are effective, the tiles can be painted without undue loss of efficiency provided the holes are kept clear of paint. The absorption characteristics vary over a wide range according to the kind of porous material employed. Absorption increases as the porosity of the material increases. Depth of the hole and thickness also effects the absorption characteristics.

Fig 9.2 shows absorption coefficient of two different perforated fiber board tiles. It is seen in Fig 9.2 that with increase in whole depth the response frequency decreases and also with increase in thickness absorption increases.

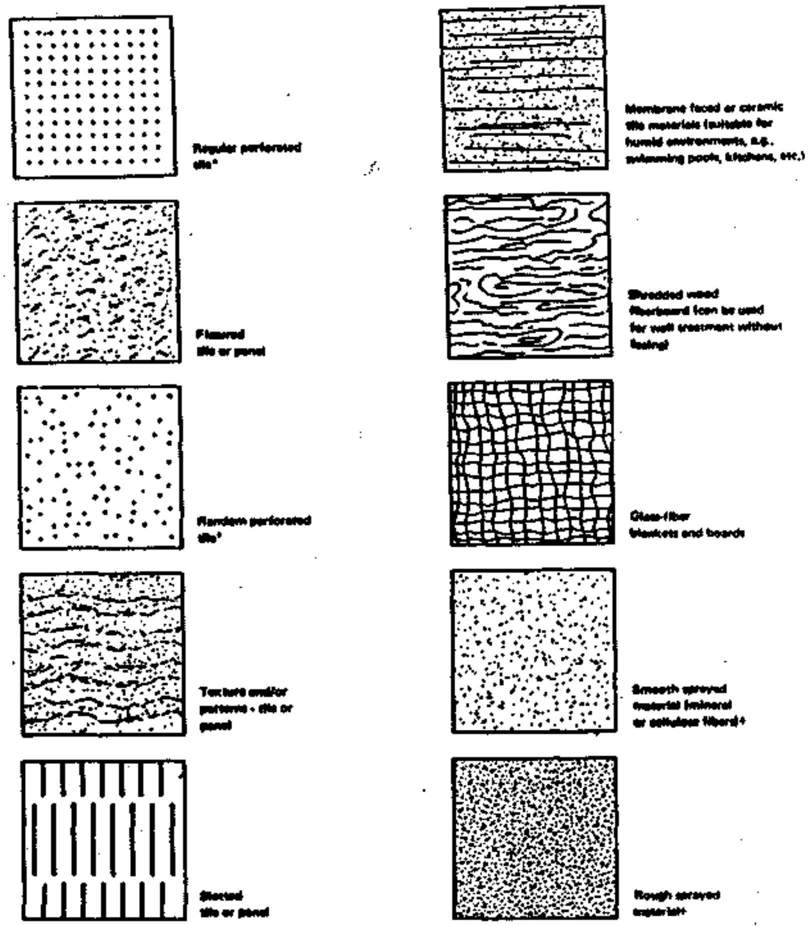


Fig 9.3

Fig 9.2 : Absorption coefficient of two different perforated fiberboard tiles (Magrab, 1975). (below)

Fig 9.3 shows some of the commercially available sound absorbing materials as given by Egan,1972. (above)

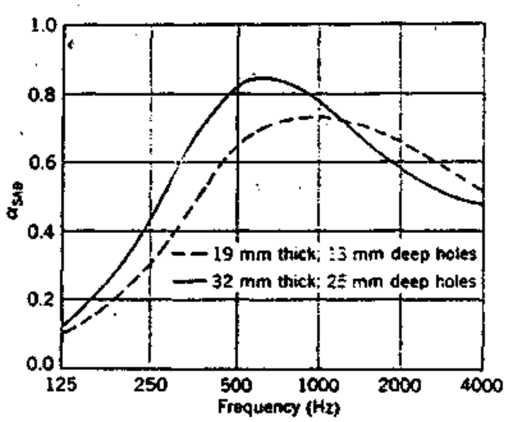


Fig 9.2

Measurement of sound absorption coefficient:

The absorption coefficient of any material varies considerably with the angle of incidence of sound waves. Two types of measurements are normally carried out, one for normal incidence and other for random incidence. The two methods to determine the absorption coefficient are as follows:

(i) Standing wave tube method, and
(ii) Reverberation chamber method.

(i) Standing wave tube method :

Srivastava, Bhandari and Dhabal, 1996 reported that the normal incidence sound absorption coefficient is measured using the standing wave tube method. It is useful for comparing the absorptivity of different materials. It can be measured with a small sample of the material. Absorption coefficient is measured with the apparatus shown in Fig 9.4. The sound wave is generated by a beat frequency oscillator at a desired frequency. The loudspeaker is fitted in one end of the tube. The sound wave reinforced in loudspeaker passes through the tube and falls on the sample normally. Some sound energy will be absorbed in the sample where as some will be reflected back. The reflected wave and the incident wave form a system of standing waves inside the tube. Since the energy of the reflected wave depends on the absorpton properties of the sample the maxima and minima of sound pressure along the tube measured by the probing tube attached with a microphone gives a measure of absorption properties. The probe tube is gradully moved away from the sample and readings corresponding to maxima (Pmax) and minima (Pmin) of the sound pressure are noted. With the help of the sound analyser the absorption coefficient is thus given by the formula

$$\alpha = \frac{4}{n + 1/n + 2}$$

Where, a = absorption coefficient

$$n = \frac{P_{min}}{P_{max}}$$

This experiment is done for the frequencies 125,250, 500,1000,2000,4000 Hz. The tests are conducted at normal incidence of sound on the sample according to ASTM standards c-384 ,1977.

Fig 9.4 The Standing wave apparatus for measurement of absorption

coefficients of samples at normal incidence (Sectional View)

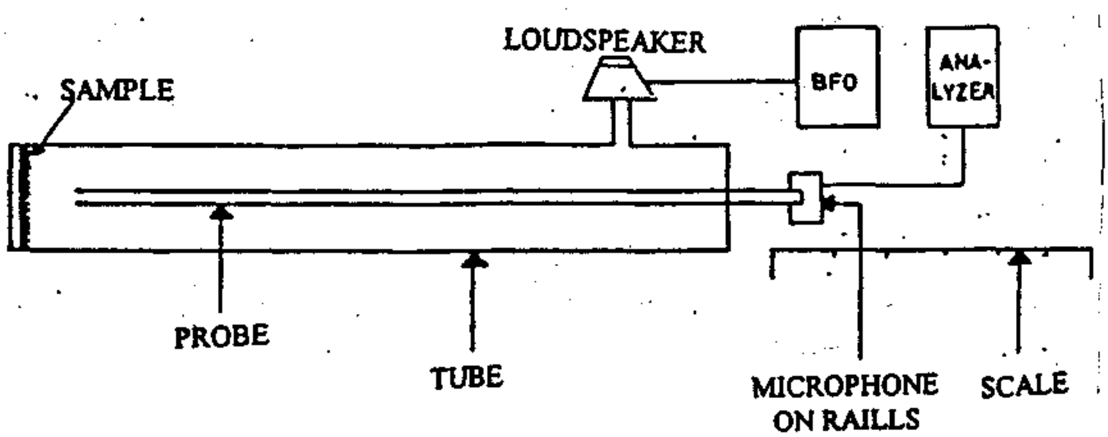


Fig 9.4 : The standing wave apparatus for measurement of absorption coefficient of samples at normal incidence (sectional view)

Limitations of Standing Wave Tube method

(1) At the lower end of the audio frequency range the sound absorptive material scatters sound rather widely as a result of which no standing wave pattern is formed. This occurs since its size is smaller as compared with the wavelength. Hence, this form of measurement is not reliable (Suri, 1966)

(2) At the upper end of the audio frequency range, the measurement are not reliable because of (a) large attenuation in the air and (b) Experimental error in the measurement of pressure at loops and nodes on account of the distance between them being very small- about an inch or two- and of the same order as the size of the microphone used (Suri, 1966)

(3) This method gives values only for normal angles of incidence of sound (Suri, 1966).

(ii) Reverberation Chamber Method :

Srivastava, Bhandri and Dhabal (1966), noted that this measurement is carried out in a special chamber known as reverberation chamber in which sound wave strikes the test sample from many directions simultaneously and therefore large areas of the sample are required. Generally, the chamber coefficient are higher than normal incidence absorption coefficient.

Here, reverberation time is to be measured when it is empty and again when the sample is laid out on the floor of the chamber as shown in fig 9.5 Reverberation time of the chamber, for a sound of a given frequency is the time required for the sound pressure level in the enclosure to decrease by 60 dB after the source has been stopped. The change or difference in reverberation time gives the measure of absorption coefficient of the material by the Sabine formula.

$$\alpha = \frac{1.6v}{S} [1/T_1 - 1/T_2]$$

Where,

a - absorption coefficient of the material

V - Volume of the chamber

S - Surface area, m^2

T1 - Empty reverberation time

T2 - Reverberation time in presence of sample of the material.

These values are more reliable and useful for acoustical designers and architects. The tests are conducted on the sample according to ASTM standards C423-81

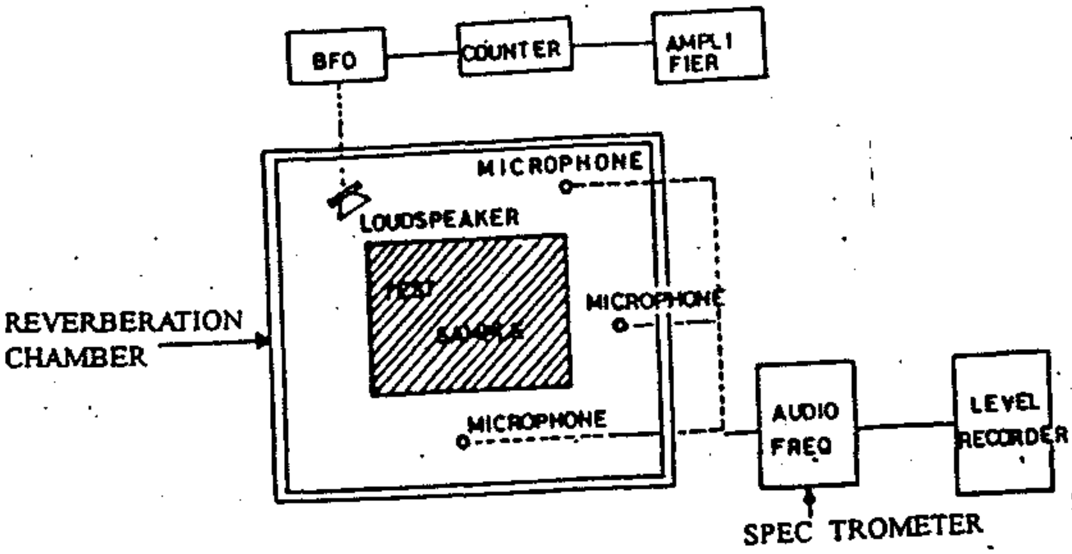


Fig 9.5 : The Experimental set up for measurements on absorption coefficient at random incidence using large samples (Floor plan of reverberation chamber)

Advantages of reverberation chamber method :

(1) This method gives an average value of the coefficient for the different angles of incidence for frequencies above 2000 Hz

(2) The area of sample, the edge effect, the mounting conditions, the variation of absorption due to the angle of incidence are all considered in this method (Suri, 1966)

Disadvantage of reverberation chamber method:

(1) At low frequencies appropriate values of the absorption coefficient are not obtained (Suri, 1966)

Thus it can be concluded that reverberation chamber method gives much more reliable values of absorption coefficient, than standing tube method. In the latter method the test conditions take in to account the possible method of application of the material in the actual field. It is observed that the majority of standard testing laboratories in different countries use the reverberation chamber method for measuring absorption coefficient of materials (Suri, 1966).

Table 9.6 gives the values of absorptive coefficients and NRC of indigenous materials with rigid backing calculated using the reverberation chamber method. This table also included information about the manufacturer of the material, its thickness, density, and the place where testing was carried out. From this table it can be concluded that orient cerwool provides maximum sound absorption among all the materials, with NRC value of 0.99.

Table 9.7 gives the values of absorption coefficients and NRC of indigenous sound absorbing materials with rigid backing calculated using the standing wave tube method. This table includes information about the manufacturer of the material, its thickness, density, and the place where testing was carried out. From table 9.7 it can be concluded that Bartex is the best sound absorbing material among all the materials, with the NRC of 0.71.

Table 9.6 : Reverberation Chamber Data for absorption coefficients of mateiials with rigid backing

S. No.	Name of Material	Manufacturer	Place and year of testing	Thickness mm	Density Kg/m^3	Absorption Coefficients Freq. Hz 125	250	500	1000	2000	4000	NRC
1.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.05	.10	.52	.75	.80	.85	.54
2.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.02	.05	.30	.55	.56	.63	.36
3.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.05	.07	.56	.68	.80	.99	.53
4.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.05	.06	.34	.56	.67	.70	.40
5.	Sitatex - Perforated	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	338	.05	.10	.61	.78	.91	.96	.60
6.	Sitatex - Perforated	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	370	.04	.05	.36	.63	.78	.99	.46
7.	Sitatex - Perforated 1964 (Standard)	M/s Plywood Products Sitapur (U.P.)	**CBRI** 1996	19	-	.04	.07	.53	.75	.98	.99	.59
8.	Sitatex - Perforated 1964 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.05	.07	.24	.47	.88	.90	.41
9.	Sitatex - Perforated 1681 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.06	.09	. .51	.82	.84	.99	.57
10.	Sitatex - Perforated 1681 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.02	.06	.22	.55	.75	.80	.38

Table Contd..

11.	Sitatex - Perforated 1964 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.04	.09	.51	.75	.91	.85	.57
	Sitatex - Perforated 1964 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.05	.06	.23	.53	.65	.81	.37
13.	Sitatex - White	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	384	.10	.18	.62	.78	74	.69	.58
14.	Sitatex - White	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	400	.05	.09	.40	.66	.82	59	.49
15.	Sitacore	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	25	-	.05	.16	.41	.46	.70	.72	.43
16.	Sitatex - Perforated 1600 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.06	.10	.45	.73	.74	.85	.50
17.	Sitatex - Perforated 1600 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.02	.07	.27	.67	.72	.46	.43
18.	Sitatex - Perforated 1681 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.06	.07	.52	.91	.91	.92	.60
19.	Sitatex - Perforated 1681 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.02	.06	.17	.6,	.72	.63	.39
20.	Sitatex - Perforated Random (White)'	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.06	.15	.63	.67	.76	.91	.55
21.	Sitatex - Perforated Random (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.02	.07	.34	.68	.72	.63	.45
22.	ScrimatMat Fibreglass	M/s The Bombay Co. Pvt. Ltd., Wallace Street Bombay	CBRI 1996	50	80	.20	.62	.99	.93	.61	.42	:79

Table Contd..

23.	Scrimat Mat Fibreglass	M/s The Bombay Co. Pvt. Ltd., Wallace Street ' Bombay	CBRI 1996	25	80	.06	.36	.99	.94	.49	.31	.70
24.	Scrimat Mat Fibreglass	M/s The Bombay Co. Pvt. Ltd., Wallace Street Bombay	CBRI 1996	50	80	.57	.80	.99	.99	.95	.99	.93
25.	Scrimat Mat Fibreglass	M/s The Bombay Co. Pvt. Ltd., Wallace Street Bombay	CBRI 1996	25	80	.29	.59	.85	.87	.84	.98	.79
26.	Uniformly perforated Jolly Board	M/s Anil Hard Board Bombay	CBRI 1996	12.7	300	.06	.12	.55	.66	.67	.76	.50
27.	Randomly perforated Jolly Board	M/s Anil Hard Board Bombay	CBRI 1996	12.7	300	.15	.18	.52	.58	.76	.58	.51
28.	Bitumen bonded Fibre insulation Bombay Board	M/s Anil Hard Board Bombay	CBRI 1996	12	300	.25	.36	.40	.45	.51	.66	.43
29.	Anil Hard Boards	M/s Anil Hard Board Bombay	CBRI 1996	18	315	.40	.45	.42	.45	.42	.42	.43
30.	Anil Hard Boards	M/s Anil Hard Boards Ltd. 8733, Desbandhu Gupta Marg, 2nd Floor Paharganj, New Delhi	CBRI 1996	**18**	451	.28	.34	.39	.45	.42	.35	.40
31.	Anil Hard Boards	M/s Anil Hard Boards Ltd. 8733, Desbandhu Gupta Marg, 2nd Floor Paharganj, New Delhi	CBRI 1996	18	406	-	.35	.36	.37	.35	.36	.36

Table Contd..

32.	Fibrosil	M/s Indian Rockwool Co. Ltd. Delhi-6	CBRI 1996	50	-	.40	.55	.90	.99	.99	.92	.88
33.	Fibrosil (Book)	M/s Indian Rockwool Co. Ltd. Delhi-6	CBRI 1996	25	-	.36	.53	.74	.93	.93	.92	.78
34.	Fibrosil	M/s Indian Rockwool Co. Ltd. Delhi-6	CBRI 1996	25	98	.06	.07	.13	.24	.54	..80	.25
35.	Fibrosil (Book)	M/s Indian Rockwool Co. Ltd. Delhi-6	CBRI 1996	50	-	.07	.16	.33	.66	.84	.92	.52
36.	Lloydwood Board	M/s Punj & Sons (Pvt.) Ltd., New Delhi	CBRI 1996	25	98	.14	.26	.99	.99	.85	.93	.77
37.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	50	40	.18	.69	.84	.90	.82	.73	.81
38.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	50	65	.36	.80	.96	.96	.94	.73	.91
39.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	50	65	.36	.75	.88	.90	.86	.73	.85
40.	Spintex (Resin bonded)	M/s tfynj & Sons Pvt. Ltd., New Delhi	CBRI 1996	25	49	.13	.32	.82	.95	.96	.94	.76
41.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	25	49	.16	.41	.84	.96	.96	.92	.79 25mm air gap
42.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	50	49	.23	.58	.85	.96	.98	.94	.84

Table Contd..

43.	Spintex (Resin bonded)	M/s Punj & Sons Pvt. Ltd., New Delhi	CBRI 1996	50	49	.28	.66	.98	.97	.95	.94	.89 25mm air gap
44.	Fibreglass Crown RBwool-lOO(RB-l)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	16	.18	.23	.54	.75	.85	.88	.59
45.	Fibreglass Crown RBwool-150(RB-2)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	24	.24	.30	.59	.78	.92	.98	.65
46.	Fibreglass Crown RBwool-200(RB-3)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	•32	.17	.23	.63	.71	.92	.92	.64
47.	Fibreglass Crown RBwool-lOO(RB-l)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	16	.16	.28	.62	.83	.84	.78	.64 25mm air gap
48.	Fibreglass Crown RBwool-150(RB-2)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	24	.26	.36	.67	.87	.91	.90	.70 25mm air gap
49.	Fibreglass Crown RBwool-150(RB-3)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	32	.23	.36	.86	.91	.91	.98	.76 25mm air gap
50.	Fibreglass Crown RBwool-lOO(RB-l)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	16	.25	.52	.79	.84	.91	.98	.76
51.	Fibreglass Crown RBwool-150(RB-2)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	24	.35	.59	.96	.98	.98	.98	.88
52.	Fibreglass Crown RBwool-200(RB-3)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	32	.31	.61	.97	.98	.98	.98	.98

Table Con td...

