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Quieting: A Home Owner's Practical Guide to Noise Control

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QUIETING!

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ABSTRACT

This publication is a guide offering practical solutions for the ordinary noise problems that a person is likely to meet in his home, while traveling and at work, The discussion describes the ways in which sounds are generated, travel to the listener, and affect his hearing and well being. Recommendations are given for controlling noise at the source and along its path of travel, and for protecting the listener. The guide instructs the reader by way of "Warning signs" on ways and means of determining whether prolonged exposure to a noisy environment may be hazardous to his hearing. General principles for selecting quiet appliances are given. The remedies for noise problems deal both with prevention and with selection of quiet alternatives to existing noise sources. Ways of searching for the sources of noise and the paths over which they travel to the listener are described. A detailed index is given for individual noise sources and the solutions to the problems they present. General ways of looking for inherently quiet homes and travel accommodations are described. In a final chapter, there are suggestions for enlisting community help where large external sources of noise must be quieted, such as those arising from public transportation and public utilities.

KEY WORDS: Airborne and structure-borne sounds; annoyance; appliance noise; health and hearing hazards; household noise; legal and community action; loudness; noise control and abatement.

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QUIETING

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Chapter 1

INTRODUCTION

WHAT IS NOISE?

One humorous definition holds that "Noise is what your neighbor makes." Of course, we all make noise ourselves, but we especially resent the intrusion of sounds that we do not choose to hear. Thus, noise may be defined as "unwanted sound."

Sound becomes unwanted because it is capable of interfering with our ability to relax or to concentrate, to work or play, sleep, study, or communicate. In short, it invades our privacy and disrupts the enjoyment and full use of our surroundings. At worst, it can affect our hearing, performance, and behavior; noise can impair both physical and mental well-being. Excessive noise represents a major public health hazard, and indeed millions of workers risk permanent hearing loss from exposure to noise in their work.

Not only is much of this noise unnecessary, but it is avoidable. Most experts will agree that modern technology for noise control can be applied to reduce much noise to acceptable levels. Often noise arises through thoughtlessness and neglect, and may be remedied by attention to a relatively few basic principles.

The objective of this Consumer Guide is to explain and illustrate in a simple manner how many of the commonly encountered noise problems can be alleviated or even eliminated.

HOW DOES NOISE ORIGINATE?

Generally speaking, noise is produced when an object or surface vibrates rapidly enough to generate a pressure wave or disturbance in the surrounding air. Air is a rather springy, elastic substance composed of small particles called molecules. The elasticity is due to the tendency of these molecules to spring back to their original positions of rest whenever they are deflected or displaced by some outside disturbance or force. As a sound wave travels through the air, the pressure fluctuations cause the

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molecules to vibrate back and forth about their normal positions of rest. In so doing, they bump neighboring molecules, imparting motion to them and then, rebounding back and forth, return to their original positions. The disturbed molecules collide with others in the same manner. The disturbance travels through the air by successive collisions, much as a billiard cue ball will impart motion to a line of billiard balls. Although each of the balls moves with the disturbance, each returns to its original position after collision with the next successive ball; only the end ball, which makes no further collision, moves forward beyond its rest position. In a similar fashion, the vibration imparted to the air travels in a chain-reaction manner from one air molecule to another until it eventually reaches our ears. Colliding molecules produce a pressure increase or a "compression" in the air; molecules rebounding away from each other produce a lower pressure or a "rarefaction". In spite of all this motion, the individual air molecules do not travel far from their original positions; it is only the pressure wave or the compression/rarefaction disturbance that moves outward, like the ripples in a pond into which a pebble is dropped. We hear sounds because our ears respond to the pressure fluctuations that have been set up in the air around us.

A few noises originate directly in the air. The most dramatic is the thunderclap that originates from a discharge of lightning. The electrical forces and the local heating create a sudden burst of overpressure that compresses the air surrounding the path. This pushes the air outward, and the motion persists until the surrounding air particles have been pushed outward by the particles driven by the original stroke. By this time, the column of air has been somewhat over-expanded, a process that cools it and lowers the pressure within it. As a result, some air molecules are sucked back into the column, and by the time they have collided with the central part of the column, a pressure rise has been generated that again pushes outward on the column. What started out as a pulse from a single instantaneous heat surge becomes a succession of high-pressure pulses separated by low-pressure pulses, which gradually diminish as the wave motion spreads outward from the column. These we recognize as the compressions and rarefactions in a sound wave.

Another noise that originates directly in the air is turbulence. You can see the swirls of turbulence that your breath generates if you blow into an illuminated column of smoke or dust, such as one illuminated by a beam of sunshine coming through a window. The swirls that you see are larger in diameter and slower in motion than the turbulence you can hear, but have the same general form as the audible turbulence generated at the edge of a jet-engine exhaust or the blades of a high-speed fan. The swirls of turbulence originate whenever a fast flow of fluid goes past a stationary or slowly-moving surface of fluid. After many years we still find the exact process a mystery, but we do know that turbulence is more likely as flow speed increases. In fact, once turbulence is started, it increases rapidly as the flow speed is increased. The rapid changes in direction and speed in a turbulent flow also result in rapid changes in pressure, which we hear as noise.

Most noises are started by the transfer of motion from a vibrating surface to the air lying next to it. If this motion is to be transferred efficiently, the radiating surface must be large compared to the spacing between successive pressure pulses. The pressure pulses travel through the air at the speed of sound, 345 meters/second (1130 feet/second - a little slower than a mile in four seconds). If the pressure can flow from the front to the back of the surface in a very short time, it can restore the neutral condition, because if the front surface of a moving object is compressing the air, the back surface must at the same time be allowing the air behind it to expand. For example, if you wave your hand slowly through the air, it doesn't generate any sound. The forward pressure causes the air to flow into the region of reduced pressure behind your hand during the time it is moving; the entire disturbance is confined to a small space about your hand.

As far as the listener is concerned, a sonic boom sounds very much like a loud thunderclap. Whereas the lightning generates an initial overpressure by electrical heating, a supersonic plane or the blade tip of a high speed helicopter generates the overpressure by compressing the air in its path faster than the high-pressure disturbance can flow away. This compression is called a "shock wave". Once the sonic boom has been created, the subsequent behavior of the sound is similar to that of thunder.

You can generate sound pressures with the motion of a small surface if there is little opportunity for the air to flow around and equalize the pressure between successive motions. It's quite possible to generate a high sound pressure if you box someone on the ear or strike a drumhead. There you are changing the pressure in an enclosed volume, and the cancellation from the back surface cannot occur.

You can hear a bumblebee because his wings are vibrating so rapidly that the individual pressure pulses, which can only move at the speed of sound, do not have time enough to travel around the tips of his wings to interfere with the rarefactions at the back of his wings. The beating of his wings generates pressure waves in the air that propagate for some distance before they die out. Since his wings beat at many times per second, we say he generates sounds at high frequency; we perceive these as being high in pitch, which is our subjective response to sounds of high frequency. In fact, we hear only the higher-pitched parts of his buzz, when he is flying freely. When he strikes against a window, for the duration of his contact with the window we hear the low-frequency parts of his buzz enhanced, because the window offers an extended surface over which cancellation of the lower-frequency (more slowly varying) pressure pulses cannot occur.

Except for our own voices, which reach us primarily through the bony structures in our heads, most sounds reach us through the air. We say they are airborne. However, sounds travel rapidly and with little loss through liquids and solids. As long as these offer an uninterrupted path, they transmit vibrations readily. In liquids and solids the speed of sound is from four to ten times as great as it is in air.

From experience, you know that if you press your ear against a wall in your home or apartment, you can hear noises arising from some distance. You may be able to identify quite clearly your own dishwasher, a distant TV set, or the compressor in the air-conditioner system. Often, when you press your ear against a water pipe, you can hear the sound of running water, perhaps originating at a neighbor's faucet. Some of us have had the childhood experience of listening to the railroad track to hear whether there was a train on the line. These are examples of structure-borne sounds.

In each case, sound waves travel through the medium because a source of noise or vibration in contact with the medium generates a disturbance that displaces the molecules of the substance carrying the sound. The disturbance continues to travel until it dissipates itself and becomes indistinguishable from the random motions of the molecules. We hear the sounds coming from a liquid or solid when they are transferred to our ears as pressure fluctuations if they occur within the range of frequencies to which our ears are sensitive. We do not normally hear the thermal vibrations of molecules because they are too small and too random to generate enough sound, and vibrations occur at frequencies for which our ears are insensitive.

THE CHARACTERISTICS OF SOUND OR NOISE.

The various physical characteristics of noise or vibration, the way they travel through materials, and how they react with the surrounding environment can be measured. In many cases they can be predicted, analyzed and explained.

When acousticians or noise control engineers get together in technical discussions about noise, words like sound power, sound pressure level, intensity, frequency and decibels frequently are mentioned. While these terms are by no means household words, most people have a rough understanding of what they represent. We perceive frequency as pitch, intensity as loudness, and are likely to be concerned with the general level of the noise rather then the absolute over- all sound power level. Of all of these terms, the most confusing is likely to be the term "decibel", although nearly all of us have some idea that it relates to measuring sound levels. Except for experience, we should all have some difficulty with relating decibels to some familiar sound, for sound levels in decibels do not translate directly into loudness. In fact, the first use of decibels was in connection with telegraphy, and the engineers who work in acoustics use the term in ways that communications engineers dispute. So, rather than tell you in detail what the decibel scale is, we'll tell you more of what it does.

Decibel, usually written dB:

Unfortunately, the decibel is not a linear unit of sound level in the same way that a foot, inch, meter or centimeter are units of length. It is a measure of a ratio of the power of a sound relative to some reference value. Usually the "threshold of hearing" is used as the reference. Because it arises from the logarithm of a ratio, one decibel is not a fixed difference, in the same way that all units of an inch or a centimeter are identical. Nevertheless, as we shall see, the convenience of the decibel scale outweighs its difficulties.

Consider for a moment the range of sensitivity of the human ear. If we were to assign the value of one unit to the smallest sound power that the ear can hear, commonly referred to as the "threshold of hearing", then a value of one million million units would be given to the greatest sound power that the ear can withstand without suffering discomfort, which defines the "threshhold of pain". (The ratio of one million million is written by engineers as 10^{12}, meaning that twelve successive multiplications by ten of the threshold power would be needed to produce the threshold of discomfort.) If one were to plot this enormous range on graph paper with graduations of a millimeter per unit of sound pressure, it would require a sheet of paper 10 kilometers (6.2 miles) long. And if we insisted upon sound power, this would require 100 kilometers (62 miles). On the decibel scale, however, the range of sound power level between the threshold of hearing and the threshold of pain would be compressed between the limits of 0 dB and 120 dB respectively, and could be plotted easily on a graph the size of ordinary tablet paper.

On this scale, the sound pressure level of 0 dB does not indicate the absence of sound; it indicates a level of sound, at a frequency of 1000 Hz, (cycles per second -- see section on Frequency and Pitch) just barely audible to a normally sensitive ear. A 1-dB difference in sound level is about the smallest relative change that the average person can detect. For each 10-fold increase in sound pressure, there is a 20-decibel gain in power level, that is, the new power is 100 times greater than the original. If the sound pressure is increased to 100 times the original pressure, the power now would be 10,000 times greater, a gain of 40 dB in power level.

Sound level meter:

Sound levels are measured with a sound-level meter, which is an instrument calibrated to read sound level directly in decibels. Basically, the instrument is an electrical device. It has a microphone that converts a sound-pressure variation in the air into an electrical signal, an amplifier powered by a battery to raise the signal level to produce enough power to operate an indicator needle, and an attenuator to adjust the signal level within the range of the meter's scale. For its basic setting, the meter reads the total of all sound within the range of frequencies normally heard by the human ear. To give you a feeling for the meanings of the meter indications, we are presenting in Table 1-1 the sorts of readings you would see if you were to take a sound-level meter and expose its microphone to common sources of sound in your environment.

Now, if your ear behaved just like the simple sound-level meter, the decibel scale would be all that you would need to measure the extent of a noise problem. However, high-pitched sounds -- the calls of birds, the upper notes of a piano, insect chirps, the consonant sounds of speech, whispers -- all can attract your attention at low power levels, in fact at levels so low that sounds of low frequency and similar intensity, as for example a distant airplane, might easily go unnoticed. The simplest way to adapt a sound-level meter to the behavior of the ear has been to provide it with weighting networks

A-Weighting, dB (A):

We can give you a picture of the way in which the ear weights sounds of equal level but different frequencies by showing you a set of "equal- loudness contours". These values are measured by asking subjects to match the loudness of a test sound against a standard sound. Usually the standard sound is a pure tone whose frequency is 1000 Hz (about that of the top note of a soprano's range). A set of these equal-loudness contours is shown in Figure 1-1, and we have superimposed some typical sound sources in their proper places in the frequency and intensity scale. Until fairly high intensities of sounds are reached, the contours are more or less parallel to one another.

The A-weighting network on a sound level meter is designed to adjust the sensitivity of the meter to sounds of different frequencies so that it behaves more nearly like the human ear at moderate sound levels. The "A-scale" weightings of a sound-level meter have been found to agree reasonably well with subjective response to the loudness of sounds. When an A-weighting network has been used with a sound-level meter, this fact often is noted by using the abbreviation dB (A). The hum of an air-conditioner might be read as 70 dB with a sound-level meter, and would be likely to read 58 dB (A) when the weighting network was used.

At high sound levels (90 dB and above) the ear seems to behave more nearly like a "flat" or unweighted sound-level meter. Sometimes this weighting is called the "C" scale. There is also a B-weighting network that is used to approximate the loudness behavior of the ear for a 60-dB contour -- i.e., it is intermediate between A and C weightings.

This guide will follow the ordinary practice of reporting A-weighted sound levels as dB(A). Many regulatory agencies of state and local government use only the dB(A) ratings when they are dealing with human responses. The "flat" scale of the sound-level meter is also sometimes marked confusingly "linear"; when data are reported simply in dB notation, they represent the unweighted readings of the sound-level meter, obtained with the flat setting of the meter.

Frequency and Pitch

The number of complete to-and-fro vibrations that a source of sound makes in one second is called the frequency of vibration. For example, if a loudspeaker cone moves back and forth 100 times in a second, the frequency of the tone it radiates is said to be 100 cycles per second, (the cone has executed 100 cycles of the same motion within one second) or, in modern metric terminology, 100 Hertz (abbreviated Hz). (Hertz was a nineteenth century scientist who discovered the alternating-current properties of spark discharges and introduced communication by radio waves.)

Since the ear senses the frequency of a sound as the pitch, on a similar though sensory scale, sounds with frequencies near 30 Hz are sensed as having very low pitch, whereas sounds near the upper frequency limit of hearing at 15,000 Hz are judged to have a very high pitch. The noise of bacon sizzling in a pan is judged to be high-pitched, whereas the rumble of distant thunder is low pitched. The 100-Hz tone we mentioned above is sensed by the listener as having a low pitch. The small, high-speed wings of a mosquito radiate a higher-pitched whine than do the larger, somewhat more slowly-vibrating wings of a bumblebee.

The ear has another perception about pitch which is important from a musical standpoint: it recognizes the doubling of frequency as producing a repeating tone quality. To produce the same pitch in different parts of the frequency range, the interval must be adjusted to be proportional to the frequency. The scale of frequencies in Figure 1-1 is adjusted for this property of hearing, and you may notice that each doubling of frequency takes up the same horizontal interval in the figure. Musicians call this the octave scale.

Loudness, Sound Pressure and Intensity

Loudness may be described as human or subjective measure of the pressure or intensity of sound. It can be ordered on a scale with limits ranging from whisper-soft to painfully loud. We have already seen that the loudness of a sound of a given intensity depends upon its frequency or pitch. However, if we present a sound of a given frequency at different levels and ask a person to assign a number representing its loudness, we find that - as a "rule of thumb" - doubling of loudness corresponds roughly to a 10 dB increase in sound level. (Experiments give from 10 to 12 dB). Table 1-2 relates changes in sound level to the average person's perception of loudness.

You can see now that Figure 1-1 gives you a picture of how the ear weights sounds of equal level but different frequencies. The ordinary noise sources are shown at their typical sound-level meter readings in dB, plotted at their dominant frequencies. These are the indications that the sound-level meter would yield as measured at the position where the sound would be most likely to be experienced: For some appliances, such as a blender or a power mower, at the position of the operator; for vehicles on a highway, at curbside; for aircraft overflights and neighborhood noise sources, outside the home; for such sounds as the ocean, bird calls, or thunder, at the position of the observer out-of-doors. Superimposed on this plot are contours of equal loudness for pure-tone sounds, depicted by the solid curved lines. On a given contour any pure tone at the sound level and frequency indicated will be judged by the average person to be equally as loud as any other tone along the curve. For example, on the lowest contour, the "threshold of hearing", a 50-Hz tone at a level of about 45 dB sounds equally as loud as a 500-Hz tone at 5 dB. The audiofrequency spectrum from 1000 to 8000 Hz (approximately the two top octaves of the piano and the next octave beyond) covers the region where your ear is most sensitive. Some of the more distressing sounds, such as the squeaking of chalk on a blackboard lie in this region. It is in this region, also, that the ear is most vulnerable to damage by noise or disease.

Phons:

In Figure 1-1, the spacing of the contours is chosen to be in even increments of the 1000-Hz standard tone, as read on a sound-level meter. The contours connect sound level values where the loudness is alike. Each contour is rated numerically for the sound-level of the 1000-Hz tone with which other tones on the contour are comparable. Although they, too, are written as dB, the units related to the contours are no longer sound level, but "phons", and now represent a level of loudness perceived to be equal in effect to the 1000-Hz tone through which the contour passes at a sound-level indicated in the decibel scale on the left-hand margin of the graph.

Pure Tone and Broadband Noise

Throughout this guide some noises may be described as pure tones, or as having pure-tone components, whereas other noises may be described as being broadband in character.

Pure Tone:

A pure tone is the sound radiated by a source vibrating at a single discrete frequency. For example, the sound emitted by a tuning fork that is properly struck is remarkably pure in tone. Similarly, striking a single key on a piano or plucking a single guitar string produces a relatively pure tone. The average person can produce a reasonably pure tone simply by puckering his lips and whistling a note. A chord struck on the strings of a guitar is an example of a tone made up of a number of pure-tone components.

Broadband Noise:

Broadband noise, on the other hand, is a complex mixture of sounds of different frequencies. Often these mixtures are changing rapidly with time. The sound produced by a nearby waterfall or a pounding surf is relatively broadband in character.

In many instances, noise sources radiate both broadband noise and puretone components. A jet plane at take-off, for example, radiates a combination of such noises. There is the shrill whine of the turbine, which may have a pure, whistle-like character, superimposed on the broadband roar of exhaust noise. The vacuum cleaner emits a siren-like sound from its impeller, generates whistling noise in some corrugated hoses, and also produces broadband air-suction sound. Wind blowing past overhead power lines often generates a pure-tone whistling sound which stands out against the background of the broadband noise of the wind.

There is some evidence that pure tones are judged to "grow" in loudness as they endure over a time interval of a number of seconds, whereas broadband noises soon reach a plateau of loudness. This is not indicated by the usual methods of measuring equal-loudness contours because comparisons ordinarily are made between sounds of similar durations. However, this feature does have a bearing on the choice of procedures for noise abatement. Special effort to remove pure tones is desirable.

TABLE 1-1

COMMON NOISE SOURCES AND LEVELS

Noise Source	Sound-Level Meter Reading, dB	Ratio, Sound-Power to Hearing Threshold	Sound Pressure at Meter Microphone, newtons/m^2
Near large jet plane at takeoff	140	10^{14}	200
Air-raid siren	130	10^{13}	
Threshold of pain	120	10^{12}	20
Thunder, sonic boom	110	10^{11}	
Garbage truck, trailer truck, at roadside	100	10^{10}	2
Power lawn mower, 5 ft (1.5 m)	90	10^{9}	
Alarm clock, vacuum cleaner, garbage disposal	80	10^{8}	0.2
Freeway traffic, 50 feet (15 m)	70	10^{7}	
Conversational speech	60	10^{6}	0.02
Average residence	50	10^{5}	
Bedroom	40	10^{4}	0.002
Soft whisper, 15 ft. (4.5 m) away	30	10^{3}	
Rustle of leaves	20	10^{2}	0.0002
Breathing	10	10^{1}	
Threshold of hearing	0	$1 (=10^{0})$*	0.00002

(In the modern metric units, sound pressures are given in "microPascals"; 0.00002 newtons/m^2 = 20 microPascals)

* The threshold of hearing is about 10^{-16} watt/cm^2; at all times you are listening to a very small fraction of a watt!

TABLE 1-2

SUBJECTIVE RESPONSE TO CHANGES IN SOUND LEVEL

Change in Sound Level	Change in Loudness
± 1 dB	Requires close attention to notice
± 3 dB	Barely perceptible
± 5 dB	Quite noticeable
± 10 dB	Dramatic; nearly twice or half as loud
± 20 dB	Striking, fourfold change

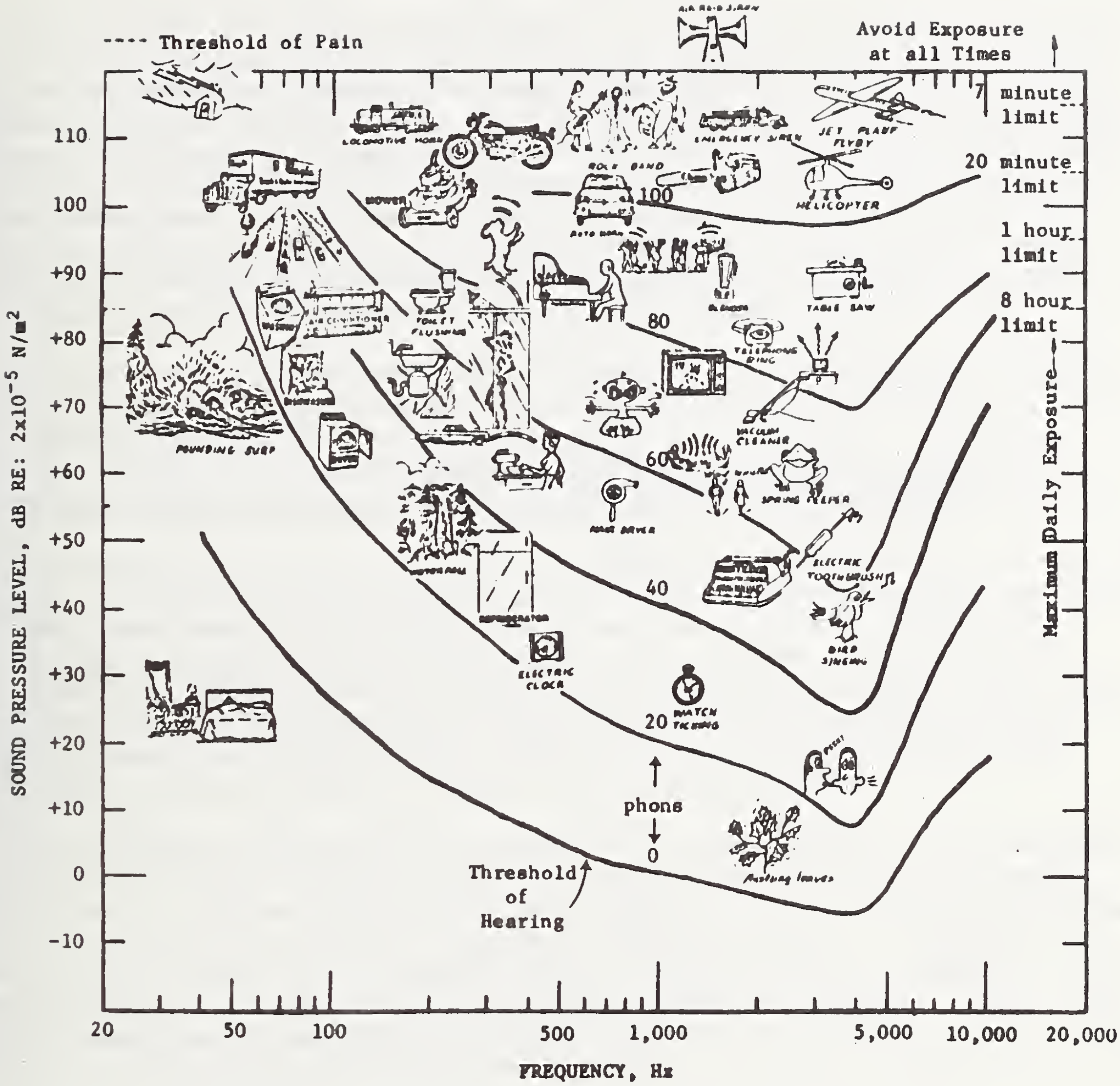


FIG. 1-1 COMMON SOUND SOURCES PLOTTED AT THEIR DOMINANT FREQUENCIES AND LEVELS AS TYPICALLY HEARD BY THE OBSERVER.

Chapter 2

NOISE AS A HEALTH HAZARD

When you are in a sound field whose level as read on a sound-level meter is 70 dB or more, even though you know consciously that you are in no hazard, some part of your body tries to run away. The signs of this are the common symptoms of nervous stress: Your heart beats more quickly; breathing becomes shallower and faster; the pupils of your eyes dilate; the small blood-vessels in your skin contract; your blood pressure rises. These are the actions of a body arousing itself to escape. In the same experiment that showed this to happen, the effects of noise on sleep were studied. Even though the human subject didn't necessarily awaken, his body responded. The only difference was that during sleep the sound level needed only to exceed 55 dB.

You can become "accustomed" to the noises in your environment, but all that this means is that you can become accustomed to eliminating the noise from your conscious attention. The physiological effects persist. If you are compelled to work in noisy surroundings, <u>the only warnings you may have of acoustically-induced stress are signs of fatigue and nervous strain.</u>

No one knows how many of the stress-induced diseases of our modern era are made more prevalent by the rising noise levels in our densely-populated cities. Note that these levels do not affect your hearing in itself. Nor do the results mean that <u>all</u> noise should be excluded. Studies of the effects of noise upon work indicate that some degree of ambient sound (which might as well be pleasant, such as the sounds of a fountain, or background music) helps maintain arousal during repetitious tasks; only the very highly-demanding mental tasks are done better in wholly quiet surroundings.

Noise damage to hearing is an insidious process. That is, the immediate effects are not a good indicator of the ultimate results of the exposure. Exposure to a mildly excessive noise level results in a temporary desensitization of the ear, the so-called "temporary threshold shift", a temporary loss of the ability to detect faint sounds. Noises likely to cause a temporary threshold shift are encountered during subway rides and airplane trips. Some degree of temporary threshold shift may be detectable even on the day following exposure, but ultimate recovery can be complete.

However, this pattern of threshold rise and recovery sometimes goes on through a number of cycles without any further evidence of damage, and then there may be a sudden failure to make complete recovery. This permanent effect - "noise-induced permanent threshold shift", sometimes abbreviated in capitals as NIPTS - is a sensorineural hearing loss. That is, the damage is located at the auditory nerve, itself, with serious consequences.

PRECAUTIONS

WARNING #1: <u>Because we have no reliable way to predict the degree of permanent loss from temporary threshold shift, a conservative policy is to avoid situations giving rise to temporary threshold shift</u>. Any person whose hearing does not recover within a few days after an exposure that induced a threshold shift should avoid any further exposure to sounds of that level, and should take positive action to protect his hearing. He should not return to that environment without protective equipment.

After exposure to sound levels of 85 dB and above for lengthy periods of time, a significant number of persons will be found to have a permanent hearing loss (NIPTS); this degree of exposure essentially doubles the incidence of hearing loss beyond what would occur from mischance and disease in the course of aging. For exposures above this level, the incidence of losses rises fairly rapidly with the sound level to which persons are exposed. Since there is some reason to believe that 80 dB represents the point from which the damage risk begins to be significant, it is obviously a good idea to avoid continuous exposure to any levels above 80 dB for any length of time comparable to a working day, and to wear ear protection if exposure is necessary. The potential damage point is indicated fairly reliably by conversational effort.

WARNING #2: <u>If you have to raise your voice to carry on a conversation at a distance of 3-5 feet from the person with whom you are talking, you are being subjected to a potentially damaging exposure.</u> Not only does it inconvenience you in your conversation at the moment; it may make it difficult for you in the future.

Figure 2-1 is a diagram of the process whereby the sounds arriving at your ear through the air reach the auditory nerve at the entrance to your brain. Like any well-engineered system, your ear has a few external protective devices. If you are exposed to an excessively loud noise, the muscle tensing your eardrum pulls taut, desensitizing it. This "stapedius reflex" takes place at sound levels between 80 and 95 dB. The point of onset of the reflex varies with individual sensitivity. Some persons can operate the stapedius reflex at will; from their experience it is evident that the desensitization is of the order of 20 dB. Thus the protection afforded by the stapedius reflex is important.

However, a burst of intense sound pressure too abrupt to give the stapedius reflex time to act can occur. This is particularly true of a shock- wave from a gun-shot or a pressure burst from a box on the ear. In that event, the drum membrane is likely to rupture, causing a temporary loss of hearing and a hazard of middle-ear infection. However, if no infection follows the injury, the membrane will heal. Except for the effect of the weight of the heavier scar tissue that is likely to form, the ultimate senistivity of the ear will have suffered little change. Desensitization due to scar tissue may be enough, in some individuals, to lower the response of the ear to high-frequency sounds, where the critical consonant sounds of speech are located, and where the cues to musical tone quality are transmitted. (Since it is sometimes necessary to lance the drum membrane in cases of middle-ear infection, with a consequent formation of scar tissue, it is clear that any ear infections must be attended to <u>at once</u> to avoid a residue of permanent loss.)

It is damage to the hair cells in the inner ear that causes the irretrievable losses that are associated with noise damage. From experiments on animals, it has been found that loss of 15-20% of the hair cells that respond to high frequencies will produce a rise in threshold of about 40 dB. This loss, for human beings, occurs first in the region most important for discrimination of the consonant sounds of speech - in the range from 4000 to 6000 Hz. If you look at the diagram in Figure 2-1, you can see that losing a fraction of the hair cells is comparable in some ways to the loss in vision that would occur if scattered areas of your retina were destroyed. Although the effect observed by measuring your threshold of hearing is simply that your threshold has risen, which is the same sort of observation that would be made if the injury were in the drum or in the chain of bones in the middle ear, something much more serious has been lost.

Loss of hair cells impairs the resolution that your ear can bring to bear on sounds. Even after amplification, the loss of resolution remains. As you can see from Figure 2-2, which shows the damage to hair cells as a result of noise exposure, nerve endings have been put out of action. The loss impairs the ability to understand conversation in the presence of noise. With a severe loss of hair cells, although a person can use a hearing aid to permit him to hear sounds at levels comparable to those heard by persons with normal hearing, he may not be very successful at recognizing speech. The average person who has suffered a sensorineural hearing loss that raises his unaided threshold above the normal by 60 dB will generally have a significant degree of difficulty in understanding speech even while he wears his hearing aid. Thus a permanent threshold shift produces a permanent impairment of hearing, and the only practical remedy is prevention.

If you have been exposed to an excessively intense noise, you are likely to notice a ringing in your ears as an after-effect. This is called "tinnitus", and it seems to represent a spontaneous firing of signal impulses by the hair cells. Also at sound levels that are potentially damaging to your hearing, you may notice that music acquires a complex, sometimes discordant sound. This is because the ear produces mixtures of tones instead of merely transmitting the sound stimuli. Only the rhythmic patterns of music may remain esthetically pleasing. At these levels, some effect is sensed on the semicircular canals of the ear that normally respond to orientation and balance. This gives a sensation of dizziness, which is perhaps cultivated by devotees of rock-music as a pleasurable sense of detachment, analogous to drunkeness. Like the over-consumption of alcohol, continuous very loud sounds lead to an end-point of seasickness and nausea. You can literally experience an "acoustic hangover".

WARNING #3: At still higher sound levels, a "tickle" sensation is felt in the ear, and with another 10 dB rise of level, a sensation of pain intrudes. The pain is an important though perhaps tardy warning. Very little exposure at the threshold of pain is needed to produce a permanent hearing loss in susceptible individuals. Another serious flaw in this warning system is the fact that at present we cannot predict who is susceptible. (There is some reason to suspect that susceptibility is enhanced by large-scale changes in the physiology of the body, as in adolescence.)

It is a fact that persons in noisy occupations and with noisy avocations are found generally to have various degrees of permanent, sensorineural hearing loss. Among the pleasures having more devastating consequences are rock music, target shooting and snowmobiling. Hearing loss due to gunshot in warfare is very prevalent. You should also be aware that the readings of an ordinary sound-level meter will fail to indicate the true level of rapidly peaking sounds because the needle of the meter is too sluggish to follow the sharp pressure changes that occur on impulsive sounds like shots, or even the sounds of a poorly-muffled internal combustion engine. (After all, it derives its power from the explosions confined in its combustion chambers.)

