

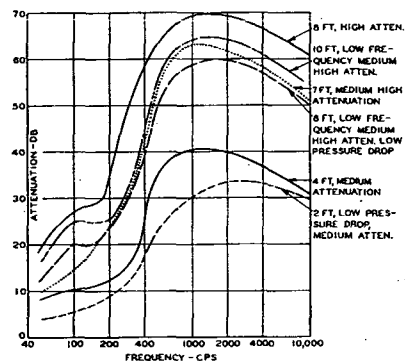


Fig. 15.... Typical Values of Sound Attenuation Through Several Types of Package Units

converted to sound pressure levels in the room, because it is sound pressure to which the ear and the sound level meter respond. The sound pressure level at a distance r from the grille opening and at an angle θ with respect to an axis perpendicular to its surface is given by the equation²⁰

$$L_p = \text{PWL} + 10 \log_{10} \left(\frac{Q}{4\pi r^2} + \frac{1}{R} \right) + 0.5 \text{ db} \quad (24)$$

where

PWL = sound power level emitted at the duct termination and is the power summation of the attenuated fan noise and the grille noise in db (see Example 3).

Q = directivity factor and is a dimensionless function of θ .

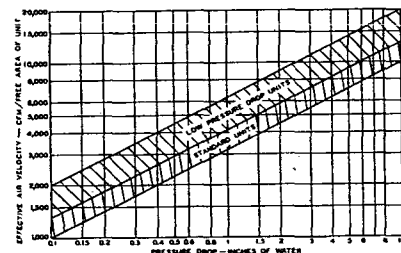
r = distance from the duct opening, feet.

R = the room constant, square feet. (R increases with the amount of acoustical absorption in the room and generally depends somewhat upon frequency.)

In Fig. 17 four methods are shown for terminating a ventilating duct in a room. In each of these cases, the noise power radiates into the room. Low-frequency sounds radiate equally in all directions. High-frequency sounds tend to beam in the direction the duct opening is facing. The magnitude of this beaming effect is described mathematically by the directivity factor Q . After the sound at any frequency has reflected from a wall, it generally travels around the room many times to produce reverberant sound. This fact appears in Equation 24, wherein the first term in the parenthesis described the direct sound (prior to reflection) and the second term described the reverberant sound (the result of many reflections).

The directivity factor Q is of importance only when the listener is near the duct termination, i.e., when r is small. At large distances, i.e., when the first term becomes negligible compared to the second, the listener hears only the reverberant sound.

For the four duct positions of Fig. 17, approximate values of Q are given in Fig. 18 for $\theta = 0$ deg and for $\theta = 45$ deg. The abscissa is the product of frequency times L assuming that the duct is approximately square with an area of 12 sq



Note: Early models of these units sometimes gave higher pressure drops than those shown above. Data of certified test laboratories on current unit should be consulted where possible.

Fig. 16.... Approximate Pressure Drop Across Typical Package Units

in. If the duct is rectangular, the value of Q should be computed for L equal to the smaller dimension.

The room constant R is defined by the equation

$$R = \frac{aS}{1 - \alpha} \quad (25)$$

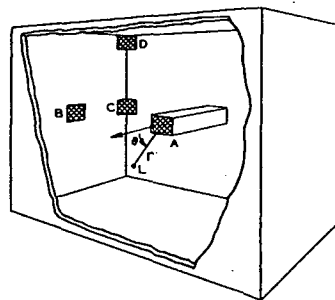
where

α = average sound absorption coefficient (dimensionless) for the room at the mid-frequency of the band of noise being considered.

S = total area of the boundary surfaces of the room, sq ft.

Where a room contains several surfaces, each with different absorption coefficients, the average absorption coefficient may be determined by the equation

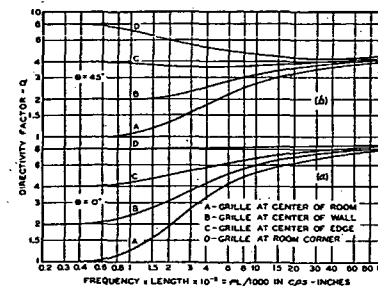
$$\alpha = \frac{S_1\alpha_1 + S_2\alpha_2 + \dots}{S_1 + S_2 + \dots} \quad (26)$$



- A. Duct projecting in the room
- B. Duct in the center of and flush with the wall
- C. Duct in the center of one edge
- D. Duct in the corner

The listener is at distance r and angle θ from the duct opening.

Fig. 17.... Four Typical Means for Terminating a Ventilating Duct in a Room



A. The value of Q is given for $\theta = 0$; i.e., directly in front of the duct opening.
B. Same as for (A) except the value of Q is given for $\theta = 45$ deg.
The frequency of f is in cps and the duct is assumed to be square with an area 12 in square inches.