53.	Fibreglass Crown RBwool-IOO(RB-l)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	16	.31	.55	.86	.87	.91	.98	.79 25mm air gap
54.	Fibreglass Crown RBwool-150(RB-2)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	24	.31	.65	.98	.98	.87	.98	.87 25mm air gap
55.	Fibreglass Crown RBwool-200(RB-3)	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	50	32	.31	.67	.98	.98	.94	.98	.89 25mm air gap
56.	Sound Deadening Quilt	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	-	.09	.29	.50	.71	.88	.89	.59
57.	Fibreglass Rigid Board	M/s Fiberglass Pilkington Ltd. Bombay	CBRI 1996	25	-	.16	.25	.65	.78	.89	.90	.64
58.	Cerwool acoustic blanket	Orient Cerwool Ltd. 402, Kailash tower Behind STC Colony, Andheri (E) Mumbai-400069	NRL 1994	25	96	.36	1.00	.94	1.00	1.00	.98	.99
59.	Wood wool boards	Anutane Boards (P) Ltd.,3A Visvesvaraya Industrial area, Bangalore-560 048	AIR 1998	20 12 19 25 38 50	400 400 400 400 400 400	.24 .15 .13 .12 .18 .12	.30 .31 .17 .33 .25 .30	.38 .48 .37 .52 .60 .75	.68 .56 .68 .80 .67 .70	.50 .56 .64 .69 .60 .66	.66 .55 .74 .71 .73 .78	.46 .43 .45 .53 .50 .43
60.	Min rock resin . bended rockwool slabs	Minwool Rock Fibers 413,4th Floor, Babukha, Estate Busheerbarg Hyderabad-500001	NPL 1992	50	48	.23	.63	.93	1.00	.99	1.00	.89

Table 9.7 : Standing wave tube data for absorption coefficient of materials with rigid backing

S. No.	Name of Material	Manufacturer	Place and year of testing	Thickness mm	Density Kg/m^3	Absorption Coefficients Freq. Hz 125	250	500	1000	2000	4000	NRC
1.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.12	.17	.21	.66	.67	.68	.43
2.	Sitatex - Perforated random (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.12	.18	.26	.45	.48	.62	.34
3. .	Sitatex - Perforated 964 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.08	.17	.28	.51	.54	.56	.37
4.	Sitatex - Perforated 1681 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.09	.15	.33	.54	.74 '	76	.44
5.	Sitatex - (Plain)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	13	-	.13	.18	.21	.18	-	-	.18
6.	Sitapore	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	25	-	.05	.11	.28	.40	.60	.43	.35
7.	Sitatex - Perforated 1964 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.07	.13	.23	.42	.66	.51	.36
8.	Sitatex - Perforated 1964 (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.09	.15	.30	.57	.71	.66	.43
9.	Sitatex - Perforated 1600 (Standard)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.08	.15	.28	.62	.70	.63	.44
10.	Sitatex - Perforated random (White)	M/s Plywood Products Sitapur (U.P.)	CBRI 1996	19	-	.09	.12	.28	.50	.52	.58	.36

Table Contd..

11.	Anil Board random (Standard)	M/s Anil Hardboard Bombay	CBRI 1996	131	-	.09	.13	.15	.22	.33	-	.21
12.	Fibrosil (Book)	M/s Indian Rockwool Co. Pvt. Ltd. Delhi-6	CBRI 1996	50	96	.07	.16	.33	.66	.84	.92	.50
13.	Fibrosil Resin Bonded Slabs	M/s Indian Rockwool Co. Pvt. Ltd., Delhi-6	CBRI 1996	25		.06	.10	.20	.46	.81	.95	.39
	Lloyd Board	M/s Punj & Sons Pvt. New Delhi-1	CBRI 1996	25	240	.06	.25	.40	.79	.82	.80	.57
15.	Fibreglass	M/s Punj & Sons Pvt. New Delhi-1	CBRI 1996	25	80	.07	.11	.15	.33	.71	.92	.37
16.	Spintex	M/s Punj & Sons Pvt. New Delhi-1	CBRI 1996	25	80	.09	.14	.22	.53	.88	.93	.45
17.	Fibreglass Crown wool	M/s Punj & Sons Pvt. New Delhi-1	CBRI 1996	25	32	.11	.14	.27	.35	.71	.90	.37
18.	Spintex	M/s Punj & Sons Pvt. New Delhi-1	CBRI 1996	25	64	.18	.18	.52	.46	.86	.96	.55
19.	Verrmculite	M/s New Kem Products Corp. Bombay-14	CBRI 1996	25	-	.12	.19	.21	.23	.26	.27	.22
20.	Bartex	M/s Bamagore Jute Factory Ltd. Alam Bazar Calcutta-35	CBRI 1996	25	-	.15	.21	.69	.97	.96	.71	.71
21.	Barmil Board	M/s Bamagore Jute Factory Ltd. Alam Bazar Calcutta-35	CBRI 1996	13	297	-	.03	.16	.33	.64	.58	.29

Table Contd..

22.	Kurlon	M/s Bamagore Jute Factory Ltd. Alam Bazar, Calcutta-35	CBRI 1996	38	-	.03	.21	.39	.46	.70	.55	.44
23.	Coir Fibre Rice Straw Building Board	CBRI, Roorkee	CBRI 1996	50	500	.09	.30	.38	.35	.40	.38	.36
24.	Coir Fibre Cement Particle Board	CBRI, Roorkee	CBRI 1996	12	-	.08	.14	.15	.21	.26	.24	.19
25.	Wood Wool Board	CBRI, Roorkee	CBRI 1996	30	450	.13	.18	.25	.46	.88	.55	.44
26.	Woodtex Insulation Board	M/s Wood India 178, M.G. Road Calcutta-7	CBRI 1996	50	400	.20	.21	.58	.70	.60	.54	.53
27.	WoodWool Insultation Board	M/s Pan Insulation 149, New Gandhi Nagar, Ghaziabad	CBRI 1996	35	350	.27	.36	.50	.74	.72	**.38**	.58
28.	Duratex (Woodwool Board)	M/s B.K. Insulation 4/5, Netaji Subhash Marg, N. Delhi	CBRI 1996	25	400	.24	.38	.58	.62	.70	.66	.57
29.	WoodWool Insulation Board	M/sB.M.Mittal, Ex. Engr. C. 1st Floor, C/3, Pushpa Bhawan M.B. Road N.Delhi-62	CBRI 1996	15	600	.15	.21	.32	.38	.56	.52	.37

Table Contd..

30.	Thermotex	M/s Vijay Udyog F-54, Ind. Area, Buland Shahar Road Ghaziabad	CBRI 1996	25	375	.20	.25	.51	.60	.61	.58	.49
31.	Thermofridge Woodwool	Asstt. Engineer, HI Civil Const. Wing, Air, C-3, Pushpa Bhawan, MB Road New Delhi	CBRI 1996	25	650	.16	.28	.32	.40	.35	.28	.34
32.	Insulation Board (Woodwool Board)	Mr. Ramesh Garg Ex.Engr.,PWD 27(DA), 8th Floor MSO Building, New Delhi	CBRI 1996	20	400	.21	.24	.38	.45	.76	.43	.46
33.	Duorfoam	Rubrofibre Pvt. Ltd. Trichur-l.Chungom Allappay (Kerala)	CBRI 1996	13	125	.07	.10	.26	.53	.58	.77	.37
34.	Gypsum Plaster Board	CBRI, Roorkee	CBRI 1996	13	125	.10	.15	.18	.21	.30	.36	.21
35.	Phosphogypsum Anhydrite Plaster	CBRI, Roorkee	CBRI 1996	13		,15	.16	.28	.30	.31	.35	.26
36.	Minwool Insulation Board	15-9-495, Mahboobganj Hyderabad	CBRI 1996	50	120	.33	.48	.58	.77	.86	.93	.67
37.	Minwool Insulation Board	15-9-495, Mahboobganj Hyderabad	CBRI 1996	50	150	-	.58	.63	.70	.86	.93	.69

Table Contd..

38.	Kinifoam Board	Shroff Textile Ltd. Fort House Dr. D.N.Road, Bombay	CBRI 1996	-	-	.24	.28	.24	.38	.24	.36	.30
39.	Hyderabad Asbestos HACP Asbestos, REF 108	Res. Manager, Hyderabad Cement Products Ltd., Sanat Nagar Hyderabad	CBRI 1996	60	650	.28	.29	.30	.36	.32	.38	.30
40.	Pheno-Therm Fenolic Foam	Bakelite Hylam Ltd. 9D, Atma Ram House 1 Tolstoy Marg, New Delhi	CBRI 1996	50	36.5	.35	.40	.42	.48	.50	.55	.45
41.	Non-Woven Carpet	M/s Uniproducts (India) Ltd., 21, Community Centre, Friends Colony New Delhi	CBRI 1996	30	450	.09	.17	.18	.23	.24	.43	.21
42.	Non-Woven Carpet	M/s Uniproducts (India) Ltd., 21, Community Centre, Friends Colony New Delhi	CBRI 1996	70	230	.15	.26	.30	.35	.41	.55	.33
43.	Non-Woven Carpet	M/s Uniproducts (India) Ltd., 21, Community Centre, Friends Colony New Delhi	CBRI 1996	30	210	.12	.21	.30	.28	.32	.38	.28
44.	Non-Woven Carpet	M/s Uniproducts (India) Ltd., 21, Community Centre, Friends Colony New Delhi	CBRI 1996	50	187	.15	.25	.36	.28	.26	.36	.29

Table Contd..

45.	Gypsum Composite Board	R.R.L., Jammu	CBRI 1996	12	1000	.10	.18	.30	.32	.28	.28	.30
46.	Anchor Ceiling Tiles Teakwood Particled Board Bonded with Phenol Formal-dehyde Synthetic Resin	The Indian Plywood Manufacturing Co. Ltd., 25/3, Mail Road, Kanpur	CBRI 1996	12	820	.05	.11	.15	.20	.26	.31	.18
47.	Cerwool Blanket	Orient Cerwool Ltd. 1212, Chiranjib Tower 43, Nehru Place New Delhi	CBRI 1996	30	96	-	.33	.56	.60	.63	.77	.53
48.	Cerwool Blanket	Orient Cerwool Ltd. 1212, Chiranjib Tower 43, Nehru Place New Delhi	CBRI 1996	30	128	-	.28	.56	.64	.69	.86	.54

Thus, it can be concluded that there are variety of sound-absorbing materials available in India which can be used for the acoustical treatment of audiological test rooms. These include porous absorbents, unperforated panel absorbents, perforated tiles and boards. Depending on the desired acoustical property, cost availability of material, fire-resistance, durability, life of the material colour, maintaince requirements and ways of installing the material, the particular sound absorbent material can be choosen for the acoustical treatment.

Materials Facings:

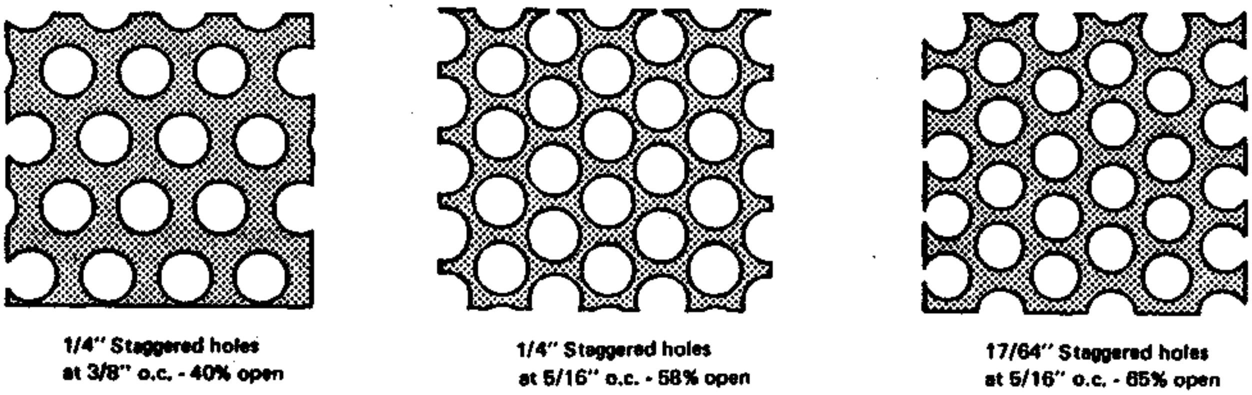
Facings are applied to the exterior surfaces of sound absorptive materials to protect the absorbent materials (Miller and Montone, 1978; Magrab, 1975). Magrab (1975) noted that facings also provide a suitable appearance. Miller and Montonel978, described two primary types of facings: perforated material facing and film facings.

(a) Perforated material facings

(b) Film facing

(a) Perforated material facings

Perforated sheet metal, expanded metal, pegboard and other materials with an open area facings are commonly used as a protective cover for sound absorptive acoustical materials (Miller and Montone, 1976; Egan, 1922). According to Magrab 1975, the effect of perforated material facings depends on its thickness and on the size and spacing of the perforations. The perforations are usually circular but they are sometimes in the form of slits. He observed that the absorption of the sound absorbing material is not appreciably reduced with small perforations of 3 mm or less in diameter and open area of about 15% of the total surface area. These facing generally tend to reduce the absorption at high frequencies so a thin sheet metal should be used. Fig.9.6 shows perforated facings with a table of suitable perforation sizes and spacings for facing materials (Egan, 1972).



Suitable perforation sizes and spacings

Hole diameter (inch)	Spacing (inch o.c.)	Notes
3/16	0.50	Safe limit for hardboard ("pegboard") material
5/32	0.40	
1/8	0.30	Most suitable for wall materials. Can be painted without clogging holes, and holes are small enough to discourage the jabbing of sharp objects into them.
3/32	0.22	
1/16	0.15	
1/32	0.08	

Fig. 9.6: Perforated sheet metal configuration with a table of suitable perforation sizes and spacings for general facing materials (Egan 1972).

(b) Film facings

Miller and Montone (1978) have reported that film facings protect the acoustical material from contaminants such as moisture (oil and water) and air borne particles (dirt and metal). Common films with their surface weights and tensile modulus as a function of their thickness are presented in table 9.8 (given by Powers and Rudinoff, 1987), Fig.9.7 depicts has the performance is modified by various thickness of a protective film and Fig 9.8 illustrates the peak performance frequency for each film material in various thickness(Miller and Monione, 1978). It is observed that even a very lightweight 0.5 ml film harms high frequency performance and heavier films show

Table 9.8
Physical properties of common plastic films[4]

Symbol	*Material*	*Thickness In.*	*Surface Wt. gram/ft²*	*Tensile Modulus PSI*
A	Polyethylene	.0005	1.42	Low
B	Polyester	.0005	1.58	High
C	Aluminized Polyester	.0010	2.88	High
D	Polyester	.0010	2.97	High
E	Polyurethane ("Korel")	.0010	2.98	Very Low
F	Polyvinyl Flouride ("Tedlar")	.0020	5.11	Mod. High
G	Polyester	.0020	6.60	High
II	Polyurethane ("Tuftanc")	.0030	7.07	Very Low
I	Polypropylene	.0050	10.75	Medium
J	Polyester	.0050	17.36	High
K	Plasticized Polyvinyl Chloride	.0150	51.29	Mod. Low

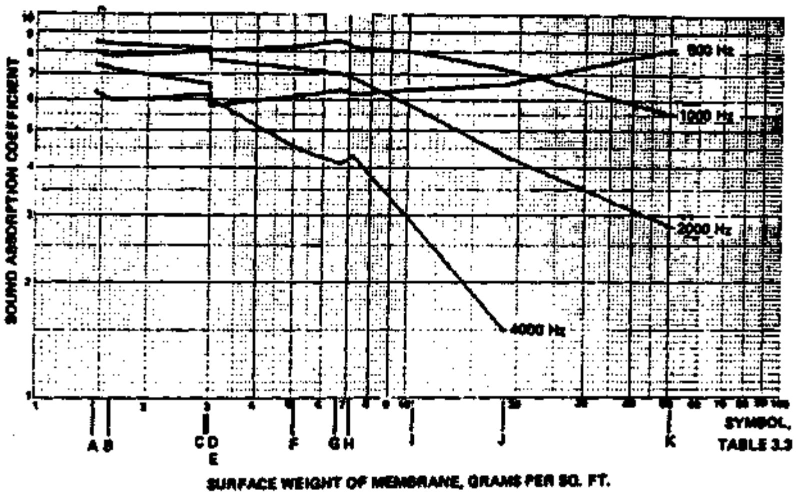


Figure 9.7 Acoustical properties of sound absorptive material as a function of film facing weight.[4]

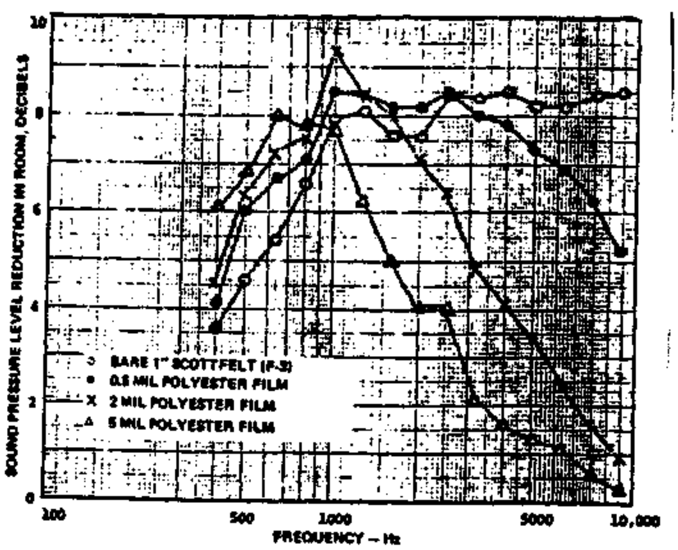


Figure 9.8 Effect of impermeable membranes on sound absorptive properties of acoustical foam.[4]

progressively more cut off at frequencies above 1000 Hz. However at frequencies below 1000 Hz, the presence of a membrane is beneficial and low frequency performance is enhanced. (Miller and Montone, 1978). Table9.9 gives absorption coefficients of various indigenous sound absorbing material with facings using the Reverberation chamber method . From this table it can be concluded that fiberglasswool (Twiga ceiling Tiles) with tissue paper facing with 50 mm air gap is the combination that results in the maximum sound absorbing coefficients (NRC of 0.99).

Table 9-10gives the standing tube data for absorption coefficients of indigenous sound absorbing materials with facings. It is observed that a composite panel (Fiberglass and perforated wood wool board) has the highest NRC value (0.59.)

Table 9.9 : Reve rberation cham ber data for absorp tion coefficients of indige n0US SOU nd abso rbing materia 1 with facing

S. NO.	Material	Bulk density	Manu-iacturer	Place and year of testing	Thick ness (mm)	Mounted method (ASTM) designation	Sound absorptioii at frequencies of						NRC
							125	250	500	1000	2000	4000Hz	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Glass wool with bonded cloth facing	Resin-bonded glass wool 80 kg/m^3	-	NPL 1982	25.00	A	0.10	0.68	0.55	0.48	0.31	0.11	0.53
2.	Glass wool with bonded metal film unperforated facing	Resin-bonded glass wool 17kg/m^3 Facing: Alumi-nium sheet 2700 kg/m^3	-	NPL 1982	30.00 0.10	A	0.24	0.40	0.80	0.66	0.30	0.06	0.54
3.	Glass wool with bonded metal film unperforated facing	Resin-bonded glass wool 23 kg/m^3 Facing: Alumi-nium sheet 2700 kg/m^3	-	NPL 1982	50.00 0.15	A	0.27	0.85	1.00	0.81	0.40	0.22	0.76
4.	Glass wool behind unperforated facing	Resin-bonded glass wool 23 kg/m^3 Facing: Rigid PVC sheet 1270 kg/m^3	-	NPL 1982	20.00 1.00	C-20	0.15	0.81	0.63	0.20	0.15	0.13	0.45

Table Contd..

