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Warnock, A. C. C.

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USING SOUND ABSORBING MATERIALS

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A.C.C. Warnock

Division of Building Research, National Research Council of Canada

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For a given noise source the behaviour of the sound it emits and the noise levels it produces within a room are largely determined by the sound absorbing properties of the materials in the room. The problem of noise transmitted to adjacent rooms is determined by the sound insulating properties of the walls and is not dealt with in this Note. For many rooms where the exact behaviour of the sound need not be examined as critically as, for example, in a lecture theatre or a concert hall, sound absorbing materials are used mainly to reduce reverberant noise levels. This Note provides some information to aid in the design of such rooms.

DESCRIPTION OF TERMS

Some of the more common terms used in this area of acoustics follow.

The sound absorption coefficient for a material is the fraction or percentage of incident sound energy that is absorbed by the material. The absorption coefficient depends on the sound frequency and values are usually provided in the literature at the standard frequencies of 125, 250, 500, 1000, 2000 and 4000 Hertz. The noise reduction coefficient (NRC) is the average of the values from 250 to 2000 Hz, inclusive, rounded to the nearest 0.05. Absorption coefficients are sometimes expressed as percentages.

The sound absorption for a sample of material or an object is measured in sabins or metric sabins. One sabin may be thought of as the absorption of unit area (1 m^2 or 1 ft^2) of a surface that has an absorption coefficient of 1.0 (100 per cent). When areas are measured in square metres, the term metric sabin is used. The absorption for a surface can be found by multiplying its area by its absorption coefficient. Thus for a material with an absorption coefficient of 0.5, 10 sq ft has a sound absorption of 5 sabins and 100 m^2 is 50 metric sabins.

The total absorption in a room can be estimated by multiplying the area of each surface by an estimated absorption coefficient for that surface and then adding together the contributions from each surface.

When a source of sound in a 'live' room is turned off, a noticeable time elapses before the noise becomes inaudible. The less sound absorbing material there is in a room the longer the sound takes to die away. The reverberation time is defined as the time in seconds required for decaying sound to decrease in level by 60 decibels (dB). Since the sound absorption in the room depends on the frequency of the sounds being considered, so also does the reverberation time.

REVERBERATION IN ROOMS

Hard surfaces such as glass, concrete, brick, wood and plaster reflect almost all of the sound incident on them. In contrast with this, soft porous materials such as glass or mineral wool, soft fabrics, clothing, people, and even the air, will absorb sound.

In an extremely 'live' or reverberant room where the surfaces are all good sound reflectors, noise can build up to produce unpleasantly high sound levels and the sound field is constant in level for all distances greater than a few metres from the source. The reverberation times in such rooms can be from 5 to 10 seconds long or more making speech at distances of more than a few metres difficult to understand.

In a reverberant room the two quantities, absorption and reverberation time, T, in seconds, can be related by the equations

$$T = 0.161\ V/A \qquad (1a)$$

$$\text{or} \quad A = 0.161\ V/T \qquad (1b)$$

V is the volume of the room in cubic metres and A is the total absorption in it in metric sabins (square metres) in the frequency band being considered.

In an extremely absorptive environment the sound level decreases by 6 dB each time the distance from a small source is doubled. There are no reflections, no reverberation and all sound comes directly from the source. This is known as free field behaviour.

In typical rooms the behaviour of the sound field can be described approximately with reference to a critical distance D. Within the critical distance the sound field behaves as in the free field case just described, as if there were no reflecting surfaces. This region is called the near field.

Beyond the critical distance, in the region called the reverberant field, the sound pressure level remains constant. The critical distance is given approximately by

$$D = \sqrt{A/2}\ \text{metres} \qquad (2)$$

where A is the total absorption in the room in metric sabins.

REDUCTION OF REVERBERANT SOUND LEVEL

When absorptive material is added to a noisy room, the reduction of sound pressure level in the reverberant field can be predicted from the equation

$$\text{Noise reduction (dB)} = 10 \log_{10} \left(\frac{\text{Absorption after addition}}{\text{Absorption before addition}}\right) \qquad (3)$$

For example, doubling the amount of absorption in a room will reduce the reverberant sound level by 3 dB. To obtain a further 3 dB improvement the amount of absorption must be doubled once again, i.e., four times more than originally existed in the room.