Fig. 18.... Directivity Factor Q for the Four Duct Configurations of Fig. 17

where

S_1, S_2 = the areas of each type of absorbing material. α_1, α_2 etc., = the absorption coefficients of each type of material at the mid-frequency of the band of noise being considered. (Values of α for many materials are published by the Acoustical Materials Association.¹⁴)

For estimating purposes, approximate values of the room constant R may be obtained from Fig. 19 as a function of room size for five classes of rooms.

The value of the second and third terms of Equation 24 (including 0.5 db) is plotted in Fig. 20 with distance r from the source as the abscissa, with the sound pressure level in decibels as the ordinate and the room constant R in sq ft as the parameter.

The directivity factor Q is given at the bottom left-hand side of the graph. The procedure for using the graph is as follows:

Determine the room constant R and the directivity factor Q for the particular direction θ of interest. Enter Fig. 20 at the bottom at the distance r . Then move diagonally to the left until the value of Q is reached. Then move vertically until the value R is reached. Then read the relative sound pressure level from the ordinate. An example is shown by the dotted line in Fig. 20 for $r = 7$ ft, $Q = 2$, and $R = 2000$ sq ft. The relative sound pressure level is added algebraically to the sound power level to yield the sound pressure level at the distance r and the angle θ in the room (see Equation 24).

It is seen from Fig. 20 that the noise from a ventilating duct is less at distances far from it than nearby. Moreover, at large distances, the levels produced in the room depend only on the power level of the source and the room constant and not on the directivity factor and the distance r .

Example 3: To illustrate the application of the noise criteria and control procedures outlined in this chapter, calculation will be made for the required treatment for the ventilation system supplying the library reading room of Fig. 21. This room has a total volume of 80,000 cu ft and may be considered as an average room for acoustic properties (see Fig. 19). The total air supply to the reading room is 6000 cfm which is equally divided between four 12 x 18 in. supply grilles located along one wall. The supply of outdoor air is from a central fan system which handles a total of 25,000 cfm at 2-in. water static pressure and requires a 15 hp motor.

Solution: It is necessary to determine the noise level in the

reading room as a result of the ventilating system, both for the position of the nearest listener to a grille, and for a position remote from the supply grilles since it is impossible to tell beforehand which will be greater. The required attenuation for acceptable octave band noise levels will then be determined.

Analysis of Fan and Duct System

The acoustic power level of the fan should be computed from Equation 18 when the specific power level is available. In this example it is assumed that the specific sound power level is not known. Therefore, employ the approximate Equations 19 or 20. From Equation 19:

$$\text{PWL}_{(\text{duct AB})} = 100 + 10 \log 15 + 10 \log 2 = 114.7 \text{ db}$$

or from Equation 20:

$$\text{PWL}_{(\text{duct AB})} = 65 + 10 \log 25,000 + 20 \log 2 = 115 \text{ db}$$

which agreement is better than the accuracy expected from these equations.

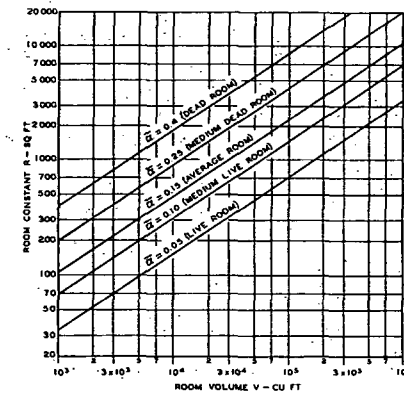
Of this total acoustic power generated by the fan the main interest is in the part that reaches the reading room. At each duct branch the power will divide approximately as the ratio of the branch duct area to the total duct area after the branch. Thus at Station B (Fig. 21) the acoustic power delivered to the 18 x 48 in. duct, neglecting any attenuation in the system, will be

$$\begin{aligned} \text{PWL}_{(\text{duct BC})} &= \text{PWL}_{(\text{duct AB})} + 10 \log \left(\frac{A_{\text{branch}}}{A_{\text{total}}} \right) \\ &= 115 + 10 \log \left[\frac{18 \times 48}{(24 \times 48) + (18 \times 48)} \right] = 111 \text{ db} \end{aligned}$$

At Station C the power division gives

$$\begin{aligned} \text{PWL}_{(\text{duct CD})} &= 111 + 10 \log \left[\frac{12 \times 48}{(18 \times 24) + (12 \times 48)} \right] \\ &= 108 \text{ db} \end{aligned}$$

Thus neglecting, at first, the attenuation in the connecting duct



These proportions give $S = 6.25V^{2/3}$. The parameter is the average sound-absorption coefficient for the room. The subjective ratings dead, live, etc., are the author's and are not necessarily in standard use. From Reference 20. Used by permission.

Fig. 19.... Value of the Room Constant R as a Function of Room Volume for Rooms with Proportions of About 1:1.5:2