where

L = Loudness in db; I = Intensity.

Thus the two whistles made a noise $10 \log_{10} 2 = 3$ db louder than one whistle and the ten whistles, $10 \log_{10} 10 = 10$ db louder than one. It would take a hundred whistles to make a noise 20 db louder than one and a thousand to make a noise 30 db louder.

MEASUREMENT OF NOISE

Since the chief acoustical problem in the ventilating or air conditioning of a building consists of reducing equipment noise, it is necessary to describe methods for measuring noise. The measurement of noise is a relatively new problem, and although there are several reliable methods, there are as yet no standardized units, scales, or instruments for measuring noise[1]. However, the *decibel* (*db*) described above is widely used in this country and England as the standard unit for noise or sound intensity—a unit of the same size, but called a *phon*, is used in Germany—and the zero level of the scale is a barely audible sound. Since the relation between subjective loudness and sound intensity is dependent upon pitch, it is customary to refer loudness to a single frequency. A 1000-cycle tone is generally accepted as the reference frequency, that is, the loudness of any sound is rated in terms of an equally loud 1000-cycle tone. Thus, a noise of 50 db means that the noise would be judged to be of the same loudness as a 1000-cycle tone which is 50 db above the normal threshold of audibility for the 1000-cycle tone.

As the frequencies decrease below 1000 cycles, the ear becomes less sensitive, until at about 30 cycles sounds are no longer audible regardless of their intensity. Similarly, for higher frequencies, the limit of audibility is reached around 7000 cycles. Thus, at frequencies below 1000 cycles, sounds of the same loudness must have a greater intensity than at 1000 cycles. This is particularly fortunate, as otherwise the low frequency sounds would mask all others.

Noise measurements are usually made by one of three methods. The first is the electrical instrument method, which uses a noise meter usually consisting of a microphone, an amplifier, and a galvanometer. Where such a meter is to measure the loudness of a noise without regard to the frequency distribution, it must contain a weighted network which electrically simulates the varying sensitivity of response of the ear to different frequencies. Where it is desired to analyze the character of the sound, filters which shut out all but certain bands of frequencies are used with the meter. A number of manufacturers make such meters.

The second method consists essentially of varying the intensity of an artificially generated sound until the noise generated is masked by the noise being measured. Obviously, this method is subject to human errors in observation to which the instrumental method is not, but in the hands of a careful observer quite satisfactory results may be obtained. One instrument used is the audiometer, which consists of a buzzer, an ear phone, and a rheostat. The phone is held a fixed distance from the ear while the resistance of the rheostat is varied until the sound of the buzzer, as transmitted electrically to the phone, can no longer be heard. Audiometers are available either for covering all frequencies, as in the noise meter, or for covering certain frequency bands only.

A third method of measuring noise, simple, yet sufficiently accurate for most field measurements, employs only three tuning forks and a stop watch. Forks having frequencies of 128, 512, and 2048 are recommended. The forks must be calibrated. That is, it is necessary to know for each fork (1) the initial intensity, in number of decibels above its threshold, immediately after it has received a standard hit or excitation, and (2) the damping rate, in decibels per second. These calibrations can be made in any well-equipped acoustical laboratory. A *standard hit* or *excitation* can be imparted to the fork by a felt-covered spring hammer, or simply by letting the fork fall from a vertical position through an arc of 90 deg, hitting a suitable pad (such as soft rubber or felt for the 128 and 512 forks and hard rubber for the 2048 fork). The average 512 steel fork will have an initial intensity, when held ¼ in. from the ear with the broad side of the prong facing the ear canal, of about 80 db, and will decay at a rate of about 1.0 db per second. Such a fork will remain audible about 80 sec in a perfectly quiet place, provided the listener has normal hearing. In the presence of a noise, it will remain audible until its tone is just *masked* by the noise. Thus, if a 512 fork, having an initial intensity of 80 db and a damping rate of 1.0 db per second, should be found to remain audible 35 sec in the presence of a certain noise, the masking effect of the noise is $80 - 35$, or 45 db.

Procedure

The method of measuring any noise is as follows: The observer, in the presence of the noise, strikes the 128 fork a standard blow. At the same instant he starts a stop watch. The fork is then held in front of the ear canal, and moved back and forth slightly, until the tone of the fork is just completely masked by the noise, at which instant the watch is stopped. This measurement is repeated at least two times. The average time is subtracted from the time the 128 fork remains audible in a quiet place. This difference multiplied by the damping rate of the fork gives the masking effect of the noise at 128 cycles. Similar measurements are made with the 512 and 2048 forks. Measurements of this type give a satisfactory description of both the intensity and the frequency distribution of the noise. The average masking effect of the noise at 128, 512, and 2048 cycles will usually be about 5 to 10 db less than the reading given by a noise meter.

NOISE IN BUILDINGS

Measurements of the intensity of speech, music and noise in many buildings, with special consideration of the noise produced by ventilating equipment, have given the results indicated by Fig. 1. The equivalent loudness of sounds in buildings varies from less than 10 db near the outlet of an air duct in a very quiet sound studio to nearly 100 db in a noisy boiler factory. It will be noted that the noise from the ventilating

[1]See Proposed Tentative Standards for Noise Measurement, and Proposed American Tentative Standard Acoustical Terminology of the *American Standards Association Sectional Committee on Acoustical Measurements and Terminology.*

Also see How Sound is Controlled, by V. O. Knudsen (*Heating, Piping and Air Conditioning*, October, 1931), and Acoustical Problems in the Heating and Ventilating of Buildings, by V. O. Knudsen (A.S.H.V.E. Transactions, Vol. 37, 1931).