5.	Glass wool behind perforated facing	Resin-bonded glass wool 23 kg/m^3 Facing: Rigid PVC sheet 10% open area 1270 kg/m'	-	NPL 1982	20.00 1.00	C-20	0.15	0.38	0.70	0.99	0.86	0.44	0.73
6.	Glass wool behind perforated facing	Resin-bonded glass wool Facing: wood particle 4% open area 800 kg/m^3	-	NPL 1982	25.00 12.00	C-25	0.15	0.63	0.98	0.34	0.25	0.49	0.55
7.	Glass wool behind perforated facing	Resin-bonded glass wool Facing: Wood particle board 12% open area 800 kg/m^3	-	NPL 1982	25.00 12.00	C-25	0.18	0.42	0.72	0.74	0.40	0.50	0.57
8.	Glass wool behind perforated facing	Resin-bonded glass wool Facing: Wood particle board 4% open area 800 kg/m^3	-	NPL 1982	50.00 12.00	C-50	0.44	1.00	0.80	0.30	0.24	0.39	0.58

Table Contd..

9.	Glass wool behind perforated facing	Resin-bonded glass wool Facing: Wood particle board 12% open area	-	NPL 1982	50.00 12.00	C-50	0.35	0.90	0.96	0.59	0.46	0.48	0.73
10.	Mineral wool behind perforated facing	Mineral wool 60 kg/m^3 Facing: Cement asbestos sheet 4% open area 1530 kg/m^3	-	NPL 1982	25.00 4.00	C-25	0.15	0.27	0.47	0.77	0.41	0.11	0.48
11.	Mineral wool behind perforated facing	Mineral wool 60 kg/m^3 Facing: Particle board 12% open area 800 kg/m^3	-	NPL 1982	50.00 5.00	C-50	0.25	0.73	1.00	0.89	0.56	0.55	0.79
12.	Mineral wool behind perforated facing	Mineral wool 60 kg/m^3 Facing: Aluminium sheet 35% open area 2700 kg/m^3	-	NPL 1982	25.00 1.20	E-100	0.24	0.39	0.60	0.52	0.41	0.35	0.48
13.	Mineral wool behind perforated facing	Mineral wool 60 kg/m^3 Facing: Aluminium sheet 35% open area 2700 kg/m^3	-	NPL 1982	25.00 1.20	E-100	0.25	0.42	0.61	0.55	0.52	0.38	0.53

Table Conld..

14.	Jute felt behind perforated facing	Jute felt: 200kg/m^3 Facing: Jute board 240 kg/m^3	-	NPL 1982	25.00 1.20	C-25	0.37	0.95	0.61	0.40	0.41	0.41	0.59
15.	Wood particle board unperforated	800 kg/m^3	-	NPL 1982	12.00	D-25	0.48	0.29	0.12	0.23	0.21	0.18	0.21
16.	Wood particle board unperforated	800 kg/m^3	-	NPL 1982	12.00	D-25	0.43	0.30	0.12	0.12	0.17	0.22	0.18
17.	Wood particle board perforated 4% open area	800 kg/m^3	-	NPL 1982	12.00	D-225	0.42	0.43	0.16	0.22	0.21	0.23	0.26
18.	Wood particle board perforated 4% open area	800 kg/m^3	-	NPL 1982	12.00	D-25	0.23	0.22	0.40	0.50	0.36	0.28	0.37
19.	Wood particle board perforated 12% open area	800 kg/m^3	-	NPL 1982	12.00	D-25	0.22	0.20	0.24	0.56	0.46	0.38	0.46
20.	Wood particle board perforated 12% open area	800 kg/m^3	-	NPL 1982	12.00	D-225	0.41	0.47	0.15	0.24	0.27	0.26	0.28

Table Contd..

21.	Wood wool board	400 kg/m^3	-	NPL 1982	12.50	D-50	0.09	0.22	0.36	0.53	0.39	0.57	0.38
22.	Woodwool board	400 kg/m^3	-	NPL 1982	12.50	E-1000	0.28	0.34	0.35	0.51	0.58	0.55	0.45,
2,	Twiga celing tiles with tissue paper (paint coat) with 50mm air gap	-	UP Tiwga Fiberglass Limited, Twiga house 3, New Delhi	AIR 1996	25mm	-	-	-	-	-	-	-	0.87
24.	Twiga celing tiles with tissue paper facing with 50mm air gap	-	-do-	AIR 1996	25mm	-	-	-	-	-	-	-	0.99
25.	Plaster on woodwool boards rigid backing	-	Anutone Boards(P) Ltd. 3A Visvesvaraya Industrial Area, Bangalore	AIR 1996	2"	-	0.40	0.30	0.20	0.15	0.10	0.10	0.21
26.	Plaster on woodwool boards 30 mm air gap	-	-do-	AIR 1996	1"	-	0.30	0.55	0.50	0.50	0.50	0.55	0.48

Table Contd..

27.	Plaster on woodwool boards 1" air gap	-	Anutone Boards (P) Ltd.,3A Visvesvaraya Industrial Area, Bangalore	AIR 1996	2"	-	0.30	0.40	0.50	0.85	0.50	0.65	0.53
28.	Plaster on wood wool boards 1" air gap	-	-do-	AIR 1996	4"	-	0.38	0.68	1.00	0.72	0.74	0.80	0.72
29.	Plaster on woodwool boards 30 mm air gap filled with rockwood	-	-do-	AIR 1996	1"	-	0.53	0.60	0.53	0.53	0.55	0.65	0.56
30.	Designer boards- chex in false ceiling with 6" air gap	-	-do-	**AIR** 1996	1"	-	0.35	0.42	0.39	0.51	0.72	1.05	0.40
31.	Designer boards- linear in false. ceiling with 6" 6" air gap	-	-do-	AIR 1996	1"	-	0.44	0.47	0.36	0.51	0.71	1.06	0.59

Table Contd..

32.	Fabric boards rigid backing	-	Anutone Boards (P) Ltd., 3A Visvesvaraya Industrial Area, Bangalore	AIR 1996	1"	-	0.05	0.16	030	0.57	0.94	0.70	0.45
33.	Fabric boards 3/4" air gap	-	-do-	AIR 1996	1"	-	0.13	0.14	0.45	0.86	0.80	0.84	0.54
34.	Fabric boards 1 1/2" air gap with glasswood	-	-do-	AIR 1996	1"	-	0.30	0.77	1.11	0.98	0.79	0.95	0.82
35.	Gypboard fully perforated regular 50 mm backing	-	Indian Gypsum Limited, 815, Tolstoy House, 15-17, Tolstoy Marg, New Delhi 110001	AIR 1993	12.5mm +50 mm	-	-	-	-	-	-	-	0.56

Table 9.10 : Standing wave tube data for absorption coefficients of indigeneous sound absorbing material with facing

S. No.	Material	Density Kg/m^3	Manu-facturer	Place and year of testing	Thick ness (mm)	Absorptive Co-efficients 125	250	500	1000	2000	4000Hz	NRC
1	2	3	4	5	6	7	8	9			12	
1.	Composite panels (Bartex + perforated ply sheet)	-	CBRI Roorker -247667 (UP)	CBRI 1996	25+12	-	0.12	0.22	0.60	0.60	0.40	0.38
2.	Composite panels (Sunn + perforated ply sheet)	-	CBRI Roorker -247667 (UP)	CBRI 1996	25+12	-	0.12	0.30	0.58	0.50	0.60	0.37
3.	Composite panels (Fiber glass + perforated woodwool boards)	-	CBRI Roorker -247667 (UP)	CBRI 1996	25+12	-	0.38	0.53	0.70	0.78	0.83	0.59
4.	Composite panels (Bartex + perforated woodwool boards)	-	CBRI Roorker -247667 (UP)	CBRI 1996	25+12	-	0.34	0.47	0.63	0.78	0.79	0.56
5.	Composite panels (Sunn + perforated wood wool boards)	-	CBRI Roorker -247667 (UP)	CBRI 1996	25+12	-	0.21	0.52	0.58	0.65	0.73	0.49

Thus, it can be concluded from the above discussed information that a lot of material facings are available in India. These materials can be mounted in different ways over the sound absorbing materials for their protection . The material facings choosen should be such that they do not affect the absorbent properties of the underlying sound absorbing materials . The selection of the facing material would also have to be based on its durability . There are a few absorbent materials available which do not require any facing material. Hence, it is not always necessary that audiology test room should have a facing material fixed over the absorption material.

10. VIBRA TION CONTROL

A vibration may be defined as a "periodic phenomenon of oscillation about a certain point of rest" . Suri (1966) noted that for vibration treatment it is necessary to introduce a discontinuity in the path of the vibration and to isolate it by mounting the machine on resilient or anti-vibrant mountings or pads.

Vibration Isolators :

Vibration isolators are placed in the path between the source of vibration and the receiving element. Some of the most common vibration control systems are discussed below:

(a) Springs :

According to Bell (1982) metal springs are the most commonly used vibration isolators, especially where large heavy equipment is to be isolated. He noted that metal springs allow for large deflections and as such are especially effective where large loads and very low forcing frequencies are present. Fig-10.1 shows a commercially available spring mounts . This isolator design consists of one or more helical coil springs which are piloted in end caps and contain a control bolt which serves as the tie-in to the equipment (Purcell, 1981).

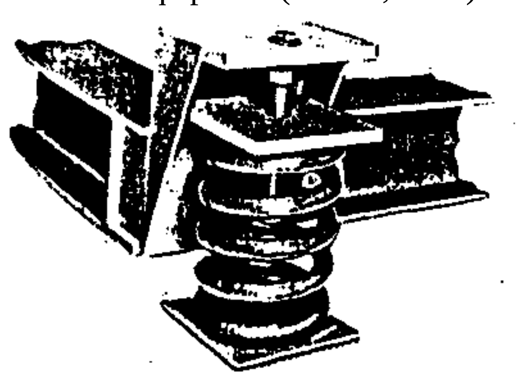


Fig 10.1 Commercially available spring mounts (Bell, 1982)

Advantages of Springs :

(1) Greater freedom in obtaining the necessary stiffness characteristics and freedom from drift and creep. (Purcell, 1981)

(2) Can withstand relatively large deflections and so provide good low frequency isolation. (Bell, 1982).

(3) Levelling adjustments are possible (Bell, 1982)

(4) It is considered permanent for the life of the machine as its properties are not affected by time (Bell, 1982)

TablelO.l gives the relative effectiveness of steel springs, rubber and cork in the various speed ranges, reported by Cherminisoff and Cherminisoff (1978).It is observed that steel springs are more effective than rubber and cork.

Range	**Rpm**	**Springs**	**Rubber**	**Cork**
Low	Upto 1200	Required	Not recommended except for shock	Unsuitable except for shock
Medium	1200-1800	Excellent	Fair	Not recommended
High	Over 1800	Excellent for critical jobs	Good	Fair to good

Table-10.1: Relative effectiveness of steel springs, rubber and cork in the various speed ranges ,Cherminisoff and Cherminisoff (1978)

Disadvantages :

(1) They possess practically no damping . Therefore, transmissibility at resonance is extremly high. (Purcell, 1981)

(2) They are a transmission path for high frequency vibration resulting in an excessively noisy product (Purcell, 1981).

Purcell (1981) reported that to overcome the disadvantages of little or no damping in coil springs, friction dampers can be designed in parallel with the load-carrying spring. Purcell (1981) suggested an another method of adding damping to a spring, by use of an air chamber with an orifice for metering the air flow.

Purcell (1981) noted that to overcome the problem of high frequency noise transmission, one or both ends of the spring can be fitted with elastomeric pads .

(b)Elastomeric Isolators :

Over a limited range of stress, elastomeric isolators can be used effectively for a wide variety of vibration isolation problems. According to Bell (1982), the most common materials selected for elastomeric mediums are natural rubber, neoprene, butyl, silicone and combinations of each. Fig-10.2 shows some of the commercially available elastomeric mounts.

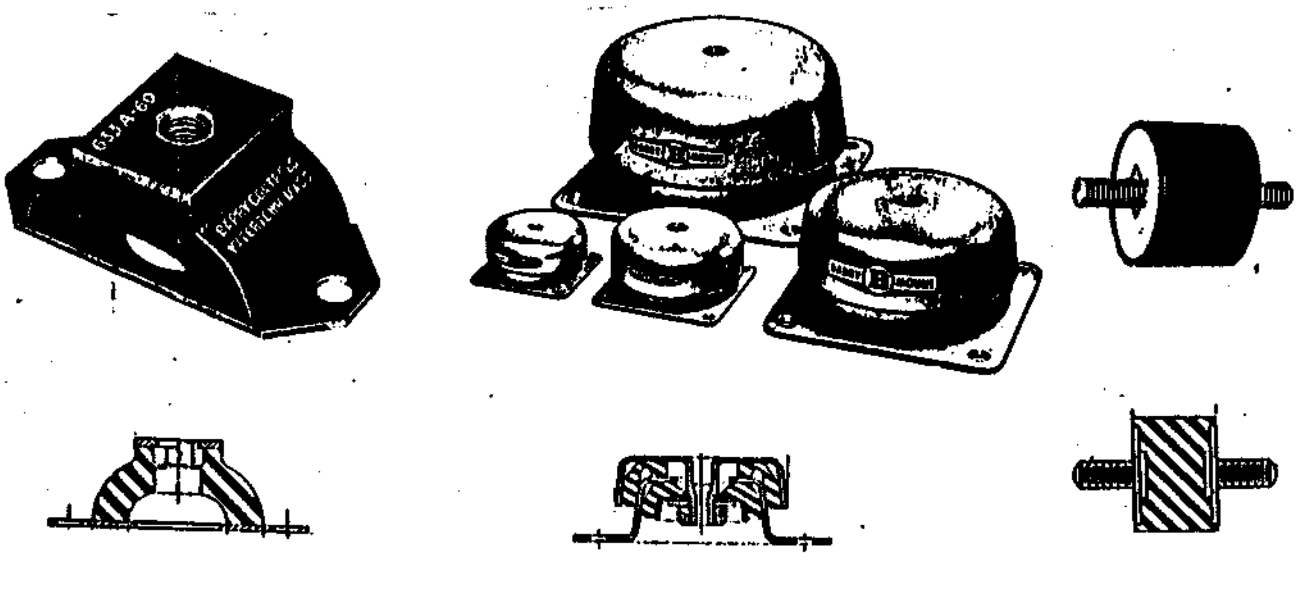


Fig 10.2: Examples of commercially available elastomeric isolators (Bell 1982)

Advantages :

(1) The elastomers can be easily molded into practically any size or shape and a range of stiffness can be controlled over a rather wide limit (Bell, 1982).

(2) It is relatively easy to design various degrees of damping, load-deflection characteristics and transmissionibility characteristics into elastomeric isolators (Purcell, 1981).

(3) Useful in preventing problems at resonance (Purcell, 1981).

(4) They can generally absorb shock energy per unit weight to a greater extent than that attainable through other forms of isolator systems (Purcell, 1981)

(5) Best suited for small machines (Bell, 1982)

(c) Isolation Pads :

Bell (1982) reported that isolation pads are simplest and most often used isolation mount. These pads are available in natural rubber, synthetic rubber, or blocks of cork, felts or fibrous glass and combinations thereof. Pads can be employed by simply placing them under the legs / base of the machine or bolted to the floor.

Advantages :

(1) Easily inserted under equipment.

(2) Available in sheets of various thickness

(3) They can be stocked to obtain large deflections and corresponding high levels of low frequency isolation.

Some of the most common pad types are discussed below :

(i) Rubber pads :

According to Bell (1982), rubber pads can be brought in sheets and cut into whatever length and width desired. Fig-10.3 shows an example of commercially available ribbed or waffled synthetic rubber pads and typical load versus deflection curves. For frequencies above 1200 cycles per hour rubber provides maximum deflections up to 0.25". Often, rubber sound isolation pads are used in conjunction with steel springs because high-frequency noises have a tendency to by-pass steel springs.

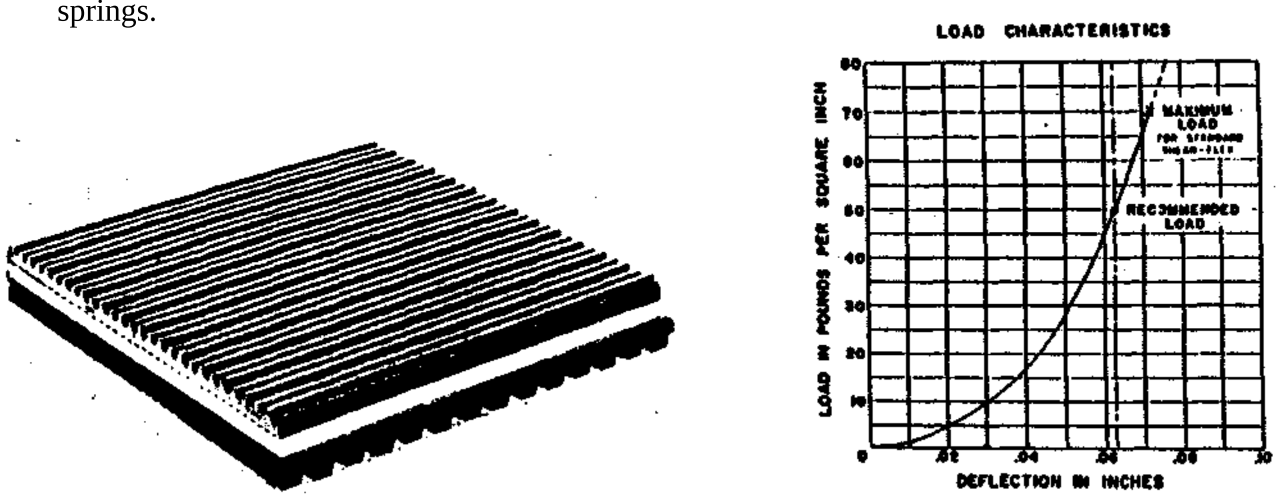


Fig 10.3: Commercial available synthetic rubber pad and its load characteristics. (Bell, 1982)

Advantages :

(1) Alkali, solutions or acids will not affect rubber

(2) For natural rubber, the temperature range is from 50° to 150° F

(3) Life span of a rubber mount is approximately five years under impact applications and seven years under non-impact applications.

Disadvantages :

(1) Degradation problem arises if it is exposed to sunlight.

(2) As rubber ages it gradually loses its resiliency.

(ii) Corks pads :

Bell (1982), described cork as the oldest insulating material and one of the most effective. A popular type of cork is made of pure granules compressed together and baked under pressure to achieve a controlled density.

Bell(1982) noted that cork are generally available commercially in blocks 6" to 10" square and thickness of 1/2" to 1". Cork exhibits a little lateral expansion in vertical compression. As a vibrator isolator, cork is limited to 1800 cycles per minute.

Advantages :

(1) Cork remains reasonably durable under exposure of acids, oils and temperatures between 0°F to 200^0 F.

(2) The stiffness of cork is very high (Bell, 1982).

Disadvantages :

(1) Small range of available stiffness as compared to rubber.

(2) Takes a permanent compression set at temperatures above 100°F.

