transmitted noise to any required degree. This applies not only to ducts between the equipment room and other rooms in a building, but also to ducts connecting adjacent or nearly adjacent rooms. By the proper use of such *filters* it is possible to eliminate all of the difficulties which arise in connection with the transmission of sound through ventilating ducts. The problem is an engineering one which can be worked out prior to the installing of the equipment, and it can be calculated in such a way as to meet the most rigorous demands for silent operation. There is a need for quantitative data regarding the attenuation or noise-reduction provided by different types of ducts, but even with the meager data available it is possible to design filters which will suppress the ordinary noises incident to the ventilating or air conditioning of buildings[4].

In general, the motion of air resulting from the ventilating of rooms is not sufficient to introduce any appreciable difficulty in auditoriums, except where noise may originate from the issuing of high-speed air from nozzles. However, by proper stream-lining of the nozzles, it is possible to work with speeds which are adequate for all practical purposes without producing any disturbing noises. Since sound is propagated with a velocity of more than 1100 fps, the velocity of the air would have to attain speeds of at least 20 to 30 fps before these wind velocities would have any appreciable influence upon the propagation of sound.

If there is to be any appreciable motion of air in an auditorium, it is advantageous to have the upper layers of air moving in a direction from the stage toward the audience, as this will tend to refract the sound waves down toward the audience. However, unless the speed of the air is as great as 20 or 30 fps, the amount of refraction will not be noticeable. Therefore, as a rule the motion of air in an auditorium does not have an appreciable effect upon the acoustical properties of the room.

EFFECT OF HUMIDITY UPON ACOUSTICS

Recent experiments[5] have shown that both the humidity and the temperature of air have a marked influence upon the rate of absorption of high-pitched sounds. Perfectly dry air is more absorptive than air containing any amount of water vapor. At relative humidities of 5 to 25 per cent, the air is highly absorptive but becomes less and less absorptive as the humidity is increased. High-frequency sounds are propagated better in cold humid air than in hot dry air, and since high-frequency sounds are particularly important for the preservation of good quality in speech and music it is advantageous to maintain the air in a room at a relatively high humidity, not less than about 55 to 60 per cent. On the other hand, where it is desirable to absorb all frequency components of sound, as for the reduction of noise in offices, it is advantageous to maintain relatively dry air.

The time of reverberation in a room is given by the following equation:

$$t = \frac{0.049V}{4mV - S\log_e(1-\alpha)} \qquad (5)$$

[4]How Sound is Controlled, by V. O. Knudsen (*Heating, Piping and Air Conditioning*, October, 1931).

[5]Effect of Humidity upon the Absorption of Sound in a Room, by V. O. Knudsen (*Journal Acoustical Society of America*, July, 1931). Also see report presented at the May, 1933, meeting of *A. S. of A.*

where

V = volume of room in cubic feet.
S = interior surface of room.
α = average coefficient of sound-absorption of the interior surface of the room.
m = the absorption coefficient of the air in the room.

The coefficient m depends upon the frequency of the sound and the humidity (and probably the temperature) of the air. At a temperature of 70 F, and for sound waves having a frequency of 4096 vibrations per second, m = 0.0027 at 25 per cent relative humidity, 0.0018 at 54 per cent, and 0.0013 at 82 per cent. It will be seen, therefore, that the absorption of sound in the air is twice as great at a relative humidity of 25 per cent as it is at a relative humidity of 82 per cent. This explains why sounds in the open travel so much better on humid days than they do on dry days. Although this dependence of absorption upon humidity is characteristic of low-frequency as well as high-frequency sound, the actual amount of absorption in the air is negligible for frequencies below about 1024 vibrations per second. However, the absorption of the higher frequencies in the air is a significant factor, and its dependence upon humidity calls for careful consideration in planning the air-conditioning equipment for buildings.

PROBLEMS IN PRACTICE

1 ● What are the characteristics of a good duct lining material for the absorption of sound?

A good duct lining should have the following characteristics: (1) high absorption qualities, (2) proper physical strength, (3) fire resistant, (4) clean with an absence of loose fibers or pieces, (5) smooth surface to reduce air friction, and (6) simple and easy application to existing or new installations.

2 ● Why do modern improvements in the acoustics and air conditioning of buildings present new acoustical problems to the heating and ventilating engineer?

In acoustically treated rooms, both outside and inside noise are reduced, and consequently the noise of ventilating equipment becomes more noticeable. The closed windows in air conditioned buildings exclude outside noise, which makes all inside noise from mechanical equipment seem louder.

3 ● Name the acoustical problems which should be solved in connection with the installation of heating or air conditioning equipment.

Selection of quietly operating equipment; adequate insulation of walls surrounding the equipment room; mounting of all vibrating equipment on flexible supports which will eliminate solid-borne vibrations; design of suitable sound filters to reduce the transmission of noise through ventilating ducts; the use of suitably low air speeds and stream-lining, where necessary, to prevent *eddy* noises.

4 ● Are good heat insulators also good sound insulators?

As a rule, no. Blankets and felted materials offer considerable insulation for sounds of high frequency, but very little for sounds of low frequency.

5 ● What is the principal consideration in the selection of elastic supports for the insulation of machinery vibration?