We are hampered in preventing a great deal of hearing loss because of a degree of bravado that causes some people to shun wearing hearing protection. Since hearing loss is subtle and invisible, perhaps it seems illogical to choose a visible means of protection. Some types of ear protectors are shown in Figure 2-3. Simple insert-type ear protectors are usable where perhaps 10-20 dB of protection is sufficient to eliminate the chance of hearing loss. In general, these are more effective for high-frequency sounds such as whistles than for low-frequency sounds such as machinery noise or jet turbulence. Cotton worn in the ears is not very effective, only a little better than nothing. However, in a pinch, you can derive some real help from cotton soaked in vaseline or soft wax (to increase its mass and sealing power), and pressed gently into your ears. Commercial ear protectors of the deformable soft plastic type make still better protection. If you are concerned about appearances, be assured that these are not as obvious as hearing loss, for a hearing loss at high frequencies destroys the referee that enables you to monitor your own speaking. Not only do you have trouble hearing other people -- because your hearing loss slurs and obliterates the consonant sounds of speech, your own speech becomes like what you hear.

At most, you can count on internally-worn ear protectors for a 10-20 dB reduction. Really effective protection is offered by over-the-ear muffs, which look like a relatively large pair of headphones. You may have seen these on the personnel working at airports. For maximum protection, both muffs and inserts may be worn. Even the combination of muffs and ear protectors, however, can offer little more than 40 dB protection, for sound can enter the body by other paths, entering via the chest cavity, the throat, and the bones of the head. If you translate that information into the conditions of your environment, you cannot remain for any length of time around sound levels in excess of 120 dB without walling yourself off from the source of sounds. In operating noisy machinery, workmen may find it necessary to observe and control the operation from the window of an isolation booth.

HEARING PROTECTION

How can you protect your hearing? The following notes may help:

Avoid Situations Where

1. You have to raise your voice to converse with anyone.
2. Ordinary melodic music sounds discordant.
3. You can't manage to talk over the telephone.

4. Sharp noises are repeatedly making your ears ring.
5. Everything seems too bright and too loud.
6. The racket makes it difficult to "think straight".
7. You begin to feel detached and a little dizzy.
8. In a short while you begin to feel tired and dazed.
9. The noise makes you feel seasick.

Your Hearing May Have Begun To Deteriorate When It Seems That

1. You have trouble recognizing what is said from the stage or pulpit.
2. You have to ask people to repeat what they say.
3. People ask <u>you</u> to repeat what you say.
4. You lose the thread of conversation at the dinner table.
5. The birds seem to have stopped singing.
6. You miss the telephone bell or the doorbell.
7. Your family repeatedly asks you to turn down the TV or radio.
8. People seem to have begun to mumble.

Be Cautious in the Use of These Devices

If you garden:
Power lawnmowers, chain saws, mulchers, lawn vacuums, lawn edgers.

For the sportsman:
Guns, speedboats, snowmobiles, motorcycles, all-terrain vehicles.

Even if you are the sheltered, indoor type of person:
Power tools, "industrial vacuum-cleaners", superpowered Hi-Fi, rock-music bands.

HOW TO AVOID RISKING YOUR LIFE AT NOISE LEVELS NOT DAMAGING TO HEARING

A high sound level can conceal the presence of rival sounds in your environment, or reduce their apparent loudness, thus removing their capacity for attracting your attention. This concealment can prove fatal.

For example, in a modern car with stereo and air-conditioning running, someone we know drove happily out of her driveway and collided with a fire engine. The car was a total wreck. Two factors militated against her: In the first place, the closed car windows attenuated exterior sounds. In the second place, although the car radio masked the motor noises and the air conditioner with pleasing sounds, it also masked out the warning siren and the engine noise of the fire truck. Since the car noises were in themselves not negligible, she was of course actually operating the radio at unduly high sound levels. In order to have overridden all this sound and caught her attention, the fire engine's siren would have had to be intense enough to offer a risk of hearing damage to the firemen themselves and to pedestrians on the street. The most common function of a siren is to alert motorists and pedestrians to clear the road for an approaching emergency vehicle. Tower or roof-mounted sirens, on the other hand, alert the populace to some impending danger, such as an air raid, or summon volunteer fire fighters as the case may be. Although the noise is intense enough to, and often needlessly does awaken large segments of a sleeping community, it fails all too frequently to achieve its main objective, that is, to alert the motorist. This failure is due to one or a combination of the following factors:

- vehicle windows are closed

- high noise level in vehicle due to operation of radio, fan or air conditioning equipment or the intrusion of engine or traffic noise

- preoccupation or distraction of driver.

For the motorist, the ideal warning device would be a small buzzer or alarm with perhaps an intense flashing light installed on the dashboard of his vehicle that could be triggered or set off by a short range radio frequency transmitter on the emergency vehicle. Both the warning buzzer and light could be modulated to buzz and flash at a gradually increasing rate as the emergency vehicle approached to alert the motorist as to its proximity.

Similar warning systems could be installed in the station house and homes of volunteer firemen. If the installation of such equipment were made mandatory in all emergency and automotive vehicles, communities would benefit from a dramatic curtailment in the use of a highly disturbing source of noise pollution and perhaps a significant improvement in the safety of conducting emergency or rescue missions.

Lesson 1: In order to hear sirens of emergency vehicles while you are driving an air-conditioned or heated car in city traffic, do not close it tightly. <u>Leave an opening of perhaps half an inch (about 1 cm) in the window next to the driver's seat.</u>

Leaving the window next to your ear raised enough to prevent "line-of-sight" access from the sounds of the road has some advantage. It will generally not interfere with the sounds of sirens and warning whistles, which are ordinarily pitched in the range from 500 to 3000 Hz, but some of the high-frequency road noises generated by tire treads and exhaust turbulence will be kept from reaching your ear at levels high enough to induce acoustic fatigue. Use your radio sparingly and at low volume when driving in any degree of traffic. You have more at stake than your hearing. However, you must still be alert because the partially open window offers no guarantee that you will hear an approaching siren.

A careful industrial study has shown that persons in noisy environments gradually require longer times to react to emergencies; we say their reaction times have increased. This points to a special hazard: Reaction time is known to have an influence on accident rate. (One of the important consequences of the consumption of alcohol, and of such medicinal agents as tranquilizers and antihistamines, is an increase of reaction time.) Further, in the noise exposure cases it was found that although for the first day or two of exposure, a rest period of an hour or more restores the reaction time, continued exposure to noise in succeeding days is no longer compensated entirely by rest.

In the industrial experiment, persons working for an eight-hour day were tested before and after each four-hour work session, with a lunch hour between. Each group in this study had just returned from vacation. By Wednesday of each week, the reaction time in the morning was lengthened a little, and full recovery did not follow the noon hour. By Thursday, and even further on Friday, the reaction time was lengthened at all times, and recovery was poorer. On Friday afternoon, the reaction time was nearly 50% longer than the normal level following extended rest. This was not due to the work: Half of the subjects of the study were merely sitting in the noisy environment beside their working companions.

Lesson 2: For maximum safety, you should break up working spells in a noisy environment by taking a full day's rest at frequent intervals. <u>It is worth noting that you can enhance the safety of your family on long trips by automobile simply by breaking the trip for at least an hour in a quiet surrounding after four hours' driving, and by making a stopover for more than a day at least every three days, preferably every two days.</u> The definition of "quiet" has been found by experiment, as well: Full recovery from acoustic exposure demands a quiet area in which the ambient noise is less than 55 dB. Since the lengthening of reaction time is primarily due to the exposure to noise, changing of drivers among the travelers within the car will not avoid this problem.

Another source of accidents that can be caused by noise not in itself at a physically damaging level is the "startle reflex". The normal human reflex at a sudden loud noise is to cringe: The eyes blink and shift, the shoulders are drawn together, the head is moved downward and away from the sound, the long muscles of the arms and legs pull them toward the trunk. Probably the startling noise of a blowout is a large part of the problem of control of a car after a blowout has occurred.

Lesson 3: <u>If you are driving a car and see a pedestrian about to cross the street, you have to measure the possibility that by blowing your horn you will trigger off a startle reflex in him and possibly in other bystanders, and weigh it against the chance that you might lack enough control to stop before you hit him.</u> Bicyclists are very vulnerable to startle reactions because they can lose direction as well as balance. If you are riding a bicycle, you should be careful to remain in a lane clear of traffic to protect yourself against a sudden startle; for the same reason a passing motorist should allow a bicyclist a wide lane, even though the small size of the vehicle does not require it.

A reflex known as "nystagmus", a sideward back and forth scanning of the eyes, is triggered off by noise. For most persons it is unlikely to occur until sounds reach quite a high level, but for susceptible persons it may become troublesome at levels below those directly injurious to hearing. Naturally, this reaction interferes with visual acuity and the judgment of distance.

Lesson 4: Since all the protection we can suggest is only a palliative measure, it is clear <u>that the best procedure for protection from noise is to cut off excess noise at the source.</u> Unfortunately, to many people, noise means power. Thus, there is some feeling that there may be a virtue in noisiness. An adolescent who removes the muffler from his car feels it "sounds more powerful", thus bigger and somewhat better than before. This is no different from the reaction of the purchaser of a lawnmower or vacuum cleaner, who has a strong feeling that the sound indicates reserve power. Manufacturers of power tools report that efforts to quiet the equipment do not pay; people feel that the equipment is somehow less powerful.

Perhaps because the quieting of equipment often removes high-frequency noise preferentially, the impression is created that the action of the equipment is stifled (as your speech would be smothered by a hand held over your mouth, quieting the consonants more than the voice). This is very far from true. Internal-combustion engines with properly resonated mufflers actually fire better, make better use of fuel, and run more steadily. Thus, the tradition among many cross-country truckdrivers of "cutting out" the muffler on open roads is actually countereffective.

To re-establish a feeling for the magnitudes involved, just remember that a sound capable of damaging your hearing need have a power flux of no more than one thousandth of a watt per square centimeter. Thus the amount of power involved in generating noise is very small; a mechanism using very little power can generate large amounts of sound (ask any parent). Noise is thus no criterion for the availability of usable power.

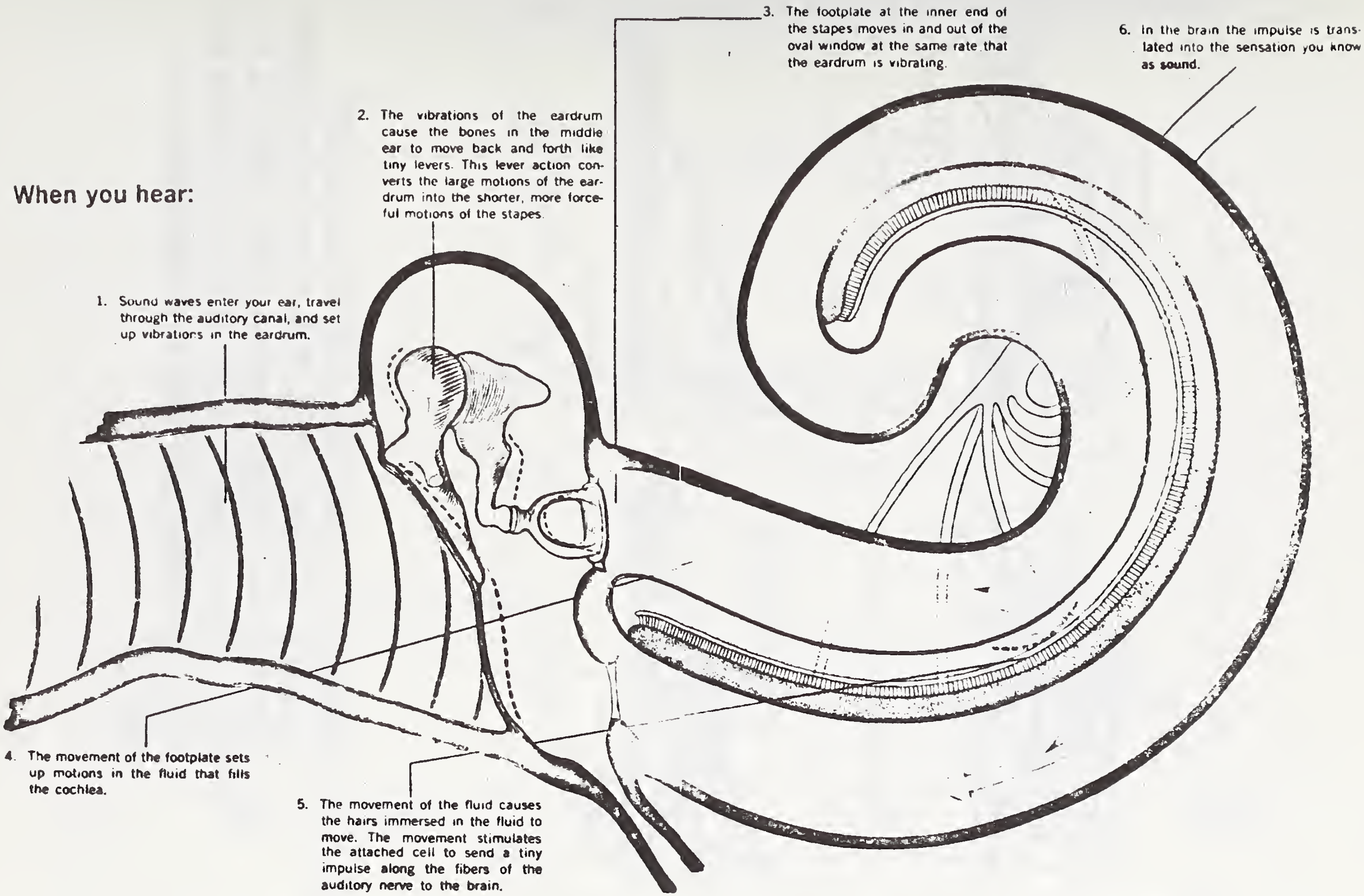


FIG. 2-1 A SCHEMATIC DIAGRAM OF HOW THE HUMAN EAR FUNCTIONS.

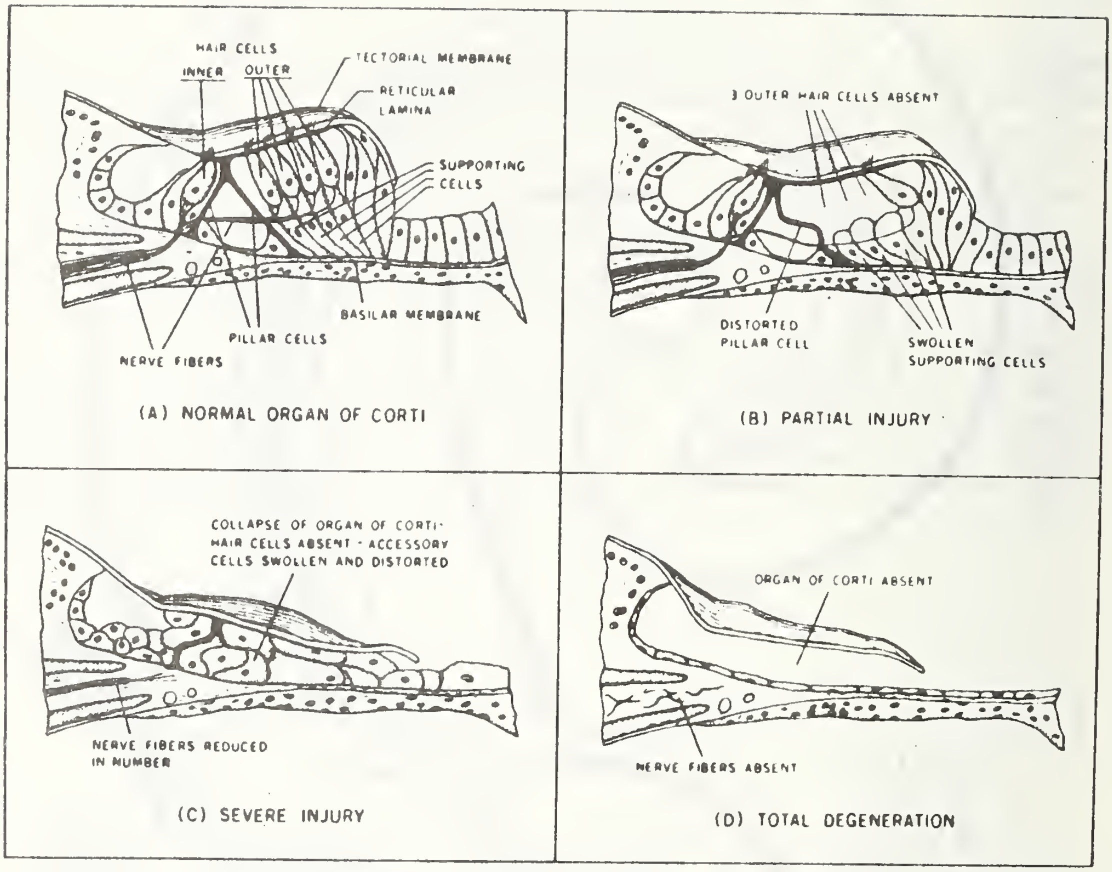


FIG. 2-2 DRAWINGS OF THE HUMAN ORGAN OF CORTI ARE SHOWN THAT ILLUSTRATE THE NORMAL STATE, PANEL A, AND THE INCREASING DEGREES OF NOISE-INDUCED PERMANENT INJURY, PANELS B, C, AND D. THIS IS WHAT YOU WOULD SEE IN A SECTION VIEW CUT ACROSS THE REGION OF THE HAIR CELLS SHOWN IN FIG. 2-1, INNER EAR.

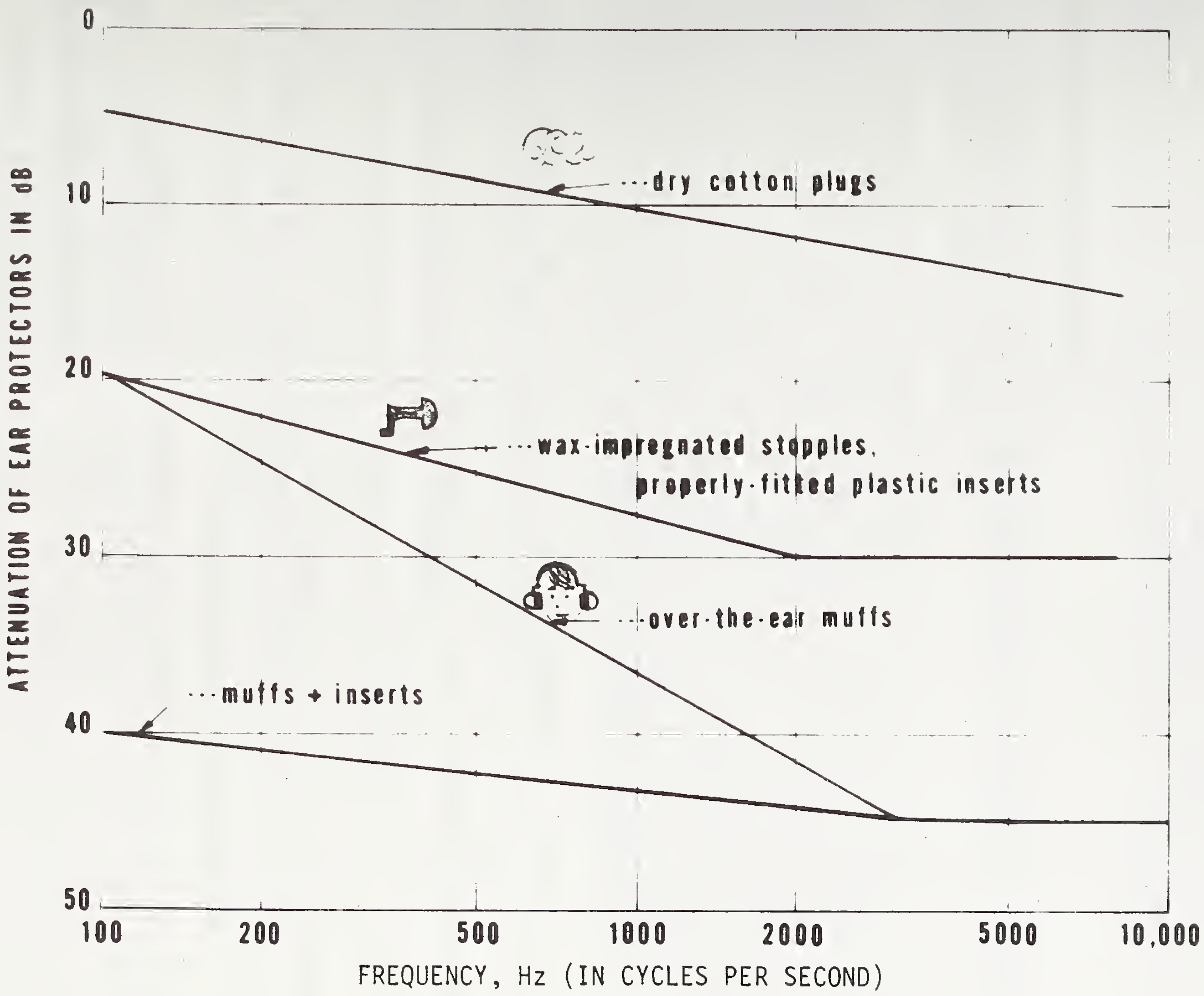


FIG. 2-3 SOUND ATTENUATION CHARACTERISTICS OF VARIOUS TYPES OF EAR PROTECTORS.

CHAPTER 3

BASIC PRINCIPLES OF NOISE REDUCTION

If you have a noise problem and want to solve it, you have to find out something about what the noise is doing, where it comes from, how it travels, and what can be done about it. A straightforward approach is to examine the problem in terms of its three basic elements: i.e., sound arises from a source, travels over a path, and affects a receiver, or listener.

SOURCE-PATH-RECEIVER CONCEPT

The source may be one or any number of mechanical devices radiating noise or vibratory energy, such as several appliances or machines in operation at a given time in a home or office.

The most obvious transmission path by which noise travels is simply a direct line-of-sight air path between the source and the listener; for example, aircraft flyover noise reaches an observer on the ground by the direct line-of-sight air path. Noise also travels along structural paths. In most cases it travels from one point to another via any one or a combination of several such paths. Noise from a washing machine operating in one apartment may be transmitted to another apartment along air passages such as through open windows, doorways, corridors or ductwork. Direct physical contact of the washing machine with the floor or walls sets these building components into vibration. This vibration is transmitted structurally throughout the building causing walls in other areas to vibrate and to radiate noise.

The receiver may be a single person, a classroom of students, or a suburban community near an airport or expressway.

Solution of a given noise problem might require alteration or modification of any or all of these three basic elements:

(1) modifying the source to reduce its noise output,

(2) altering or controlling the transmission path and the environment to reduce the noise level reaching the listener, and

(3) providing the receiver with personal protective equipment.

Let us examine the various noise control measures that can be applied in each of these categories.

NOISE CONTROL AT THE SOURCE

Select Quiet Equipment

Basically, the best way of controlling noise at its source is to select quiet equipment or appliances initially. When shopping, look for equipment that carries a low-noise certification or rating - preferably backed with a copy of the certifying laboratory's test report. Some appliances and equipment feature or advertise noise-control design or construction - look for descriptive terms such as "sound conditioned," "acoustically treated", "quiet operation", and similar phrases that may be used in advertising copy or in owner's manuals. However you must be on guard because such descriptive phrases as "whisper quiet" may well be deceiving!

Unfortunately, the selection of mechanical equipment and appliances that feature noise ratings or that specifically call attention to noise control design is extremely limited. Thus, the buyer must resort to his own wit or know what to look for in order to choose quiet equipment. The key words to remember in making purchasing decisions are "<u>slower</u>" and "<u>lower</u>," particularly as they apply to the operation of the equipment. The speed of moving parts, flow velocities, gas or fluid pressure differentials, and power ratings all affect noise output. By looking for equipment displaying "slower" and "lower" operation characteristics you can be relatively assured of quieter operation. For example, large slow-speed fans are substantially quieter than small high-speed fans for a given air flow; low horsepower motors are less noisy than those with high horsepower ratings; likewise low-pressure, low-velocity air ventilation or fluid distribution systems are virtually noiseless compared with their high- pressure, high-velocity counterparts.

Whenever possible, the buyer should conduct a side-by-side comparison noise test for various makes or types of appliances or equipment. This can best be done by dealing with a supplier who carries a wide selection of appliances or equipment made by several manufacturers and who is willing to demonstrate their operation in the show room. This, of course, is possible when shopping for small domestic appliances such as vacuum sweepers, window air conditioners, etc. However, large mechanical installations, such as central heating or air conditioning systems can only be properly evaluated in-place.

In summary, the guidelines to use in selecting quiet equipment are:

(1) low-noise certification,

(2) advertisement of "quiet" operation, evidence of noise-control design,

(3) emphasis on "lower" and "slower" operating characteristics,

(4) comparative side-by-side noise tests in the dealer's showroom,

(5) Visit the site of actual installed equipment of the type you are considering, for purposes of making your own survey or subjective evaluation of noise output.

<u>REQUIREMENTS FOR QUIET OPERATION</u>

Most mechanical devices such as automated appliances and machinery are complex noise generators that contain numerous sources of noise. For example, the overall noise radiated by a clothes washer may be generated by the drive motor, gear train, pump, pulleys, cams, bearings, electrical switches, automatic valves, and water flow. Reducing the noise output of such a device usually requires a considerable amount of study to identify the major sources of noise and their respective transmission paths. In other words, it is important to know whether it is the motor, gear train or the pump that is the main cause of noise - and whether the noise is radiated directly from the source into the air as airborne noise, or whether it is transmitted structurally as vibration to other parts and surfaces of the machine which, in turn, vibrate and radiate the noise.

A thorough study of the cause of machine noise is important because the sound from major noise sources must be attenuated before reduction of the noise from secondary sources, such as surface vibration, will have any significant effect. The need for these investigations increases with increasing size and complexity of the machinery. In short, the larger and more complicated the machine, the more difficult it is to quiet.

Obviously, the most effective way of manufacturing quiet equipment is to incorporate good noise control techniques in the basic design stage. This is, of course, a concern of the equipment designer and manufacturer. But if you, as a consumer, are familiar with certain principles governing noise in equipment operation you can know what to look for when making a purchase, or when attempting to control noise from appliances and equipment. Whether one is concerned about designing quiet equipment or faced with the problem of quieting an existing noisy device the following recommendations and corrective measures should be considered and applied wherever possible.

1. REDUCE IMPACT OR IMPULSIVE FORCES

Many machines and items of equipment are designed with parts that strike forcefully against other parts, producing noise. Often, this striking action, or impact, is essential to the machine's function. A familiar example is the typewriter - its keys must strike the ribbon and paper in order to leave an inked letter-impression. But the force of the key also produces noise as the impact falls on the ribbon, paper and platen.

Other common devices that produce impact noise include quick-acting cut-off valves found in washing machines and furnace humidifiers. The loud "thump" they often make can be startling, annoying or, in the case of furnace noise, they can disturb sleep.

Several steps can be taken to reduce noise from impact forces. The particular remedy to be applied will be determined by the nature of the machine in question. Not all of the steps listed below are practical for every machine and for every impact-produced noise. But application of even one suggested measure can often reduce the noise appreciably. A knowledge of the principles underlying impact-noise reduction can also assist you in purchasing quieter equipment.

a) reduce weight, size or height of fall of impacting mass.

b) Cushion the impact by inserting a layer of shock-absorbing material between the impacting surfaces. (For example, insert several sheets of paper in the typewriter behind the top sheet to absorb some of the noise-producing impact of the keys hitting against the platen.) In some situations, you may insert a layer of shock-absorbing material behind each of the impacting heads or objects to reduce transmission of impact energy to other parts of the machine.

c) Whenever practical, one of the impact heads or surfaces should be made of non-metallic material to reduce "resonance or ringing" of the heads. Fig. 3-1 shows the application of measures a, b, and c.

d) Substitute the application of a small impact force over a long time period for a large force over a short period to achieve the same result.

e) Smooth out acceleration of moving parts; apply accelerating forces gradually. Avoid high peak acceleration or jerky motion.

f) Minimize overshoot, backlash, loose play in cams, followers, gears, linkages, etc. This can be achieved by reducing the operational speed of the machine, better adjustment, or by using spring-loaded restraints or guides. Machines that are well made, with parts machined to close tolerances generally produce a minimum of such impact noise.

2. REDUCE SPEED IN MACHINES, AND FLOW VELOCITIES AND PRESSURES IN FLUID SYSTEMS

Reducing the speed of rotating and moving parts in machines and mechanical systems results in smoother operation and lower noise output.

Likewise, reducing pressure and flow velocities in air, gas and liquid circulation systems lessens turbulence resulting in decreased noise radiation.

(a) For quiet operation, fans, impellers, rotors, turbines, blowers, etc., should be operated at the lowest bladetip speeds that will still meet job needs.

(b) Use large-diameter low speed fans rather than small-diameter high-speed units for quiet operation. <u>In short, maximize diameter and minimize tip speed</u>.

(c) Centrifugal squirrel-cage type fans, sometimes used in furnaces or on exhaust ducts, are less noisy than vane axial or propeller type fans, all other factors being equal, as illustrated in Fig. 3-2.

(d) Water pressure in individual home, office, or apartment plumbing systems should be limited to 35 pounds per square inch (1800 Torr) and flow velocities of the order of 6 ft/sec (2 m/sec) for quiet operation. A competent plumber can perform these adjustments.

(e) In air ventilation systems, a 50-percent reduction in air flow velocity may lower the noise output by 10 to 20 dB, or roughly 1/2 to 1/4 of the original loudness. Air flow velocities of 8-10 ft/sec (3 m/sec) as measured at a supply or return grille produce a level of noise acceptable in most residential or office areas. Reduction of air flow velocity can best be achieved by installing a greater number of ventilating outlets, or by increasing the cross-sectional area of the outlet grilles.

3. BALANCE ROTATING PARTS

One of the main sources of machinery noise is structural vibration caused by the rotation of poorly balanced parts such as fans, fly wheels, pulleys, cams, shafts, etc. Measures used to correct this condition involve the addition of counter weights to the rotating unit or the removal of some weight from the unit as indicated in Fig. 3-3. You are probably most familiar with noise caused by imbalance in the high-speed spin cycle of washing machines. The imbalance results from clothes not being distributed evenly in the tub. By redistributing the clothes, balance is achieved and the noise ceases. This same principle - balance - can be applied to furnace fans and other common sources of such noise. On some furnace fans driven by a single belt, an unbalanced load may be applied if the belt can move out of direct alignment with the motor and fan pulleys; if the load is applied symmetrically through a pair of belts driving pulleys on either side of the fan and the motor shafts, both shafts will tend to stay centered and the pulleys aligned, resulting in less noisy operation and reduced wear.

4. REDUCE FRICTIONAL RESISTANCE

Reducing friction between rotating, sliding or moving parts in mechanical systems frequently results in smoother operation and lower machine noise output. Similarly, reducing flow resistance in air, gas and liquid distribution systems results in less noise radiation. In most cases, applying any one or a combination of the following corrective measures should provide a noticeable reduction in noise output.

<u>Reducing Resistance In Mechanical Systems</u> (See Fig. 3-4)

<u>Lubricate</u>: all rotating, moving, sliding, meshing or contacting parts should be lubricated with appropriate lubricant for quiet operation.

<u>Align</u>: Proper alignment of all rotating, moving or contacting parts results in less noise output. Maintain good axial and directional alignment in pulley systems, gear trains, shaft coupling, power transmission systems, bearing and axle alignment, etc.

<u>Polish</u>: Highly polished and smooth surfaces between sliding, meshing or contacting parts are required for quiet operation, particularly where bearings, gears, cams, rails, and guides, are concerned.

Balance: Static and dynamic balancing of rotating parts reduces frictional resistance and vibration which result in lower noise output.

Avoid eccentricity or out-of-roundness: Eccentricity or off-centering of rotating parts such as pulleys, gears, rotors, shaft/ bearing alignment causes vibration and noise. Likewise, out-of-roundness of wheels, rollers, and gears cause uneven wear resulting in flat spots which generate vibration and noise.

Reducing Resistance In Air or Fluid Flow Systems (See Fig. 3-5)

The key advice to effective noise control in such systems is "streamline the flow". This holds true regardless of whether one is concerned with air flow in ducts or vacuum sweepers, or water flow in plumbing systems. Streamline flow is simply smooth, nonturbulent, low-friction flow, but it is the essential requirement for quiet operation of any type of fluid flow system.

The two most important factors which determine whether flow will be streamline or turbulent are flow velocity and the cross-sectional area of the flow path - that is, the pipe diameter. The rule of thumb for quiet operation is to use a low-velocity, large-diameter pipe system to meet a specified flow capacity requirement. However, even such a system can inadvertently generate noise if certain aerodynamic design features are overlooked or ignored. A system designed for quiet operation will employ the following features:

Low-flow velocities: Low-flow velocities avoid turbulence, one of the main causes of noise. Flow velocities should be of the order of 8 to 10 feet per second (3 m/sec) in domestic forced-air heating and ventilation systems and plumbing systems for quiet operation.

Smooth boundary surfaces: Duct or pipe systems with smooth interior walls, edges, and joints, generate less turbulence and noise than systems with rough or jagged walls or joints.

Simple layout: A well-designed duct or pipe system with a minimum of branches, turns, fittings and connectors is substantially less noisy than a complicated layout.

Long-radius turns: Changes in flow direction should be made gradually and smoothly. It has been suggested that turns should be made with a curve radius equal to about five pipe diameters or major cross sectional dimension of the duct.

Flared sections: Flaring of intake and exhaust openings, particularly in a duct system, tends to reduce flow velocities at these locations, often with substantial reductions in noise output.