(3) It is adversely affected upon contact with strong alkaline solutions.

(4) It will rot from repeated wettings and dryings.

(5) It can not be molded, hence is available only in slab form (Bell 1982).

(iii) Felt pads :

Bell (1982), reported that felt pads used as isolators are generally graded in terms of density, ie. hard, medium, soft. The soft grades typically can be loaded up to 50 pound per square inch (psi), medium grades to 100 psi, and the hard most dense pads to 200 psi. Felt pads are commercially available in 1/2" to 1/3" thickness. The most common thickness is 1".

Advantages :

(1) Where extremely high loads are anticipated, stacks of 1" pads are formed to provide the required deflection.

Disadvantages :

(1) Felt materials are organic so they deteriorate very rapidly in the presence of typical oil or solvents.

(iv)Fibrous glass pads :

Bell (1982), noted that fibrous glass pads have a vibration characteristics much like felt pads. The pads are commercially available typically in l/2"and 1" thickness.

Advantages :

(1) The fibrous glass pads can be stacked for low frequency isolation.
(2) The fibrous pads are inert and highly resistive to oil, solvents, acids etc.

(d) Helical Isolators :

Bell (1982), described helical isolators as heavy-duty assemblies of standard stainless wire cable attached between metal retainers. Fig. 10.4 shows some of the commercially available helical isolators. According to Bell (1982) each isolator type has its own stiffness characteristics depending on cable diameter, number of strands per cable, cable length, twist and number of cables per section.

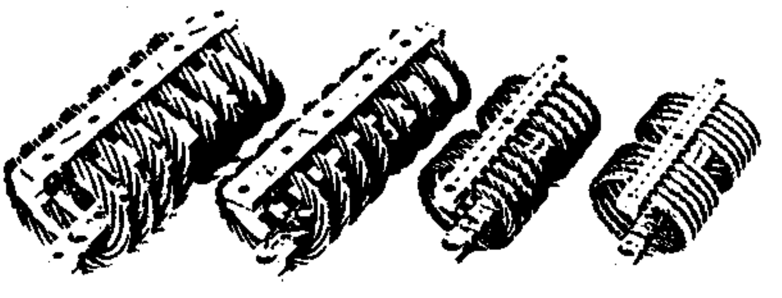


Fig 10.4: Commercially available helical isolators. (Bell, 1982)

Advantages :

(1) Excellent isolation is available down to the range of 5 to 7 Hz with inherent damping provided by flexural hysteresis due to rubbing and sliding friction between the strands.

(2) It can be used in any orientation.

(3) It is highly resistant to worst environment.

(e) Pneumatic isolators :

Purcell (1981), described pneumatic isolators as airfilled, reinforced rubber bellows, with mounting plates on top and bottom. Figl0.5 shows a commercially available pneumatic isolator along with construction details.

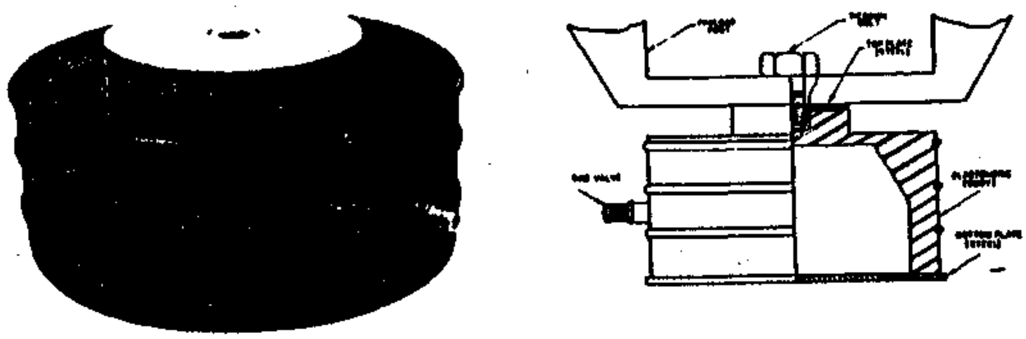


Fig 10.5:A commercially available pneumatic isolator along with construction details. (Bell, 1982)

Advantages :

(1) These isolators can provide very low natural resonant frequencies with small static deflection (Purcell, 1981).

Disadvantages :

(1) Bell (1982), noted that pneumatic isolators can be used in compression only and also only **a** single, nearly absolute vertical orientation is possible for them.

(f) Inertial bases of frames :

Bell (1982) reported that inertia base generally consists of a steel frame with isolation mounts attached as shown in figure 10.6 .now the frames are generally of steel beam construction designed to be used as is or to accept poured concrete, serving also as an inertial block.

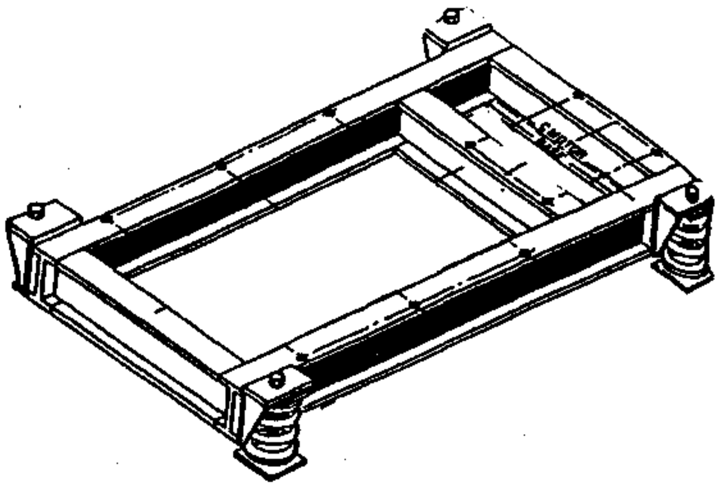


Fig 10.6 A commercially available inertia frame or base with spring isolation mounts. (Bell, 1982)

Advantages :

(1) Provide for easy installation (Bell, 1982)

(2) Prevent differential movement between driving and driven members (Bell,1982).

(3) Reduce the system centre of gravity, thus reducing undesirable rocking (Purcell,1981;Bell,1982).

(4) Reduce motion of Equipment during start-up and shut down. (Purcell,1981;Bell,1982).

(5) Addition of concrete lowers the systems natural frequency. (Bell, 1982).

(g) Flexible connectors :

Bell (1982) noted that flexible connectors are used dominantly to isolate rotating and vibrating machinery from ducts or pipes. It plays an important role in vibration and noise control. These connectors are usually flanged or threaded for ease of installation and are available in various sizes of straight or elbow sections. Fig 10.7 shows an example of flexible coupling.

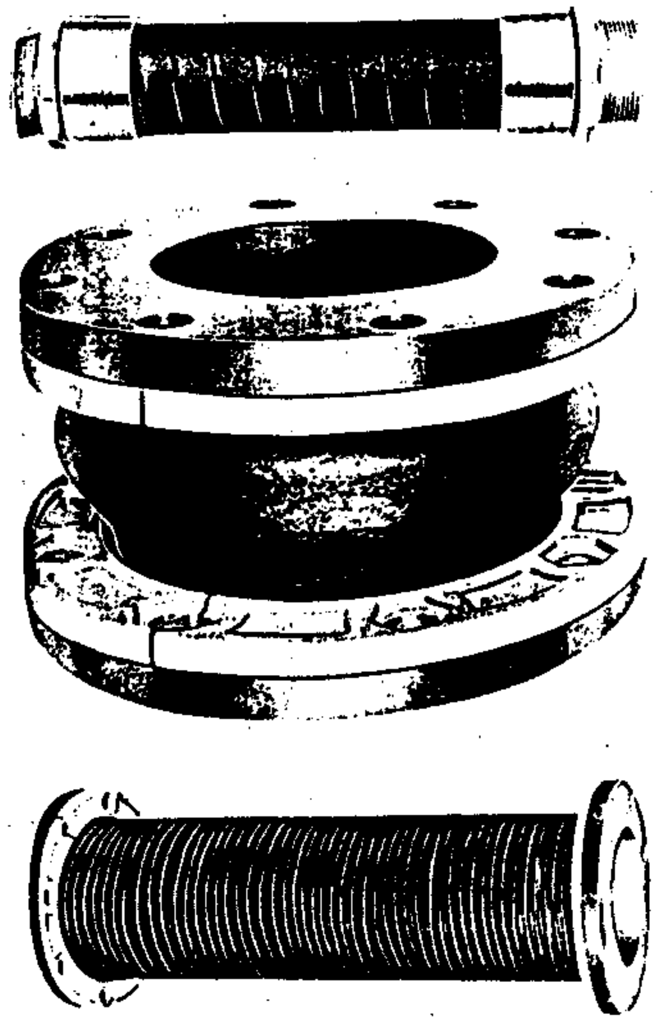


Fig 10.7: Composite showing high pressure rubber connections to control structure- borne vibration in pipes. (Bell, 1982)

According to Bell (1982), in high pressure fluid systems, steel reinforced rubber connectors are generally the best isolators (Fig. 10.7) and in low pressure air handling systems, flexible sleeves or hoses work well and are easy to install.

From the above literature on vibration control it can be concluded that there are various kinds of materials available as vibration isolators which can be used in the audiometric test rooms to avoid the transmission of vibrations. Springs are found to have the maximum number of advantages. However, elastomeric isolators are reported to be used most commonly due to the ease with which it can be utilized. Depending on the requirement isolation pads, isolation mounts, springs, inertial bases of frames can be used for the vibration isolation purpose. For the connection between machinery and duct/pipes flexible connections should be provided to minimize the transmission of vibrations.

11. VENTILATION

Audiological test rooms require an adequate supply of air at a comfortable temperature and humidity. Air in testing room can be piped in and exhausted through ventilating openings. To do so requires installation of an air conditioning system (Snow, 1965).

Pradhan and Soni (1983), defined air conditioning as the technique of simultaneous control of temperature, humidity,cleanliness and motion of air in the confined area. This chapter provides description about the minimum ventilation , requirements different types of air conditioning systems and methods of controlling noise levels of each components of the air conditioning systems, used in the audiological test rooms.

Minimum ventilation requirement.

To give occupants a feeling of outdoor freshness, some amount of fresh air has to be brought inside the room. The amount of fresh air to be brought in depends on the number of persons occupying the premises, type of activity, volume of the premises, and amount of heat, moisture, and odor generation (Yanoch 1994). The amount of ventilation air recommended by IAC Bulletin 5.0003.5,1995 for the audiological test room are 100 cfrn (2.85 m^3/.min), 2.00 cfrn (5.66 m3/min) and 300 (8.50 m^3/min). It is observed from the table 11.1 that rooms with smaller dimensions (eg. 3'-4" x 3'-0" x 6'-6") require lesser amount of ventilation air and rooms with larger dimensions (eg 10'-0"x 9'-4" x 6'-6") require higher amount of ventilation air.

Table 11.1 : Ventilation air for audiometric rooms (IAC Bulletin 5.003.5,1993)

S.No.	Dimensions (ft. in)			Ventilation cfm (m3/min)
	Width	Length	Height	
1	3'-4"	3'-0"	6'-6"	100(2.85)
2	4'-0"	3'-4"	6'-6"	100(2.85)
3	4'-0"	6'-4"	6'-6"	200 (5.66)
4	5'-4"	7'-0"	6'-6"	200 (5.66)
5	6'-4"	6'-0"	6'-6"	200 (5.66)
6	6'-0"	7'-4"	7'-9"	200 (5.66)
7	*7'-4"*	7'-0"	6'-6"	200 (5.66)
8	7'-0"	8"-4"	6'-6"	300 (8.50)
9	7'-0"	8'-4"	7'-9".	300 (8.50)
10	7'-8"	9'-8"	7'-9"	300 (8.50)
11	8'-0"	9'-4"	6'-6"	300 (8.50)
12	8'-8"	10'-8"	7'-9"	300 (8.50)
13	9'-0"	8'-4"	6'-6"	200 (5.66)
14	l0'-0"	9'-4" .	6'-6"	300 (8.50)

Yanocha (1994) reported that the amount of ventilation air required will vary from 5 to about 60 air changes per hour. It is seen that air charges of about 60 per hour usually create some discomfort because of high air velocities Eckel (1999) recommended 15 air changes per hour for the audiological test rooms.

Types of **air conditioning systems:**

Several air conditioning systems are now available in market such as, central air conditioning systems, packaged air conditioning systems (window type), split systems, packaged chillers, built up air conditioning systems(Yanocha, 1994; Arora and domkundwar 1987; Pradhan and Soni,1983).

Among the above mentioned types of air conditioning systems, not all are suitable for the audiological test rooms. Among them only split and central air conditioning systems can be used in the audiological test rooms as they involve an installation of ducts for the distribution of air to various parts of the conditioned space and also for taking it back to the cooling coil of the air conditioned system. The noisy components of the systems can be located away from the audiological test rooms (Yanocha, 1994; Pradhan and Soni, 1983). Several researchers have reported that for the audiological test rooms, a suitable ducting system is essential for air conditioning (Martin, 1991; Dunn, Dunn and Harford, 1995, Murthy and Jacob, 1971; Bhattacharya, Tripathin and Chatterjee, 1983).

The air conditioning systems which can be used in audiological test rooms are described below:-

a. Split systems:

According to Yanocha (1994), in split systems the noisy components of the system, notable the refrigerant compressor and air - cooled condenser or cooling tower fans, are located outdoors, away from the air handling units. In these cases,the air-handler is the only component located within the occupied area. It is usually selected for low revolutions per minute to minimize fan noise. For these installations,chilled-water piping must be extended from the cooling coil to the remote compressor and condensing unit, including operating controls. This arrangement is preferred for buildings which require quiet operation.

b. Central air conditioning systems

According to Domkundwar and Arora (1987), in at central air conditioning system, all the components of the system are grouped together in one central room and conditioned air is distributed from the central room to the required places through extensive duct work. It is generally used for the load above 25 tons of refrigeration and 2500 m^3/min of conditioned air. The system may use one of the following methods to supply the conditioned air.

1. Air is conditioned in the central conditioned room and is supplied to the required rooms with controlled air discharge in each room.

2. The water is chilled in the central conditioned room and is supplied to the required rooms with individual flow control.

3. Individual evaporator in each room with thermostatic flow control or direct expansion system. If a fresh air duct is used, the required fresh air is mixed with the return air and the mix is sent through the cooling air. In case of water-cooled air conditioning systems, many times water is cooled in the cooling tower and recirculated because of shortages of water for condensing purpose.

Hence, a split or central air conditioning system can be installed in audiological test rooms. But the exact levels of noise generated by these systems are not quoted in literature.

Sources of noise in air conditioning systems.

Hemond(1983) observed that installation of an air conditioning system in a sound treated room increases the level of noise in the room due to production of air-borne systemic noises and structure borne noises by the various components. The sources of noise in the system are as follows: -

1. Fan / mechanical equipment room noise
2. Motor noise
3. Compressor noise
4. Blower noise
5. Duct noise

1. Fan / mechanical equipment room noise

In case of split and central air conditioning systems the noisy components of the system such as compressor, condensate pumps, fans, fan motors are located in a separate room i.e. fan / equipment room, which is away from the sound treated room. In this room the outside noises can enter the system through fresh air intake louvers. (Hemond, 1983).

The fan room and the equipment it contains requires special consideration to reduce the ambient noise level. Hemond, (1983) noted that the walls, floors and ceiling of the room should be treated with acoustically absorbent materials. Fig 11.1. gives a diagram of a mechanical equipment room treatment (Egan, 1982). It is seen in this figure that the room is acoustically treated with sound absorbing material. The base of the fan is supported by vibration isolators. Flexible connections are provided between the fan and the adjacent structures/The fan is properly balanced and has smooth well lubricated bearings. Pipes or ducts penetrating into the concrete slab of the floor below which is packed with glass fiber and caulked with non hardening sealant on both the sides to avoid any direct connection between the floor and pipes/ducts. Resilient support is provided for pipes with the help of isolation hangers.

Graham (1975) suggested that walls of the equipment room should be heavy in order to prevent transmission loss to the adjacent rooms. Also, the entire fan assembly should be isolated from the equipment room floor by vibration isolators.

To summarise, the fan, mechanical equipment room should be carefully sound treated, in order to avoid transmission of air borne sounds or structures borne sounds to the audiological test rooms

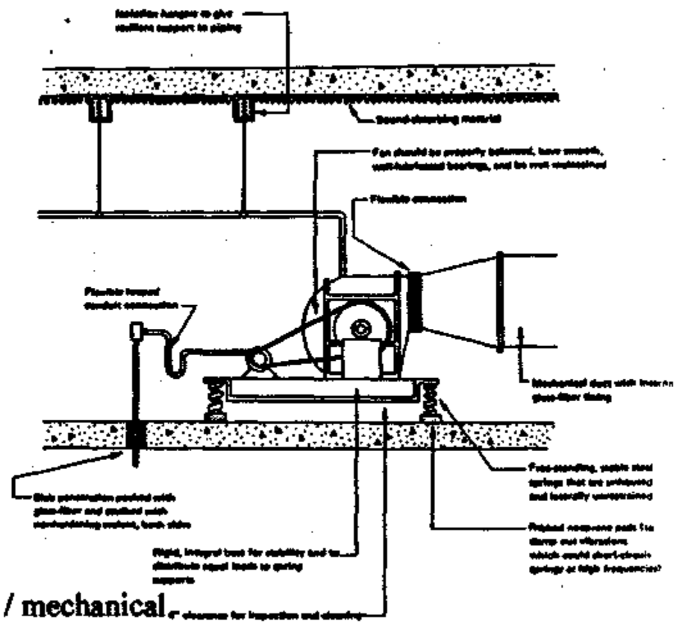


Fig 11.1 Diagram of an acoustically treated far / mechanical room (Egan, 1972)

2. Fan noise

According to Hemond, 1983, the fans are usually classified into two types:- Axial and Centrifugal fans. Among these, Centrifugal fan is the most commonly used fan for air conditioning systems as it creates lesser noise than axial fans. Arora and Domkundwar (1987)noted that axial fans most of energy is created at high frequencies ,so it is more noisier. Given below is the description on centrifugal fans and the ways in which its noise can be controlled.

(i) Centrifugal fans

Bell 1982, described, centrifugal fans as low-pressure high flow volume devices. Centrifugal fans are of two basic types - backward/forward curved and radial. According to Hemond, 1983, centrifugal fans emit a broad band type of noise with some discrete tones being more prominent. The noise from centrifugal fans is a combination of discrete tones at the blade-passage frequency and aerodynamic noise from the shearing action of the blade and the resultant turbulence.

Agnon, Barten, Werfer, Gikadi and Neise (1976) gave a noise control procedure for centrifugal fans which reduces both the harmonic and the random noise component. In the centrifugal fan constructed by them, the volute of the fan casing was made from perforated steel metal covered with a layer of non-woven fabric. The volute itself was mounted in a closed box and the space between the volute and the walls of the box was filled with rockwool. Thus, the pressures at the volute which were excited by the turbulent flow in the casing were absorbed before they radiated into the far-field.

Graham (1975), in order to reduce the amount of fan noise radiated to the supply air ductwork, attached an attemcator on both the inlet and the outlet (Figl 1. 2.) He also, equipped the fan with a vibration break in the discharge section between the fan the continuing ductwork to prevent the transmission of vibration from the fan casing to the attached ductwork.