It is important to remember that Eq. (3) only applies in the reverberant field. Increasing the absorption in a room will reduce noise levels from a machine only for those employees beyond the critical distance. The operator or those close to the machine will be exposed to sound coming directly from it and additional absorptive material will not change the sound levels.* Equation (2) should be used to estimate where the reverberant field begins.

TYPES OF ABSORBING MATERIALS

The absorption coefficients of the many types of sound absorbing materials available are influenced by a number of factors. In general the greater the porosity of a given volume of material, the greater its sound absorbing capability. Thus glass wool is more absorbent than wood chips and nonporous polystyrene foam is a very poor sound absorber. For sheet materials the absorption coefficients vary with mounting technique, e.g., (i) increasing the thickness increases the absorption at all frequencies unless the absorption coefficient is already close to 1.0; (ii) increasing the air gap between the sheet and a solid backing surface increases the absorption at the low frequencies; (iii) covering the sound absorbing material with a very lightweight sheet of plastic or a protective layer more than 10 per cent open reduces the absorption coefficients slightly at the higher frequencies only.

Absorptive materials are often applied in patches or strips of material or suspended as rectangular panels or other forms. These suspended shapes are known as unit absorbers. It is quite common for materials tested in a laboratory reverberation chamber as a small sample or collection of small samples to exhibit absorption coefficients greater than 1.0. This is a real effect caused by diffraction. In such cases the measured absorption coefficients are very strongly influenced by the size of the patches or samples and the spacing between them. Test reports, usually available from manufacturers, should be consulted to determine the appropriate coefficients for any proposed installation.

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* An exception to this occurs when the noisy machine and its operator are situated close to walls or other reflecting surfaces. Here the use of sound absorbing material correctly placed on these surfaces can provide some noise reduction.

Many common materials, drapes, carpets and furniture also absorb sound to varying degrees. Table 1 illustrates some of the foregoing points with representative values of absorption coefficients for a variety of materials.

AMOUNT OF ABSORPTIVE MATERIAL REQUIRED

The types of rooms that can be treated using these equations as a basis for calculation are listed in Table 2 together with recommended average reverberation times. These times are meant as a guide and need not be achieved exactly.

The acoustical treatment of the types of rooms listed is quite straightforward. From the recommended reverberation time and the room volume, the required absorption in sabins is calculated using Eq. (1b). The appropriate choice of type and location of material is then made considering thermal, mechanical and other physical requirements such as condensation control. The area of each material is multiplied by its noise reduction coefficient value to obtain its contribution to the total absorption; the total is compared with the design requirement and any necessary adjustments made. The reverberation time should then be calculated for each frequency band using the appropriate absorption coefficients to ensure reasonable agreement with the recommended average value. It is quite usual for the reverberation time at the lower frequencies to be as much as twice as long as those at the middle frequencies. If the variations with frequency are excessive, change of materials or methods of mounting may be necessary.

In many of the rooms listed in Table 2 it will be quite adequate to install a good quality acoustical ceiling, a carpet or the equivalent. This is the case, for example, in hotel or apartment corridors. In small offices and dwelling rooms, the normal furnishings and occupants themselves usually provide enough absorption. In general, however, for best performance acoustical materials should be distributed over as many of the room surfaces as possible. An example of poor application would be an acoustical ceiling in a very high room with very little other absorptive material present. Sound would then be quite free to circulate in the horizontal plane and the room would be more live than calculation would suggest.

In a few of the cases listed in Table 2, particularly where speech intelligibility is important, it is necessary to exercise some care in the positioning of the sound absorbing material. For example, in conference rooms the ceiling immediately above the table should be hard and sound reflecting. The sound absorbing materials should be restricted to the floor, walls and ceiling perimeter. Similarly, in a classroom where the teacher addresses the students from one end of the room, it is good practice to make the centre portion of the ceiling sound reflecting to provide useful voice reflections. In such cases it is probably advisable to obtain professional help or else consult a good textbook.

It is important during the design phase to include the absorptive properties of the normal contents of the space, i.e., people, merchandise, essential furnishings and sometimes air. This would be important in a sports arena, for example. In a department store the absorption provided by the merchandise will vary widely from place to place, but as a rough guide the absorption values for a typical carpet may be assumed.

Example: Determine the necessary acoustical treatment for a gymnasium with a volume of 2720 m^3 and a ceiling area of 340 m^2.