Streamline transition in flow path: Changes in flow path dimensions or cross-sectional areas should be made gradually and smoothly with tapered or flared transition sections to avoid turbulence. A good rule of thumb is to keep the cross-sectional area of the flow path as large and as uniform as possible throughout the system.

Remove unnecessary obstacles in flow path: The greater the number of obstacles in the flow path, the more tortuous, turbulent and hence, the noisier the flow. All other required and functional devices in the path such as structural supports, deflectors, and control dampers, should be made as small and as streamlined as possible to smooth out the flow patterns.

If you are building or remodelling a home or other building tell the architect or builder of your concern for achieving a quiet environment, and ask specifically if these design features have been included.

5. ISOLATE VIBRATING ELEMENTS WITHIN THE MACHINE

In all but the simplest machines, the vibrational energy from a specific moving part is transmitted through the machine structure forcing other component parts and surfaces to vibrate and radiate sound - often with greater intensity than that generated by the originating source itself. For example, a water pump fastened to a side panel of a washing machine will cause the panel to vibrate and produce greater noise output as illustrated in Fig. 3-6.

The vibration generated by moving or rotating parts of a machine should be confined as close as possible to the area containing the source of vibration. In short, the vibrating unit must be isolated as much as possible from the structural frame or machine housing. The most effective method of vibration isolation involves the resilient mounting of the vibrating component on the most massive and structurally rigid part of the machine. All attachments or connections to the vibrating part in the form of pipes, conduits, shaft couplers, etc., must be made with flexible or resilient connectors or couplers - otherwise the vibrational isolation afforded by the resilient mounts will be bypassed or shortcircuited. For example, pipe connections to a pump resiliently mounted on the structural frame of a machine should be made of resilient tubing, preferably as close to the pump as possible. Resilient pipe supports or hangers may also be required to avoid bypassing of the isolated system. In addition to these measures it is often good practice in the case of large machines or appliances such as washing machines, dryers, refrigerators or air conditioning equipment to set the entire machine on resilient mounts to prevent vibrational excitation of the supporting floor, and thus avoid radiation of noise into the area below or adjacent areas. These measures are illustrated in Fig. 3-7.

6. REDUCE RADIATING AREA (See Fig. 3-8)

Generally speaking, the larger the vibrating part or surface, the greater the noise output. The rule of thumb for quiet machine design is to minimize the effective radiating surface areas of the parts without impairing their operation or structural strength. This can be done by making parts smaller, removing excess material, or by cutting openings, slots or perforations in the parts. For example, replacing a large vibrating sheet metal safety guard on a machine with a guard made of wire mesh or metal webbing might result in a substantial reduction in noise in some cases, because of the drastic reduction in surface area of the part. (In other cases, parts with perforations, slots or other openings, permit air leakage through or around the part as it moves, thus eliminating air pressure buildup, the chief cause of flexing and pulsation. Such action when there is no air leakage gives a popping sound - as the noise produced when squirting oil from an oil can.)

7. APPLY VIBRATION DAMPING MATERIALS (See Fig. 3-9)

Since a vibrating body or surface radiates noise, the application of any material which reduces or restrains the vibrational motion of that body will decrease its noise output. Generally speaking, when such materials are applied to a vibrating body they dissipate the vibrational energy in the form of frictional heat which is generated by the flexing, bending and rubbing of the fibers or particles of the damping material. For example, these materials could be applied to surfaces of washing machines, dryers, refrigerators, room air conditioners, etc, to help control noise due to vibration. Of course, you would probably apply the materials to the inside surface to preserve the appearance of the appliance. Three basic types of vibration damping materials are available:

(a) liquid mastics which are applied with a spray gun and harden into relatively solid materials, the most common being automobile "undercoating"

(b) pads of rubber, felt, plastic foam, leaded vinyls, adhesive tapes or fibrous blankets which are glued to the vibrating surface;

(c) sheet metal viscoelastic laminates or composites which are bonded to the vibrating surface.

The type of material best suited for a particular vibration problem depends on a number of factors such as size, mass, vibrational frequency and operational function of the vibrating structure. However the following guidelines should be observed in the selection and use of such materials to maximize vibration damping efficiency:

(a) Damping materials should be applied to those sections of a vibrating surface where the most flexing, bending or motion occurs. These usually are the thinnest sections.

(b) For single layer damping materials, the stiffness and mass of the material should be comparable to that of the vibrating surface to which it is applied. This means that single layer damping materials should be about two or three times as thick as the vibrating surface to which they are applied.

(c) Sandwich materials made up of metal sheets bonded to mastic ("sheet-metal viscoelastic composites") are much more effective vibration dampers than single layer materials; the thicknesses of the sheet metal constraining layer and the viscoelastic layer should each be about one-third the thickness of the vibrating surface or panel of the appliance to which they are applied.

8. REDUCE NOISE LEAKAGE FROM THE INTERIOR OF THE APPLIANCE

(See Fig. 3-10)

In many cases machine cabinets can be made into rather effective soundproof enclosures through simple design changes, and the application of some sound absorbing treatment. Substantial reductions in noise output may be achieved by adopting some of the following recommendations, especially if some of the vibration isolations techniques discussed earlier are also used.

(a) Seal or cover all openings

(i) All unnecessary holes or cracks, particularly at joints, should be caulked or closed off.

(ii) All electrical or plumbing penetrations of the housing or cabinet should be sealed with rubber gaskets or a suitable non-setting caulk.

(iii) If practical, all other functional or required openings or ports which radiate noise should be covered with lids or shields edged with soft rubber gaskets to affect an airtight seal. For example, the lid of a top-loading washing machine may be fitted with a rubber gasket or with rubber strips to prevent the escape of the noise from the agitator.

(iv) Other openings required for exhaust, cooling or ventilation purposes should be equipped with mufflers or acoustically lined ducts.

(v) Relocate or direct openings away from operator and other people.

(b) Apply acoustical materials

(i) Install sound absorbent lining on inner surfaces of cabinet to reduce noise buildup in the reverberant cavities. (We will discuss reverberation further in Section 3 under Factors Affecting the Travel of Sound)

(ii) Apply vibration damping material to inner surfaces of all vibrating panels.

9. CHOOSE QUIETER MACHINERY WHEN REPLACING APPLIANCES

This advice is, of course, of little comfort if you find yourself the owner of a new, noisy appliance. In due time, though, it will need to be replaced, and this is an opportunity for choosing an effectively QUIETED device. However, some minor changes in accessories can reduce noise problems:

(a) Replace plastic blender containers with containers made of heavy glass. Often both alternatives are available; glass costs very little more.

(b) Substitute rubber or plastic cans for noisy metal trash cans. Some laminated metal trash cans have been made for industrial use; the new concern with quiet may make them desirable for ordinary domestic use.

(c) Use wood or fibreboard cabinets instead of the noisier metal units.

(d) Select sliding or folding closet doors made of wood or laminate instead of metal doors which usually rattle or vibrate when moved.

(e) High velocity air flowing over the corrugated surfaces inside a hose often generates a whistling noise. Replacing the corrugated hose of a vacuum cleaner with a smooth surface hose will reduce this noise.

(f) Replace small high-speed floor fans or exhaust fans with larger, slower-moving units.

(g) Substitute a belt-driven furnace blower operated by a shock-mounted motor for a direct motor-coupled blower.

NOISE CONTROL IN THE TRANSMISSION PATH

After you have tried all possible ways of controlling the noise at the source, your next line of defense is to set up barriers or other devices in the transmission path to block or reduce the flow of sound energy before it reaches your ears. This can be done in several ways:

you can absorb the sound along the path,

you can deflect the sound in some other direction away from you by placing a reflecting barrier in its path, and

you can contain the sound by placing the source inside a sound- insulating box or enclosure.

Selection of the most effective technique will depend upon various factors such as size and type of source, intensity and pitch of noise, and nature and type of environment. In addition one should have a basic understanding of the characteristics and behavior of sound that influence its propagation or travel through the air.

As we mentioned before, a sound wave traveling through the air creates a succession of compressions -- high-pressure waves -- followed by rarefactions, or low-pressure waves. These waves move away from the source in an alternating manner much like the spreading of ripples in a pond into which a pebble was dropped, as illustrated in Fig. 3-11. The distance between adjacent peaks of the high pressure waves is the wavelength of the sound. The frequency of the sound "f" and its speed of travel "c" determine "λ" the wavelength. These three quantities are related by the equation $c = f\lambda$. Since the speed of sound in air is relatively constant for all frequencies, the wavelength decreases as frequency increases. Sound travels at a speed of about 1130 feet (345 m) per second. Therefore, the wavelength for a 100 Hz tone would be approximately 11 feet (3.45 m) whereas for a 1000 Hz tone it would be about 1.1 feet (34.5 cm). As we shall see, both frequency and wavelength affect the propagation of sound in air and the manner in which it interacts with the environment.

FACTORS AFFECTING TRAVEL OF SOUND

1. Absorption: Soaking Up Sound

We know from experience that air absorbs sound, especially high-pitched sounds. That is why we hear only the low-pitched roar of exhaust noise of a high-flying jet plane and not the shrill high-pitched turbine noise we normally hear at the airport when the plane takes off. The low pitched rumble of distant thunder sounds almost harmless compared to the sharp terrifying crack of thunder when heard close by. The high pitched components of a thunderclap are absorbed by the air before they reach a distant listener.

Air absorbs high-pitched sounds more effectively than low. However, if the distance between a source and a listener is great enough, low-pitched sounds also will be absorbed appreciably by the air. For example, we might not hear any sound at all from a jet plane flying at an altitude so great that only its vapour trail is visible.

Unfortunately, in most buildings, the masses of air are inadequate to provide any useful sound absorption. With the exception of very large auditoriums, convention halls, or sport arenas, the absorption of sound by air within typical buildings or rooms is negligible. However, in most buildings and rooms a significant degree of sound absorption can be achieved through proper furnishings. Because of their soft porous qualities, such materials as draperies, carpeting, and exposed towelling are excellent sound absorbers. Upholstered furniture and bed furnishings also have good sound absorbing characteristics. However, the installation of acoustical tile on ceilings in rooms, corridors and staircases is a practical method of controlling noise along its path of travel. Depending on the type of installation, and the frequency distribution of the noise, acoustical ceilings can absorb from 50 to 80% of the sound energy that strikes the surfaces. A soft, thick carpet with felt padding placed on the floor will absorb about 50 to 60% of airborne sound energy striking it. In addition, it will muffle impact and footstep noise very effectively. Pleated drapery will absorb about as much sound energy as carpet for the same amount of surface coverage. With these materials on ceilings, floors and walls, much of the sound energy is absorbed along the path before it can cause annoyance in other areas.

Unfortunately, like air, drapery and carpeting absorb high-pitched sounds much more effectively than low. When sound waves strike a fabric, they penetrate into the pores and air pockets of the material. There they bounce around haphazardly causing air in the pores and the fibers of the material to vibrate; this motion dissipates the sound energy in the form of heat because of frictional resistance between air molecules and fibers.

Because of their long wavelengths, low-pitch sound waves require materials that are many times thicker and have much larger pores and air pockets than those used for absorbing high-pitched sounds. For efficient absorption of low frequency sounds, the thickness, openings and pores of the acoustical material should bear the same proportion to the wavelengths of these sounds as the thickness, openings and pores of absorbers for high-frequency sounds bear to their respective wavelengths. Unfortunately materials for absorbing low-frequency sounds are somewhat impractical because of their large size and bulkiness.

Although sound waves generally keep on traveling in the direction in which they originally started, high-pitched sounds tend to follow a path that appears to be narrower and somewhat straighter than a low-pitched sound path. We have noticed how highly directional the sound of a "hiss" or "psst", or a whistling tea kettle is compared, for example, with the rumbling sound of a washing machine. This is due to the fact that because of their short wavelengths, high-pitched sounds are propagated in a beam-like manner with very little spreading. Low-pitch sounds, on the other hand, tend to spread out uniformly in all directions from the noise source because of their long wavelengths.

The assumption that sound travels in straight lines is valid for wavelengths that are short compared to the dimensions of open spaces, rooms or passage ways. Sound waves travel in straight lines until they encounter some obstacle in their path. If the obstacle is small compared to the wavelength of the sound, its direction of travel will hardly be disrupted. On the other hand, if the obstacle is large compared to the wavelength of sound, the wave will be deflected in its direction of travel.

2. Sound Reflection: Bouncing of Sound

When a sound wave strikes a solid flat surface that is large compared to the wavelength of sound, the wave is reflected similar to the way a sunbeam is reflected from a window pane -- or a ball bounces off the walls of a handball court. As sound waves strike a flat surface, they rebound at an angle equal to the one at which they originally struck the surface, as shown in Fig. 3-12.

A listener exposed to both the direct waves and reflected waves from a distant sound source will perceive the direct wave to be much louder than the reflected wave. At one time or another, you might have noticed that an echo of a person's handclap or a yell in a large hall or canyon seemed to be much less intense than the original sound. This reduction in loudness of the reflected wave or echo is due to the longer distance it traveled, and also to the loss of energy due to absorption by both the reflecting surface and perhaps the air. However, in a reverberant room or space, the reflected and direct sound waves tend to merge to produce a sound that is louder than the direct sound alone.

Sound reflection frequently is not only desirable but can be put to practical use. When properly used it will enhance the sound of music, or, as in the case of a band shell, it will amplify the music reaching the audience.

You, perhaps, have taken advantage of this phenomenon, if you have mounted your stereo loudspeakers on a wall or in the corners of a room to get greater sound intensity for the same setting of the volume control.

3. Reverberation: Re-echoing of Sound

Have you ever noticed upon entering a bare, unfurnished room how much louder your voice appears to be? This is caused by the repeated reflection of the sound waves by the surfaces of the room. The merging of these reflected waves builds up the noise level. This effect, which is called "Reverberation", is most prominent in rooms with hard reflecting surfaces such as a typical bathroom with its ceramic tile and plaster surfaces. This phenomenon, more so than any other, gave birth to the so-called BATHROOM BARITONE. Rooms like the bathroom, which are highly reverberant, would be described as being acoustically "Live". Many basement areas and recreation rooms would fall in this category. Bedrooms and living rooms, on the other hand, would be considered as acoustically "Dead" because of the large amounts of sound absorbent materials normally found in these rooms. Obviously, the Bathroom Baritone rarely performs in such rooms because his powerful voice suddenly would sound weak or dead, just like the environment.

Highly reverberant rooms tend to be excessively noisy. The most effective method of dealing with this problem is to install a large amount of sound absorbent treatment in the form of carpeting, drapery, upholstered furniture or an acoustical ceiling. <u>As a rule of thumb, if the sound of a person's handclap or a shout in a particular room takes longer than a second or two to die away, the room is too reverberant, and should be acoustically treated</u>.

Although excessive reverberation of sounds in most instances is a problem associated with the interior of buildings or rooms, it can occur in the outdoors as well, The most common example is the reverberant echoing and rumble of thunder in mountainous areas. The high noise levels caused by the reverberation of traffic noise between tall buildings in major cities is familiar to all of us. The court areas of U shaped apartment buildings tend to be excessively reverberant and noisy, particularly if they are used as recreation areas or if they face traffic arteries. Very little can be done to remedy problems of natural origin; however, man-made problems can be avoided through proper planning in the design stage. For example, a U shaped court yard should not front on a traffic artery.

4. Diffraction: Bending or Squeezing of Sound

When a sound wave encounters an obstacle or an opening which is comparable in size to its wavelength, the sound will bend around the obstacle or squeeze through the opening with little loss of energy, as in Figs. 3-13a, 3-13b. This action is known as "Diffraction". Diffraction occurs when sound waves strike the edge of a solid barrier. This edge acts as a focal line from which a new train of waves is generated. These new waves which spread out into the area behind the barrier are of the same frequency as the original waves but lower in intensity. This explains why we can hear traffic noise from a busy highway even though it is hidden from view by a large building or a hill.

With regard to sound passing through small openings, you may have noticed how readily sound passes through a door that is slightly ajar. With the conventional practice of installing doors with a 1/2 to 3/4 inch (13-19 mm) air space at the bottom to provide for the circulation of return air, it is not surprising that we get no privacy even when the door is closed. The amount of sound energy that passes through a small hole or hairline crack in a wall is far greater than one would predict based on the size of the crack. This points out how important it is to caulk or seal all cracks or openings in walls, doors, etc., which separate areas where privacy is desired.

Inside buildings, the combined effects of diffraction and reflection explain how sounds travel along winding corridors, up staircases and through duct systems with surprising ease.

In open spaces, sound coming from a point source tends to spread out in a front that is spherical in shape. The power at any point away from the source drops in proportion as the surface area of a sphere centered at the source increases. For each doubling of distance, the surface area increases fourfold. Consequently, for each doubling of the distance from the point at which the source is located, the power drops to one-fourth; the power level drops by 6 dB.

By a point source we mean any noise source that radiates noise uniformly in all directions. Almost any source that is located at a distance from the observer that is large compared to the size of the source acts like a point source, even though the source itself may be relatively large. Thus, a power mower located at a distance of 100 feet (30 m) from the listener, and a large noisy factory located at a distance of 1/4 mile (0.4 km) from the listener could both be considered as point sources so far as the listener is concerned.

Increasing your distance from a source of noise is a practical means of noise abatement, if you can manage it. If you can quadruple your distance from a point source of noise, you will have succeeded in lowering its loudness by at least one-half or roughly 12 dB. If you have to contend with an extended or a line source such as a railroad train, the noise level drops by only 3 dB for each doubling of distance from the source. The main reason for this lower rate of attenuation is that line sources radiate sound waves that are cylindrical in shape. The surface area of such waves only increases twofold for each doubling of distance from the source. However, when the distance from the train becomes comparable to its length, the noise level will begin to drop at the rate of 6 dB for each subsequent doubling of distance. Figures 3-14a and 3-14b illustrate how the noise levels drop as distance increases from both types of noise sources.

If due consideration is given to controlling the noise at the source, and further noise reduction is required, then the transmission path between the noise source and the receiver must be altered or modified in order to reduce the flow of sound energy reaching the receiver. This can be done in a number of ways.

"QUIETING" IN THE PATH

1. Separate the Noise Source and Receiver As Much As Possible

In open air, the noise level drops roughly 6 dB for each doubling of the distance from the source to the receiver. Indoors, the noise level generally drops from 3 to 5 dB for each doubling of distance in the near vicinity near the source. However, further from the source, reductions of only 1 or 2 dB occur for each doubling of distance, due to the contributions from the reflection of sound off hard wall and ceiling surfaces.

2. Use Sound Absorbing Materials

Sound absorbing materials such as acoustic tile, carpets, and drapes placed on ceiling, floor or wall surfaces can reduce the noise level in most rooms by about 5 to 10 dB for higher pitched sounds, but only by 2 or 3 dB for lower- pitched sounds. Unfortunately, such treatment provides no protection to an operator of a noisy machine who is in the midst of the direct noise field. For greatest effectiveness, sound absorbing materials should be installed as close to the noise source as possible. However, because of their light weight and porous nature, acoustical materials are ineffectual when applied to wall or ceiling surfaces to prevent the transmission of either airborne or structure-borne sound from one room to another. In other words, if you can hear people walking or talking in the room or apartment above, installing acoustical tile on your ceiling will not reduce the noise transmission. In most cases, the installation of a soft, thick carpet on the floor above will reduce the transmission of footstep noise substantially. However, reduction of both footstep and conversational noise might require the addition of either a floating floor or a resiliently suspended gypsum board ceiling to the existing floor-ceiling construction.

3. Use Sound Barriers and Deflectors

Placing barriers, screens, or deflectors in the noise path can be an effective way of reducing noise transmission, providing that the barriers are large enough in size, and depending upon whether the noise is high-pitched or low-pitched. Wood or metal panels lined with acoustical materials and placed in front of or around some noisy machine might attenuate the noise reaching a worker on the other side by about 10 to 15 dB if the noise is high-pitched. For example, in a room relatively free of echoes, the noise from a card-punch machine, which as a fundamental frequency of about 3000 Hz can be reduced in the shadow of a barrier about 5 feet (1.5 m) on a side by at least 10 dB. Low-pitched noise, however, might be reduced by only 4 or 5 dB. Fig. 3-15 illustrates the application of measures 1, 2, and 3.

If intruding sound originates out-of-doors, you may be able to quiet the interior of your house by increasing the degree to which it is sealed off from its environment. Windows and doors are common leaks for both sound and heat. Properly fitted and sealed storm windows and doors will cut down the intrusion of outdoor sounds as well as reduce heat transfer.

4. Use Acoustical Lining

Noise transmitted through ducts, pipe chases, electrical channels, or other passages can be reduced effectively by lining the inside surfaces of such passageways with sound absorbing materials. In typical duct installations, noise reductions of the order of 2 to 3 dB per linear foot of 1" (2.5 cm) thick acoustical lining are quite possible for high-pitched sounds. (In metric units, the reduction is about 10 dB/m for an acoustical lining 2.5 cm thick.) A comparable degree of noise reduction for the lower pitched sounds is considerably more difficult to achieve because it usually requires at least a doubling of the thickness and/or length of acoustical treatment. Various types of duct lining and silencers are illustrated in Fig. 3-16.

5. Use Mufflers, Silencers, or Snubbers

Mufflers or silencers should be installed on all gasoline or diesel engines, regardless of size, including those used in model airplanes, toys, power tools, etc. Such devices should also be used in all installations in which large quantities of high-pressure, high-velocity gasses, liquids, steam or air pass through narrow openings or are discharged into the open air as illustrated in Fig. 3-17.

6. Use Vibration Isolators and Flexible Couplers

In cases where the noise transmission path is structure-borne in character, vibration isolators in the form of resilient mountings, flexible couplers, or structural breaks or discontinuities should be interposed between the noise source and receiver. For example, spring mounts placed under an appliance or machine may prevent the floor from vibrating; or an expansion joint cut along the outer edges of a floor in a mechanical equipment room may reduce the amount of vibration transmitted to the structural frame or walls of a building. Such measures are illustrated in Fig. 3-18.

7. Use Enclosures

Sometimes it is much more practical and economical to enclose a noisy machine in a separate room or box than to quiet it by altering its design, operation or component parts. The walls of the enclosure should be reasonably massive, and airtight to contain the sound. Absorbent lining on the interior surfaces of the enclosure will reduce the reverberant buildup of noise within it. Structural contact between the noise source and the enclosure must be avoided, or else the source vibration will be transmitted to the enclosure walls and thus short circuit the isolation. Figures 3-19 and 3-20 show the design and effectiveness of various enclosure configurations. Total enclosures should be used where large noise reductions are required, i.e., exceeding 15 dB. Partial enclosures of "L" or "U" shaped configurations may be adequate in areas requiring smaller noise reductions.

PROTECT THE RECEIVER

When exposure to intense noise fields is required, as when operating chain saws or other very noisy equipment, measures must be taken to protect the receiver from hearing damage. This can be done by employing some of the following techniques.

USE EAR PROTECTORS

Molded and pliable earplugs, cup type protectors, and helmets are commercially available as hearing protectors. Such devices may provide noise reductions ranging from 15 to 35 dB. However, such devices should be used only as a last resort, after all other methods have failed to lower the noise level to acceptable limits.

ALTER WORK SCHEDULE

Suppose you have done all that it is possible to do to quiet an appliance - and still it makes noise! You may be able to choose the times of its operation to minimize the disturbance of your life and that of your neighbor. Waiting until later on Saturday and Sunday mornings to operate your lawn mower and power saw won't reduce their noise levels, but it may reduce the intensity of objections. Inherently noisy operations, such as street repair, municipal trash collection, factory operation and aircraft traffic should be curtailed at night and early morning to avoid disturbing the sleep of the community.

Limit the amount of continuous exposure to high noise levels. In terms of hearing protection, it is preferable to schedule an intensely noisy operation for a short interval of time each day over a period of several days rather than a continuous 8-hour run for a day or two.

At home there are several intensely noisy chores such as gardening or landscaping with power mowers, tillers, and chain saws to name a few. If the home owner is concerned about protecting his hearing, he should intersperse periods of quiet activity during such chores to rest his ears. In short, he should avoid finishing intensely noisy jobs in continuous or overly prolonged runs, unless, of course, he is wearing ear protectors.

In an industrial plant employing a large number of people, such a schedule would benefit not only the operator of the noisy equipment but also other workers in the vicinity. Indeed, this practice would be even more beneficial if the noisy work were performed at night or at some other time when a minimum number of employees would be exposed. This assumes, of course, that noise created at night would be confined to the plant area and thus not disturb residential areas.

IS THERE AN ACOUSTICAL PERFUME?

Masking is a very prominent feature of the behavior of our ears. If you listen to a pure tone against a background of rival sounds, it will seem to fade as the rival background increases. In fact, the sounds of ordinary surroundings are sufficient to obscure recognition of our heart beats and breathing, which are quite audible in a very quiet place. For some people, the awareness of breath sounds is enough to break up the rhythm of breathing, and this becomes a source of discomfort.

However, sounds are masked only by rival sounds that are quite near them in pitch. Thus, the songs of birds cannot obscure the snoring of a person sleeping. Although lower-pitch masking has a greater effect on high-pitch sounds, the requirement that the masker must be in the pitch range of the tone to be masked is dominant, as we can recognize from the fact that orchestral music is hear as an ensemble. Effective masking requires a broad-band source of masking sound, if you can't predict the frequency range of the noise, or have to deal with broad-band interference.

In order to make conversational speech less obtrusive, as in a crowded restaurant, some use has been made of background music as an "acoustical perfume". Clearly the requirement for broad-band masking imposes the use of relatively bland, complex harmony, with limited range of volume. Other usable sources of acoustical perfume are rippling brooks and splashing fountains.

However, efforts to use acoustic perfume for reduction of noise annoyance are not likely to succeed if the noise levels rival the levels of conversational speech. In order to override these levels, the sound background must begin to intrude into the higher levels where the ear's behavior is nonlinear. As a result, sounds would no longer necessarily retain their harmonious character. Where people working in noisy areas have been allowed to bring in radios, it will be observed that the listeners prefer strong rhythmic patterns and solo melodies.

A general characteristic of acoustical perfume is evident: it can be used to enhance the surroundings in an excessively quiet environment. People prefer some noise as opposed to not enough noise or too much noise. Most people feel quite comfortable in an environment with a low level, steady, soothing, unobtrusive sort of background noise, such as can be found along secluded beaches, forests, or quiet countrysides. However, it is impossible to produce a peaceful environment in an already noisy place merely by obscuring the sounds with rival stimuli.

Although the use of masking noise can be beneficial in certain cases, it has been extended and overemphasized to the point where it fails more frequently than it succeeds. The concept of "masking noise" in this context simply involves using an artificially induced noise or the ambient acoustical environment beneficially for "masking" or overriding annoying intruding sounds. A descriptive definition of masking noise might be any steady sound which has the following pleasing characteristics:

(a) low intensity with a wide-band frequency distribution, void of any pure-tone components;

(b) an omnidirectional source, such that its location is not evident to the observer;

(c) the ability to over-ride or mask intruding noise without becoming annoying itself.

Many examples of sources of masking noise are given in the literature; the most commonly mentioned being vehicular traffic and heating and air conditioning equipment. Unfortunately neither is suitable. Traffic noise is seldom steady and heating or air- conditioning equipment is cyclic. Hence such masking noise may itself become a source of annoyance. Likewise, using acoustic perfume to "trade off" or compensate for acoustically inferior party walls in the design of apartment buildings usually backfires. However, commercial devices which electronically produce masking noise can be used to improve privacy in specialized situations. For example, using acoustic perfume in the reception or waiting room of professional offices of doctors, dentists, or lawyers provides additional privacy for the patient or client.

However, the presence of masking noise by whatever name interferes to some extent with the ability to discriminate sounds. Thus, the presence of acoustic perfume in a doctor's office might interfere with his stethoscopic examination of a patient, for example. Physicians have reported, for example, that it becomes difficult to interpret the sounds from a stethoscope if the surrounding sound levels exceed 45 dB.

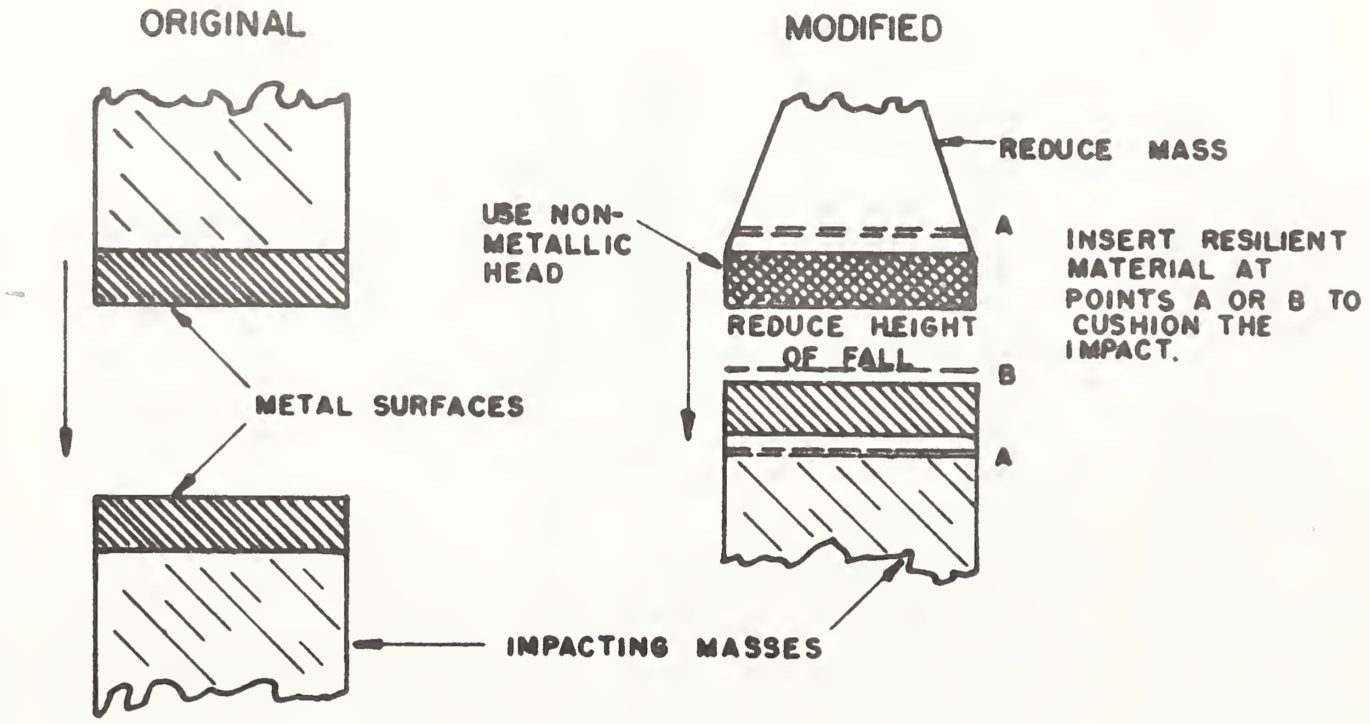


FIG. 3-1 REDUCTION OF IMPACT FORCES

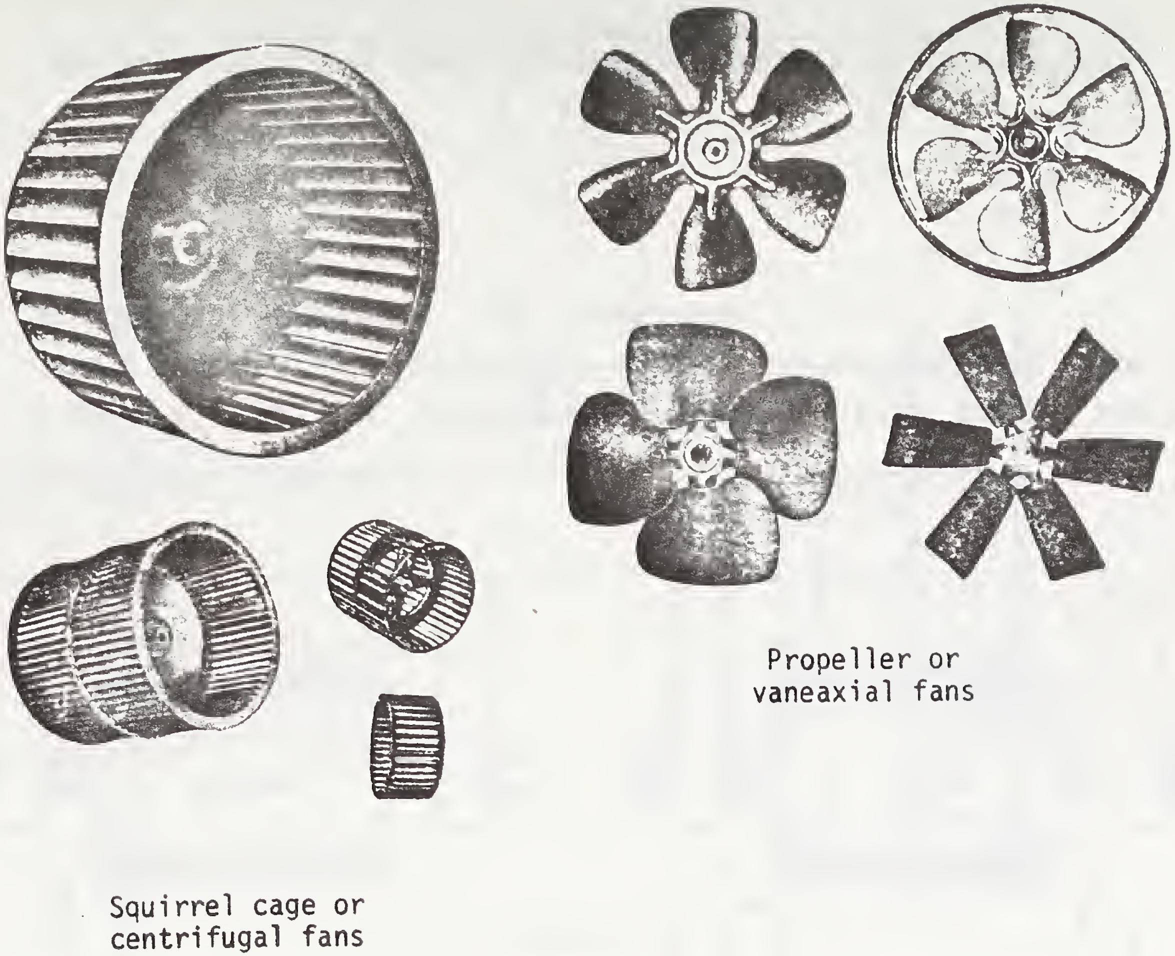
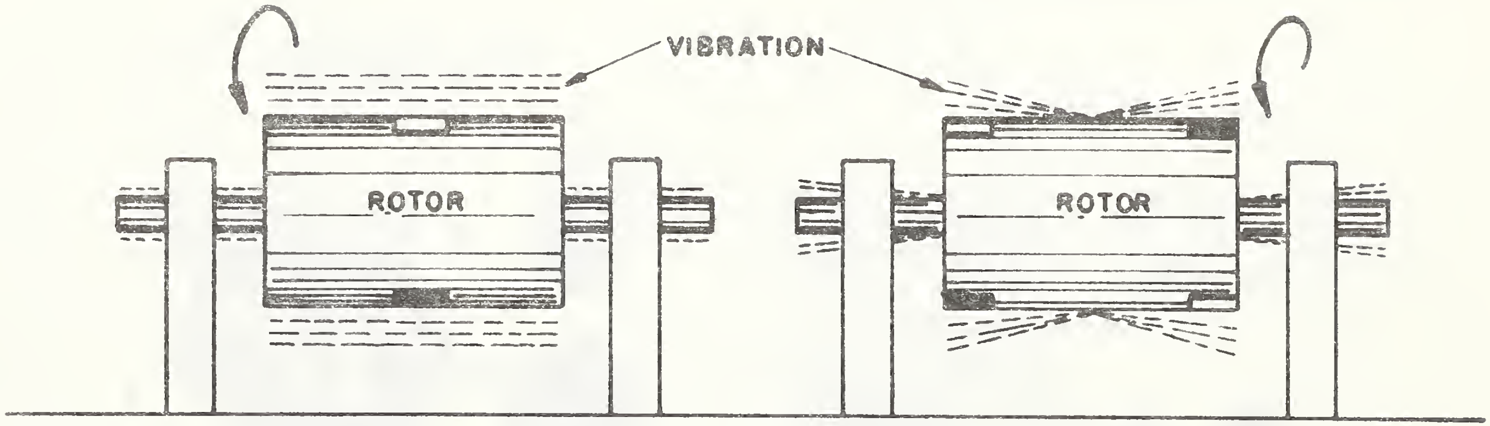