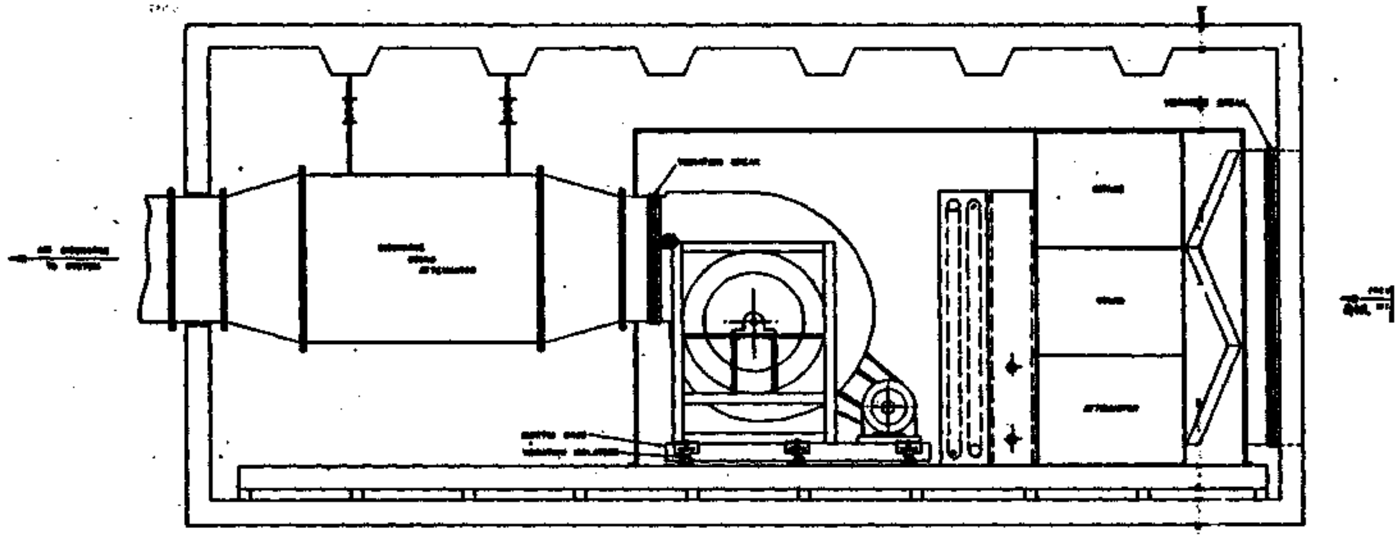


Fig 11.2. Diagram of an attached attenuator to centrifugal fan for sound attenuation.(Graham 1975)

Bell 1982 reported that the noise produced by centrifugal fans can be controlled by utilization of absorptive, parallel or circular baffle type silencers. These type of silencers have good high frequency attenuation and minimal aerodynamic pressure loss. Fig l1.3. shows a simple approach where a tubular silencer is installed on the inlet of the fan through an adaptor section, and a parallel duct- type silencer is installed on the exhaust. A flexible compiling of dense material adapts the silencers of the fan and provides vibration isolation between the fan and ductwork. Vibration mounts should be provided to isolate the fan from the floor or support platform.

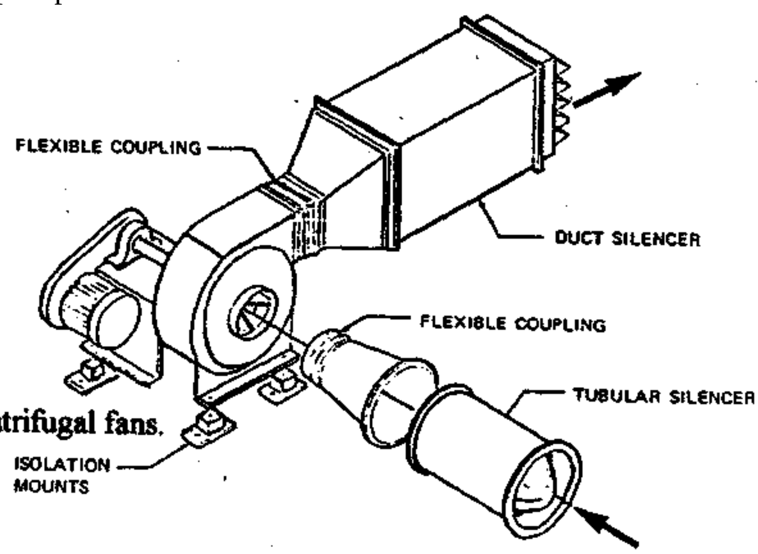


Fig 11.3 Noise control element for **centrifugal fans.** (Bell, 1982)

Degnan (1978) suggested that quiet fans can generate an excessive amount of noise energy if improperly installed. He gave a few guidelines which can be used to reduce the structure borne noise and air borne noise for fans. These guidelines are following: -

1. By mounting the fan on resilient mounts.
2. By separating it from any inlet or discharge ducting with rubber flexible connecting sections, and
3. By insuring that the fan itself is not in contact with any other solid structure.

Degnan (1978) reported that airborne noise is generated due to poor inlet and discharge conditions. To reduce the air- borne noise, the flow of air into the fan impeller should be as smooth as possible with no abrupt expansion, contractions or turns.

Arora and Domkundwar (1987), noted that lower speed fans should be used in the air conditioning systems as they generate less noise.

Thus, it can be concluded that in audiological test rooms, centrifugal fan should be installed for the air conditioning systems. The fan installed should have proper air flow, lower speed and should be isolated from the duct, floor and ceilings or any other adjacent component.

3. Motor noise

According to Barnes, Beranek and Newman, (1982) the main noise sources of electric motors include ventilation noise of the cooling air, electromagnetic noise caused by the periodic forces between the stator and rotor, and mechanical noise of the bearing and brushes.

Control of motor noise sources

Noise associated with motor can be controlled by the following methods: -

a. Use of 1800 rpm or slower speed motors (Thumann and Miller 1976)

b. Modification of fan blade. (Thumann & Miller 1976).

c. Installations of acoustical materials inside motor casing (Thumann & Miller, 1976)

d. Use of Motor mutes or silencers. A muffler can be used on the fan intake (Thumann and Miller)

e. A smaller diameter fan with a higher allowable temperature rise in the motor (Barnes, Beranek & Newman, 1982)

f. Additional shrouds and enclosures around the motor (Barnes, Beranek, & Newman, 1982) and

g. Use of large, slow running motors than smaller fast running ones because their force comes from weight and not from speed (Noon, 1999).

Reducing electromagnetic noise of motors

Electromagnetic noise can be reduced by the following ways as reported by Barnes, Beranek and Newman (1982)

a. By proper selection of stator and rotor slot design.

b. Decreasing flux densities.

c. Designing core and frame members to avoid resources structures, and

d. By selection of precision bearings and proper brushes.

Barnes, Beranek and Newman, 1982, noted that increased efficiency is obtained through the use of more iron in the core and larger diameter conductors .This results in a lower flux density and lower noise level due to the electromagnetic field.

For vibration isolation Leonard, 1956 suggested that the blower and its driving motor of the ventilating system should be mounted on a base weighing about three times the combined weight of the motor and blower. The base should be isolated from the floor slab with vibration isolators. The electrical power must be delivered to the motor through flexible conduit. Any rigid connection between the floor slabs and the mounting base should be avoided.

Thus the above information indicates that for audiological test rooms a large, slow running motor for the air conditioning system is more efficient in reducing the noise level. The motor should be installed in such a way that it has minimum connection with adjacent structures like the floor, ceiling.

4. Compressors:

Hemond 1983, classified compressors into two types - Axial flow compressors and Centrifugal compressors. According to Cheremissnoff and Cheremissnoff (1983) the compressor may be driven by either a motor or steam turbine. In addition, a gear train system may be required to match the speed of the driver to the components. Compressors may be used by themselves, such as a plant or instrument air compressor, or used in conjuction with refrigeration equipment. The compressor, along with the driver and gear, are all potential noise offenders.

The sound spectra of centrifugal compressors is broadband, Table 11.2. gives the sound power frequency spectra for a typical 800 Hp centrifugal compressor package.

Octave Band Centre Frequency, **Hz**								
	63	125	250	500	1000	2000	4000	8000
Lw	95	95	95	101	102	102	103	102

Table 11.2 Octave band sound power levels of an 800 Hp Centrifugal compressors (dB re 10-12 watt). (Thuman & Miller, 1976)

A major source of noise in the compressor is turbulence. To reduce the noise level, the compressor must be isolated from the distribution network and it should be supported on resilienty supported inertia blicks (Cheremissnoff and Cheremissnoff; 1978).

Thumann & Miller, 1976 noted that to minimise the noise, it is suggested that sound cloth or a 1" layer of glass fiber with a 2 pound per square foot layer of sheet lead and a 0.006 aluminium jacket be used to insulate the compressor form its adjacent structures.

According to Egan (1972), large, low speed reciprocating compressors should be isolated by springs and inertial blocks. High speed centrifugal compressors require less isolation and often can be isolated properly with several layers of ribbed neoprene.

To summarise, a large, slow speed compressor should be installed for air conditioning systems in audiological test rooms with sufficient care taken to reduce the transmission of air borne noise and structure-borne noise.

5. Blower noise

Blowers are high- pressure devices used often for conveying materials or products. These are of two types-

(1) Centrifugal fans with a radial wheel construction operated at high speeds.

(2) Rotary positive displacement blowers.

Noise control procedures for blowers with centrifugal fens is same as for centrifugal fans discussed before (Bell, 1982).

Rotary position displacement blowers

According to Bell 1982, it consists of two counter-rotational lobelike gear impellers as shown in fig 11.4 As each impeller lobe passes the blower inlet, it traps a definite volume of air or gas and carries it around the case to the blower outlet. This cycle repeats itself four times with every complete revolution of the driving shaft. Hence, the character of the noise is dominantly periodic with dicrete tones at the compression frequency and integer ordered fourier harmonics thereof

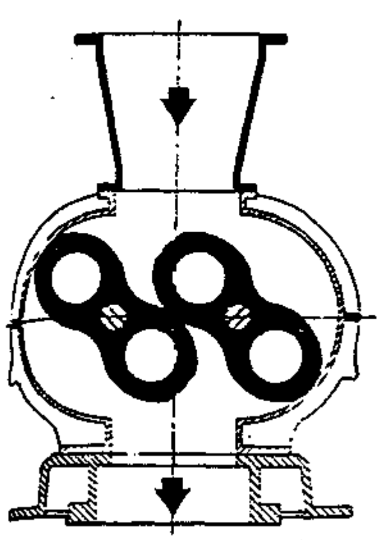


Fig 11.6: Rotary position displacement blower. (Bell, 1982)

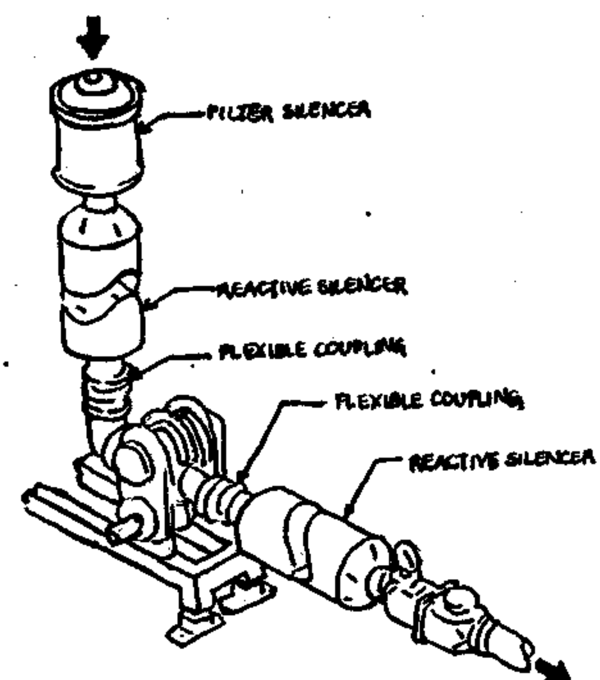


Fig 11.5: Blower with silencers installed (Bell, 1982).

Noise control of Blowers.

Because of the discrete and dominantly low - frequency character of blower noise, reactive chamber - type silencers are especially effective. In most installations a silencer will be required on both the inlet and exhausted as given in fig 11.5. In addition, an inlet filter may also be required. As such, including a filter- silencer provides additional noise reduction (Bell, 1982). He noted that, it is extremely important to provide vibration isolation between the blower motor unit and the floor or support plat form. Isolation between the blower and the connecting pipe ducts is best achieved by including a high-pressure reinforced flexible coupling in the duct 3 to 5 diameters from the blower.

Note :- A note of caution here - frequently the flexible coupling provides a major acoustical leak since the transmission loss through the coupling is lower than the heavy walled pipe. However, this problem can be overcome by simply wrapping the coupling area with a composite of 1 in polyurethane foam and 1 lb/ft^2 dense vinyl (Bell, 1982).

Finally even with all the noise reduction measures included as outlined, noise levels in close proximity will likely to be in the range of 85 to 95 dBA. The resultant levels are due to general mechanical noises associated with gears and bearing and noise transmitted through the case. So, therefore, for critical noise sensitive installations, serious consideration should be given to enclose the blower (Bell, 1982).

Thus, a blower with an attached silencers can be installed for air-conditioning system in the audiological test rooms. Also, care should be taken to isolate blower from other equipments to minimise the noise levels.

6.Duct system

According to Suri (1966) noise in the duct system is caused by the turbulence of the moving air in the duct system and is due to obstacles, such as sharp bends, take off branches etc. Hemond (1983) noted that the potential noise sources within the duct system are dampers for controlling air flow, distributional terminal boxes for distributing air from main lines to branch ducts, grills, registers and ceiling diffusers. The noise increases with the velocity of air flow and is, therefore, the highest near the fan and in the main supply duct (Suri, 1966).

Controlof noise and duct system

A large portion of the noise in a duct can be controlled at the design stage by careful attention to some of the standard design components. Noise can be controlled in the duct in the following ways,

(1) Reduction of turbulence:- Noise is best controlled by minimising the turbulence itself through proper design of bends, branches, splitters and dampers etc, which direct the airflow (Hemond 1983). Egan (1972) suggested the use of smooth duct turns. Fig 11.6 illustrate some of the common noise sources in the duct system and the ways in which noise can be attenuated in them.

(2)Distance:-Increase the distance between the fan room and audiological room to attenuate the sound in ducts (Egan 1972)

(3) Comer and valves:- Right angle bends, branch take offs and difrusers should be designed with rounded corners and control valves used should have smooth comers instead of sharp edges as shown in fig 11.6 (Hemond, 1983).

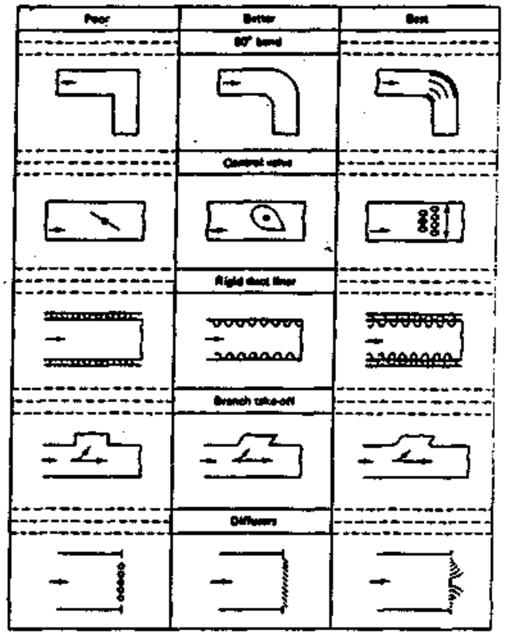


Fig 11. 6 Noise evaluation of the system components of an air distribution system.(Hemond, 1988)

(4) Size of Grills .registers and diffusers:- Grills, registers, and diffusers should be sized for a minimum of air flow since these units are inherently noisy. The noise levels are a function of the face velocity. Hence, Hemond (1983) suggested that these units should be designed for the lowest practical velocity to provide for adequate air circulation in the receiving room.

(5) Distribution boxes:- Hemond (1983) noted that distributional boxes designed to distribute air to several adjacent locations from a main air duct can produce significant noise reduction by leaving the box with acoustically absorbent material.

(6) Pressure reducing valves:- A correct sized pressure reducing value with an aerdynamic design should be used for a specified airflow to provide attenuation according to hemond (1983). Attenuation characteristics of a typical pressure reducing

value is given in Fig 11.7.

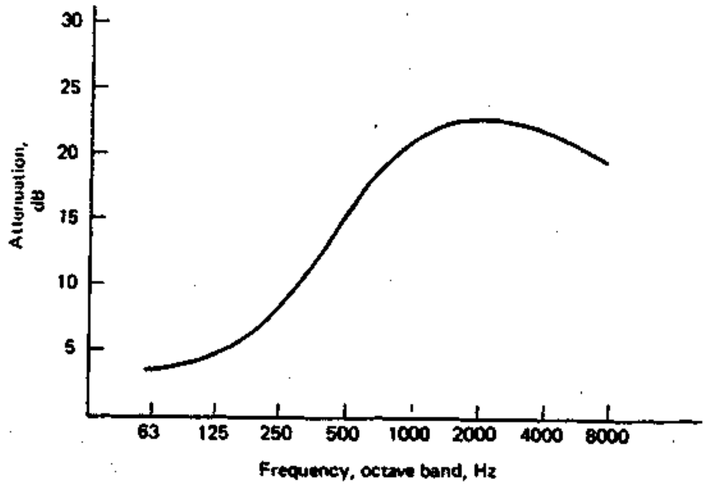


Fig 11.7 Attenuation of typical pressure reducing valves.(Hemond, 1988)

(7) Mixing boxes:- Mixing boxes designed to mix cold and hot air before it is distributed through a diffuser to the receiving space should be acoustically treated with an adequately designed acoustic liner (Hemond, 1983).

(8) Reducing flow velocity:- High air velocities in ducts can be reduced by changing the dynamics of flow. This on be done through multiple stages of pressure reduction or diffusion.

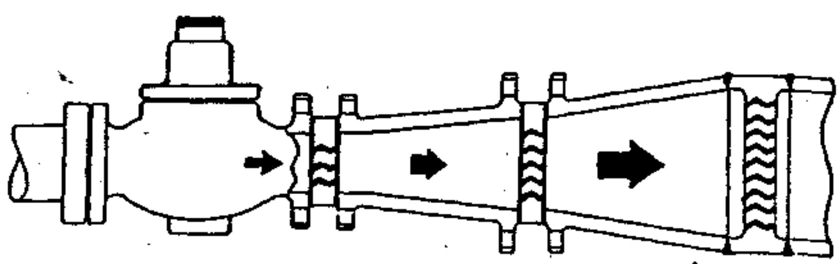


Fig 11.8 Schematic of pressure reduction throttle system showing expansion plates (Bell, 1982)

In multiple stages of pressure reducing system, the gas velocity is sequentially lowered in each expansion chamber as shown in fig 11.8 (Bell, 1982) by utilizing expansion plated. In addition plates act as a diffuser reducing turbulent mixing. According to Bell etal. 1976, noise levels reduction upto 20 dB can be achieved with a three plate configuration as shown in the fig 11.8. However, each chamber introduces back pressure which is often undesirable and can be a limiting factor (Bell 1982).

Another approach to reduce the flow noise is through the use of diffuser. Shown in Fig 11.9 is a schematic drawing of an installed cage and in line diffuser. Boger, (1971) reported that with diffuser alone noise reduction in the range of 10 to 18 dB is possible.