From Table 2 the recommended reverberation time is 1 second and from Eq. (1b) the required absorption is 438 metric sabins. The sound absorbing material can be applied on both ceiling and walls and should be able to withstand a certain amount of impact. Slotted sound absorbing concrete blocks are extremely useful in gymnasiums, swimming pools, machine shops and similar places since they can fulfill structural requirements as well as providing sound absorption. The NRC for these blocks is given in Table 2 as 0.6.

Suppose, in this case, a spray-on cellulose fibre is to be applied directly to a rigid ceiling (Table 2, NRC = 0.55). The resulting ceiling will contribute 187 m sabins. This leaves 251 m sabins to be provided by the slotted sound absorbing blocks, i.e., an area of 418 m^2. The calculated reverberation time at 125 Hz is 1.4 seconds and at 4000 Hz it would fall to 0.93 sec. This is quite acceptable. (The contribution of the air is not important in this case.)

CONCLUSION

This method of approach has definite limitations, but it may be applied without serious error to the types of rooms listed here. The design of special purpose rooms such as auditoriums, theatres, recording studios and so on is best left in qualified hands.

TABLE 1: Representative values of absorption coefficients for some common acoustical materials

Sample	Third Octave Centre Frequency (Hertz) 125	250	500	1000	2000	4000	NRC
Glass fibre on hard surface							
(i) 25 mm (1") thick	0.06	0.25	0.55	0.9	0.9	0.9	0.65
(ii) 50 mm (2") thick	0.2	0.5	0.8	0.95	0.95	0.95	0.8
(iii) 75 mm (3") thick	0.3	0.8	0.95	0.95	1.0	1.0	0.95
(iv) 100 mm (4") thick	0.4	0.9	1.0	1.0	1.0	1.0	1.0
Glass fibre, 50 mm (2") thick, 25 mm (1") air space behind	0.3	0.7	0.9	1.0	1.0	1.0	0.9
25 mm (1") thick on 400 mm (16") air space	0.50	0.90	0.80	1.0	1.0	1.0	0.95
25 mm (1") glass fibre covered by 5% open perforated layer	0.05	0.25	0.5	0.8	0.25	0.15	0.45
25 mm (1") glass fibre covered by 10% open perforated layer	0.05	0.25	0.5	0.8	0.6	0.4	0.45
Wood wool boards 25 mm (1") thick							
(i) no air space	0.05	0.15	0.3	0.55	0.65	0.75	0.40
(ii) 25 mm (1") air space	0.1	0.25	0.35	0.55	0.65	0.75	0.45
(iii) 400 mm (16") air space	0.45	0.50	0.45	0.60	0.70	0.80	0.55
Mineral fibre ceiling tiles							
(i) no air space	0.05	0.15	0.5	0.75	0.65	0.50	0.50
(ii) 400 mm (16") air space	0.3	0.4	0.55	0.8	0.7	0.55	0.60
Free hanging glass fibre absorbing units	0.65	0.75	0.80	1.0	1.3	1.25	0.95
Sprayed-on fibre 15 mm (5/8") thick on solid surface	0.05	0.15	0.45	0.8	0.90	0.90	0.60
Glass fibre filled slotted sound absorbing concrete blocks	0.7	0.8	0.6	0.5	0.45	0.4	0.60
Cork tiles 25 mm (1") thick on solid backing	0.05	0.1	0.2	0.55	0.6	0.55	0.5
Typical carpet	0.02	0.06	0.15	0.40	0.60	0.65	0.3
Lightweight drapes	0.03	0.05	0.1	0.2	0.25	0.35	0.15
Heavy weight drapes	0.13	0.35	0.6	0.8	0.75	0.75	0.65
Audience in upholstered seats per unit floor area	0.39	0.57	0.8	0.9	0.9	0.85	0.8
Air absorption Relative humidity 50% (metric sabins per 100 m^3)	--	--	--	0.3	0.9	2.4	--

TABLE 2: Recommended average reverberation times in seconds for spaces which can be acoustically treated using this approach.

Space	Average Reverberation Time (Seconds)
Classrooms; museums; libraries; restaurants; offices; hotel, apartment and office corridors	0.75 or less
Gymnasiums; machine rooms; computer rooms; swimming pools; airport lobbies; department stores; general purpose assembly rooms; conference rooms; cafeterias.	1.0 or less
Sports arenas	2.0 or less