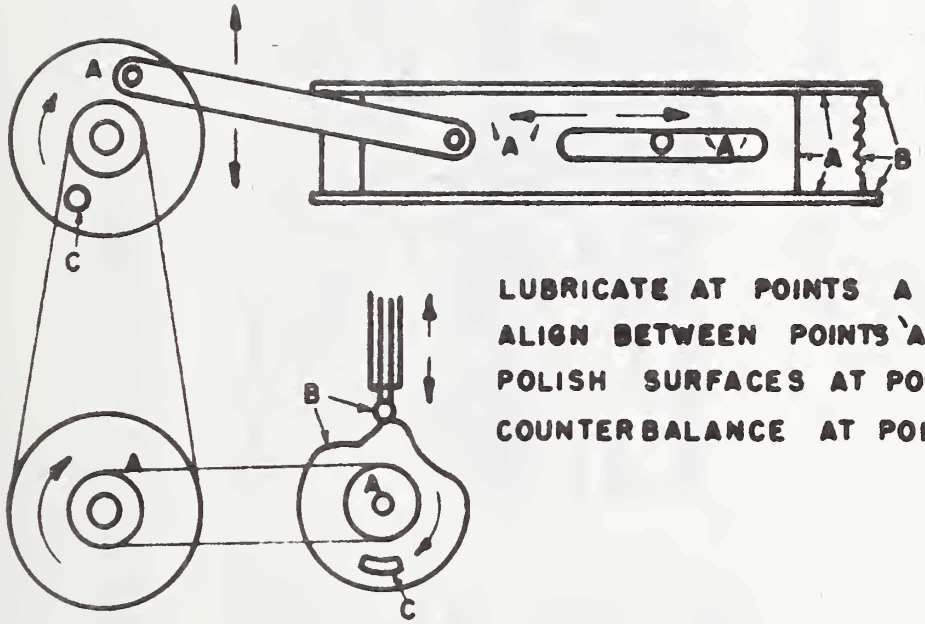
FIG. 3-2 FOR A GIVEN MASS FLOW, SQUIRREL CAGE FANS GENERALLY ARE LESS NOISY THAN PROPELLER-TYPE FANS.



(a) STATIC UNBALANCE. (b) DYNAMIC UNBALANCE.

BLACK BLOCKS ARE HEAVY PARTS OF ROTOR THAT CAUSE VIBRATION. WHITE BLOCKS ARE LOCATIONS WHERE COUNTERWEIGHTS MUST BE PLACED TO ELIMINATE THE VIBRATION.

FIG. 3-3 EFFECTS OF STATIC AND DYNAMIC UNBALANCE ON ROTOR OPERATION



LUBRICATE AT POINTS A
ALIGN BETWEEN POINTS 'A'-'A'
POLISH SURFACES AT POINTS B
COUNTERBALANCE AT POINTS C

FIG. 3-4 REDUCING FRICTION OF ROTATING AND SLIDING PARTS

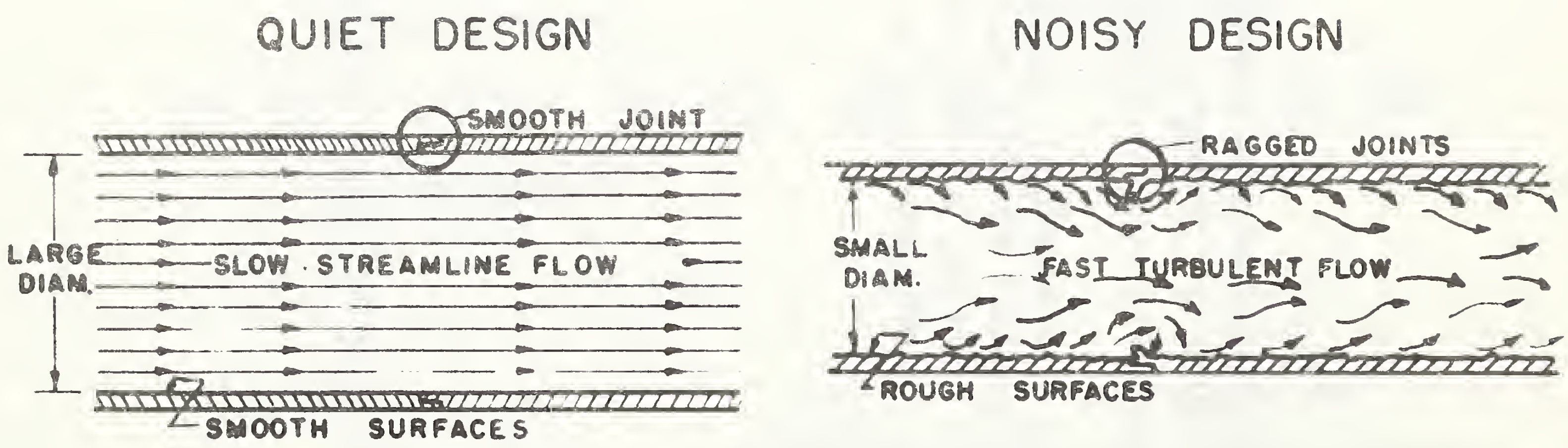


FIG. 3-5a DESIGN OF QUIET FLOW SYSTEMS

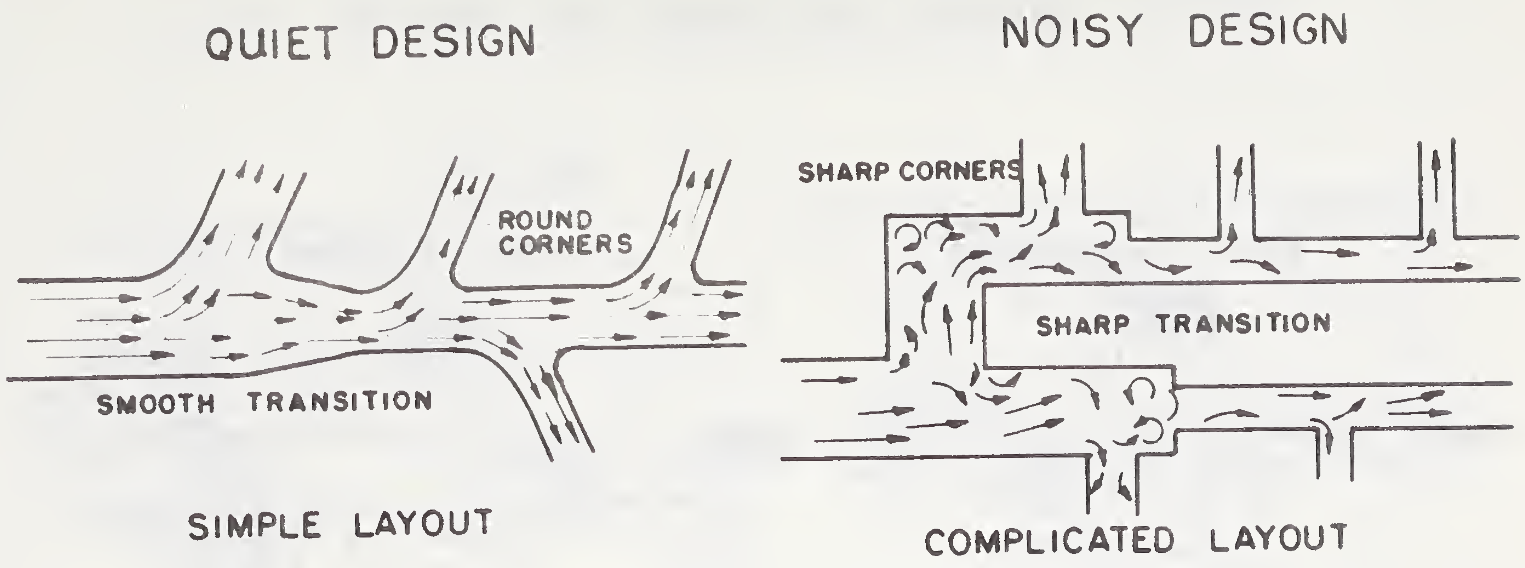


FIG. 3-5b DESIGN OF QUIET FLOW SYSTEMS

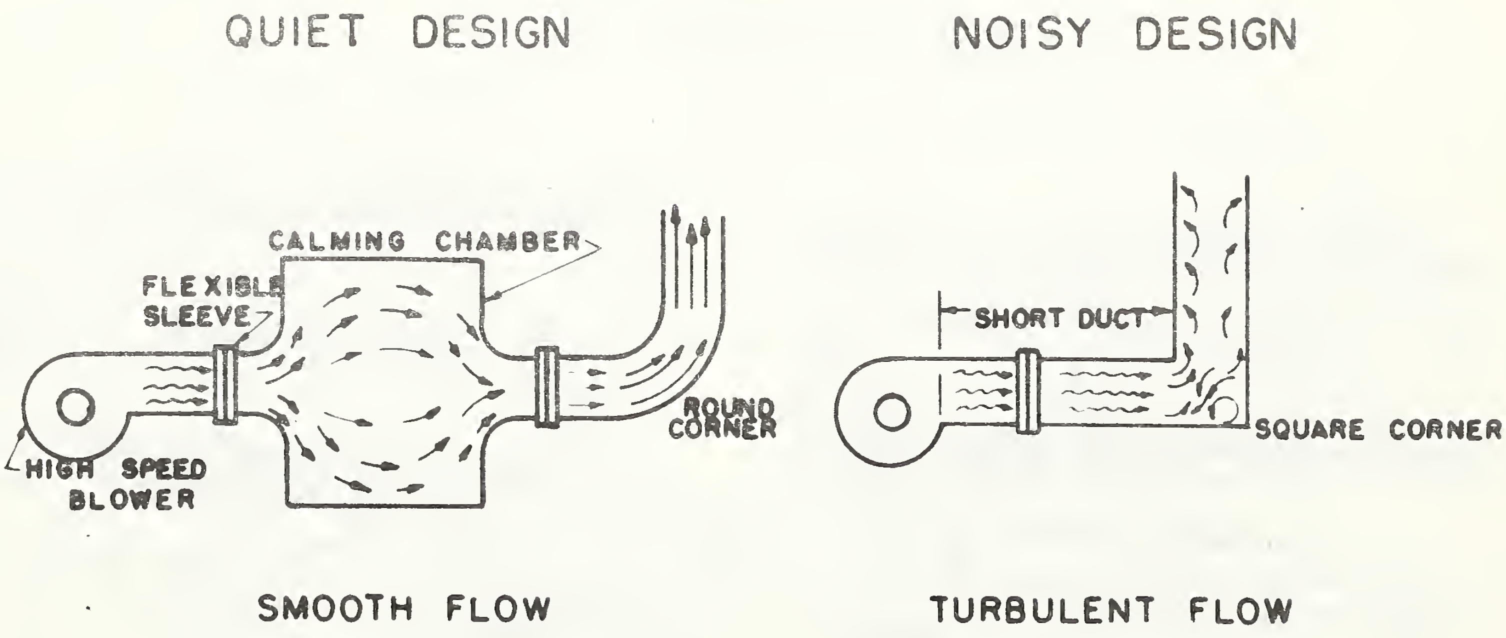


FIG. 3-5c DESIGN OF QUIET FLOW SYSTEMS

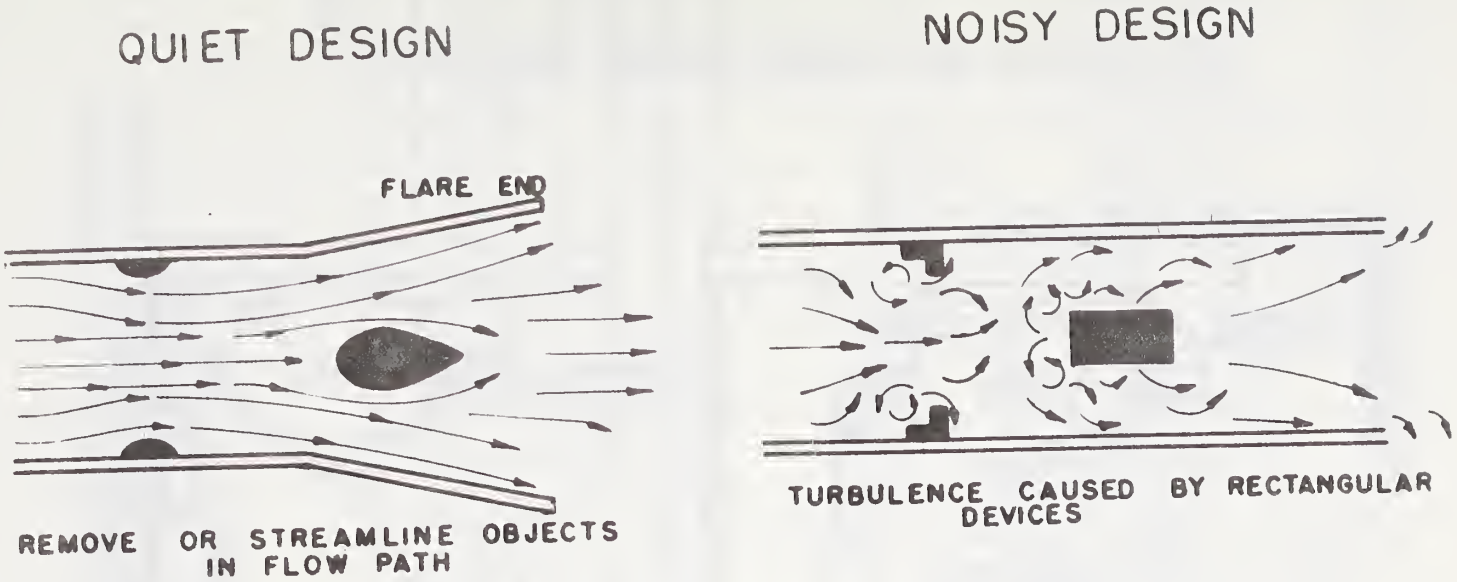


FIG. 3-5d DESIGN OF QUIET FLOW SYSTEMS

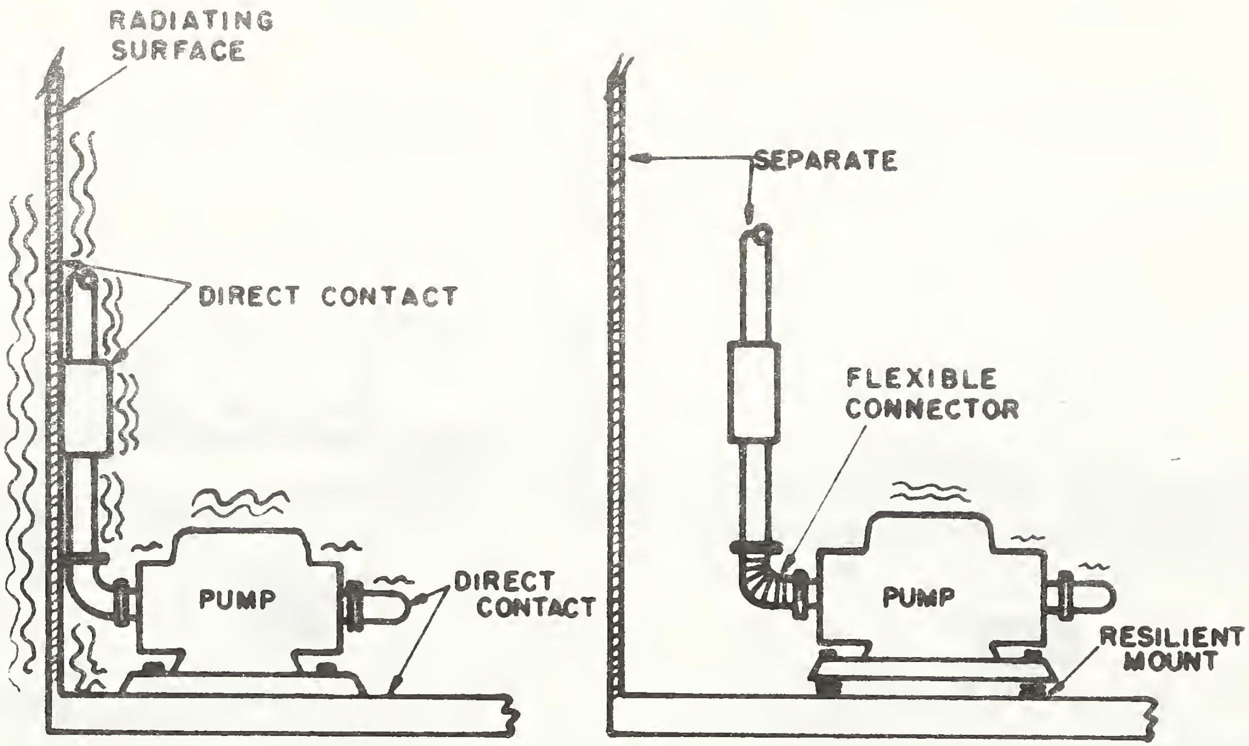
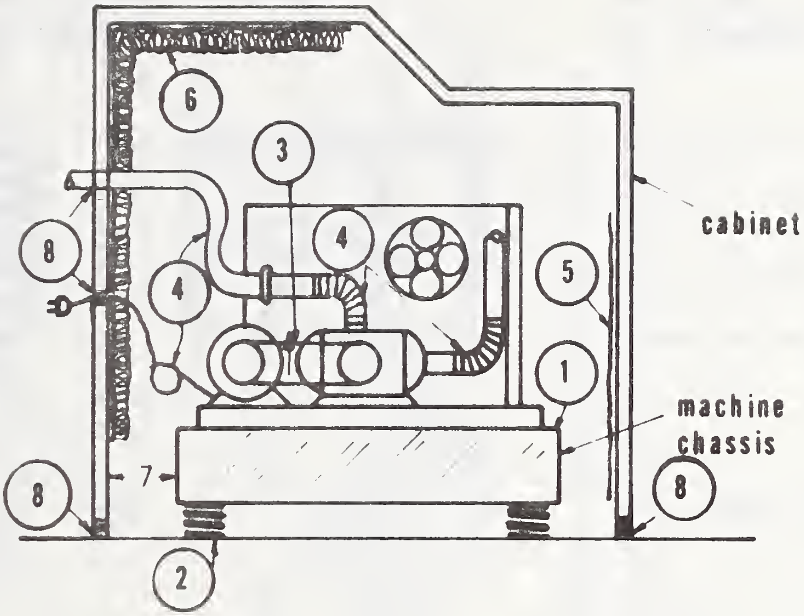


FIG. 3-6 ISOLATE LARGE RADIATING SURFACES FROM VIBRATING PARTS



1. Install motors, pumps, fans etc. on most massive part of the machine.
2. Install such components on resilient mounts or vibration isolators.
3. Use belt drive or roller drive systems in place of gear trains.
4. Use flexible hoses and wiring instead of rigid piping and stiff wiring.
5. Apply vibration damping materials to surfaces undergoing most vibration.
6. Install acoustical lining to reduce noise buildup inside machine.
7. Minimize mechanical contact between the cabinet and the machine chassis.
8. Seal openings at the base and other parts of the cabinet to prevent noise leakage.

FIG. 3-7 TECHNIQUES TO REDUCE THE GENERATION OF AIRBORNE AND STRUCTUREBORNE NOISE IN MACHINES AND APPLIANCES

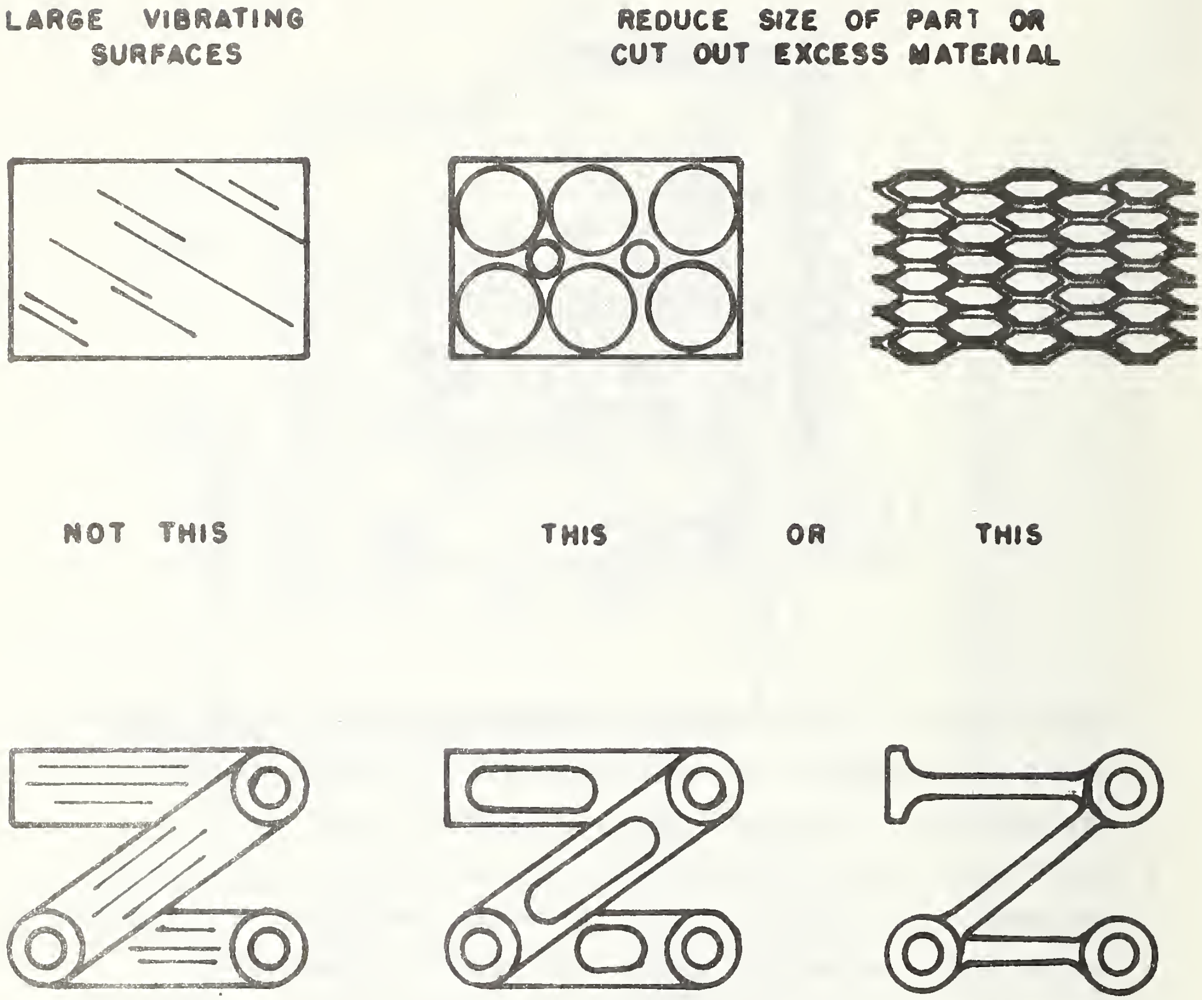


FIG. 3-8 REDUCE RADIATING AREA OF VIBRATING PARTS.

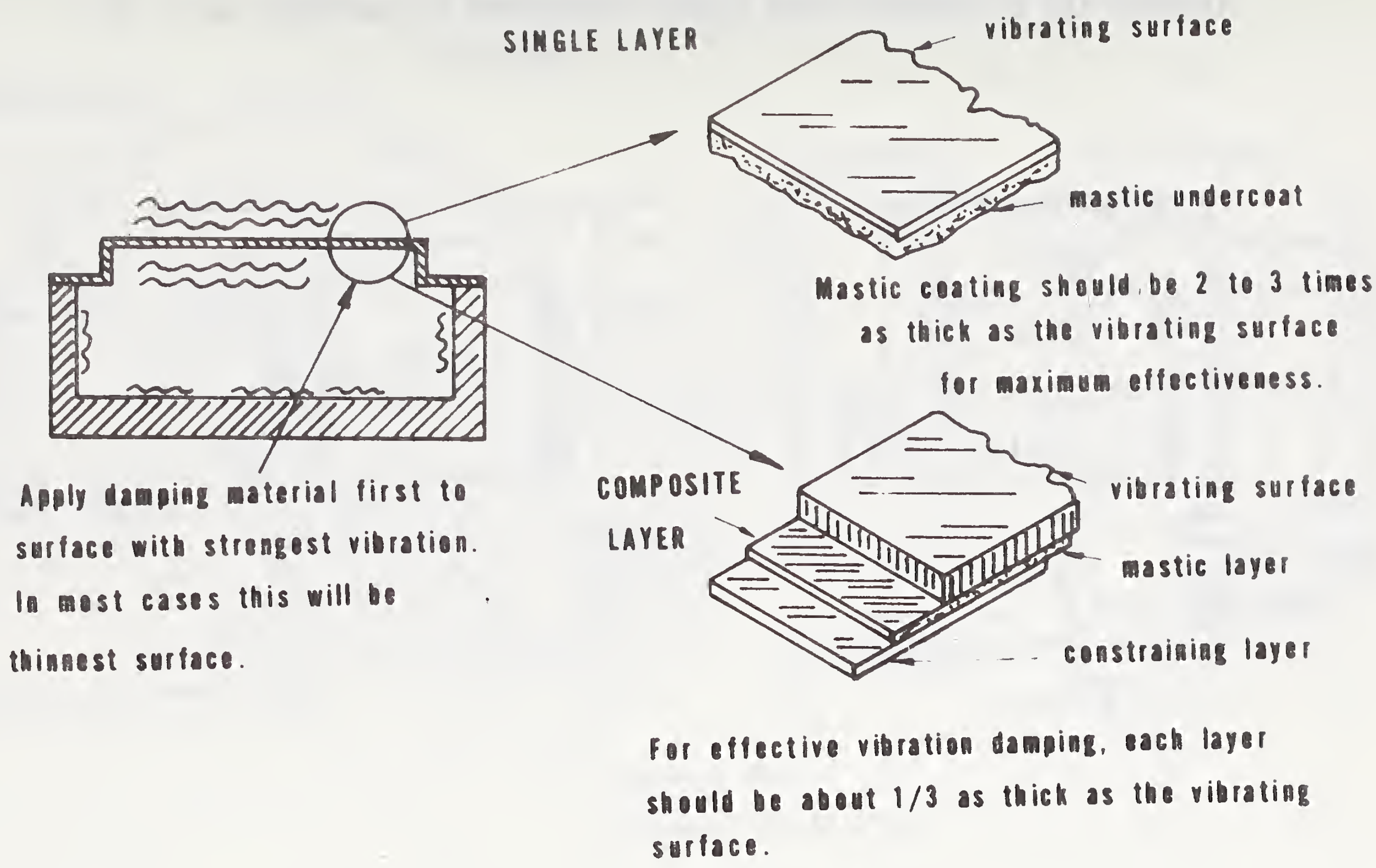


Fig. 3–9 REDUCING VIBRATION WITH DAMPING MATERIALS.

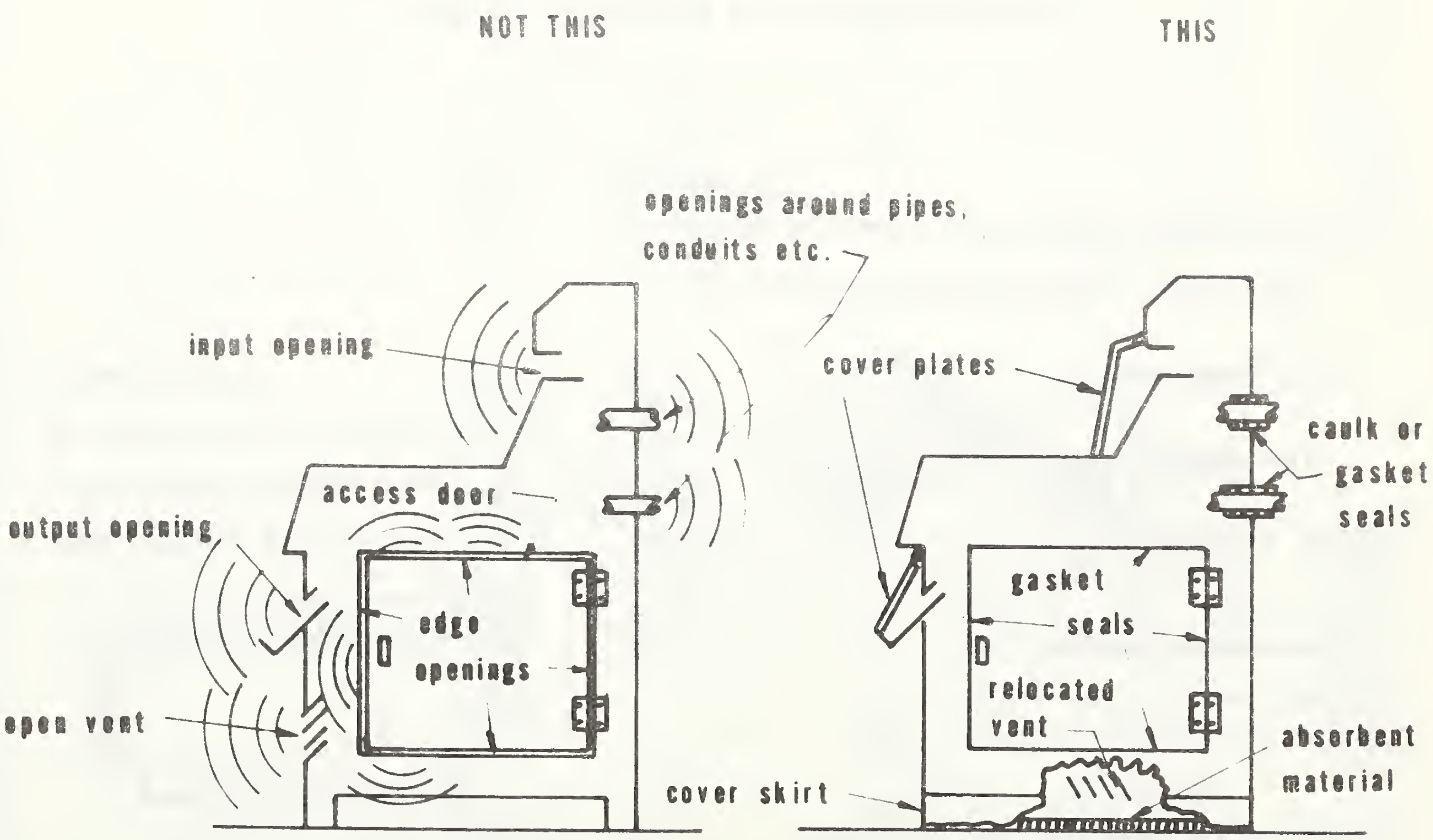


Fig. 3-10 REDUCING THE RADIATION OF NOISE FROM OPENINGS IN THE MACHINE.