According to Bell (1982), in either approach (ie.using expansion plates or diffusers, careful attention must be given for proper sizing to assure proper valve operation.

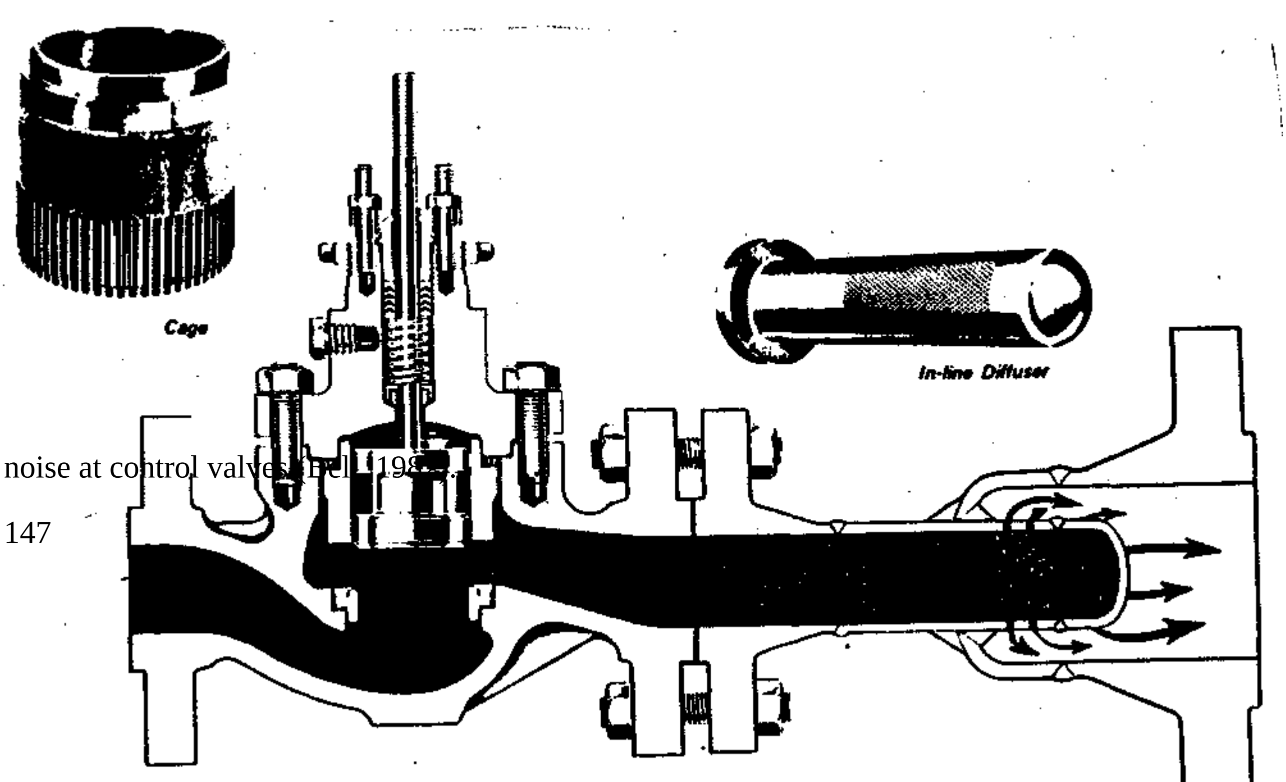


Fig11.9 Schematic showing installed cage and in-line diffuser for reducing aerodynamic noise at control valves (Bell 1982).

(9) Inclusion of a plenum chamber:-

Ginn (1978), noted that inclusion of a plenum chamber in the ducts, reduces the noise transmitted by the ducts. These chambers are the only effective remedy for low frequency noise. Plenum chambers should be made as large as possible and should be lined with a thick layer of sound absorbing material. Additional absorption can be obtained by installing boffles within the chamber. A plenum chamber attached to the duct system is shown in the Fig 11.10.

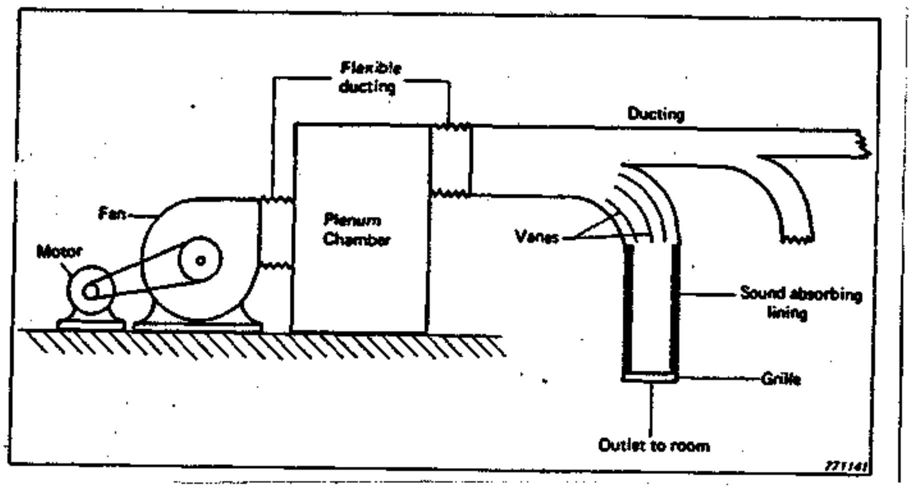


Fig 11.10 Essential elements of a ventilation system. (Ginn, 1978)

(10) Use of silencers:

Purcell (1981) reported that silencers come in many shapes and sizes and most of them can be classiffied into four types.

(i) Absorptive,

(ii) Reactive,

(iii) Dissipative, and

(iv) dispersive or diffusive.

(i) Absorptive silencers

Absorption silencers use sound absorbing materials, usually of the porous absorber type, to decrease the sound transmitted by increasing the absorption within (Purcell, 1981). It is also called as parallel baffle silencer. According to Hemond (1983), absorptive silencers attempt to achieve a high acoustic performance by splitting the air steam with aerodynamically designed baffles providing an exposure to a large amount of absorbing material in a relatively short distance. Each baffle is constructed with perforated walls backed by highly absorbtive materials which usually has a base of glass or mineral wool as shown in fig 11.11 (Beranek, 1971). The acoustical performance of this type of packaged silencer depends primarily on the width of the air passage between the baffles, the thickness of the baffle itself, and a length of the baffle. With decrease in the spacing between the baffle and increase in thickness of baffles, the acoustical performance improves of the packaged silencer, but along with it pressure is developed in the unit. So, a balance between the pressure loss and the attenuation which is desired is essential (Hemond, 1983).

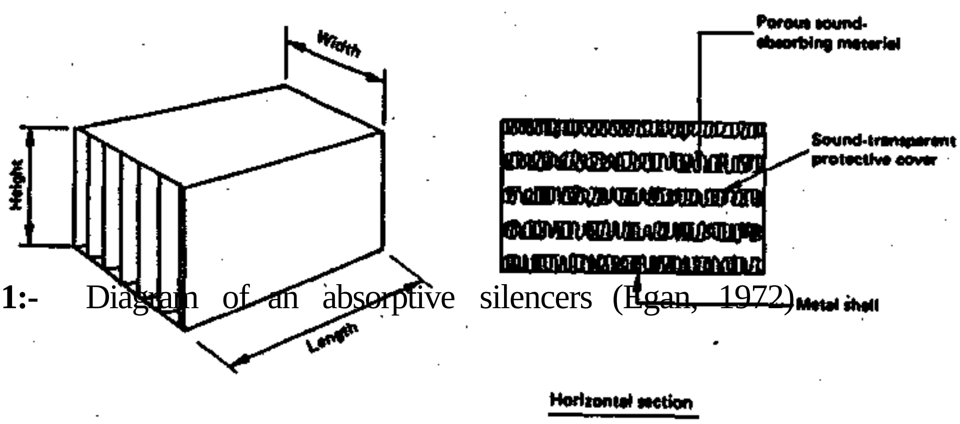


Fig 11.11:- Diagram of an absorptive silencers (Egan, 1972)

(ii) Reactive silencers:- Reactive silencers employ the principles of the Helmholtz resonator and the expansion chamber (Purcell, 1981). Hemond (1983) reported that the performance of reactive silencers depends upon the energy losses during reflection andexpansion of sound waves as they impinge upon or pass by physical discontinuities in the flow path. The simple types of reactive silencers upon which the more complex types are developed are discussed below,

(a) Helmholtz resonator:

The Helmholtz resonator is a classic case of a highly effective but limited to a single frequency (or narrow range of frequencies) type of reactive silencers as frequencies)
type of reactive silencers as shown in fig 11.12 (Hemond, 1983). According to Pucell (1981), they have a good noise reduction over only a narrow range of frequencies centere around the fundamental resonant frequency. Several of these can be used in series (with proper design adjustments) if the peaks occur at other well defined frequencies.

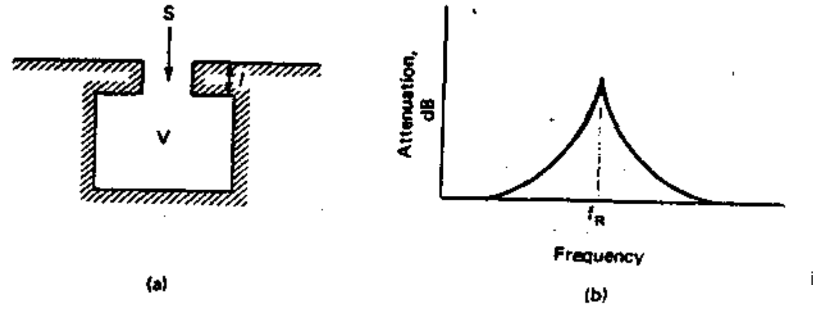
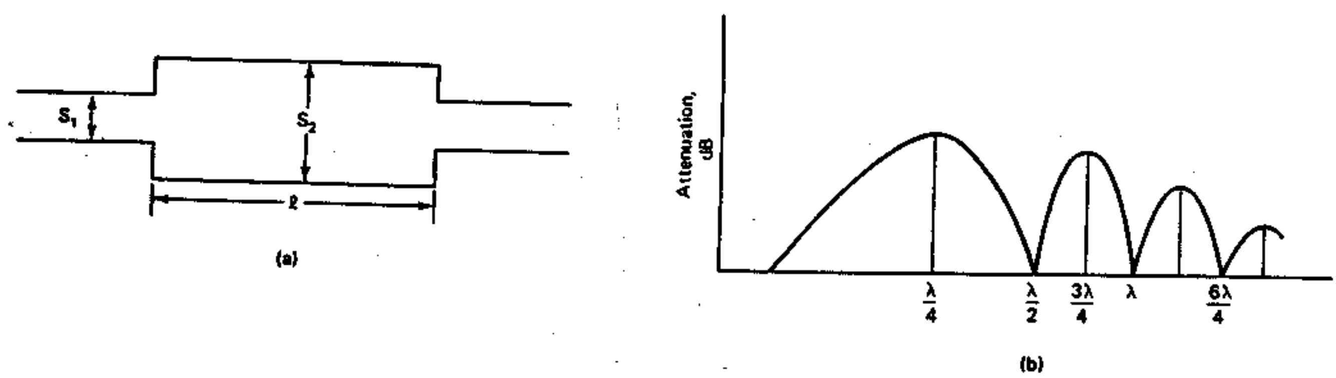


Fig 11.12 Helmholtz resonator (Hemond, 1983).

(b) Single expansion chamber:

Purcell (1981) noted that it is a simplest form of a reactive chamber in the duct work carrying the sound. In this at each change in the cross-sectional area of the duct the independence change causes a reflection of the sound waves. This reflection added to the subsequent destructive interference with the incoming sound results in a noise reduction along the duct. Fig 11.13 shows a typical single expansion chamber and its spectral performance.



Figl1.13 Single expansive chamber (Hemond, 1983).

According to Purcell (1981) and Hemond (1983), complex designs by combining the concept of the Helmholtz resonator and the expansion chamber have been developed which offer broad frequency performance. Hemond (1983) has found these broad- band attenuators are more useful at low frequencies than the absorptive silencers,

(iii) Dissipative silencers:

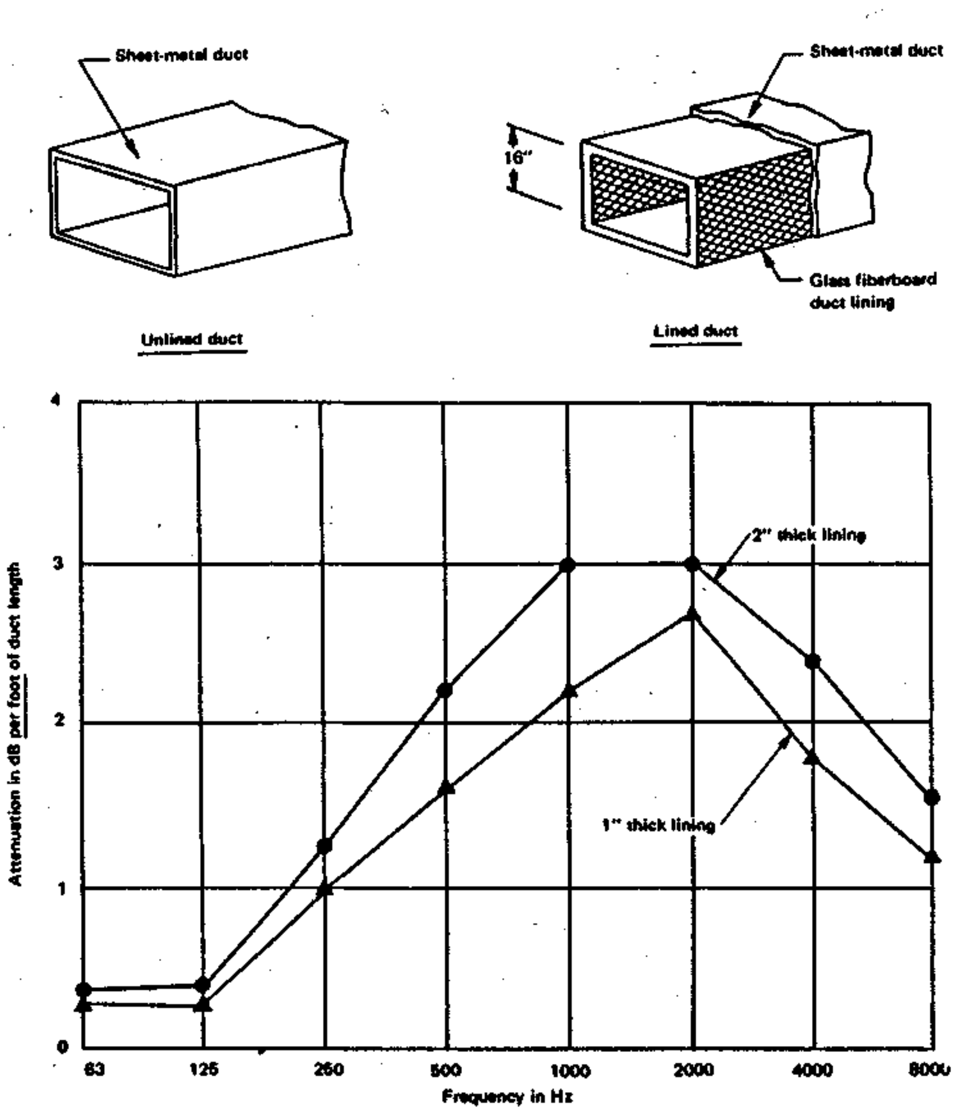
Purcell (1981) denoted that dissipative silencers are used for damping the sound through internal damping. This is generally gained by incorporating perforations or ports in the flow passage tubes so that main flow passage resistance is not increased.

(iv) Dispersive or diffusive silencers :

Dispersive or diffusive silencers reduce noise by preventing its generation. These are pressure reducing devices. By diffusing high velocity, turbulent, gas flow to a lower velocity, less turbulent flow, less noise is generated. Generally the diffuser will tend to produce high frequency noise so a sound absorbing material is included to reduce this effect (Purcell, 1981). Hence any of the above mentioned silencers can be installed in the duct. Many times even combinations of these silencers are used.

(10) Lining the duct-

Sound absorbent materials can be introduced in a duct as lining to reduce the noise transmission. According to Hemond (1983), the lining should begin at the plenums located just before and after of the fan. The thickness of the liner typically ranges from 1"to 2" and should be located on all four sides of the air duct. Fig 11.14 shows a rectangular duct with glass fiber lining and the attenuation characteristics per foot of duct length at different frequencies for ducts with 1" and 2" thick lining. It is seen that with increase in the thickness lining material attenuation increases.



Figll.14: (Above) Rectangular duct with glass fibre lining and(below) attenuation characteristics for 1" and 2" thick glass fibre in several simple ducts which contains absorbing linings of various thickness.(Egan, 1972).

They observed that the attenuation characteristics depends primarily on the thickness and the flow resistance value of absorbing materials. The frequency which gives maximum value of the attenuation, decreases as the thickness and the flow resistance value increases because of the reduction of the velocity materials

.

Zhu, Li, Wu and Zhang (1988), studied the influence of thickness of the absorbing material on noises reduction and found that an optimum thickness exists at which the attenuation is maximum Fig 11.15 shows the attenuation spectra of absorbing materials at different thickness .It can be noted that as the thickness of absorbing material increases, the noise reduction characteristics at low frequency is improved, but the characteristic at high frequency deteriorates.

Zhu, Li, Wu and Zhang (1988) also studied the influence of density on attenuation and found that the low density absorbing materials provide better the attenuation spectrum. Fig 11.16 shows the spectrum characteristics of sound absorbing materials at different density. It is observed that material with density of 15 Kg /m^3 provides maximum attenuation.

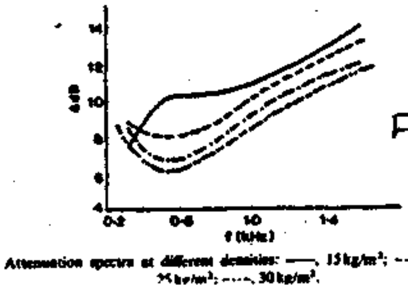


Fig 11.16

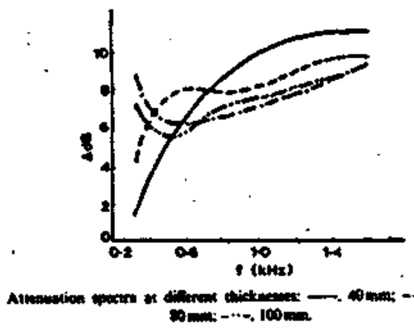


Fig 11.17

Fig 11.16 Attenuation spectra at different density of sound absorbing material and Fig 11.17 attenuation spectra at different thickness.

Purcell (1981) reported that case of rectangular ducts, it is more convenient to use an absorber of the board type rather than a blanched glass and mineral wool baits and boards are suitable absorbers.

(12) Minimise cross-talk noise: When a common duct supplies air to both the experimental and control room, transmission of noise takes place through the duct from one room to the another Fig 11.17. This is known as the cross- talk noise. Egan (1972) suggested the following ways isolation.

(1) Increasing the distance between the two room registers.

(2) Lining of the duct with internal glass fibre.

(3) Provision of sound-attenuating mufflers.

(4) Proper seal is required around the openings.