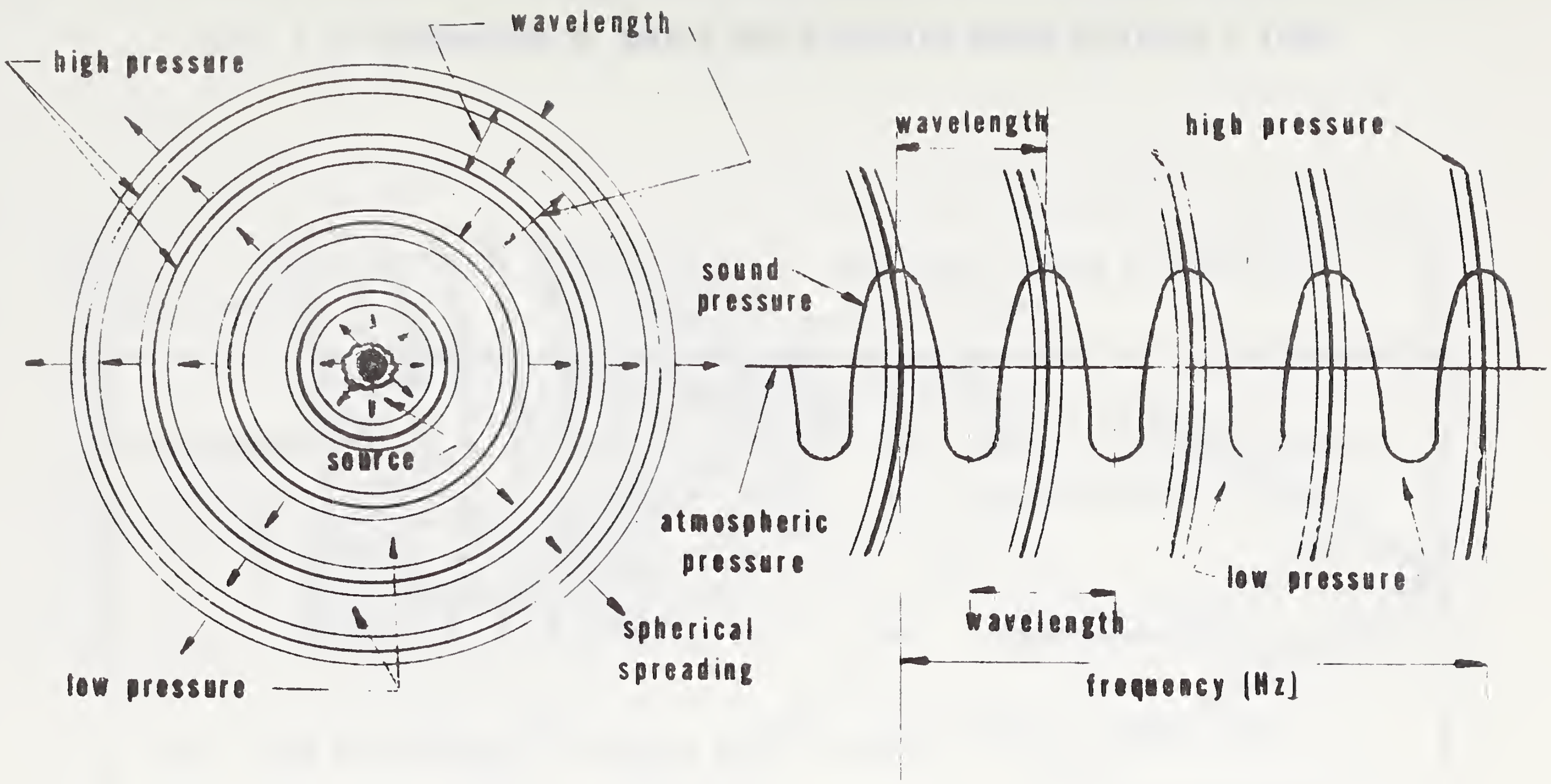


Fig. 3-11 PROPERTIES OF SOUND WAVES

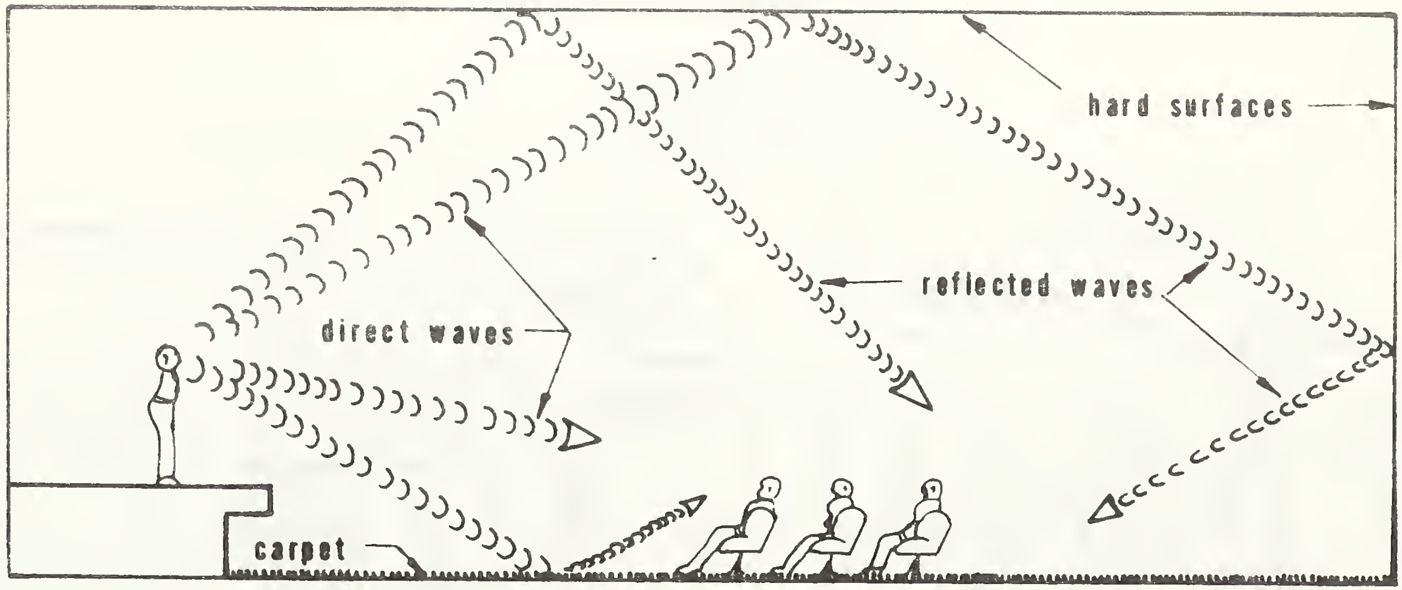


Fig. 3-12 PROPAGATION OF DIRECT AND REFLECTED SOUND WAVES IN A ROOM

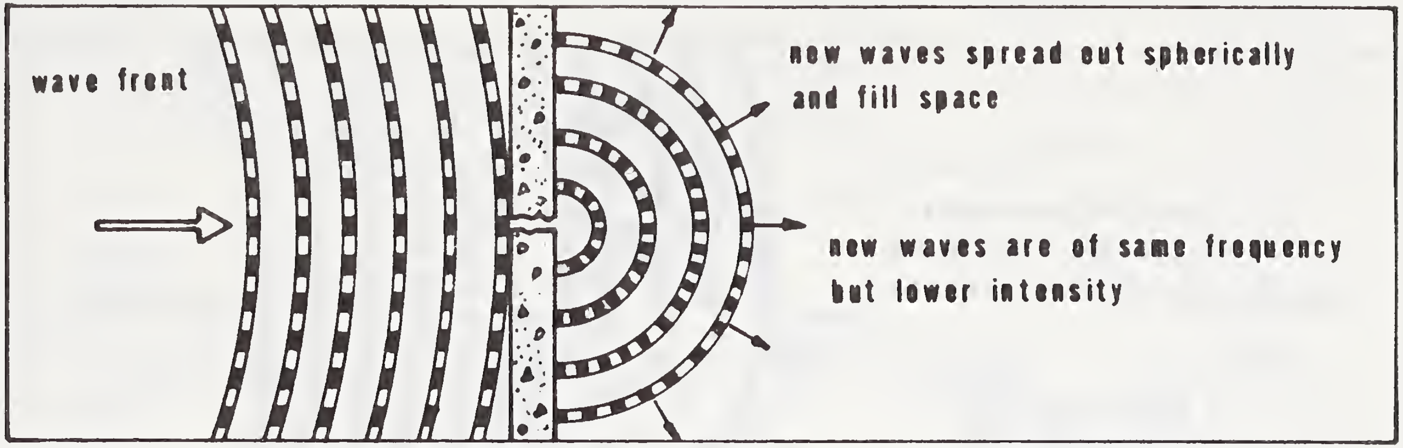


Fig. 3-13a DIFFRACTION OF A SOUND WAVE PASSING THROUGH A SMALL HOLE

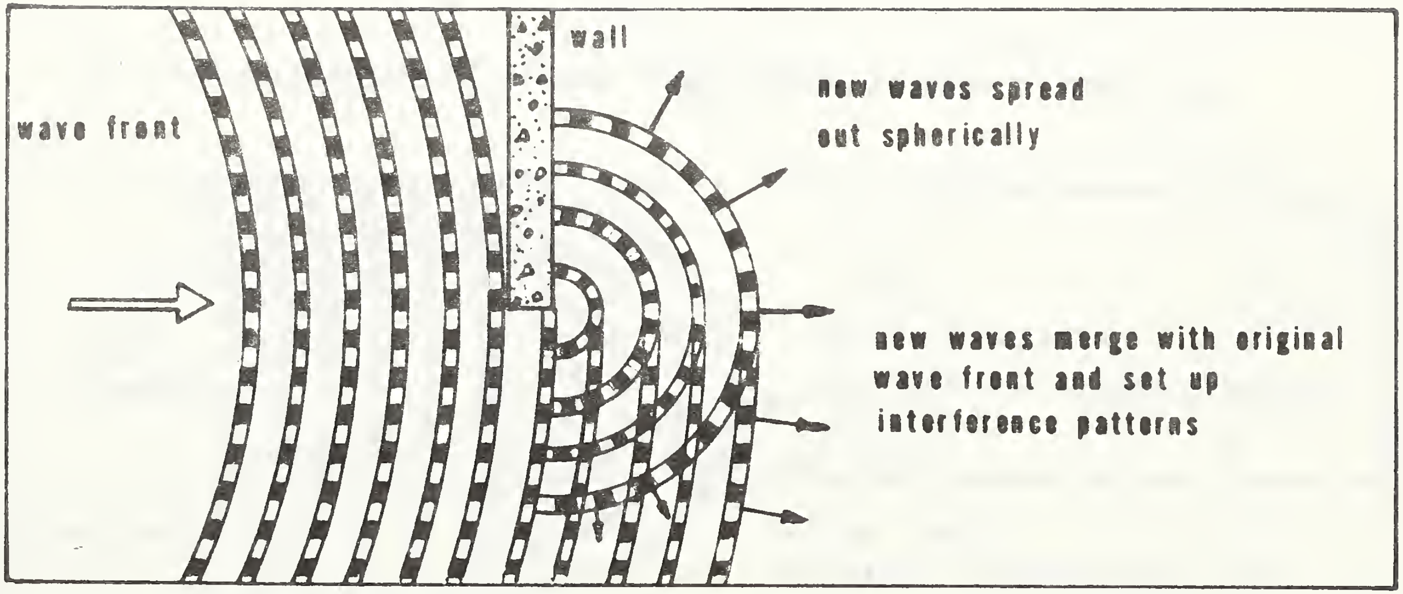


Fig. 3-13b DIFFRACTION OF A SOUND WAVE AT THE EDGE OF A WALL

FIG. 3-14a REDUCTION IN NOISE LEVEL WITH DISTANCE FROM A POINT SOURCE.

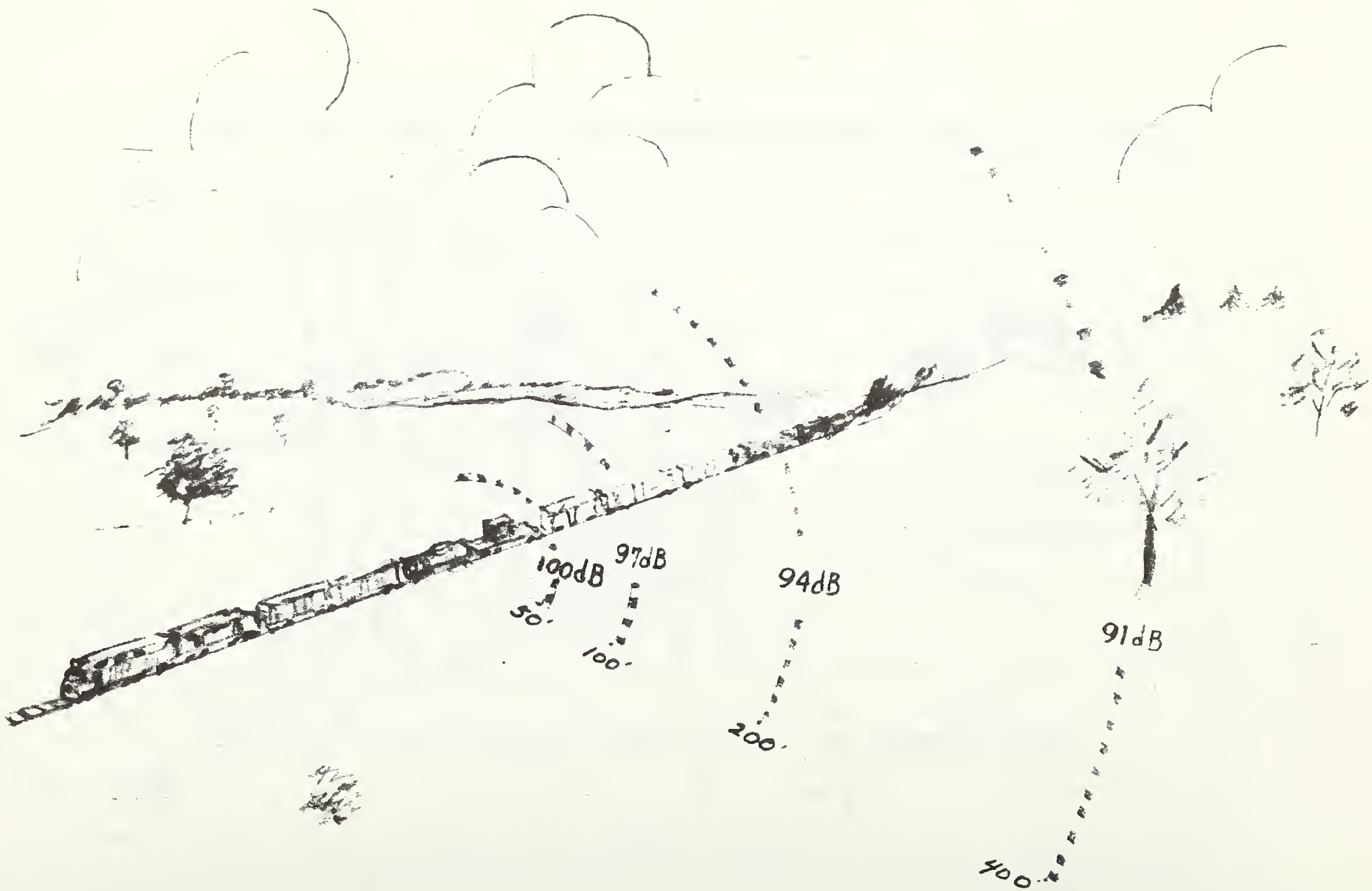


FIG. 3-14b   REDUCTION IN NOISE LEVEL WITH DISTANCE FROM A LINE SOURCE.

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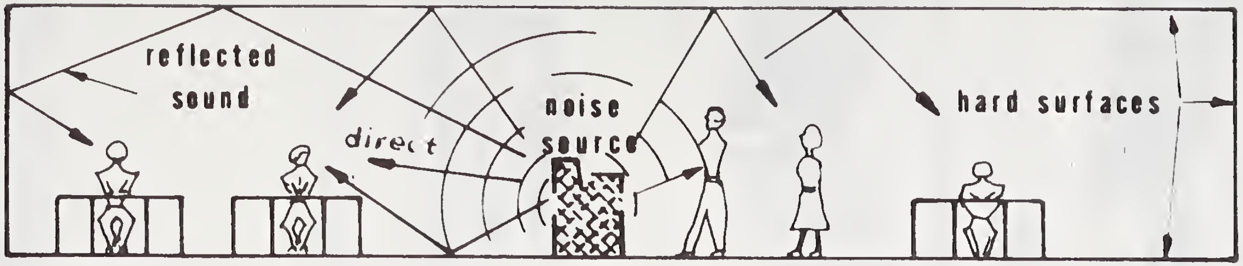

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FIG. 3-15 NOISE CONTROL OF THE TRANSMISSION PATH

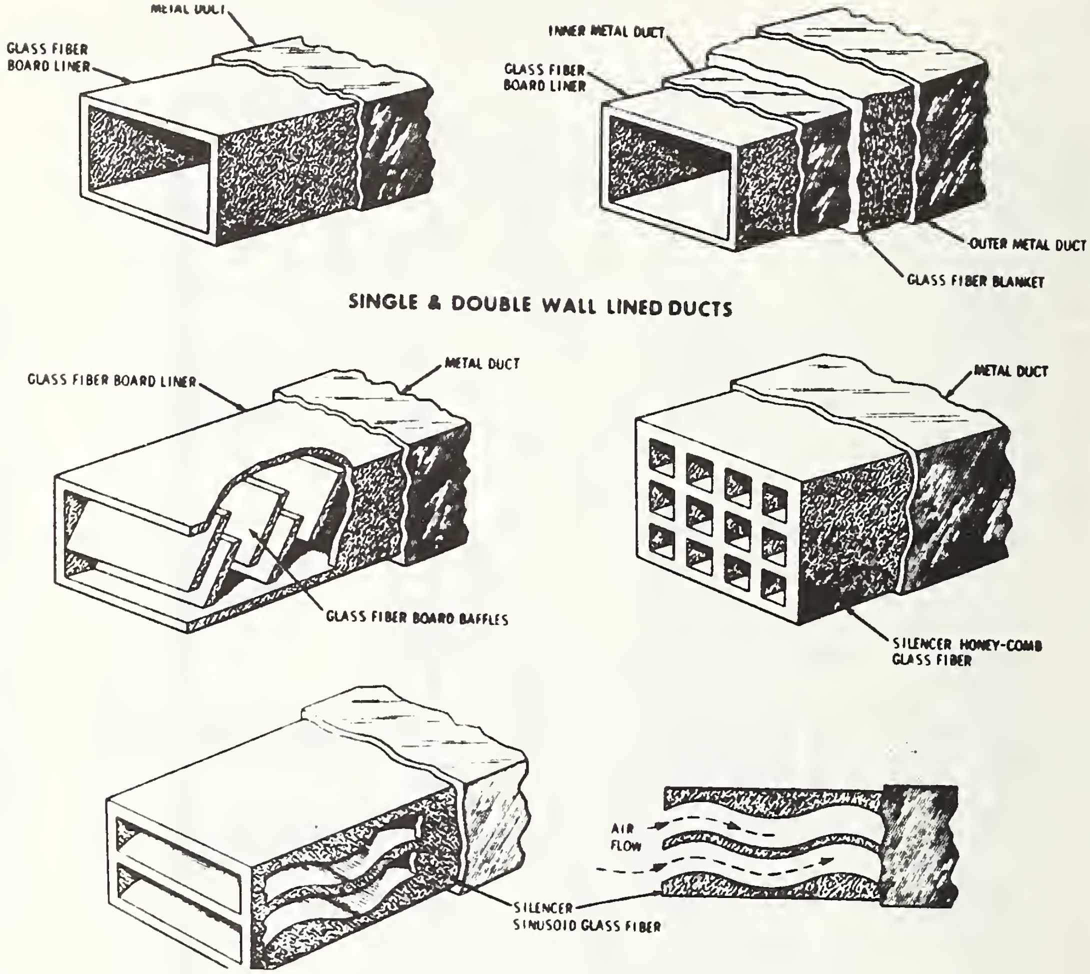

FIG. 3-16 VARIOUS TYPES OF ACOUSTICAL DUCT LINING, BAFFLES, AND SILENCERS.

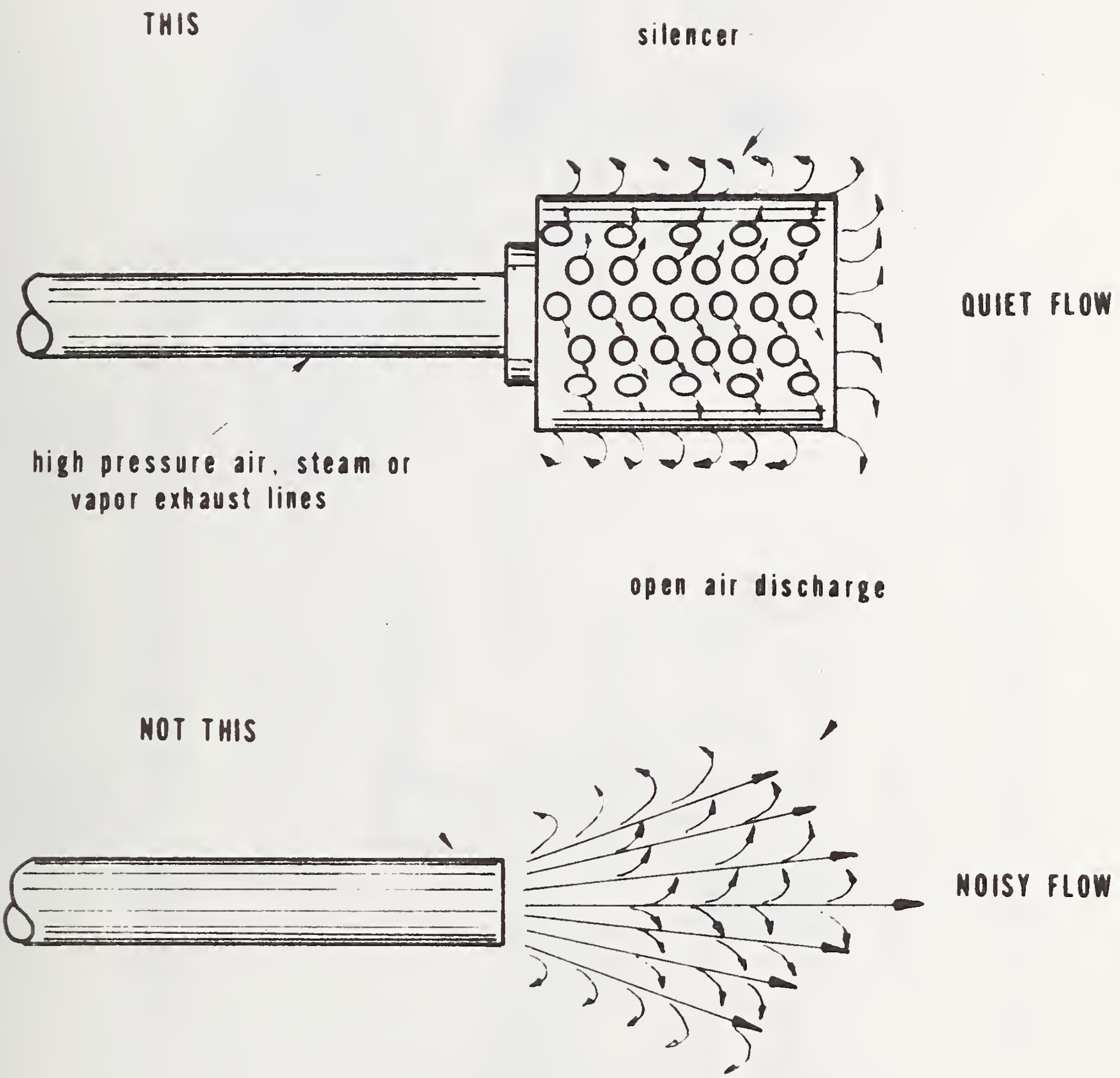

FIG. 3-17 SILENCER FOR HIGH PRESSURE EXHAUST LINES

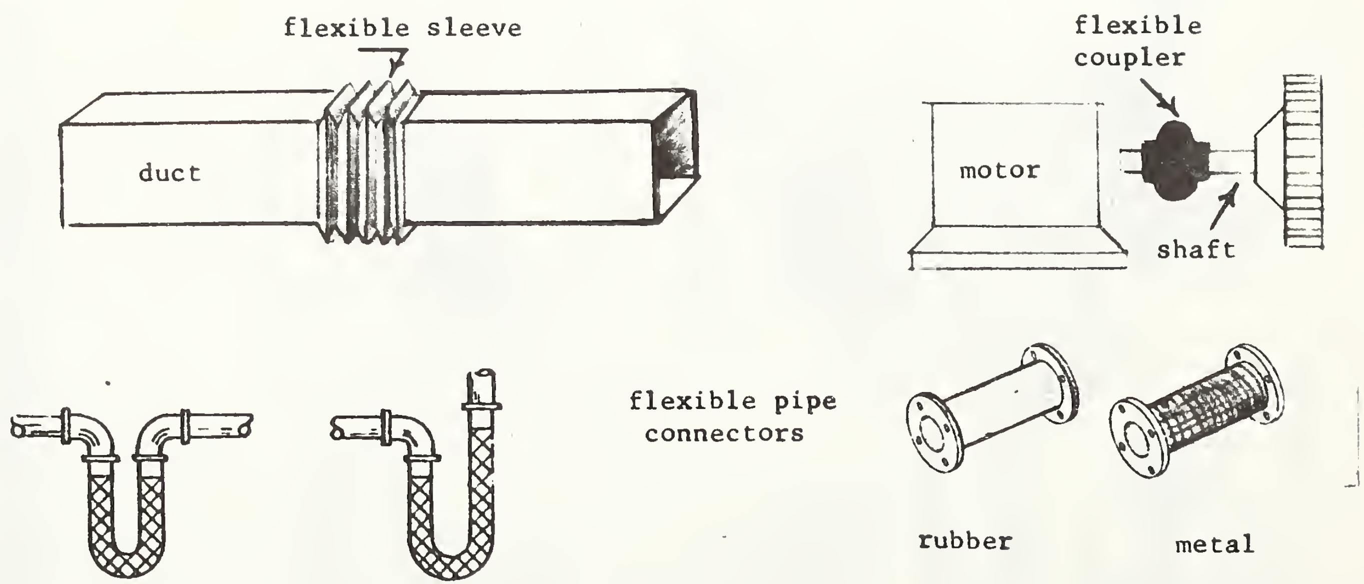

FIG. 3-18a VARIOUS TYPES OF FLEXIBLE CONNECTORS.

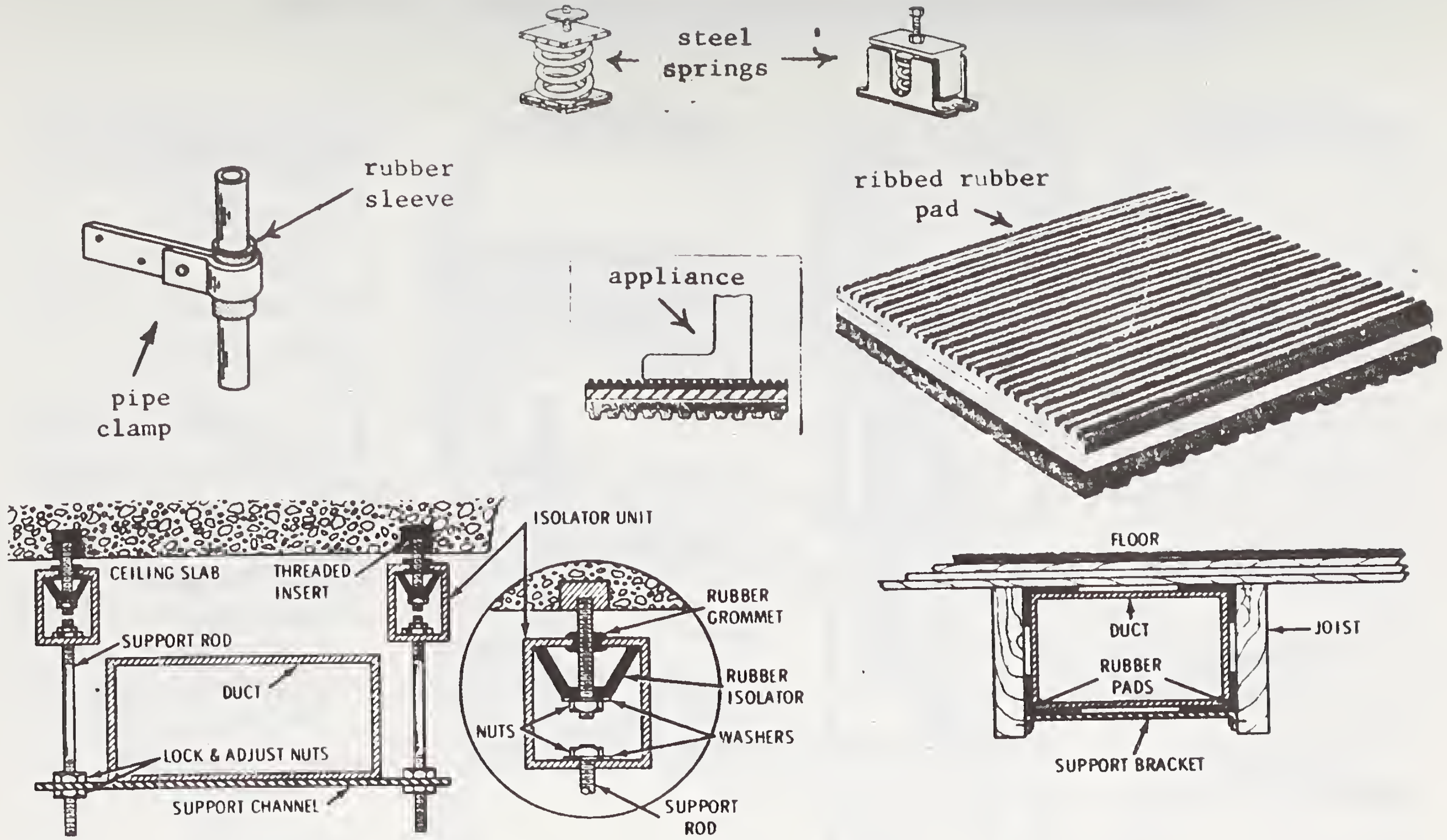

FIG. 3-18b VARIOUS TYPES OF VIBRATION ISOLATORS.

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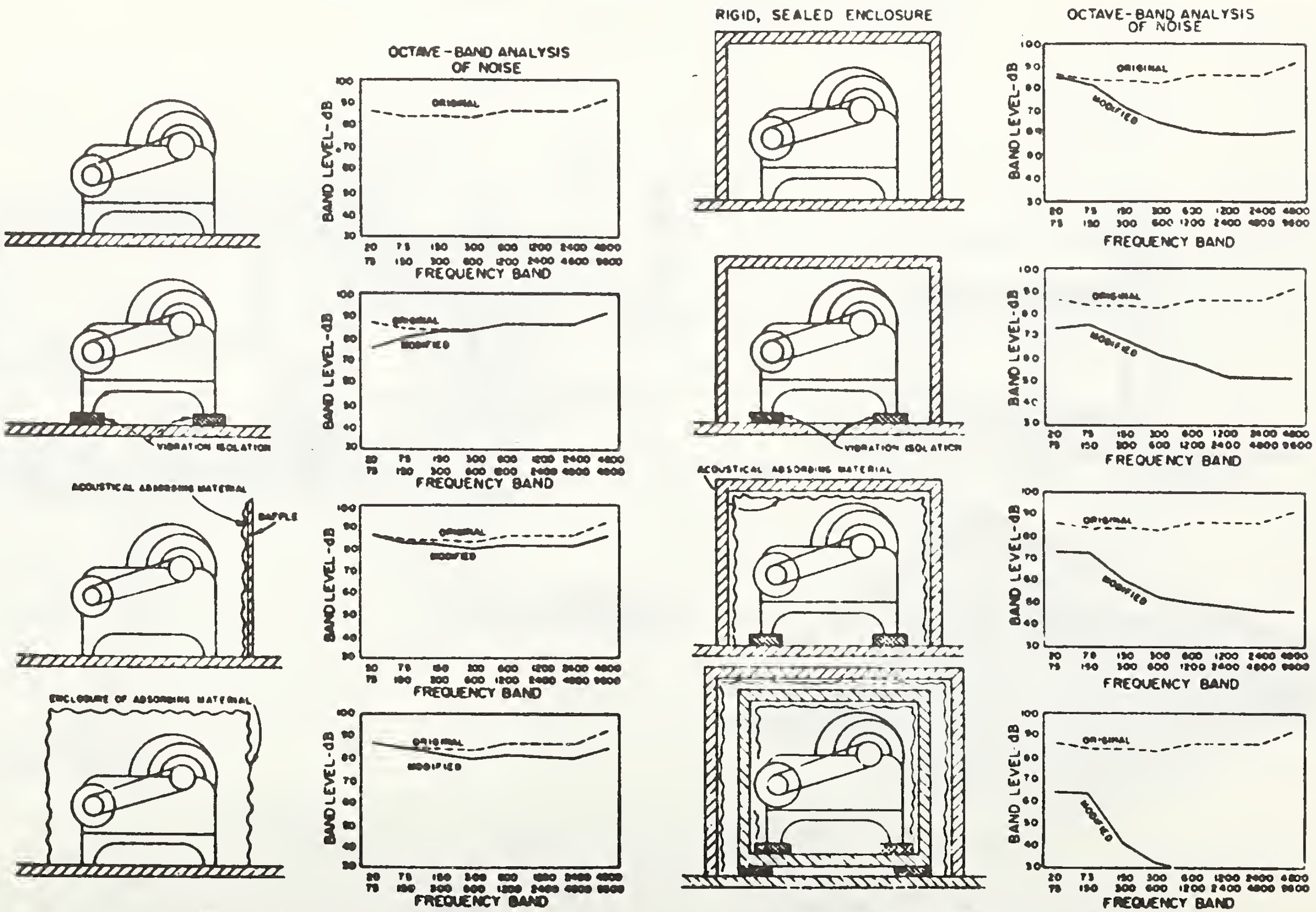


Courtesy of General Radio Company

Courtesy of General Radio Company

FIG. 3-19 EFFECTIVENESS OF VARIOUS NOISE REDUCTION TECHNIQUES.

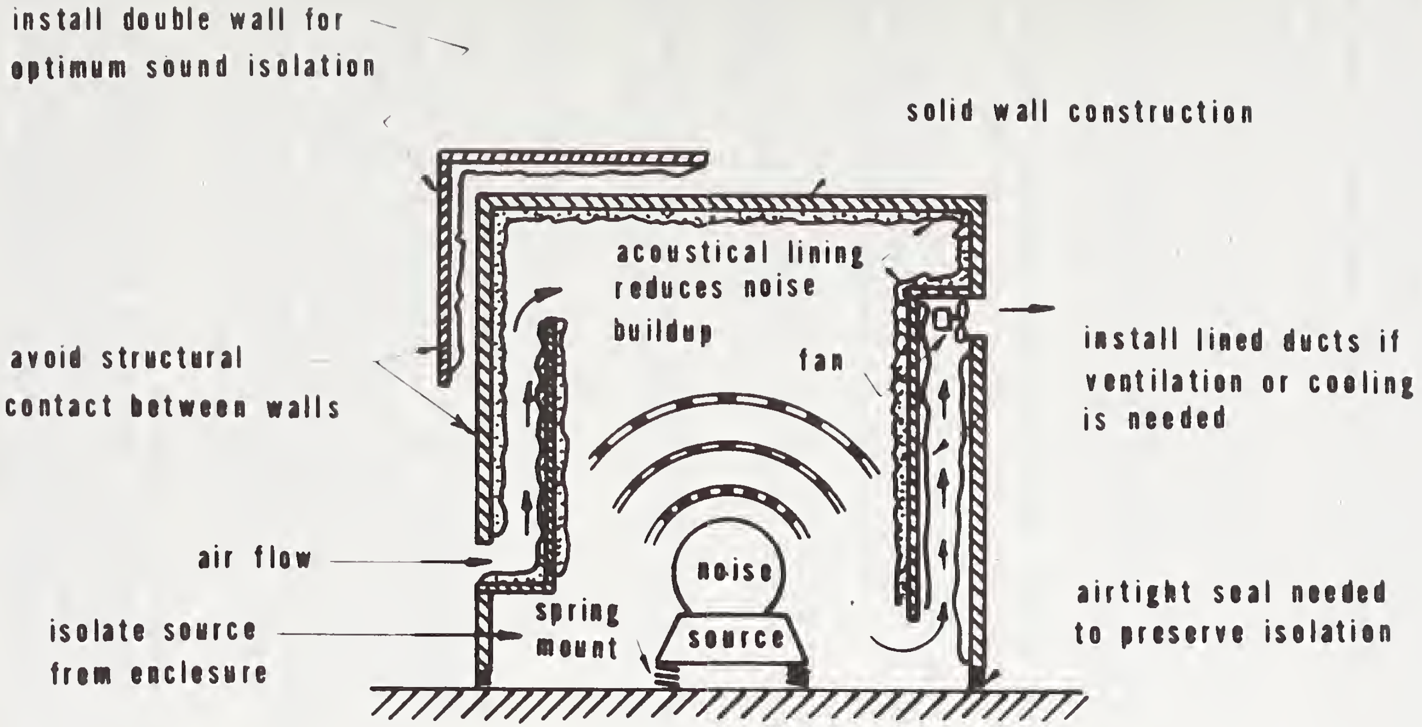


FIG. 3-20 DESIGN OF AN EFFECTIVE SOUND ISOLATING ENCLOSURE REQUIRING AIR CIRCULATION FOR COOLING.

Chapter 4

NOISE CONTROL AT HOME

The peace and quiet traditionally associated with the home is fast disappearing. Indeed at times the noise levels within and outside the home or apartment approach those found in industrial plants. As a consequence, the typical homeowner or apartment dweller finds it rather difficult to isolate himself from the noise. This unfortunate situation is due primarily to the following factors:

(a) Increasing use of noisy appliances in virtually all areas of the home.

(b) The open-space layout of many homes. Wide doorless passage ways between rooms, waist-high partial walls, and open screen room dividers obviously permit noise to travel freely to all areas of the home.

(c) The poor sound insulation provided both by the exterior shell of the dwelling and by the partition walls, floors, and doors within.

(d) The intrusion of neighborhood noise, the level of which unfortunately is increasing with the growth of automobile and aircraft traffic, and with the use of outdoor powered equipment and appliances.

Figures 4-1 and 4-2 illustrate some of the more common indoor and outdoor sources of noise that the typical apartment dweller or homeowner is exposed to on a daily basis.

If you expect to be successful at controlling noise in your home, you must have a basic understanding of how noise travels from one area to another within the home.

TRANSMISSION OF AIRBORNE AND STRUCTUREBORNE NOISE:

The control of noise in the home involves reducing the travel or transmission of both airborne noise and structureborne noise, whether generated by sources within or outside the home. By airborne noise we mean noise that is produced initially by a source which radiates directly into the air. Many of the noises we encounter daily are of airborne origin; for example, the roar of an overhead jet plane, the blare of an auto horn, voices of children, or music from our stereo sets. Airborne sound waves are transmitted simply as pressure fluctuations in the open air, or in buildings along continuous air passages such as corridors, door ways, staircases and duct systems.

The disturbing influences of airborne noise generated within a building generally are limited to the areas near the noise sources. This is due to the fact that airborne noises usually are of much smaller power and are more easily attenuated than structureborne noise. The sound from your neighbor's stereo system may cause annoyance in rooms of your apartment which are adjacent to his, but rarely in rooms farther removed unless doors or passageways are open.

Structureborne noise occurs when wall, floor or other building elements are set into vibratory motion by direct contact with vibrating sources such as mechanical equipment or domestic appliances. This mechanical energy is transmitted throughout the building structure to other wall and floor assemblies with large surface areas, which in turn are forced into vibration. These vibrating surfaces, which behave somewhat like the sounding board of a piano, transmit their motion to the surrounding air causing pressure fluctuations that are propagated as airborne noise into adjacent areas.

The intensity of structureborne noise generally is much higher than that produced by a wall or floor structure when it has been excited into vibration by an airborne sound wave, because the vibrating source is more efficiently coupled to a structural member than it is to the surrounding air. Unlike sound propagated in air, the vibrations are transmitted rapidly with very little attenuation through the skeletal frame of the building or other structural paths. These vibrations frequently reach large light-frame structures which perform rather efficiently as sounding boards, and radiate the noise at high levels.

"SOUNDING BOARD" EFFECT

It might be well to consider briefly the so-called "sounding board effect", a reinforcement or amplification of sound, which so frequently is involved in the radiation of structureborne noise. Generally speaking, the efficiency of a sound radiator varies directly with the ratio of its surface area to the wavelength of sound; the larger the area of a radiator the greater its effectiveness. A sound source with a small radiating surface, such as water pipe, produces relatively little airborne sound; but on the other hand, it will radiate higher pitch sounds more efficiently than lower pitch sounds, all other factors being equal. If a small vibrating source, which by itself radiates little airborne noise, is rigidly or mechanically coupled to a large surface such as plywood or gypsum wall panel, the intensity or volume of sound will be substantially reinforced or amplified. A piano provides an illustration of this effect. If we were to remove the sounding board of a piano, the sound generated by the vibrating strings would be almost inaudible, because of their small radiating surface.

Under certain conditions, airborne noise may produce structureborne noise which in turn may be radiated again as airborne noise. For example, an airborne sound wave striking one side of a wall may cause the entire wall to vibrate like a solid panel. Thus, the sound is transmitted to the other side of the wall from which it is radiated as airborne sound. However, some of the wall vibration will be transmitted to the supporting floor, adjacent walls, and through other structural members to various parts of the building where it eventually emerges as airborne sound.

There are many noise sources which generate both airborne and structureborne noise simultaneously. In fact, this type of noise source is very common. Sources usually considered to be strictly airborne noise generators may produce a substantial amount of structureborne noise and vibration if they are fastened rigidly to wall and floor structures. For example, a high-power loudspeaker built into a wall enclosure might cause not only the wall to vibrate but perhaps the rafters as well. Every noise source has vibrating elements which radiate noise. A window air conditioner suspended in mid-air would produce a substantial amount of airborne noise; however, when the unit is mounted in a conventional manner a combination of both structureborne and airborne noise of greater intensity is produced, due to the induced vibration of the window and supporting wall. Occasionally, a noise source may produce vibrations so low in frequency that they can be felt but not heard. In some instances, such a source may induce a wall or floor structure to resonate at its own natural frequency, which may be in the audible range. Thus, the low-pitched drone of a passing airplane may cause a wall or window to resonate at a higher pitch than that radiated by the plane itself.

Since both airborne and structureborne noise cause pressure fluctuations in the air which can be perceived by the ear as sound, it is not easy to tell whether sound has reached you mainly through a structural path or through the air.

Sometimes location of the source of sound requires considerable search. For example, there was a man, living in an apartment building, who was haunted by a "ghost" piano. From time to time, it played softly in his living room, but when he walked up and down the corridor outside his apartment, it was gone. Eventually, bothered not by its intensity, but by its mysterious origin, he hired an acoustical engineer to locate the source. The puzzle remained until the architect's drawings were examined. The sound of the ghostly piano reached him through a main load-bearing beam, anchored at one end to the exterior wall of his living room, and at the other end to the outside wall of the apartment on the opposite side of the building. There, a grand piano sat, with two of its legs positioned over the beam. The vibrations of the piano that were transmitted via the beam induced a wall in the man's apartment to vibrate and thus to radiate the sound.

FLANKING NOISE TRANSMISSION

The movement of noise from one completely enclosed room to an adjoining room separated by a continuous partition wall may be either by direct transmission through that wall, or by indirect transmission through adjoining walls, ceilings and floors common to both rooms or through corridors adjacent to the room. Noise transmission by indirect paths is known as "flanking transmission." Quite frequently one is faced with a noise transmission problem that involves a combination of both direct and indirect transmission paths, and in which noise from the indirect path may be the more serious offender. Such indirect or flanking transmission commonly occurs with structureborne as well as airborne noise.

The chief flanking transmission paths of airborne noise between two adjacent rooms usually involve common corridors, ventilation grilles, duct systems, open ceiling plenums which span both rooms, louvered doors, and close spacing of windows between rooms. In addition to the flanking paths, there may be noise leaks, particularly along the ceiling, floor and side wall edges of the partition wall. Also, noise leaks may occur frequently around pipe and conduit penetrations, back-to-back installations of cabinets and electrical outlets in the partition wall. Imperfect workmanship may result in serious noise leaks, e.g., poor mortar joints in masonry core-walls which often are concealed behind furred walls, panels or built-in cabinets.

As we see in Fig. 4-3 airborne noise may travel from one room to another over any number of different paths, some of which are not only complicated but often hidden from view.

Flanking transmission paths of structureborne noises, as illustrated in Fig. 4-4, are about as numerous and difficult to trace as those of airborne noise. Noise and vibration-producing equipment such as fans, compressors, pumps, ventilation and plumbing systems readily communicate their vibrational energy to the building structure if no precautionary measures are taken. The vibration travels quickly over long distances through the skeletal building structure with no appreciable attenuation, forcing other building elements like wall and floor assemblies in other parts of the building to vibrate and to radiate noise. While noise or vibration transmission problems between adjacent rooms are relatively simple to resolve, it may be extremely difficult to determine the reasons for excessively high noise or vibration levels in rooms far removed from the noise sources. The difficulty arises in tracing the specific flanking paths and identifying the operating equipment at fault. However, a good rule to follow is to conduct an inspection of the apartment building in order to locate all excessively noisy areas; identify and examine the major noise sources in each area, including their mountings and other accessory equipment and hardware to which they are connected. Then starting with the noisiest source try to reduce as much as possible the airborne noise radiation and vibrational motion of the source, using the various techniques discussed throughout this guide. This, of course, presupposes that the building owner or management will permit such a survey to be done. However, most owners faced with noise complaints can be induced to cooperate, especially if the chances are good that the installation of some inexpensive treatment or simple devices would alleviate the noise problem, as for example inserting vibration isolators under a pump or elevator motor; or perhaps installing pressure reducing valves in certain locations of the building plumbing system.

GENERAL SOLUTIONS FOR NOISE CONTROL IN THE HOME

General solutions for the control of noise in the home or apartment involve a three step approach, namely:

(1) Stop or reduce the transmission of airborne sound by installing a wall or floor structure in its path. Ideally, the structure should reduce the level of intruding sound sufficiently to make it inaudible, or at

least nondisturbing in areas where privacy is desired. The sound insulating effectiveness of a single wall is weight dependent. Based on the mass law, there is a gain of about 5 dB in sound insulation or transmission loss for each doubling of the weight of the wall. However, single walls are not very effective where a high degree of sound insulation is required. For the same overall weight, a double wall or one using resilient studs or channels can be made to provide a higher degree of sound insulation than a single wall.

(2) Stop or reduce the transmission of impact or structureborne noise by installing a structure, whether a wall or a floor, that will cushion the impact or interrupt the path of vibration. In the case of a concrete floor slab, a thick soft carpet with felt or rubber padding will be adequate. In addition to the carpeting, a floor of light-frame construction might require a gypsum board ceiling suspended on resilient channels to achieve the same degree of impact isolation.

(3) Stop or reduce sound reflection which tends to amplify or buildup the level of noise, particularly in rooms. Ordinary room furnishings like carpeting, drapery and upholstered furniture are effective sound absorbers and should, therefore, be used to control excessive reflection. Sound reflection off hard ceiling surfaces can be minimized by the installation of an absorptive ceiling.

Application of these three principles is illustrated in Fig. 4-5.

SOUND ABSORPTION VS SOUND INSULATION

The reduction and control of noise, whether in machinery, buildings, or rooms, generally involves the use of sound absorbing materials and sound insulating materials. Contrary to public opinion, these materials have different properties and are used for different purposes, which can not be interchanged. But due to confusion, both materials often are misused.

It may be well to clear up the popular misconception that sound absorbent materials also are effective as sound insulators, i.e., materials which prevent the transmission of sound through them. Unfortunately that is not the case. Acoustical tile applied to the walls of a noisy room will reduce the noise level within the room appreciably, but will provide only a trivial reduction in the amount of noise normally transmitted through the wall to an adjoining room. This seemingly odd behavior can be explained as follows.

At a speed of about 1130 ft./sec. (345 m/sec), a sound wave might be reflected 10 or more times from the surfaces of a typical room in just a fraction of a second. With each contact with an absorbing surface, the sound wave loses some of its energy. Thus, the listener perceives a noticeable reduction in the noise level within the room. But consider for a moment the very first contact of the sound wave with the absorbing surface. The wave enters the material, loses perhaps 2 to 3 dB in sound energy, which is hardly noticeable, strikes the wall and is transmitted through it.

Sound absorbing materials like acoustical tile, carpeting and drapery are poor sound insulators because of their soft, porous and lightweight construction. Consider a wall made of such materials; it is quite obvious that such a wall would provide virtually no resistence to the passage of sound through it. A brick wall on the other hand, is a very poor absorber of sound but, it is an extremely effective sound insulator. Because it is massive, it resists the passage of sound. Perhaps a better example illustrating the difference between absorption and insulation is the ordinary blotter. The blotter is a very good absorber of liquids, but one would never consider using blotting paper to form the walls of a swimming pool. When the blotter absorbs the liquid to its saturation point, the liquid readily passes through it and leaks away.

WARNING! Because they act as poor barriers to the transmission of sound, acoustical absorbers <u>should never</u> be used on walls and ceilings for the sole purpose of preventing the transmission of sound through such structures.

KITCHEN NOISE

With rare exception, the kitchen is the noisiest room in the home. This is due in part to its reverberant characteristics, but primarily to the frequent and oftentimes simultaneous operation of the various types of very noisy power-driven appliances ordinarily found in the kitchen. These include garbage disposers, dishwashers, blenders, mixers, can openers, ice crushers, exhaust fans, etc. Although kitchen noise generally subsides before bedtime and thus rarely causes any problems of interference with sleep, it ranks as one of the most irritating disturbances during daytime or early evening periods of relaxation and entertainment. Even though most kitchen appliances are operated for relatively short periods of time, it is the intensity, random intermittency and the periodic or cyclic characteristics of the noise that are especially annoying, as for instance the noise associated with filling, washing, draining and rinsing cycles of a dishwasher. Kitchen noise like most building noise problems can be avoided if good noise control techniques are incorporated early in the design stage of the home. This can best be done by adopting the following design and noise control features.

(1) Choose a floor plan which locates the kitchen as far as possible from such noise sensitive areas as bedrooms, studies or formal living rooms.

(2) Design the kitchen as a completely enclosed sound insulated room.

(3) Select "quiet" appliances and insist on proper vibration isolated mounting or installation, and

(4) Install sound absorbing materials on room surfaces to reduce the noise buildup due to excessive reverberation. Materials such as acoustical ceiling tile, draperies and curtains, carpets or throw rugs and even racks of exposed towelling can provide a considerable reduction in kitchen noise level.

What can be done to control the noise from an existing kitchen with typical appliances and furnishings? A significant reduction of both the level of noise in the kitchen area and the amount of noise escaping to other areas of the home can be achieved by adopting the recommendations preferably in the order illustrated in Fig. 4-6, and described in greater detail below.

Install Doors

Completely enclose the kitchen area by installing doors in all passageways. Doors should be of solid core construction and equipped with soft rubber or plastic gaskets at the top, sides and at the bottom, as illustrated in Fig. 4-7. Hinged or sliding doors may be used, providing good edge seals are maintained. Such an installation will confine the noise to the kitchen area.

Control Appliance Noise

1. Vibration isolate appliance from the floor

   Place pads of resilient materials such as sponge rubber, ribbed neoprene or solid rubber under the legs or corners of large, heavy appliances like wash machines, dryers, and refrigerators to prevent the transfer of machine vibration to the supporting floor. Pads measuring 1/4 to 1/2 inch (about 10 mm) in thickness with an area of about 2 square inches (13 cm^2) should provide adequate vibration isolation for most large appliances. Placing a metal plate on top of the pad will tend to distribute the load more uniformly, especially if the appliance is equipped with leveling-screw legs.

2. Isolate appliance from the wall

   Under no conditions should any appliance make rigid contact with a wall. A space of at least 2 inches (5 cm) should separate the appliance from the wall. Flexible plastic or rubber hoses should be used in the installation of food waste disposers, and of dish or clothes washers to avoid the transfer of machine vibration to the walls containing the plumbing outlets or fixtures. Otherwise, the vibrating walls acting like sounding boards would tend to amplify the machine noise.

3. Isolate Appliance from Cabinet Enclosure

   Appliances such as dishwashers, disposers, compactors, etc. which are built into or enclosed by counter-type wall cabinets should preferably be installed with a perimeter strip type gasket or spacers made of soft rubber to vibrationally isolate the cabinets from the machine. A strip gasket 1/4 inch (6 mm) thick and 1/2 inch (13 mm) wide attached to the top and side edges of the cabinet opening into which the appliance is to be installed would provide adequate isolation.

   Small countertop appliances such as blenders, mixers, ice crushers, can openers, etc. should be placed on small pads or fitted with button- type feet of soft rubber to prevent the transfer of vibration to the countertop.

As a temporary measure, folded towels placed under small appliances can be effective. However, in using these schemes, one must be careful to avoid blocking any air vents used for cooling purposes that might be located in the base of the units. Otherwise, the appliances might tend to overheat with prolonged use.

A soft rubber sleeve-type gasket inserted between the mounting flange of a waste disposer and a sink basin will tend to prevent the sink from vibrating and thus amplifying the disposer noise, as illustrated in Fig. 4-8.

4. Isolate cabinet enclosure from wall

Countertop wall cabinets with built-in appliances tend to vibrate excessively when the devices are used. To prevent the transmission of the vibration to the back wall, strip gaskets, as described above, should be inserted between the back of the cabinet and the wall. This will eliminate the tendency of the wall to act as a soundingboard. Such gaskets will also reduce impact noise radiation caused by stocking of cabinet shelves, closing of drawers and cabinet doors.

5. Isolate small appliances

In most cases it is extremely difficult to reduce the noise output of the small countertop appliances that you presently own; the devices usually are built so compactly that it is virtually impossible to vibration isolate the case or housing from the motor and gear trains, which as a rule are the main sources of noise. The lack of room also precludes lining the case with sound absorbent material. Sometimes lining the inside surfaces of an appliance with a metal or lead foil-backed adhesive coated tape will damp the vibration of the case and thus result in some reduction of the noise. Aside from operating the units at low speeds, about all the owner can do is to vibrationally isolate the units from the counter tops by placing soft rubber pads under the base. This scheme at least prevents the counter top from amplifying the noise as a sounding board and thus results in a noticeable reduction in the overall noise.

Placing rubber mats in sink basins, and on countertops alongside the cook range, and under dish drying racks or baskets will cushion or absorb the impact noise caused by handling of dishes, pots and pans; further, such mats will tend to suppress the drumhead type amplification of impact noise by the hollow reverberant cabinets.

6. Cushion impact noise in the cabinets

Install soft rubber or cork tile on the shelves and back surfaces of the kitchen cabinets to minimize the impact noise caused by placing dishware or food supplies in the cabinets. The tiles will cushion or absorb the impacts caused by such chores.

Placing soft rubber bumpers or small strips of foam rubber on the inside edges of the cabinet doors will reduce the noise caused by the closing or slamming of the doors.

7. Apply vibration damping material

Sink basins equipped with a food waste disposer should be undercoated with a thick layer of a mastic type vibration damping material or other types of vibration dampers as illustrated in Fig. 3-9. Such treatment will suppress the vibration of the sink and resulting noise caused by operation of the disposer.

Damping treatment applied to the interior surfaces of the metal cabinets and tumblers of larger appliances, especially washing machines and dryers, would result in a noticeable reduction of noise due to cabinet vibration.

8. Install acoustical lining

Installing acoustical tile on the interior walls of the sink cabinet will minimize the noise buildup in the hollow reverberant enclosure. If space permits, this treatment should be applied to the cabinet that encloses the dishwasher or any other appliance.

9. Install exhaust fans on rubber mounts

Most ceiling exhaust systems use high speed, noisy propeller fans that are mounted rigidly to the ducts, which in turn are connected to the ceiling by means of the fan grilles. These structural paths carry the fan vibration to the ceiling, which acts like a large sounding board and amplifies the noise. You can reduce the noise level noticeably by following this three-step procedure: If possible, remount the fan on rubber grommets or spacers to isolate it from the duct, as shown in Fig. 4-9. In addition, try to break contact between the duct and the ceiling by inserting a soft sponge rubber gasket or spacers between the grille and the ceiling. Operate the fan at its lowest speed.

In the case of a hood type fan installed directly above the stove, it is unfortunately much more difficult to reduce the noise output because of the severe space limitations. In most situations, the only measures you can use to lower the noise are to operate the fan at its slowest speed, and to keep the oil and grease from accumulating on the fan blades and clogging up the pores of the filter pack. If it is at all possible to do so, install the fan on rubber mounts; this will reduce the noise due to hood vibration.

When replacement of a ceiling or hood exhaust fan is due, remember that squirrel-cage type fans are less noisy than propeller blade units.

The ideal solution to avoid exhaust fan noise is to install a squirrel- cage fan on rubber mounts at the discharge end of the duct instead of at the intake end in the kitchen ceiling. These measures combined with some acoustical lining near the fan and a flexible link between the duct and the ceiling would result in a relatively noiseless operation. These measures should be used in the installation of bathroom exhaust fans as well.

10. Install acoustic ceiling

The installation of an acoustic ceiling in the kitchen area will absorb a noticeable amount of noise. For ease of cleaning and maintenance, vinyl or membrane faced tile are available. Draperies, curtains and racks of exposed toweling also are good sound absorbers, particularly at high frequencies.

11. Install carpet or foam-backed tile

Installation of foam-backed tile or an indoor/outdoor type carpeting, which is stain resistant, is an effective way of reducing impact noise caused by footsteps and dropped objects.

12. Quieting of large appliances

The application of basic noise-control principles in the early design stages of large appliances would eliminate much of the noise and disturbance such devices cause. This, of course, is a corporate responsibility which manufacturers may choose to neglect or ignore as long as it does not interfere with market sales. The consumer, unfortunately, has neither the technical background nor the equipment or supplies to effect any substantial reductions in noise output. The only noise control measures he can employ are:

(a) install ribbed neoprene or soft rubber pads under the units.

(b) adjust screw-leveling legs to prevent units from wobbling.

(c) tighten all loose parts and panels to prevent them from rattling.

(d) install soft foam rubber gaskets along the perimeter edges of doors, of washing machines, dryers, and dishwashers to prevent noise from inside the machines.

(e) with such units in operation, run your fingers lightly over the surfaces of the machines to find areas of greatest vibration. At these points install vibration damping materials on the inside surfaces. This will tend to supress the vibration and reduce the noise output.

(f) apply glass fiber board on the interior surfaces of the cabinets to reduce the noise buildup in these reverberant enclosures.

(g) the more technically competent person might try mounting motors and pumps on resilient isolators and inserting rubber sleeves around pipes and conduits at points of support or contact with large cabinet surfaces.

Incorporation of the above acoustical measures will make a substantial reduction of the noise in the kitchen area.

RECREATION OR PLAY ROOMS

Other rooms of the home can be as noisy as the kitchen. These rooms are the family or recreation rooms, where members of the family, especially children, are permitted to watch television programs, listen to their stereo sets, play games or practice their music lessons. Such rooms tend to be somewhat reverberant and noisy because the wall and floor surfaces and furniture generally found in these rooms are made of hard materials designed to be stain resistant and unbreakable.

Installing acoustic tile on the ceiling, drapery on the walls, and perhaps placing a few pieces of shag carpeting on the floor will reduce the noise buildup, and the resultant distraction and annoyance.

Popular games like darts, table tennis, and billiards commonly found in recreation rooms can be made less disturbing, without detracting from the fun, by placing a rubber pad behind the dart board, undercoating the tennis table with a vibration damping compound, and by placing rubber pads at the bottom of the billiard pockets and lining the ball return chutes with rubber or cork tile. Such treatment will cushion the impacts and muffle the resultant noise and distraction.

The use of earphones or headsets by family members listening to TV or stereo will reduce the noise level appreciably in the recreation room.

However, while such measures will reduce noise levels in the recreation room, they do little to keep the noise from spreading to other areas of the home where privacy may be desired even during daylight hours. The most effective measure to decrease the leakage of noise from the room is to seal it off with sound insulating doors, as was recommended in the case of the kitchen area.

Basement Recreation Rooms

In one story homes, special attention must be paid to prevent the transmission of sound from recreation rooms located in basements to noise sensitive areas on the floor above. In many cases, recreation rooms are located directly below bedroom and study areas where privacy is most desired. The installation of a sound insulating ceiling assembly will alleviate such problems. A ceiling assembly which will provide adequate sound insulation under most circumstances would consist of the following construction as illustrated in Fig. 4-10.

(a) if the floor joists are exposed, install a 3 inch (7.6 cm) thick layer of glass fiber insulation between the joists,

(b) attach metal resilient channels to the under edges of the joists. The channels should be installed so that they are perpendicular to the joists and spaced 2 feet (60 cm) apart.

(c) Attach a 5/8-inch (16 mm) thick layer of gypsum board to the resilient channels with self-tapping screws.

(d) Provide a 1/4-inch (6 mm) clearance around the perimeter edge of the ceiling to avoid contact with the walls, and fill the space with a resilient non-setting caulk.

(e) To reduce excessive reverberation in the recreation room, cement acoustic tile to the gypsumboard surface. As mentioned previously, the application of the acoustic tile will not improve the sound insulation of the new ceiling construction, but will only reduce the noise level in the recreation room.

Install a sound insulating door with proper gaskets at the entrance to the staircase leading to the basement recreation room. This measure will confine the noise to the recreation room area.

Install carpeting on the stairs to absorb both airborne noise and the impact noise of footsteps.

CORRIDORS, HALLS, STAIRCASES

In most apartments and homes, corridors or halls separate the noisy kitchen and family areas from the bedroom and study areas where a relatively high degree of privacy and quiet is desired. The most effective way of preserving this privacy is to install a solid core door at the entrance of the hall leading to the bedroom area. Such doors, when installed with proper gaskets, become very effective barriers against the noise escaping from the kitchen or family room areas of the home. In addition, installing a soft thick carpet in the hall and staircase will muffle the impact noise of foot steps and reduce reverberation thus leading to a quiet environment.

IMPROVING THE PRIVACY OF YOUR BEDROOM, STUDY AND BATH AREAS

Although interference with a person's sleep is least to be tolerated, especially at night, there are times when one desires quiet and privacy during the day. Areas requiring such privacy are the bedroom, study, and bathroom areas. Unfortunately, in most homes and apartments the lack of privacy in these areas is obvious. This arises from the use of the following building constructions and practices:

(a) thin, veneer, hollow-core doors,

(b) open air spaces under doors that provide for the circulation of return air, and

(c) the poor sound insulation provided by light interior walls throughout the home, particularly in bedroom areas.

The most common practice of installing a forced-air ventilation system in some central closet location in most homes and apartments is largely responsible for the lack of privacy in many areas of the home. Such a system relies upon using a central hall or corridor as the main air return duct. All other rooms bordering on this hall vent the return air through open air spaces under the doors.

The obvious solution to this problem is to:

(a) install solid core doors with perimeter gaskets and a drop closure,

(b) if possible, install separate return air ducts in each rooms. Sometimes this can be done in one-story houses, if the floor joists and ductwork are exposed in the area below. If this is not possible, install acoustically lined air transfer grilles or ducts, which are commercially available, as illustrated in Fig. 4-11.

During construction of the house, similar return air ducts could have been built between the studding of the bedroom walls, by simply lining the inside surfaces of the wallboard with acoustical duct liner and providing an outlet grille at the top of the duct on the hall side of the wall, and an intake grille at the bottom of the duct on the bedroom side of the wall.

The sound insulation of the existing wall may be improved by eliminating sound leaks or by adding another layer of wallboard.

If a higher degree of sound insulation is required, laminate a 1/2" (13 mm) thick layer of gypsum wallboard to the existing wall with a resilent non-setting adhesive as illustrated in Fig. 4-12. Provide a 1/4" (6 mm) air space along the perimeter edges of the wall and fill the space with a non-setting caulk compound.

If one is disturbed by conversation, TV noise, etc., coming through the walls in bedroom areas, he should also look for noise leaks at the base of the walls and at electrical outlets.

IMPROVING THE SOUND INSULATION OF WALLS

Many walls, especially party walls separating appartment units, are particularly vulnerable to noise leakage. The installation of back-to-back electrical outlets, medicine cabinets, and master TV outlets are common causes of noise leakage. Openings around pipe penetrations and duct work are also causes of noise leakage. Cracks at the ceiling and floor edges of walls caused either by settlement or poor construction allow the transmission of noise from one space to another.

The sound insulation of many such walls can be improved simply by eliminating the noise leaks and flanking paths.

(a) Sealing holes and cracks:

All holes or openings around plumbing fixtures, piping and drain pipes should be enlargened slightly to provide a clearance around the pipe. The opening should then be filled with a fiber glass packing and sealed completely with a resilient caulk. This same treatment should be used in openings around ducts and grilles.

Settlement cracks at the ceiling edge of a wall should be sealed with a resilient caulk, preferably applied under pressure with a caulking gun. Cracks at the floor edge of the wall should be handled in the same manner, although it might require removing the toe molding and base boards to do a thorough job.