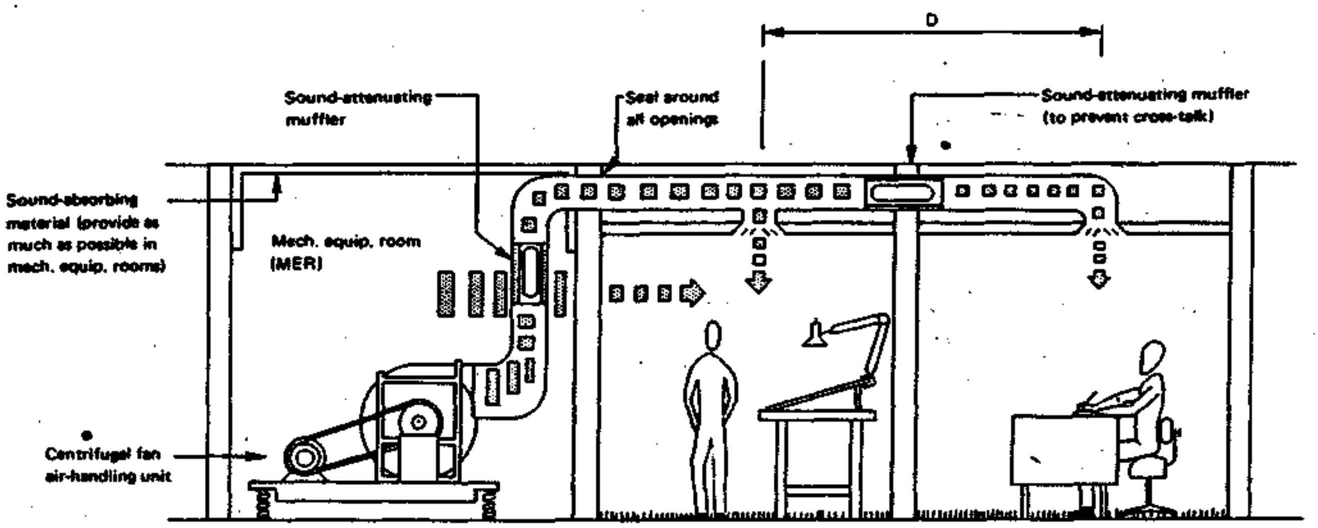


Fig 11.16 Control of cross talk noise (Egan, 1972).

Protective facings for duct:

Beranek (1971), noted that in a ventilating duct without protecting facing, the high velocity gases flowing past the material results in a tearing off of particles of the material and is a cumulative process which eventually may lead to complete deterioration. In addition, turbulence in high velocity flows subjects the materials to vibration which may lead to further deterioration. To protect the sound absorbing material, protective facing should be placed over it. Table 11.3 gives quantitative information on the allowable limits of structures for noise control in the presence of high speed gas flows (Sound research laboratories Ltd,1976). The thickness of the perforated, protective facing materials shown in Table 11.3 are governed by both gas temperature and gas velocities. For ventilating systems the thickness of the perforated facing is generally 20 gauge,

TABLE 10.8 Protective Facings for Acoustical Linings Subjected to High-velocity Gas Streams*

Materials	Maximum allowable velocity in straight runs	Materials	Maximum allowable velocity in straight runs
A. Ventilating ducts		*B.* Large panels (e.g., test cell applications	
1. Uncoated lining, see Note 1	25 ft/sec 8 m/sec	1. Same construction as A4	75 ft/sec 25 m/sec
2. Coated lining, see Note 2	30 ft/sec 10 m/sec	2. 20 gauge perforated metal, minimum 25% open area, Wire screen, Glass fiber cloth	180 ft/sec 60 m/sec
3. Blanket, 20 gauge perforated metal, minimum 25% open area	75 ft/sec 25 m/sec	3. Three layers 20 gauge perforated metal, minimum 25% open area, shown separated by 2 corrugated perforated sheets, Wire screen, Glass fiber cloth, Blanket	300 ft/sec 100 m/sec
4. Blanket, Perforated facing as in *A*3, Glass fiber cloth	125 ft/sec 40 m/sec		

Air flow →

Notes: 1. Examples of suitable materials: Johns-Manville, Microtex, Micro-bar, Coustic.
2. Examples of suitable materials: Johns-Manville, Microlite, Tenu-Mat. Microtes Gustin Bacon. Ultra* Liner; Owens-Corning, Fibergias.
*** For additional information see Ref. 13. Note that the air is assumed to be flowing on the perforated facing on the left of each sketch.**

Table 11.3: protective facings for acoustical linings subjected to high velocity gas streams (Sound Research Laboratories, 1976).

Leskov, Osipov and Yudin (1969) to prevent the sound absorbing materials from being blown away used various laminar covers comprising films or fibre or perforated sheets or else wire nets.They found that even very thin film covers considerably reduce sound attenuation at high and medium frequencies. Additional blow-off tests carried out by Leskov et al. (1969) showed that laminar covers consisting of glass cloth having 35 - 40 CGS rays air flow resistance and perforated sheets with added mass not exceeding 0.02 Kg/m^2 which in practice do not reduce the sound fibre from being blow off by an air flow speed of upto 18m/sec (no test were carried out at greater speeds).

To conclude, duct installed in the air- conditioning system should have smooth bends and branch take-off, pressure reducing valves, lining of sound- absorbing material with a protective facing over it and proper silencers .Also ,the velocity of air or water flow in the duct should be kept low to minimise the transmission of noise.

Air conditioning systems are the weakest point in the control of noise in sound treated room .Installation of these systems generates both structure-borne and air-borne noise . Each of the component of air conditioning system such as compressor , fan , motor, ducts, grilles, diffusers, blowers, branches, bends, splitters, dampers, registers, distributional boxes, mixing boxes, valves require an acoustical treatment. Among these components blowers , and ducts generate the noise inside the test rooms. As far as possible the noisy components of the system should be kept away from the test area Hence, for the ventilation of the sound treated rooms it is better to install a split or a central air conditioning system.

12.ELECTRICAL CONTROLS :

Electrical controls are required for providing power to the equipment as well as for lighting. At times, electrical controls may also be required for the air conditioning systems.

Electrical Connections for Equipment :

The electrical connection between the instruments in the control and test rooms are provided through switch boards, suitable jacks, adaptors and wires. According to Murthy and Jacob (1971), suitable jacks should be provided to maintain acoustical integrity of the room. Pipes and holes should not be used for this purpose.

Bhattacharya, Tripathi and Chatterjee (1983) for the audiological rooms constructed at Ahmedabad, recommended that the necessary connections be provided in the control room to avoid any accidents in the patients room due to short circuiting. They also suggested that a small hole could be drilled on the observation window to pass the cables in to the patient's room.

Murthy, Murthy and Ramanjaneyulu, (1976), utilized shielded microphone cables from the control room to the test room, for the audiological test room constructed in Manipal. These cables were fixed before the walls were acoustically treated. The ends of the cables were fixed to suitable jacks which were connected to suitable boxes and a polyethylene tube was used to carry these cables across the wall.

Pancholy, Chhapgar and Mohanan (1978) for the audiological test room at the National Physical Laboratory, recommended making of small, cable entry holes in the door frames to pass the signal and power cables into the room. These holes were just large enough to allow the cables to go through and were further sealed with mastic after the cables were laid. Also minimum extension lines should run along the floor of the equipment IAC Bulletin 5.0003.5 (1993), recommended provision of a jack panel consisting of ten switch craft, 3-wire phone type jacks with covers and connectors. Two ED grommeted holes were provided through the window. A factory wore "Power panel" consisting of two rocker switches to control lights and fans independently and one duplex outlet were provided inside the room. In addition, two duplex outlets to plug in lights and fans were provided outside the room. One ten foot long power cord and plug for connection to the power supply was used. Also all the audiometric testing rooms with two room design were provided with one surface 6-outlet plug strip underneath window in control room.

Figl2.1 shows the assembly for jack panel of multi wall rooms as provided by Tracoustics (1984). This jack panel consists of a Nylon shoulder washer, a nut, a black cap which is removed before using the panel, a metal screw and a connector. Figl2.2 shows a diagram of phone jack connector utilized in audiometric rooms constructed by Acoustic Systems,Texas (1984). In these jacks, a plug can be inserted to make the necessary circuit connections.

Lighting :

Adequate lighting should be provided in the test area with minimum heat dissipation and sound reflecting surfaces (Pancholy, Chhapgar and Mohanan, 1980). It is preferred that the lighting be soft (Murthy and Jacob, 1971).

According to Snow (1965) some fluorescent lighting fixtures create high noise levels because of humming parts and this can be avoided by selection of quiet fluorescent units or through the use of ordinary incandescent bulbs.

Eckel (1999) recommended the use of incandescent or fluorescent light with remote ballast to avoid ballast hum for adequate lighting.

Pancholy, Chhapgar and Mohanan (1980), found tungsten-filament lamps and fluorescent tube lights unsatisfactory because they dissipated heat and had sound reflecting surfaces. This problem was solved by use of blended mercury vapour lamps (eg. Phillips type MLL-160W). These lamps have a filament ballast incorporated in the bulb which eliminates the humming noise from the external chokes normally required for such lamps. Two lamps each of 60mm in diameter and 100mm long were used by them.

Table. 12.1 summarizes the lighting arrangements used in a few of the audiological test rooms It is seen that usually incandescent bulbs are utilised in audiology test rooms.In addition, even mercury vapours lamps and tungsten filament bulbs are used.

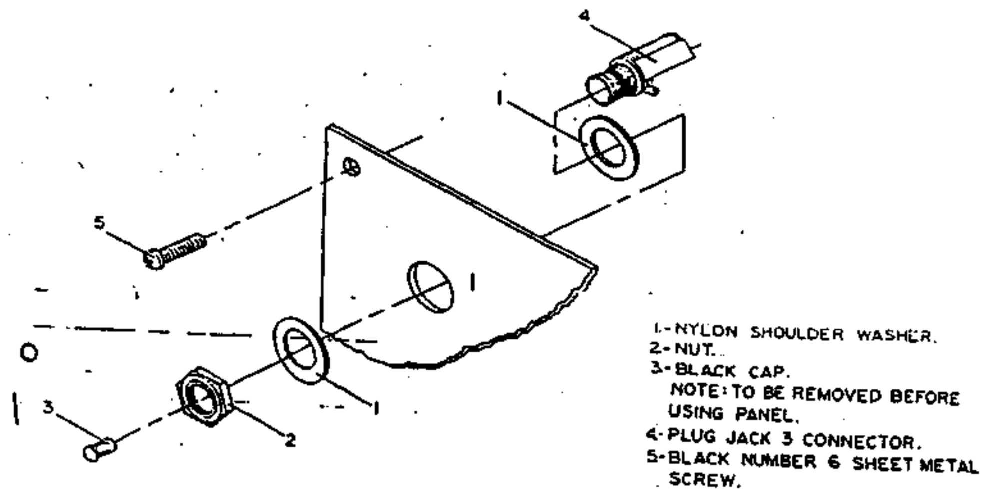


Fig 12.1: Assembly for jack panel of multi-wall rooms, Tracoustic (1984).

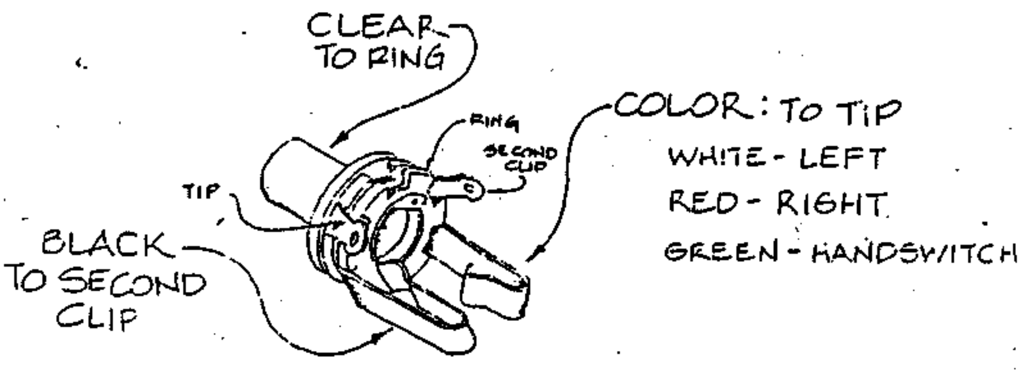


Fig 12.2: Phone jack connector, Acoustic Systems (1984)

From the above discussed information on electrical connections , it can concluded that most of the experts insist on provision of a small hole to pass the cables from one room to another and use of suitable jacks, adaptors, switch-boards and shielded wires for connecting the equipment in the audiological test rooms. These are suggested so that the transmission noise through these connections can be minimized.

SI. No.	Source / Audiological Test center	Lighting
1	Murthy and Jacob(1971),AIISH	Incandescent bulbs in white domes
2	Bhattacharya Tripathi and Chatterjee (1983), Ahmedabad	Local lighting with tungsten filament bulbs
3	IAC Bulletin 5.0003.5, 1993	Incandescent lights
4	Murthy ,Murthy and Ramanjaneyulu (1976), Manipal	Indirect lightings provided above the observation windows
5	Pancholy, Chhapgar and Mohanan (1980), National Physical Laboratory	Phillips blended mercury vapour lamps, Type MLL-160W)
6	Eckel Industries (1999)	Incandescent or fluorescent with remote ballasts

Tablel2.1: Lighting arrangements used in a few of the audiological test rooms.

From the review of literature on lighting for audiological test rooms it can be concluded that most of the experts suggest use of lights which are soft, quiet and have minimum heat dissipation and sound reflecting surfaces.

SUMMARY

This project aimed at providing information about the construction of audiological test rooms and also, about the various indigenously available acoustical materials which can be used in the construction. The ambient noise levels of these rooms should meet the criteria for permissible ambient noise given by ANSI standard (1991) or ISO standard (1989).

To enable the noise levels of audiological test rooms to be within the permissible limits the following suggestions are given;-

1. Location :-The site selected for the construction of the audiometric rooms should be away from noise areas.

2.Dimensions :- The dimensions of the audiological test rooms should be based on number of person who will be occupying the test area, cost no of equipment to be placed within the room. In double room situation, dimensions of both control and experimental room should be decided.

3.**Walls** :- A single, double, composite or a metal stud wall can be constructed for the audiological test rooms. All of these walls are capable of providing average transmission loss of above 50 db. However , to be equally effective a single wall would much heavies than double walls. However, double walls would occupy more space metal stud walls occupy the least space but are more costly. Thus based on the amount of transmission loss required material available, finance constraints and structural constraints, any of these walls can be chosen for the construction of the audiometric test

room.

4.Celings :-A false or a suspended celing can be constructed making use of sound absorbing materials.

5. Floors :- **A** floor with different combination of resilient materials placed over it or a floating floor may be constructed. The floating floor can be made of concrete slab or wood. It is preferable to construct a floating floor for the audiological test rooms.

6.Doors :- A multilayered "sandwiched" composite door for the audiological test rooms usually prefer for these. Either a single door or double doors can be constructed for these rooms. Double doors are usually recommended as they have more TL to an effective seal is required for these doors.

7. **Observation Windows** :- Windows with two or three glass sheets of different thickness with an air-gap should be installed. An effective seal is required around the window to prevent leakage of sound waves.

8. Sound insulating material :- Sound insulating properties of various materials is discussed in this project such as lead, masonry walls, wooden panels, partitions, glass wool etc.

9. Sound absorbing materials :- Different kinds of sound absorbing materials such as porous material, unperforated and perforated tiles and boards are available in Indian. The sound absorption co-efficient and noise reeducation co-efficient (NRC) of various indigenous sound absorbing materials is reported in this project, Attention should be paid to the different properties of these materials such as incompatibility, fire propagation index, heat insulation, acoustical efficiency, colour. A variety of material facings are also available which can be used for the protection of sound- absorbing material.

10.Vibration isolation :-Vibration isolation is mainly required for the various components of air conditioning system. A variety of materials are available for it such as steel springs, elastomers, isolation pads of cork, rubber, felt, inertial based of frame, flexible coupling.

11. **Ventilation** :-For audio metric test rooms a ducting system is required for air conditioning. A split or central air-conditioning system are the most suitable kinds of air-conditioning system for the noisy components of the system are located away from area to be air - conditioned. An insulation of both structure- born and air - borne noise through the noisy components of the system such as compressor fan, motor is very essential.

12.ElectricaI controls and lightings :- Suitable jacks, adaptors, switch boards, insulated wires, switches are required for the controls and connection of different instruments. Noiseless, soft and lighter with minimum heat dissipative and sound selecting surfaces are required for audiological test rooms.

This project gives a complete picture of the construction audiological test rooms. Information regarding the indigenously available material for the construction of sound protected rooms is also discussed.

GLOSSARY

Axial Fan : [Mech Eng] A fan whose housing confines the gas flow to the direction along the rotating shaft at both the inlet and outlet.

Bearing : [Mech Eng] A machine part that supports another part which rotates, slides or oscillates in or on it.

Batt: [Mater] A blanket of insulating material usually 16" wide and 3" to 6" thick,used to insulate building walls and roofs.

Batten : [Build] l.A sewed timber strip of specific, dimension - usually 7 inches (18cm) broad, less than 4 inches (10cm) thick, and more than 6 feet (1.8 m) long - used for outside walls of houses, flooring and such.2. A strip of wood nailed across a door or other structure made of parallel boards to strengthan it and prevent warping.

Build: Building construction.

Butt: [Build] The bottom or cover edge of a shingle.

Casing : [Build] A finishing member around the opening of a door or window [Mech Eng]. A fire-resistant covering used to protect part or all of a steam generating unit.

Conduit : [Elec] Solid or flexible metal or other tubing through which insulated electric wires are run. [Eng] Any channel or pipe for conducting the flow of water or other fluid.

Cam : [Mech Eng] A plate or cylinder which communicates motion to a follower by means of its edge or a groove cut in its surface.

Caulk: [Eng] To make a seam or point airtight ,watertight ,or steamtight by driving in caulking compound, dry pack, lead wool ,or other material. [Mater] Material used to caulk seams.

Cold rolling : [Met] Rolling metal at room temperature to reduce thickness or harden the surface ; results in a smooth finish and improved resistance to fatigue.

cfm: cubic feet per minute.

Centrifugal Compressor : [Mech Eng] A machine in which a gas or vapor is compressed by radial acceleration in an impeller with a surrounding casing and can be arranged, multistage for high ratios of compression.

Civ Eng: Civil engineering

Compressor : [Mech Eng] A machine used for increasing the pressure the pressure of a gas or vapor. Also known as compression machine.

db: decibels

Des Eng: Design Engineering

Duct : [Mech Eng] A fluid flow passage which may range from a few inches in diameter to many feet in rectangular cross section, usually constructed of galvanized steel, alluminium or copper, through which air flows in a ventilation system or to a compressor, supercharger or other equipment at speeds ranging to thousands of feet per minute.

Duplex: [ENG] Consisting of two parts working together or in a similar fashion.

Duplex Cable : [Elec] Two insulated stranded conductors twisted together, they may have a common insulating covering.

Elec: Electricity

Electr: Electronics

Eng: Engineering

Eng Acous: Engineering Acoustic.

Facing : [Civ Eng] A covering or Casting of some material applied to the outer face of embarkments, buildings and other structures.

Fl Mech: Fluid mechanics.

Flux density : [Nucleo] The product of the number of particles per unit volume and their average velocity.

Floating Floor : [Build] A floor constructed so that the wearing surface is separated from the supporting structure by an insulating layer of mineral wool, resilient quilt, or other material to provide insulation against impact sound.

Fluorescent lamp : [Electr] A tubular discharge lamp in which ionization of mercury vapor produces radiation that activates the fluorescent coating on the inner surface of the glass.