(b) Sealing leaks behind back-to-back outlets and cabinets:

If you hear your neighbor's noise coming through an electrical outlet, remove the cover plate and examine the opening. If necessary, remove <u>your</u> outlet box, pack glass fiber wadding around the remaining outlet, and insert a 1/16-inch (1 mm) thick sheet of lead to form an airtight barrier walls. Reinstall your outlet box, fill the remaining voids with the glass fiber and put the cover plate back on.

If the party wall is of wood stud construction, you may be able to rewire and install your outlet in the adjoining stud space. Fill the voids around both outlets with the glass fiber wadding and seal the former opening with a piece of wallboard.

Noise transmission through recessed medicine cabinets can be handled in a similar manner. However, if space permits, you may be able to insert a gypsum board or a sheet of plywood as a barrier between the two cabinets. In this case you should caulk the perimeter edges of the intervening barrier before installing your cabinet.

(c) Eliminating flanking paths:

The chief flanking paths in homes and in apartment buildings are open ceiling plenums, attic spaces, basement areas and crawl spaces which span freely across dwelling units or adjacent rooms. Such areas should be completely subdivided with full height partitions or barriers installed directly above and below the party walls separating the dwelling units or rooms in question.

Measures for control of noise leaks and flanking paths described in items (a), (b), and (c) are illustrated in Figures 4-13 and 4-14.

If the above recommendations fail to improve the sound insulation of the party wall, then modifications to the existing wall must be made. For moderate annoyance, the attachment of an additional layer of gypsum board to the existing wall, as illustrated in Fig. 4-12, would be adequate. A much higher degree of privacy would require the attachment of a wall of special design to the existing wall. The new wall, as shown in Fig. 4-15, would be constructed as follows:

(a) fasten wood furring members, spaced 16" (40 cm) on centers vertically, to the existing wall.

(b) nail resilient metal channels perpendicularly to the furring members; channels should be spaced 24" (60 cm) apart.

(c) fill the space between the existing wall and the channels with a glass fiber blanket.

(d) attach 1/2" (13 mm) thick gypsum wallboard to the metal channels with self-tapping screws.

(e) provide a 1/4" (6 mm) clearance around the perimeter edge of the wallboard to avoid restraining contact with adjoining surfaces of the room; fill the clearance gap with a resilient non-setting caulk.

IMPROVING THE SOUND INSULATION OF FLOOR-CEILING CONSTRUCTIONS

A floor-ceiling construction separating two rooms or apartment units will provide adequate sound insulation or privacy, if it can reduce the intrusion of conversational or TV noise and footstep or impact noise to non-disturbing levels.

If you are disturbed by the transmission of only footstep or impact noise from the room above, the installation of a soft thick carpet, preferably on a felt or foam rubber pad on the floor above will eliminate the problem in most cases.

If both footstep and conversational or TV noise from the room above annoy you, modifications to the existing ceiling must be made to remedy the problem. A gypsum board ceiling supported on resilient channels should be attached to the existing ceiling. This second ceiling, which is illustrated in Fig. 4-16 would be constructed as follows:

(a) attach wood furring members, spaced 16" (40 cm) on centers to the existing ceiling.

(b) nail resilient metal channels perpendicularly to the furring members; channels should be spaced 24" (60 cm) apart.

(c) fill space between the existing ceiling and the channels with a glass fiber blanket.

(d) gypsum wallboard, 1/2" (13 mm) thick should be fastened with self-tapping screws to the resilient channels.

(e) provide a 1/4" (6 mm) clearance around the perimeter edge of the wallboard ceiling to avoid contact with the walls, and fill the gap with a resilient, non-setting caulk.

This ceiling assembly should not only eliminate the airborne noise transmission, but should make a substantial reduction in the footstep noise level. However, if additional reduction in footstep noise is desired, then a carpet and pad placed on the floor above will solve the problem.

CONTROL OF FLOOR SQUEAKING (See Fig. 4-17)

Squeaking floors cause considerable irritation because they generally produce high-pitched noises to which the average person's hearing is highly sensitive. Although the squeaking floor problem is more commonly found in homes of wood frame construction, it occurs quite often in apartment buildings with concrete floors surfaced with wood block or strip flooring.

Causes of Floor Squeaking:

In general, floor squeaks are caused by the rubbing or sliding of sections of finished flooring over the subfloor. Movement between adjoining wood blocks, strips or sections of both sub-flooring and finish floor also cause squeaking. This problem usually is the result of faulty workmanship, the use of defective materials or poor structural design, such as:

(a) poor nailing: The most frequent cause of floor squeaking is the failure to nail the sub and finish flooring materials tightly and securely together and to the supporting joists or structural floor. This failure results from the use of undersize or improper nails, excessively wide spacing of the nails and faulty nailing practices in general.

(b) defective materials: Another cause of floor squeaking is the use of warped or twisted floor joists, buckled or bowed subflooring sheathing or wood block or strip flooring with defective tongues and grooves. When layers of such materials are fastened together, air-pockets or gaps form between them resulting in poor support. This allows the materials to rock, move or deflect under foot which caused the squeaking. Excessive moisture or humidity: The installation of dry flooring in damp areas often results in squeaking floors because the absorption of moisture by the flooring causes it to swell or buckle.

(c) poor structural design: Although a floor joist system may be adequately designed in terms of structural and load requirements, it may deflect sufficiently under foot traffic to permit movement of the surface flooring; this generally occurs when either the depth of the joist is too shallow or the spacing between joists is too wide for a given floor span.

For reasons of economy, the practice of inserting a layer of building paper between the finish and sub-flooring surfaces to avoid sliding or rubbing contact has been largely discontinued.

Methods of Avoiding Floor Squeaking:

If you plan to build your own home, remember that the best way to eliminate the problem involves:

(a) using straight, true, properly seasoned flooring materials and joists,

(b) building a rigid well-constructed and properly supported floor system,

(c) controlling proper moisture content of flooring prior to installation,

(d) inserting building paper or felt between finish and subfloor layers to eliminate rubbing or sliding contact,

(e) employing good nailing techniques.

Ways to Remedy Existing Problems:

If you have floors that squeak, the following recommendations should help you correct the problem.

(a) With someone walking over that section of the floor that squeaks, closely examine the finish floor to see if it moves excessively.

The light beam from a flashlight placed on the floor will tend to show floor deflection or motion more vividly.

(b) If your finish floor consists of wood block or strip flooring, and you detect no movement, lubricate the tongues of wood blocks or strips with mineral oil applied sparingly at the seams between adjacent boards.

(c) Loose or bowed finish flooring may be securely fastened to subflooring by surface nailing with ring type or serrated nails into the subfloor and preferably the joists. Recess the nail heads and fill the hole with a wood sealer that matches the floor color. If the nails tend to split the flooring, predrilling a very fine hole through the finish floor before nailing will eliminate the problem.

(d) If the floor joists are exposed, and the finish flooring is warped, you can drill clearance holes through the subfloor and drive wood screws through the holes into the finish floor. The screws will draw the two layers of flooring tightly together.

(e) In places where the joists are warped or bowed, gaps will occur between the subflooring and the joists. Inserting wedges or shimming material tightly in the gap usually will remedy the problem. If the gap is very long, a 2" x 4" brace pressed up against the subfloor and nailed securely to the warped joist will provide adequate support.

(f) Excessive deflection of the structural floor due to lightweight or widely spaced joists may be corrected by the insertion of a few extra joists, if the under surface of the floor is exposed. However, if there is a finished ceiling below the floor, cross- beaming with support columns may be the most expedient corrective measure.

CONTROL OF STAIR SQUEAKING (See Fig. 4-18)

Stair squeaking may be caused by:

(a) loose or warped treads (the flat horizontal steps), or

(b) the binding and rubbing of the treads against the top or bottom edges of the risers (the upright or vertical boards).

Remedies:

(a) If the treads are loose, they should be nailed securely to the center and side stringer (the saw tooth side frame that supports the staircase).

(b) If the treads are warped, inserting wedges between the tread and stringer usually will eliminate the rocking motion of the tread when it is stepped on. Drilling clearance holes through the treads, where they are supported by the stringer, and driving long wood screws through the holes into the stringers will pull a warped tread down tightly onto the stringer.

(c) Lubricating the top and bottom of the risers edges with mineral oil or spray silicone often will remedy the squeaking problem.

(d) Sometimes nailing the front edge of the tread to the riser or inserting thin wedges at the bottom of the risers will correct the squeaking problem.

(e) If the backside of the stairs is accessible, the back edges of the treads may be nailed to the risers. Additional bracing also may be added by fitting a 2" x 4" brace between the stringers, pressing it up against the bottom edge of a riser and nailing it securely to the stringers.

CONTROL OF HEATING, VENTILATING AND AIR-CONDITIONING SYSTEM NOISE: (See Figures 4-19 and 4-20)

The noise problem associated with heating, ventilating and air-conditioning systems is due primarily to the current trend of installing, in homes and apartments, small compact units driven by noisy high-speed, motor-coupled blowers. The blowers usually are coupled to short unlined supply ducts, and open corridors serving as centralized air return ducts, which aggravate the problem.

The problem reaches serious proportions when, for economic reasons, such units are installed in a closet centrally located in a house or an apartment. The typical closet provides virtually no sound attenuation. Because of its light-frame construction, louvered door, and large return air grille, the noise radiates with undiminished intensity throughout the home or apartment.

Homeowners and tenants alike often complain that their sleep is seriously disturbed throughout the night because of the noisy equipment. The noise also is a constant source of irritation and annoyance to them even during their leisure hours. However, they have no choice but to tolerate the noise or else suffer the discomfort of a poorly heated or air-conditioned dwelling, if they turn off the equipment.

Causes of the Noise

(a) Motor and Blower: In a typical installation, the high-speed motor and blower, which generally are coupled together, are the main sources of noise. The mechanical noises of bearings, brushes and switches and the siren-like "blade-frequency" noise of the blower is transmitted both by air through the duct passages and by vibration of the ductwork to supporting wall and floor structures. The "blade frequency" noise of the blower may be determined by multiplying its number of revolutions per minute, by the number of blower blades and dividing the product by 60.

(b) Noise Resulting from Air Flow and Turbulence: Ventilation systems using high-speed blowers are characterized by high air- flow velocities. High velocity air flowing past obstacles in the duct air stream (sharp corners, ragged joints, dampers and grilles) generate a considerable amount of turbulence. The highly turbulent air flow, which usually occurs at the discharge port of the blower, is the predominent cause of duct vibration in most ventilation systems.

(c) Rigid Mounting of the Equipment: In most installations, the heating and air-conditioning equipment is mounted directly on the floor with all ducts coupled directly to wall and floor structures. As a consequence, the wall and floor structures are set into vibration and radiate the noise with increased intensity throughout the dwelling.

(d) Central Air Return Duct: The installation of the central return duct of a typical home size unit has two serious short-comings. The return duct usually is coupled to the blower by a short- length, unlined duct with a relatively large cross-sectional area. As a result, the grille end of the duct radiates the noise from the motor-blower and air turbulence with undiminished intensity. Since there often are no air return ducts in individual rooms, entrance doors are undercut approximately one inch at the bottom to provide passage of the air and thus complete the circulation system. Unfortunately, the large air gaps under the doors are extremely efficient flanking noise paths which allow the noise to intrude into bedroom or other rooms where privacy is most desired.

If you are planning to build a home, insist that the builder selects quiet equipment and installs it properly for quiet operation. Equipment should be selected on the basis of low noise output. The more progressive manufacturers provide sound power ratings of most types and sizes of equipment they market. Such ratings, which frequently contain sound power levels in various frequency bands under different load conditions, are useful for acoustical design purposes. A few salient points worth remembering are:

(1) It is less expensive to install quiet equipment than to reduce the noise output of a cheaper unit by costly acoustical treatment or construction.

(2) Centrifugal or squirrel-cage fans are less noisy than vaneaxial propeller fans, all other factors being equal.

(3) For a given air flow capacity, large-diameter, slow-speed, belt-driven blowers are substantially less noisy than small-diameter, high-speed motor-coupled blowers.

(4) Basement or slab-on-grade locations, far removed from living quarters, are preferred for the typical heating and cooling equipment installations. Attic locations should be avoided.

(5) For purposes of noise control, it is more advantageous to install equipment with output capacities which are greater than required, instead of installing smaller units which must labor continuously at maximum speed in order to meet the building's minimal heating or cooling requirements.

Although the above advice may be useful to the potential homebuilder, it unfortunately offers no comfort to the family who has a noisy heating and air-conditioning system in their home or apartment.

If you have a noisy heating and ventilation system, check the following listing of possible noise sources; adopting some of the recommended remedies may reduce the noise output significantly.

<u>Remedies</u>:

Motor and Blower:

(a) lubricate or oil bearings,

(b) clean blower blades,

(c) if blower is belt driven, replace worn or frayed belts, adjust tension on belt to prevent belt resonance "drumming" and check pulley alignment,

(d) mount motor and blower on resilient isolators, if possible,

(e) reduce the rotational speed of the blower, a 25% reduction may decrease the total noise output as much as 8 dB. However, consult with a professional heating and air-conditioning engineer for proper advice and instructions, especially if rewiring of motor connections is required.

(f) install acoustical duct liner on the interior surfaces of the motor-blower enclosure.

Mounting of Equipment:

(a) Place vibration isolators under both the motor blower and the heating and air-conditioning equipment. Sufficient isolation may be obtained by mounting all the equipment on a 5/8" (16 mm) thick plywood base resting on a 5/8" (16 mm) thick pad of glass fiber.

A 2-1/2" (6 cm) square, 5/8" (16 mm) thick pad of ribbed rubber or neoprene covered with a hardboard or metal plate placed under each corner of the equipment would also provide adequate isolation.

(b) Insert flexible canvas or plastic connectors at the blower end of both the supply and return ducts.

The above measures should reduce the noise output significantly.

Central Return Air Duct:

(a) All interior surfaces of the return air duct should be treated with acoustical duct lining, or

(b) the duct should be fitted with a suitable prefabricated silencer.

Central Closet Installation:

(a) Replace the louvered door with a solid core door equipped with a perimeter rubber gasket and a threshold drop closure.

Caution: The door louvers provided the ventilation of the closet for proper heating and combustion. It is necessary that the ventilation be maintained by other means. See next item.

(b) If the wall studs are exposed, build or install an acoustically lined air transfer grille, as illustrated in Fig.4-11. to preserve the required ventilation and noise isolation.

(c) Nail resilient channels horizontally to the studding, spaced 24" (60 cm) apart; fill space between the channels and the backwall with glass fiber blanket; attach 1/2" (13 mm) thick gypsum wallboard to the channels with self tapping screws.

(d) Install a ceiling of construction similar to item (c) in the closet.

(e) Apply acoustical tile to both ceiling and wall surfaces in the closet to reduce noise buildup.

The above measures, most of which are illustrated in Figs. 4-20, 21 and 22, should improve the sound insulation of the closet walls substantially.

CONTROL OF DUCT NOISE: (see Figures 4-21 and 4-22)

Because metal ducts are extremely efficient transmission paths of airborne noise and vibration, considerable attention must be given to the proper design, construction and installation of duct networks.

Equipment Noise

Airborne noises such as motor hum, blower-blade noise, bearing or pulley noise furnace ignition, flame noise, the creaking and snapping noise due to the expansion and contraction of metal parts are easily transmitted through the ducts.

If any of these noises are a source of annoyance, you can reduce the level of noise output substantially by installing sound absorbing lining material or a prefabricated silencer in the ductwork. Such treatment is most effective when it is installed in both supply and return branch ducts serving the individual rooms, and preferably at the open or grille end of the duct. The installation of a ten-foot length of duct liner, as measured from the grille or diffuser, may reduce the loudness of the noise as much as 50% or 10 dB.

Cross Talk

Metal ducts carry noise like speaking tubes on a ship. Thus noise from one room may be carried to another room through an unlined duct serving both rooms. For example, this problem of "Cross Talk" frequently occurs in a common return duct serving back-to-back bathroom installations, or in common ducts in which the grille openings serving separate rooms or apartment units are too closely spaced. Such problems also arise in exposed, thin-wall main ducts which span across adjacent apartment units, even though such ducts might not have any grille openings. Household noises may penetrate the thin walls of the ducts in one apartment, travel through the short duct passage through the party wall and emerge through the thin-wall duct of the adjoining apartment. Noise transmission from one room to another may also occur by way of openings and holes around poorly sealed duct penetrations through wall and floor structures.

Such noise transmission paths short-circuit the sound insulating effectiveness of the intervening party walls and floor structures.

If you are disturbed by noises from an adjoining room or apartment that seem to be coming through a ventilation grille or the walls of the duct in your room, try one or more of the following remedies to alleviate the problem.

(a) Line the intervening duct run with acoustical material or install a sound silencer, preferably at the wall junction.

(b) Remove existing grille, seal opening, and reinstall grille in the duct at a location as far as possible from the party wall.

(c) Seal all openings where ducts penetrate through the wall.

(d) If the noise is coming through the duct wall enclose the duct in a box made of gypsum wallboard.

Duct Noises

The creaking and snapping noises caused by the expansion and contraction of ductwork due to temperature variation often are a source of disturbance.

Likewise the booming noise caused by the ballooning and collapsing of thin-wall ductwork as the "blower" cycles on and off may be loud enough to interfere with a person's sleep.

If you are troubled by noisy ducts, the following measures may be useful in reducing or controlling the noise:

(a) Support ducts on resilient mounts or hangers to prevent wall and floor structure from amplifying the noise. The resilient mounting will permit the ducts to expand and contract without binding against some wall or floor construction.

(b) Wrap the ductwork with two or three layers of building paper which will act as a vibration damper. The paper may be taped in place or held with wire ties. This treatment will tend to suppress any vibration set up in the duct walls and restrain the "ballooning" action of the duct by adding some much needed mass and bracing to the flimsy duct work.

(c) Install 3/4" (19 mm) thick glass-fiber-board sound absorbing lining on the inside surfaces of the ducts where "ballooning" occurs. The glass-fiber board, which is rigid enough to support the duct walls, and to act as a vibration damper, will also absorb some of the noises generated within the duct system.

(d) Using sheet-metal screws, install braces made of metal bars or folded strips of sheet metal across the largest or widest sections of ductwork or at places wherever "ballooning" occurs. The braces will provide adequate support of the duct walls and thus prevent this type of motion.

Air Flow Noise

High velocity air flow generates noise not only within the ducts but at the face of the outlet grille or diffuser as well. The intensity of flow noise is strongly velocity dependent. For a given duct area, decreasing the flow velocity 50% may decrease the output noise level as much as 15 to 24 dB.

Air flow velocities of about 15 feet (4.5 m) per second are quite acceptable for most homes and apartments. However, to be on the safe side, flow velocities in noise sensitive areas should be lowered to about 8 or 9 feet (2.5-3 m) per second.

The most expedient way of reducing air flow velocity is to decrease the rotational speed of the blower, providing that it does not interfere with the heating or cooling efficiency of the system.

Grille Noise

Noises generated within induction units or at the faces of outlet grilles or diffusers give rise to numerous complaints from tenants. The intensity and characteristics of such noise are dependent upon the airflow velocity and the size and design of the outlet units. For example, high velocity air striking the face of an outlet grille often generates a high-pitch whistling noise.

Removel of the grille is a simple expedient test to determine the cause of noise. If there is no appreciable reduction in the noise output without the grille, the noise may be due to turbulence within the discharge duct or some other source farther back in the duct system. If there is a marked reduction in the noise output without the grille, it is evident that the grille was at fault and therefore should be replaced with one of better design, or the air flow speed should be reduced if practicable.

The following points are worth remembering when choosing outlet grilles and diffusers for quiet operation.

(a) Grilles or diffusers which radiate little noise are made of heavy-gage metal with widely-spaced streamlined deflectors devoid of any sharp corners or edges.

(b) A low-spread air diffuser will generate substantially less noise than a large spread unit, all other factors being equal.

(c) Grilles constructed of wire mesh or perforated metal facings with large openings are less noisy than those with tightly woven or small openings which restrict the air flow.

Furnace Combustion Noise

There are two types of noise associated with furnace combustion that sometimes cause annoyance. They are the muffled explosion noise when the gas or oil is ignited and the very high-pitched whistling noise caused by high-velocity gas flow through the fuel nozzle or burner jets.

The most expedient way of dealing with this problem is to have a heating engineer adjust the fuel pressure or install nozzels with proper openings for quiet operation.

If the furnace operation is still too noisy following such adjustments, the installation of sound absorbing material in the ductwork will reduce the noise to acceptable levels.

Steam Heat Noise

The hammering and knocking noises in steam pipes and radiators may result from water being trapped in the lines. This frequently is caused by vapor lock, partially open valves or improper drainage of pipes and radiators.

If you have noisy radiators, you may alleviate the problem by:

(a) Opening all valves completely to allow trapped water in the system to drain back to the boiler.

(b) Placing thin blocks or wedges under the legs of the radiator opposite the input end to increase the drainage angle, and thus allow any trapped water to drain away.

(c) Replacing faulty pressure release valves.

(d) Inserting heat-resistant resilient material around the pipes at points of support or penetrations through walls or floor structures, to eliminate the rubbing contact and the resulting noise caused by the expansion and contraction of the pipes.

Noise from Baseboard Heating Systems

Homeowners and apartment dwellers alike frequently complain about the noisy operation of baseboard heating systems, in particular the hot water heating system and the electrical heating system.

Hot Water Baseboard Heaters

Causes of Noise

The noise produced by such heaters generally is caused by:

(a) the expansion and contraction of pipes, heater components and housing,

(b) water flow and turbulence, and

(c) pump and motor vibration.

Remedies

(a) Heaters and associated piping generally creak at joints, connections and points of support or contact with building structures during expansion and contraction due to temperature variation. When the units are rigidly connected to walls and floors, these structures behave like sounding boards and amplify the noise. Therefore, in order to minimize this problem, heat-resistant resilient sleeves or collars should be placed at all pipe clamps, supports and penetrations through wall and floor structures. Similar measures should be taken to isolate the heater units from the walls and floors using heat-resistant resilient spacers and leg mounts. Soft asbestos pads may be used for this purpose.

Reducing the expansion and contraction noise of the heater assembly itself is somewhat more difficult to achieve. Sometimes, attaching braces of folded sheet-metal strips to the long narrow panels of the heater assembly will suppress the noise due to buckling and popping of the panels during the heating cycle.

Securely fasten all loose panels and hardware on the heater assembly to suppress buzzing and rattling noises.

(b) If the pipes tend to "sing" a high-pitched noise, this is an indication that there is high-velocity, turbulent flow in the system, which generally is caused by using an oversize, high-speed pump and undersize piping.

This problem can best be alleviated by decreasing the rotational speed of the pump or replacing it with a slow-speed model

(c) Pumps and driving motors should be mounted on resilient pads to prevent vibrational excitation of the floor.

Flexible hoses similar to auto heater or radiator hoses should be installed in a "U" shaped configuration between the pump and pipe system to suppress the transmission of pump vibration to the pipe system.

Installing a surge tank in the system at the discharge end of the flexible hose will further suppress vibrations from the pump and dissipate pulsation from the impeller.

Electrical Baseboard Heaters

Causes of Noise

(a) The major source of noise is the expansion and contraction of the heater assembly and component parts and the amplification of the noise by wall and floor structures in direct contact with the heating system.

(b) Another source of annoyance is a low frequency resonance of the heater assembly, which sounds like the low-pitched hum of a transformer.

(c) Some installations have individual thermostat controls in each room. The clicking of a thermostat in the still of the night can be extremely irritating, particularly if a person is trying to sleep.

Remedies

(a) To alleviate the noise of expansion and contraction of the heater assembly, use the method discussed above for hot water heaters.

(b) In a typical installation, the low-pitched humming noise generally is radiated at amplified levels by a large wall which is directly connected to the resonating heater assembly. Structurally isolating the heater from the floor and wall with heat-resistant, resilient spacers and leg mounts should reduce the noise output to acceptable levels.

Attaching braces of folded sheet-metal strips to the long narrow panels of the heater assembly will further suppress the low-pitched humming noise or resonance.

(c) If your thermostat is excessively noisy, remove the cover plate to determine what type of unit was installed. The noisy thermostats generally use bi-metal, electromagnetic- assisted contact elements which operate off high or line voltage. The "Silent" thermostats use mercury-filled tubes as the contact elements and operate off a low voltage supply. Consult with your heating engineer for advice regarding replacement or interchange of such units.

There are a number of methods that may be used to reduce the clicking noise of thermostats. However power must be shut off before the following methods can be tried.

(1) Remove the cover plate and remove the thermostat from the electrical box. Reinstall the unit with rubber grommets or other resilient mounts to isolate it from the box and wall structure. Replace the cover plate.

(2) If additional noise reduction is desired, wrap the outside surfaces of the electrical box with a thin layer of lead or metal foil-backed tape to damp the vibration. Place lead or tape on the back of the cover plate.

CONTROL OF PLUMBING NOISE
(See Figs. 4-23, 24, 25, and 26)

Most homeowners and apartment dwellers readily admit that noise arising from the use of plumbing facilities anywhere within the home generally can be heard throughout the dwelling, and frequently in adjacent dwelling units as well. Probably because of this characteristic invasion of a person's privacy, plumbing noise ranks not only as an irritating disturbance but as the most offensive noise to which building occupants are exposed.

In any case, it is extremely difficult to isolate yourself from plumbing noise or to prevent it from disturbing other occupants in the building.

Causes of Plumbing Noise and Methods of Control

Water pipes and fixtures are rather ineffective noise radiators because of their small radiating areas. The major problem arises when such sources are rigidly coupled to large efficient noise radiating surfaces such as wall, ceiling and floor structures. Such surfaces, acting as sounding boards, radiate the noise at amplified levels.

Techniques for the reduction and control of common types of plumbing noises are given below. They are listed in preferential order and should be combined for greatest effectiveness.

Isolation of Plumbing System

Unfortunately, most of the plumbing system is installed within the walls and is thus inaccessible to the home owner or apartment dweller. He, therefore, is somewhat limited in the measures he can take to correct the major cause of plumbing noise problem, that is to vibration isolate the piping from all large wall and floor surfaces which act as sounding boards. However, he should make every attempt to isolate exposed piping with bands or sleeves of rubber, neoprene or glass fiber at all points of support, including pipe clamps, straps, and penetrations through wall and floor structures. If necessary, oversized clamps should be used to accommodate the thickness of the resilient sleeve.

Expansion and Contraction of Pipes

The expansion and contraction of pipes produce a staccato-like series of creaking, squeaking and snapping noises which are caused by the sliding or binding of the pipes against studding or other supports. Isolating the pipes from building structures as described above will alleviate the problem.

Noise from Turbulence and High-velocity Water Flow

High water pressures with resultant high flow velocities cause turbulence particularly around bends, valves, taps and connectors which usually contain many sharp edges and constrictions. The familiar hissing noise, occurring frequently at partially opened taps, is associated with turbulence. It has been suggested that this noise is due to the combined action of eddies and collapsing water vapor bubbles.

Although turbulent flow is considered to be the chief cause of plumbing noise, the onset of cavitation in a plumbing system will result in much higher noise levels. Both conditions may exist simultaneously, especially around restrictions in high pressure systems. Cavitation is associated with the collapse of vapor bubbles, which are formed at some restriction by a critical combination of high velocity and low pressure.

High velocity flow in a plumbing system, due chiefly to undersized piping, gives rise to turbulence which frequently generates excessive noise. A noticeable reduction in noise level may be obtained by using proper size piping to lower the water velocity. Flow velocities of the order of 6 ft/sec (2 m/sec) or less in domestic systems have been found to be quite acceptable. Specified flow capacity requirements can be met and a substantial reduction in noise can be obtained by using both pressure regulators and larger diameter piping in the plumbing system.

High-pressure plumbing systems are inherently noisy, due to the resultant turbulent flow generated within such systems. The static pressure of main water-supply lines of buildings with three stories or less should be regulated so that it will not exceed 50 psi (2500 Torr). The water pressure in branch lines serving individual apartment units should not exceed 35 psi (1800 Torr). In high-rise structures where high-pressure main supply lines are required, pressure reducers or regulators should be used in supply branches at various floors to maintain water pressure within the above limits.

Pipe Hammering, Chattering and Vibration

The noisy hammering of a plumbing system is usually caused by the sudden interruption of water flow; for example, by a quick-closing tap. The sharp pressure build up at the point of interruption forms a shock wave which reflects back and forth in the system. The multiple reflections produce a series of hammer-like noises which gradually decrease in loudness as the energy of the shock wave is dissipated. The sudden release of pressure by a quick-opening valve which discharges into a section of piping with a narrow restriction, elbow or tee connector also may cause hammering of the plumbing system.

Noise in plumbing systems is frequently caused by motor driven pumps which, by virtue of rigid mechanical coupling, transfer the vibrational energy of the motor, or the pump to the piping system.

Noises due to such sources are easily recognized, since they consist mostly of pure tones associated with the rotational speed of the pumps or motors. The current trend toward using miniaturized, high-speed, shaft-coupled motor pumps has intensified this problem.

Defective, loose or worn valve stems, faucet washers or seals give rise to intense chattering of the plumbing system. The defective device frequently can be pinpointed without difficulty, since immediate use of the device causes the vibration which generally occurs at some low flow velocity setting and diminishes or disappears at a higher flow setting. For example, if vibration occurs when a particular faucet or tap is opened partially and diminishes when fully opened, the faucet more than likely has some loose or defective parts.

The above pipe noise problems generally can be alleviated by using flexible connectors and air chambers in the piping system and by replacing worn or defective valves, faucet washers and refinishing pitted valve and washer seats.

Flexible connectors should be used in coupling supply and drain pipes to vibrating appliances such as pumps, garbage disposers, clothes and dishwashers. Since such appliances frequently have electrically operated shut-off valves, air chambers or other shock absorbing devices should be installed in supply and drain lines to prevent water hammering of the plumbing system. The air pockets, rubber inserts or spring elements in such devices act as shock-absorbing cushions.

Noise from Draining and Dripping Water

The draining of water from bath tubs, basins and toilets produces gurgling noises which frequently are more annoying than those associated with the filling of such units. The noise problem is intensified when vertical drain systems do not run directly to the basement, but branch off into horizontal pipe runs which usually are supported from floor joists. Falling water striking the horizontal piping sets the drain system into vibration which in turn is transmitted to the building structure.

The noise of splashing of water such as that associated with filling a bath tub can be irritating. Attaching a long resilient hose to the faucet which will reach the bottom of the tub, is an effective way of eliminating this noise problem. In the case where the noise of a dripping faucet is a source of annoyance in the still of the night, as a temporary solution, attaching a string or draping a wash cloth from the faucet will channel the water drops to the drain without noise. Of course, replacing the worn washer seal would be a more permanent solution.

Noise Due to Entrapped Air in Pipes

A relatively common noise problem generally confined to newly constructed buildings is that caused by entrapped pockets of air in the plumbing systems. The combined action of water pressure and compression of the air pockets may produce intense noise and vibration disturbances which are characterized by explosive bursts, spewing and spitting of water and air from open faucets or taps and hammering or knocking of the piping system. Such problems seldom are a source of complaints, unless they persist for extended periods. Generally speaking, the problem eventually corrects itself by gradual release of the entrapped air through continued use of the plumbing services.

HOW TO DESIGN A QUIET PLUMBING SYSTEM

If you are planning to build a home with a quiet plumbing system, you must incorporate the following design elements in the early stages of your building plan.

(a) Vibration Isolate all Plumbing Systems:

A typical modern home or apartment may have three separate piping systems; the hot and cold water supply system, the drainage and venting system, and the hydronic piping system, which includes air-conditioning, and steam and hot water heating systems. One of the most effective solutions to pipe noise problems is to keep the pipe isolated with resilient sleeves and hangers from building structures with large radiating surfaces such as walls, ceilings and floors. Pipes in buildings behave like tuning forks using such structures as sounding boards to amplify the noise levels.

(b) Use a Simple Plumbing Layout:

A well designed plumbing system with a minimum of fittings and bends is substantially less noisy than a complicated layout. Proper size fittings and large-radius elbows or bends should be used for quiet performance. Large diameter piping should be used for all main supply lines. Separate branch lines of smaller diameter should be installed to serve each individual area where required.

(c) Install Pipes Away from Quiet Areas:

Pipes should not be installed in any walls, enclosing bedrooms, living rooms, studies or other rooms where privacy and quiet surroundings are essential. For example, in order to prevent the transmission of noise into bedroom areas, supply and drain pipes should not be installed in walls separating bathrooms and bedrooms. Piping should be installed in partition walls which separate adjacent bathroom or kitchen areas. Supply and drain pipes must be isolated from internal studding or wall surfaces.

(d) Install Quiet Fixtures:

Siphon-jet toilet and flush tank fixtures with adjustable flow valves are considerably less noisy than conventional models. Taps and faucets using full-ported nozzles and equipped with anti-splash or aeration devices produce little noise.

(e) Install Bathroom Fixtures on Resilient Bases and Mounts:

Bath tubs, toilets and shower stalls should be set on underlayments of cork, rubber, neoprene or other resilient materials or installed on floating floors to reduce the transmission of noise due to falling water. Likewise, the fixtures should be vibration isolated from supporting walls by means of resilient gaskets. Such mounting precautions should be observed with respect to installation of wash basins and faucet fixtures as well.