Furring: [Build] Thin strips of wood or metal applied to the joists, studs, or wall of a building to level the surface, create an air space, or add thickness.

Grommet : [Eng] 1. A metal washer or eyelet. 2. A piece of fiber soaked in a packing material and used under bolt and nut heads to pressure tightness.

Galvanize : [Met] To deposit zinc on the surface of metal by the processes of hot clipping, sherardizing or sometimes electroplating.

Hinge : [Des Eng] A pair of metal leaves forming a jointed device on which a swinging part turns.

IIC: Impact Insulation Class

Impeller : [Mech Eng] The rotating member of a turbine, flower, fan, axial or centrifugal pump or mixing apparatus. Also known as Rotor.

Impervious : [Sci Tech] Not permitting water or other fluid to pass through. Also known as impermeable.

Incandescent Lamp : [Elec] An electric lamp that produces light when a metallic filament is heated white-hot in a vacuum by passing an electric current through the filament. Also known as filament lamp; light bulb.

Joist: [Civ Eng] A steel or wood beam providing direct support for a floor.

Jack : [Elec] A connecting device into which a plug can be inserted to make circuit connections, may also have contacts that open or close to perform switching functions when the plug is inserted or removed.

Louver: [Build] An opening in a wall or ceiling with slanted or sloping slots to allow sun and ventilation and exclude rain, may be fixed or adjustable and may be at the opening of a ventilating duct.[Eng] Any arrangement of fixed or adjustable slot like opening to provide ventilation. [Eng Acous] An arrangement of concentric or parallel slats or equivalent grille members used to conceal and protect a loudspeaker while allowing sound waves to pass.

Latch : [Eng] Any of various closing devices on a door that fit into a hook, notch or cavity in the frame.

Linoleum : [Mater] A floor covering made by applying a mixture of gelled linseed oil, pigments, fillers and other materials to a burlap backing, and curing to produce a hard, resistant sheet.

Mastic : [Mater] Mixture of finely powerdered rock and asphaltic material used for highway construction.

Mater: Materials.

Mech Eng: Mechanical Engineering.

Met:Metallurgy.

Metal lath : [Eng] A mesh of metal used to provide a base for plaster.

Metal Leaf: [Met] Metal sheet ,thinner than foil formed by beating.

Neoprene : [Mater] A synthetic rubber with outstanding resistances to ozone, weathering, various chemicals, oils and frame, made by polymerization of chloroprene (2-chlorobutadiene-l,3); varies from amber to cream in colour, used in paints, putties, adhesives, shoe soles, tank linings, and rubber products.

NRC: Noise Reduction Coefficient

Plenum : [Eng] A condition in which air pressure within a enclosed space is greater than that in the outside chamber.

Plenum chamber : [Eng] An enclosed space in which a plenum condition exists; air is forced into it for slow distribution through ducts.

Putty : [Mater] A cement of dough consistency made of whiting and boiled linseed oil and used in fastening glass in sashes and sealing crevices in woodwork.

Pugging : Materials used to pack the space under finish floor to improve sound insulation by providing additional mass at low cost and by additional damping.

Parquet flooring : [Build] Wood flooring made of strips laid in a pattern to form design.

Psi : Pound per square inch.[Mech] A unit of pressure equal the pressure resulting from a force of 1 pound applied uniformly over an area of 1 square inch.

Propeller : [Mech Eng] A balded device that rotates on a shaft to produce a useful thrust in the direction of the shaft axis.

Rotor : [Elec] The rotating member of an electrical machine or device, such as the rotating armature of a motor or generator, or the rotating plates of a variable capacitor,

RPM : Revolution per minute [Mech] A unit of angular velocity equal to the uniform angular velocity of a body which rotates through an angle of 360° *(2n* radians), so that every point in the body returns to its original position, in 1 minute.

Refrigerant: [Mater] A substance that by undergoing a change in phase (liquid to gas, gas to liquid) releases or absorbs a large latent heat in relation to its volume, and thus effects a considerable cooling effect ; examples are ammonia, sulphur dioxide, ethyl or methyl chloride and the fluorocarbons, such as Freons, Ucon and GSenetron.

Stator: [Elec] The portion of a rotating machine that contains the stationary parts of the magnetic circuit and their associated windling.

Strands : [Eng] A protective covering, usually of metal plate or sheet.

Suspended Ceiling : [Build] The suspension of the furring members beneath the structured members of a ceiling.

Sandwich Construction : [Des Eng] Composit construction of alloys, plastics, wood or other materials consisting of a foam or honeycomb layer laminated and glued between two hard outer sheets. Also known as Sandwich laminate.

Sci Tech: Science and Technology.

Screed: [Civ Eng] A straight edged wood or metal template, fixed temporarily to a surface as a guide when plastering or concreting.

Seal : [Eng] l.Any device or system that creates a non-leaking union between two mechanical or process- system elements, for example, gaskets for pipe connection seals, mechanical seals for rotating members such as pump shafts and liquid seals to prevent gas entry to or loss from a gas - liquid processing sequence. 2. A tight, perfect closure or joint.

Shingle: [Mater] A rectangular piece of wood, metal, or other material that is used like a tile and arranged in overlapping rows for covering roofs and walls.

Stud wall : [Build] A wall formed with timbers ; studs are usually spaced 12-16 inches [30-41 cm] on center.

STC: Sound transmission class.

Sill: [Build] The lowest horizontal member of a framed partition or of a window or door frame.

Tungsten Filament : [Elec] A filament used in incandescent lamps, and as an incandescent cathode in many types of electron tubes, such as thermionic vaccum tubes.

Vortex : [Fl Mech] l.Any flow possessing vorticity ; for example, an eddy, whirlpoor, or other rotary motion.2. A flow with closed streamlines, such as a free vortex or line vortex.3.A tubular surface consisting of the collection of vortex lines which pass through a small closed curve.

Volute : [Des Eng] A spiral casing for a Centrifugal pump or a fan designed so that speed will be converted to pressure without shock.

Vane : [Mech Eng] A flat or curved surface exposed to a flow of fluid so as to be forced to move or to rotate about an axis, to rechannel the flow, or to act as the impeller; for example, in a steam turbine, propeller fan, or hydraulic turbine,

Wedge: [Des Eng] A piece of resistant material whose two major surfaces make an acute angle.

REFERENCES

Acoustic Systems. (1984) - Brochure on audio metric testing booths.

Agnon, R, Bartenwerfer, M., Gikadi, T., and Neise, W. (1976). Noise reduction methods in centrifugal fans. In RX.Kerlin (Ed.). Inter-Noise 76 proceedings (pp. 43-46). New York: Institute of Noise control Engineering.

Akamatsu, and Koyama, S. (1975). Silent fans for air - fin cooler and cooling tower. In K.Kido (Ed). Inter-noise 75 proceedings, (pp. 315-318). Sendai 980: Tohoku University.

Ando, Y., and Kosaka, k. (1970). Effect of humidity on sound absorption of porous materials. Applied Acoustics, 3 (3), 201-206.

ANSI S3.1=1991. Cited in Wilber, LA. (1994). Calibration, Puretone, Speech and Noise signals. In J.Katz (Ed.). Handbook of Clinical Audiology (pp.73-94). Baltimore : Wilkins and Williams.

Anutone Acoustical Panels - Brochure. Bangalore: Anutone Boards (P) Ltd.

Arora, S.C., and Domkundwar, S. (1987). A course in Refrigeration and Air conditioning. Delhi: Dhanpat Rai and Sons.

Barnes, J.D., and Beranek, B., and Newman, I. (1982). Electric motor noise control over the past ten years. In J.G.Seebold (Ed.). Inter-noise 82 proceedings (pp. 95-98). New York: Noise Control Foundation.

Bell, L.H. (1976). Cited in Bell, L.H. (1982). Industrial Noise Control-fundamentals and applications, New York and Basel: Marcel Dekker.

Bell.L.H. (1982). Industrial Noise Control: Fundamentals and Applications. New York and Basel: Marcel Dekker, Inc.

Bies, D. A. (1971). Acoustical properties of porous materials. In L.L.Beranek (Ed.). Noise and vibration control (pp=406-433). New York: McGraw-Hill, Inc.

Bhandari, P. S. and Srivastava, R. K. (1977). Acoustical design of partitions for open spaces. Building Digest-123. Roorkee : CBRI.

Bhandari, P. S., Srivastava, R. K. and Dhabal, R. L. (1985). Noise and its control. Building Research Note-33. Roorkee : CBRI.

Bhandari, P. S., Srivastava, R. K., and Dhabal, R. L. (1996). Data bank on sound absorbing material. Building Research Note-81. Roorkee : CBRI.

Bhatnagar, S. K. (1991). Non-combustibility of materials. Building Research Note-78. Roorkee: CBRI.

Bhatnagar ,S. K., Sharma, S. K., and Singh, S. (1991). Smoke generation by lining materials. Building Research Note-76. Roorkee: CBRI.

Bhatnagar, S.K., and Yadav, N L. (1998). Fire propagation index of lining materials. Building Research Note-74., Roorkee: CBRI

Bhattacharya, S. K., Tripathi, S. R., and Chatterjee, S. K. (1983). The constructional features and the sound attenuation characteristics of an indigenansly constructed acoustic chamber. JASI, 11(1), 66-72.

Boger, (1971). Cited in Bell, L. H. (1982). Industrial noise control -fundamentals and applications. New York and Basel: Marcel Dekker.

Cammerer, A., and Durhammer, B. (1934). Cited in Utley, W. A., and Mulholland, K. A. (1967). The transmission loss of double and triple walls. Applied Acoustics, 1(1), 15-20.

Cheremisinoff, P. N., and Cheremisinoff, P. P. (1978). Industrial noise control handbook. Michigan: Ann Arbor Science.

Cook, R. K. and Chrzanowski, P. (1956). Transmission of air-borne noise through walls and floors . In C. M. Harris (Ed.). Handbook of noise control (pp. 20.1-20.46). Newyork : Mc Graw-Hill, Inc.

Cops, A. and Soubrier, D. (1988). Sound transmission loss of glass and windows in laboratories with different room design. Applied Acoustics, 25 (4), 269-280.

Degnan, F. T. (1978). Design considerations for selecting and installing the optimum vaneaxial fan to minimise ventilation system noise. In W. W. Lang (Ed.). Inter noise 78 (pp. 625-630). New york: Noise Control Foundation.

Doelle, L. L. (1972). Cited in Magrab, E. B. (1975). Environmental noise control. Newyork: John Wiley and sons, Inc.

Dunn, H. H., Dunn, D. R., and Harford, E. R. (1995). Audiology business and practice management .California: Singular Publishing Group, Inc.

Eckel, A. (1999). Website: http // www. eckel. ca / eckel. Mass : Eckel Industries of Cannada.

Egan, M.D. (1972). Concepts in Architectural Acoustics. Newyork : Mc Graw Hill, Inc.

Ginn, K .B. (1978). Architectural Acoustic, (Ed.) . Bruel and Kjar.

Graham, J. B. (1973) . Acoustical consideration for the selection of fans for new facilities . In D.R .Tree (Ed.). Noise - Con 73 Proceedings (pp. 343- 347). Newyork : Institute of Noise Control Engineering.

Graham, J. B. (1975). Fan selection and installation. In W. W. Lang (Ed.). Noise-Con 75 Proceedings (pp. 343=359). New York: Noise Control Foundation.

Green, D. W., And Cameron, C. W. (1981). Scound transmission loss of gypsum wallboard partitions . Report # 1. Unfilled steel stud partitions. JASA ,71(1), 90-96.

Green, D. W. and Sherry, C. W. (1982) Sound transmission loss of gypsum wallboard partitions having cavities filled with glass fiber batts. JASA, 71 (4), 902-907.

Green, D. W. and Sherry, C. W. (1982). Sound transmission loss of Gypsum wallboard partitions. Report # 3.2 "X 4" wood stud partitions, JASA, 71(4), 908-914.

Hemond, C. J. (1983). Engineering Acoustics and Noise control. New Jersy: Prentice Hall, Inc.

Hornbostel, L. (1978). Construction materials-Types, Uses and Applications. New York : John Wiley and Sons, Inc.

IAC Bulletin 5.0003.5 (1993). Specification for LAC medical / Life Sciences examination and Research rooms. New York: Industrial Acoustic Company, Inc.

IAC Bulletin 5.0102.4 (1993). Audiometric Testing Room Model 401-A-SE 'spaSAVER™'. New York: Industrial Acoustic Company, Inc.

IAC Bulletin 5.0103.0 (1995). Audiometric testing room Model 402 "Conomy spa SAVER", New York: Industrial Acoustic Company, Inc.

IAC Bulletin 5.0103.1 (1995). Audiometric Testi ng Room Model Tetra ™ "spaSAVER ™". New York: Industrial Acoustic Company,Inc.

IAC Bulletin 5.0104.2 (1998). Model HL "spa SAVER ™": Audiometric Testing Room. New York: Industrial Acoustic Company, Inc.

IAC Bulletin 5.0703.0 (1997). Acoustical and structural specifications .... "Mini" series 250-LP sound shelter. Yew York : Industrial Acoustic Company, Inc.

India Gypsum Co. - Technical Mannal. New Delhi: India Gypsum Ltd.

ISO-8253 1989. Cited in Wilber, L. A. (1994). Calibratian, Puretone, Speech and Noise signals. In J. Katz. (Ed.). Handbook of Clinical Audiology (pp.73-94). Baltimore: - Wilkins and Williams.

Leskov, E. A., Osipov, G.-L., and Yudin, E. J. (1969). Experimental investigation of splitter duct silencers. Applied Acoustics, 2(3), 47-55.

Magrab, E. B. (1975). Environmental noise control. New York: John Wiley and Sons, Inc.

Martin, F. N. (1991). Introduction to Audiology. New Jersey: Prentice Hall, Inc.

Merritt, F. S. (1994). Wall, floor and ceiling systems. In F. S. Merritt and J. T.Ricketts (Eds). Building design and construction handbook (pp. 11.1-11.16). New York: Mc Graw Hill, Inc.

Mohanan, V., Sambasivam, R., and Sebastion, R. (1987). The effects of location of damping layer in a false ceiling construction with perforated panels proceedings of National symposium on Acoustics (pp.-382-384.) Acoustical society of India.

Mohanan V., Sharma, D., and Chhapgar, A F. (1982). Absorption characteristics of jute boards with an attached cone at the centre. JASI, 20(4), 136-138.

Moreland, J. B. (1981). Low frequency noise reduction of acoustic enclosures. In, A Royster, F. D. Hart and N. D. Steward (Eds.). Noise-Con 81 proceedings (pp. 59-64). New York: Noise Control Foundation.

Miller,R. K., and Montone, W V. (1978). Hand book of acoustical enclosures and barriers. Georgia: The Fairmont Press, Inc.

Mirowska, M. (1979). The influence of structure on sound absorbing properties of inorganic fibrous materials. In S. Czarnecki Inter-noise 79 proceedings, (pp. 389-392). Warszawa: Institute of Fundamental Technological Research of the Polish Academy of Science.

Murthy, S. S. and Jacob, K.T. (1971). Sound treated room in a speech and hearing clinic. JAIISH,2,87-91.

Murthy, S. S, Murth, .M .N. V., and Ramanjaneyulu, P. (1976). Sound treated room at kasrturba medical college hospital, Manipal. JAIISH, 7, 59-64.

Nabelek, A. K. and Nabelek, IV. (1978). Principles of Noise control. In Libscomb (Ed). Noise and Audiology (pp.58-79). Baltimore : University Park Press.

National Physical Laboratory (1982). Acoustic Properties of some Indigenous materials. JASI, 10(4), 139-144.

Noon, (1999) http//www. eckel. ca / eckel. Eckel Industries of Canada.

Obata,T., Hirata, M., Ohnaka, I., and Nishiwaki. (1975). Attenuation characteristics of lined ducts. In K.Kido (Ed.). Interaoise 75 proceedings, (pp. 663-666zz0. Sendai 980: Tohoku University

Pancholy, M., Chhapgar, A. F., and Mohanan, V. (1981). Design and construction of an anechoic chamber at the National Physical Laboratory of India. Applied Aconstics, 14(12), 101-111.

Pradhan, A. C, and Soni, M. L. (1981). Refrigeration and Air conditioningTheory and Practice. Delhi: Dhanpat Rai and Sons.
Powers, W. R., and Rudinoff, C. D. (1975). Cited in Miller, R. K., and Montone ,W. V. (1978). H. B.of Acoustical enclosures and barriers . Georgia : The Fairmont Press, Inc

Price, A. J., and Mulholland, K. A. (1968). The effect of surface treatment on sound-absorbing materials. Applied Acoustics, 1(1), 67-72.

Purcell, W. E. (1981). Materials for noise and vibration control. Sound and Vibration, 15(7), 4-28.

Rao, N. P., and Reddy, K. C. (1981). Sound absorption in some indigenous building materials. JASI, 9(4), 122-125.

Renault,L (1939). Cited in Suri.RL. (1966). Acoustics : Design and Practice. Bombay : Asia Publishing House.

Schnltz, T. T. (1971). In L. L.Beranek (Ed). Noise and Vibration control New York: Mcgraw Hill, Inc.

Shenoda, F. B. (1979). Computation of sound insulation of double and triple-glass layer windows at normal sound incidence. JASI, 8(3), 1-6.

Snow, W. B. (1965). Audiometric test environment. In. A. Glorig (Ed.)., Audiometric: Principles and practices (pp.97-107). Baltimore: Willams and Wilkins.

Sound Research Laborateries Limited (1976). Cited in Miller R. K., and Montone, W. V. (1976). H. B. of Acoustical enclosures and Barriers . Georgia: The Fairmont Press, Inc.

Suri, R. L. (1966). Acoustics: Design and Practice. Bombay : Asia Publishing House.

Thumann, A. P. E., and Miller, R. K. (1976). The silencers. In K.C.Williams (Ed). Secrets of noise control (pp. 177-208). Georgia: the Fairmont Press.

Tracoustics (1984)- Brochure on audiometric testing booths. U.S.A: Acoustic systems.

Turner, A. E., and Robinson, W. D. (1968). The effect of absorbent materials in the cavity of massive double walls. Applied Acoustics, 1(1), 73-76.

U. P. Twiga Fiberglass Limited- Brochure. New Delhi: Twiga house.

Utley, W. A. ,and Fletcher, B. L. (1969). Influence of edge conditions on the sound insulation of windows. Applied Acoustics, 2(2), 131-136.

Utley, W. A., and Mullholland, K.A. (1968). The transmission loss of double and triple walls. Applied Acoustics, 1(1), 15-20.

Wilber, L. A. (1994). Calibration, Puretone, Speech and Noise signals. In J. Katz (Ed). Handbook of Clinical Audiology (pp. 73-94). Baltimore: Wilkins and Williams.

Wong ,J. G., and Qiang, G. G. (1982). Performance of sound transmission loss 6f metal stud lightweight panel partitions. In J. G. Seebold (Ed.). New York: Noise Control Foundation. Inter-noise-82 proceedings (pp. 475-778).

Yanocha, F. C. (1994). Heating, Ventilation and Air Conditioning. In F. S. Merritt and J. T. Ricketts (Eds.). Building Design and Construction handbook. New york: Mcgrano Hill, Inc.

Zhu, Z. C, Li, Y. X., Wu, J. L, and Zhang, Y. (1988). A study of optimization for rectangular ducts .Applied Acoustics , 25(2), 113-121.