(f) Seal Air Leaks Around Pipe Penetrations:

To prevent noise leaks, seal all openings around pipe penetrations through wall and floor structures with a non-setting waterproof caulking compound. Party walls between bathrooms should be completely finished to floor level on both sides, particularly in back-to-back tub and/or shower installations. Failure to surface the walls behind tubs results in serious noise transmission problems. Likewise, both subflooring and finish flooring in bathroom areas should be completely finished before tubs and shower stalls are installed.

(g) Enclose Large Pipes:

Large diameter pipes in high pressure systems, frequently radiate considerable noise, especially when they are exposed. Such pipes should be boxed in gypsum board enclosures, preferably lined with acoustical material. An alternate, though somewhat less effective, technique is to enclose the pipes in thick glass fiber jackets with heavy impervious outer coverings of plastic or leaded-vinyl materials. It has been suggested that the glass fiber jackets should have a density of about 6 lb/cu ft (96 kg/m^3) and a thickness of at least 3 inches (18 cm). The impervious covering should weigh at least 1 lb/sq ft (5 kg/m^2).

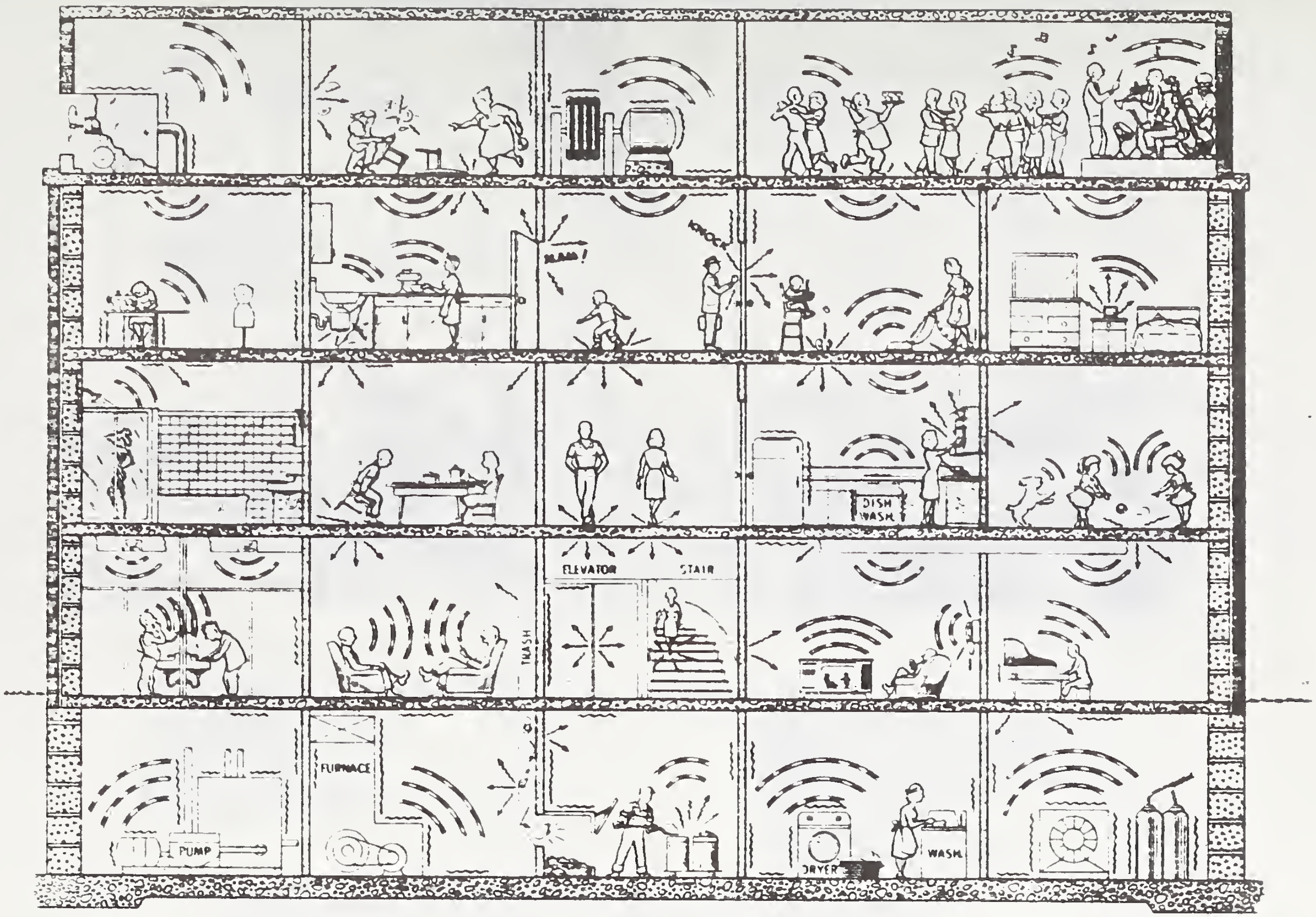


FIG. 4-1 COMMON INDOOR SOURCES OF NOISE

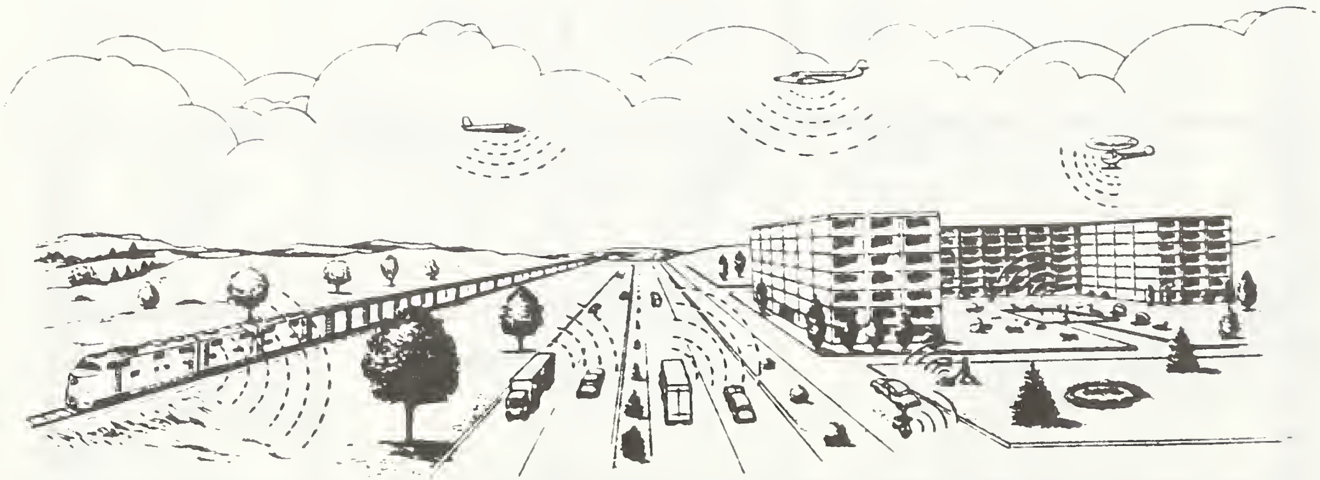
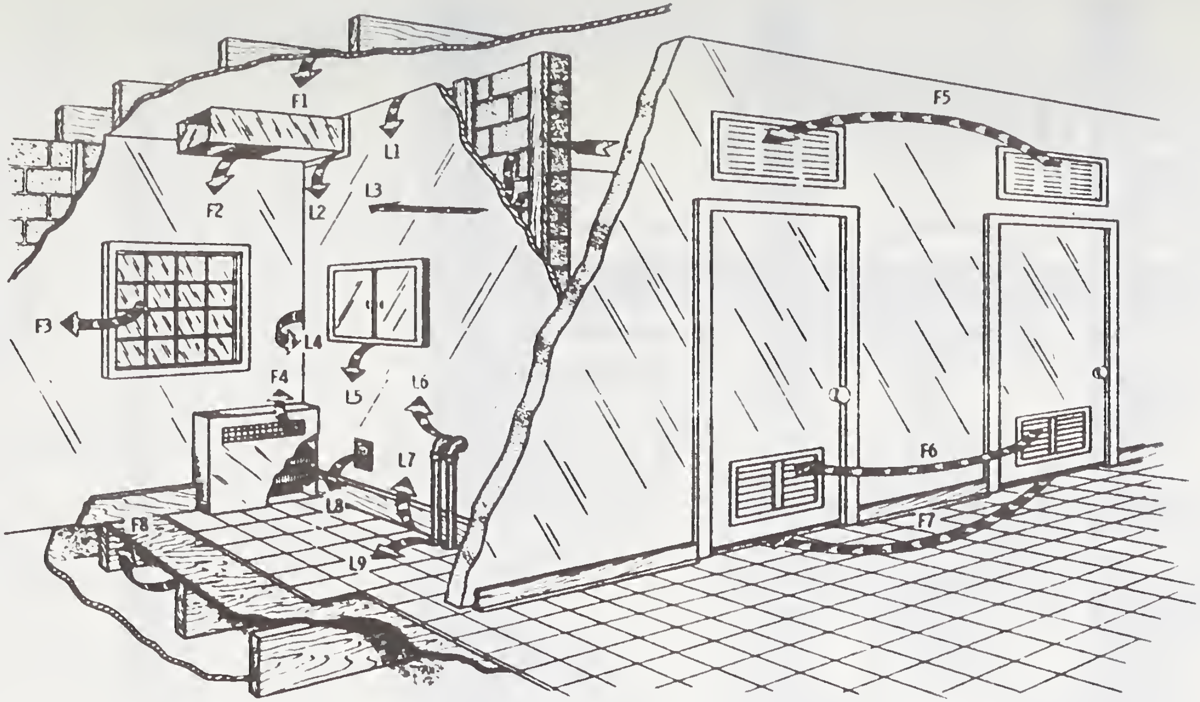


FIG. 4-2 COMMON OUTDOOR NOISE SOURCES.



FLANKING NOISE PATHS

F1 OPEN PLENUMS OVER WALLS, FALSE CEILINGS
F2 UNBAFFLED DUCT RUNS
F3 OUTDOOR PATH, WINDOW TO WINDOW
F4 CONTINUOUS UNBAFFLED INDUCTOR UNITS
F5 HALL PATH, OPEN VENTS
F6 HALL PATH, LOUVERED DOORS
F7 HALL PATH, OPENINGS UNDER DOORS
F8 OPEN TROUGHS IN FLOOR-CEILING STRUCTURE

NOISE LEAKS

L1 POOR SEAL AT CEILING EDGES
L2 POOR SEAL AROUND DUCT PENETRATE
L3 POOR MORTAR JOINTS, POROUS MASONRY BLK
L4 POOR SEAL AT SIDEWALL, FILLER PANEL ETC.
L5 BACK TO BACK CABINETS, POOR WORKMANSHIP
L6 HOLES, GAPS AT WALL PENETRATIONS
L7 POOR SEAL AT FLOOR EDGES
L8 BACK TO BACK ELECTRICAL OUTLETS
L9 HOLES, GAPS AT FLOOR PENETRATIONS

OTHER POINTS TO CONSIDER, RE: LEAKS ARE (A) BATTEN STRIP A/O POST CONNECTIONS OF PREFABRICATED WALLS, (B) UNDER FLOOR PIPE OR SERVICE CHASES, (C) RECESSED, SPANNING LIGHT FIXTURES, (D) CEILING & FLOOR COVER PLATES OF MOVABLE WALLS, (E) UNSUPPORTED A/O UNBACKED WALL BOARD JOINTS (F) EDGES & BACKING OF BUILT-IN CABINETS & APPLIANCES, (G) PREFABRICATED, HOLLOW METAL, EXTERIOR CURTAIN WALLS.

FIG. 4-3 COMMON NOISE TRANSMISSION PATHS IN BUILDINGS.

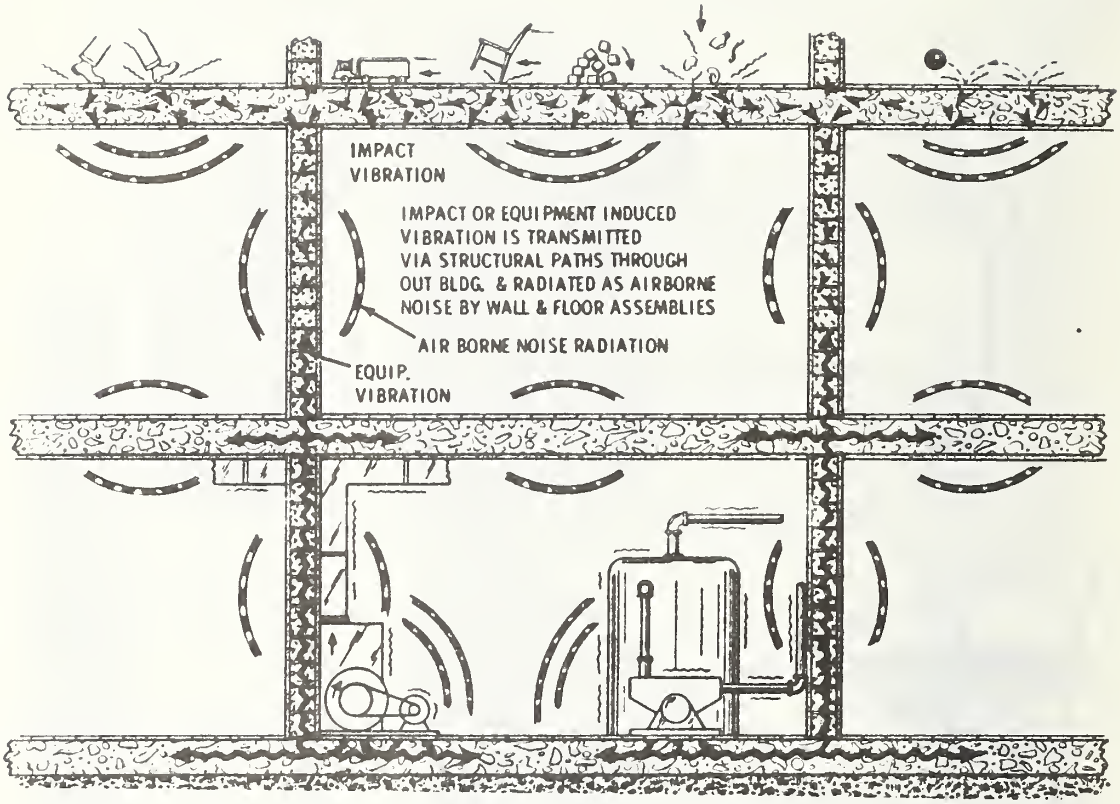
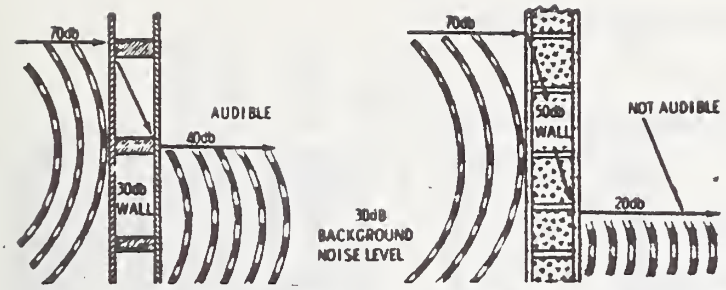
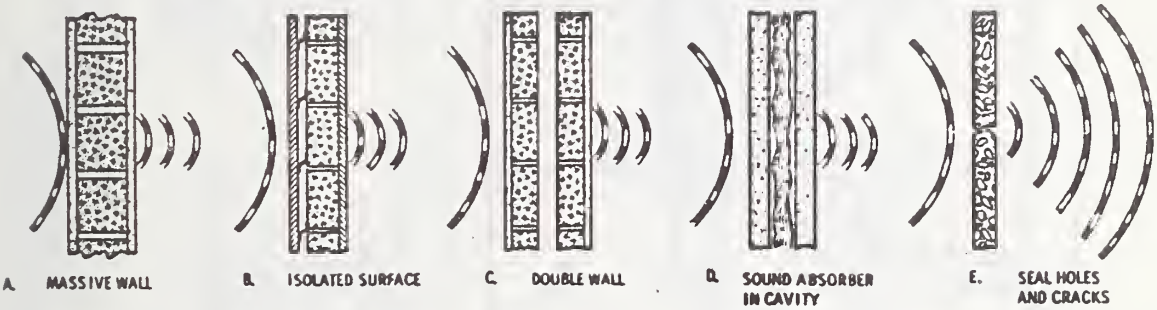


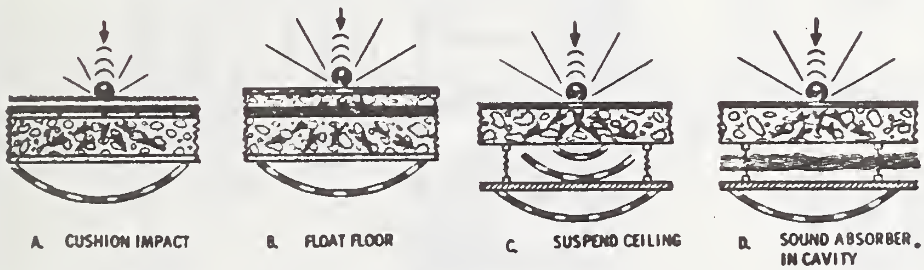
FIG. 4-4 COMMON VIBRATION AND NOISE PATHS IN BUILDINGS.



The objective is to reduce level of the transmitted noise below level of background noise.



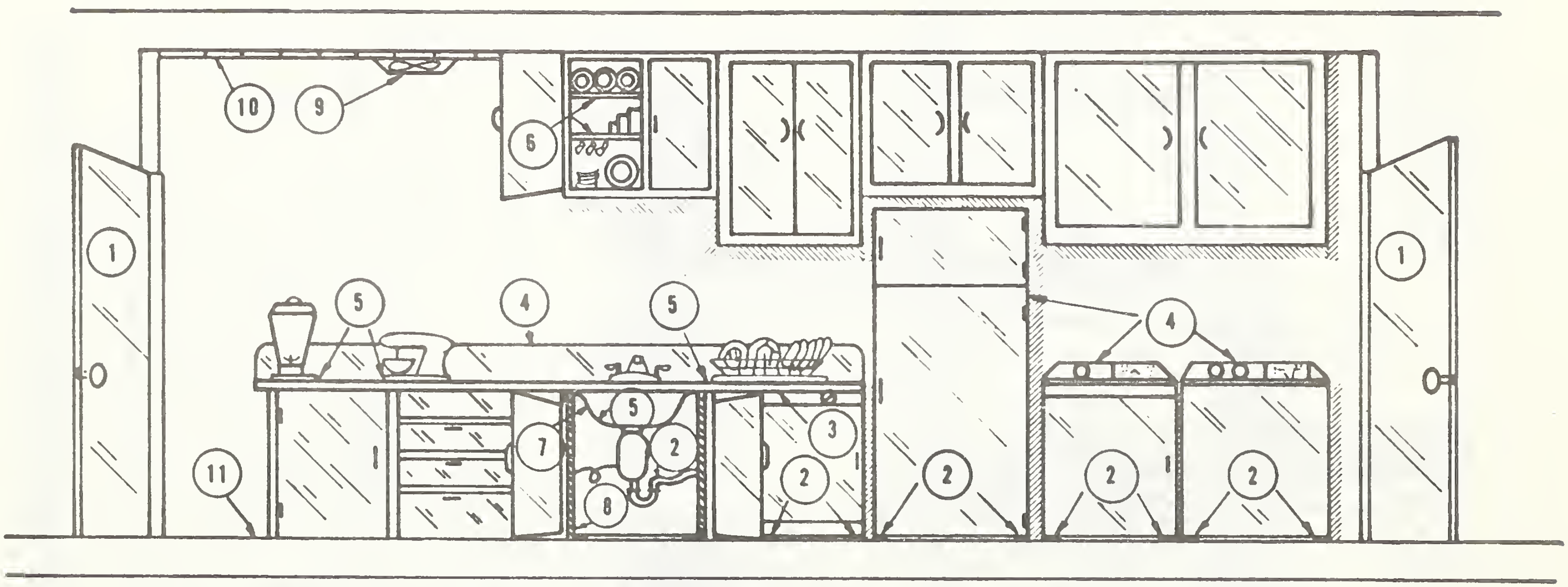
Techniques for the control of airborne noise



Methods for the control of impact noise; the objective is to absorb the impact and to break direct structural connections.

Reducing reflection and noise buildup with sound absorbent furnishings.

FIG. 4-5 GENERAL SOLUTIONS FOR NOISE CONTROL IN THE HOME.



(1) Install solid door with gaskets

(2) Use vibration isolators & mounts

(3) Isolate appliance from cabinet with rubber gasket

(4) Insert rubber gaskets behind cabinets and appliances to avoid wall contact

(5) Place rubber pads under small units, dish racks and in sink basins

(6) Install rubber or cork tile on backs and shelves of cabinets

(7) Apply vibration damping material

(8) Install acoustic tile

(9) Install exhaust fan on rubber mounts

(10) Install acoustic ceiling

(11) Install carpet or foam backed tile

FIG. 4-6 RECOMMENDATIONS FOR REDUCING KITCHEN NOISE.

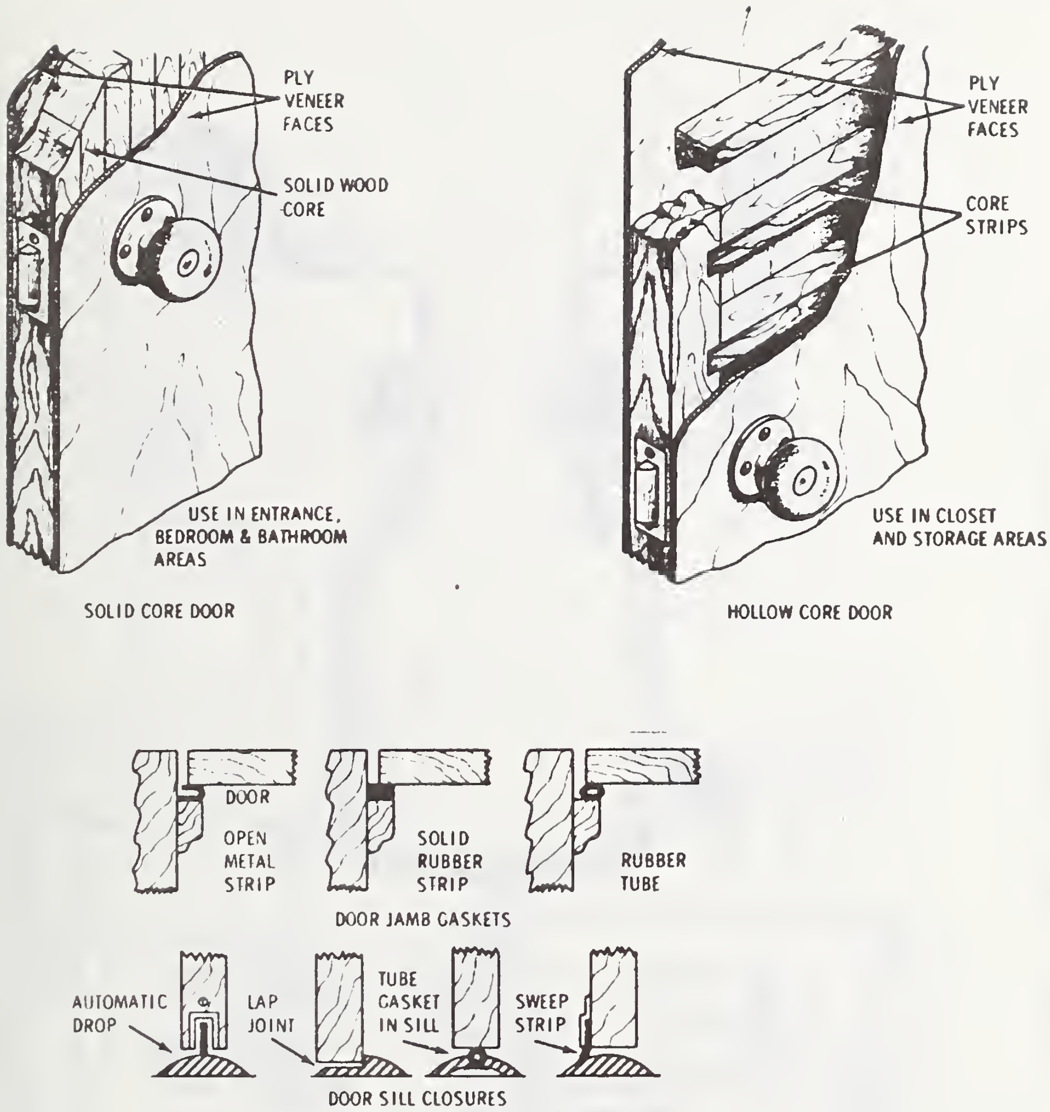
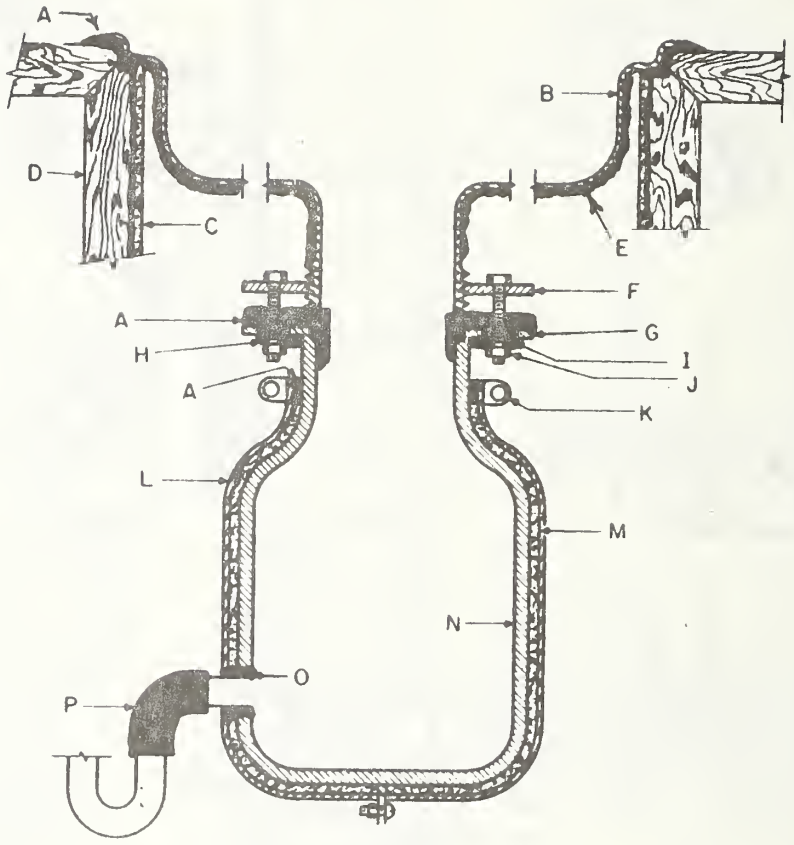


FIG. 4-7 PROPER INSTALLATION OF SOUND INSULATING DOORS.



A - RUBBER GASKET
B - SINK
C - ACOUSTIC MAT'L
D - CABINET
E - MASTIC COAT

F - RING PLATE
G - DISP'L - FLANGE
H - STEEL WASHER
I - RUBBER WASHER
J - NUT

K - RING CLAMP
L - METAL COVER
M - GLASSWOOL
N - DISP'L - HOUSING
O - RUBBER SLEEVE
P - RUBBER HOSE

FIG. 4-8 DESIGN AND INSTALLATION OF A GARBAGE DISPOSER FOR QUIET OPERATION.

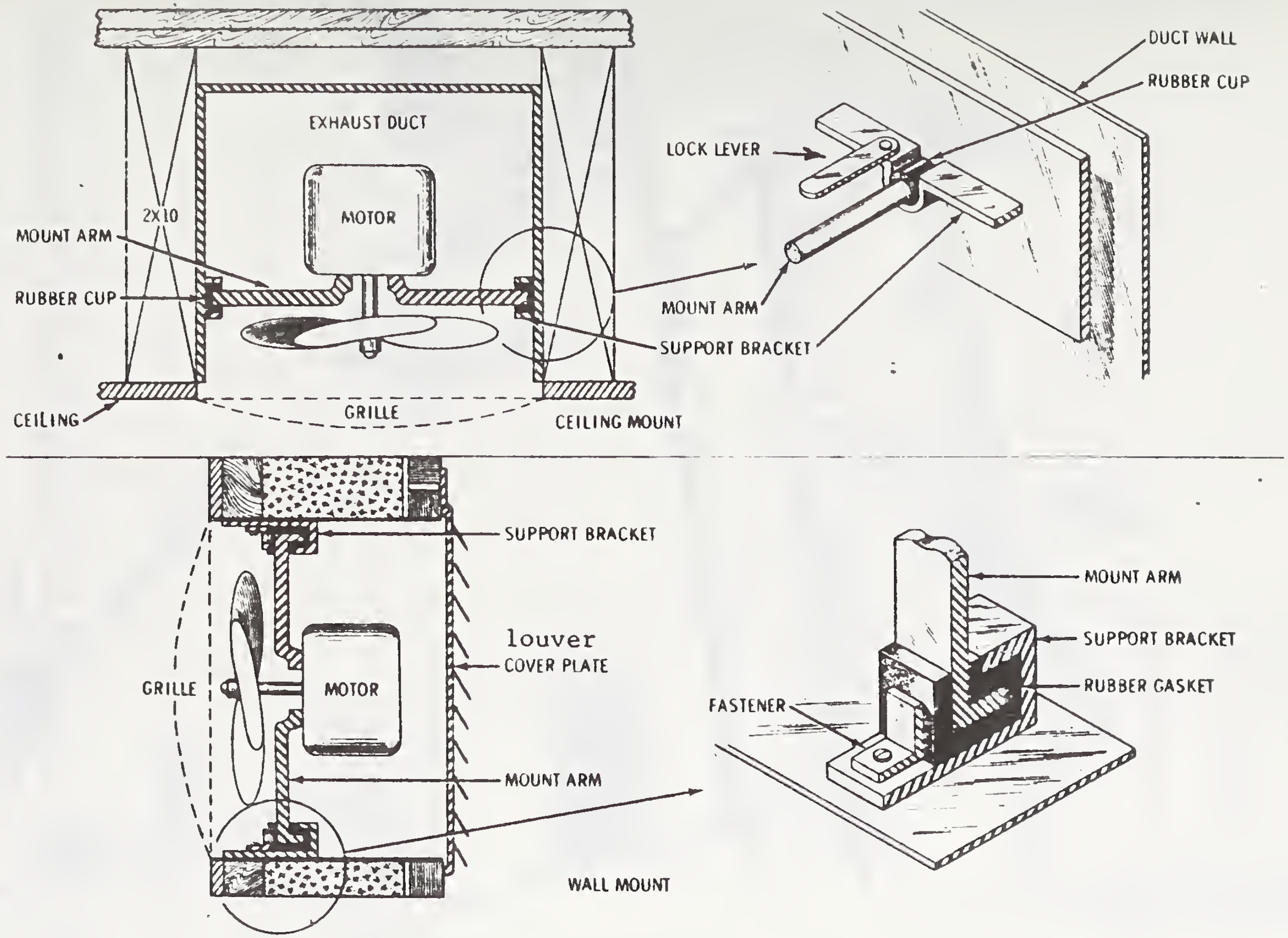
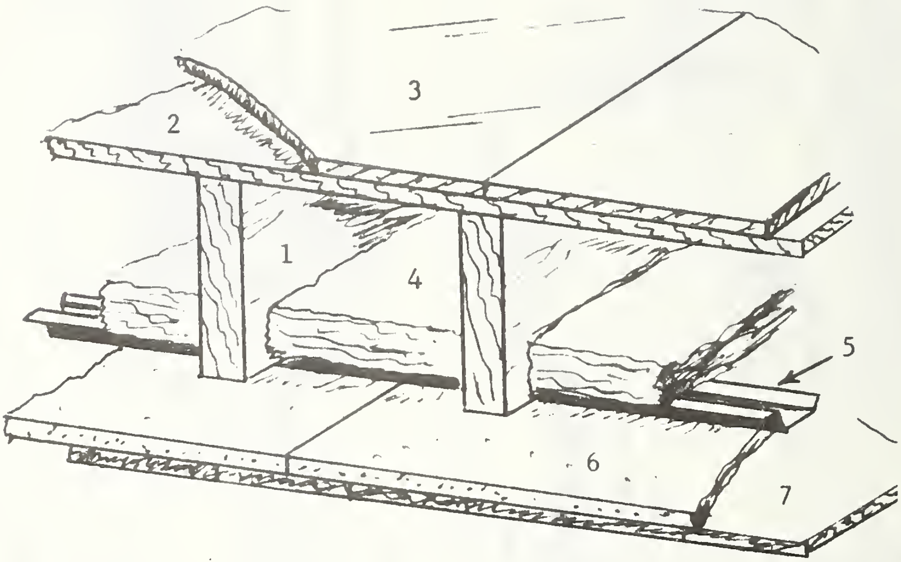


FIG. 4-9 PROPER INSTALLATION OF AN EXHAUST FAN.



1. wood floor joists
2. wood subfloor
3. wood finish floor
4. glass fiber blanket, 3 in thick
5. resilient metal channels
6. gypsum board, 5/8 in thick
7. acoustical tile

FIG. 4-10 DESIGN OF A SOUND INSULATING CEILING FOR A BASEMENT RECREATION ROOM.

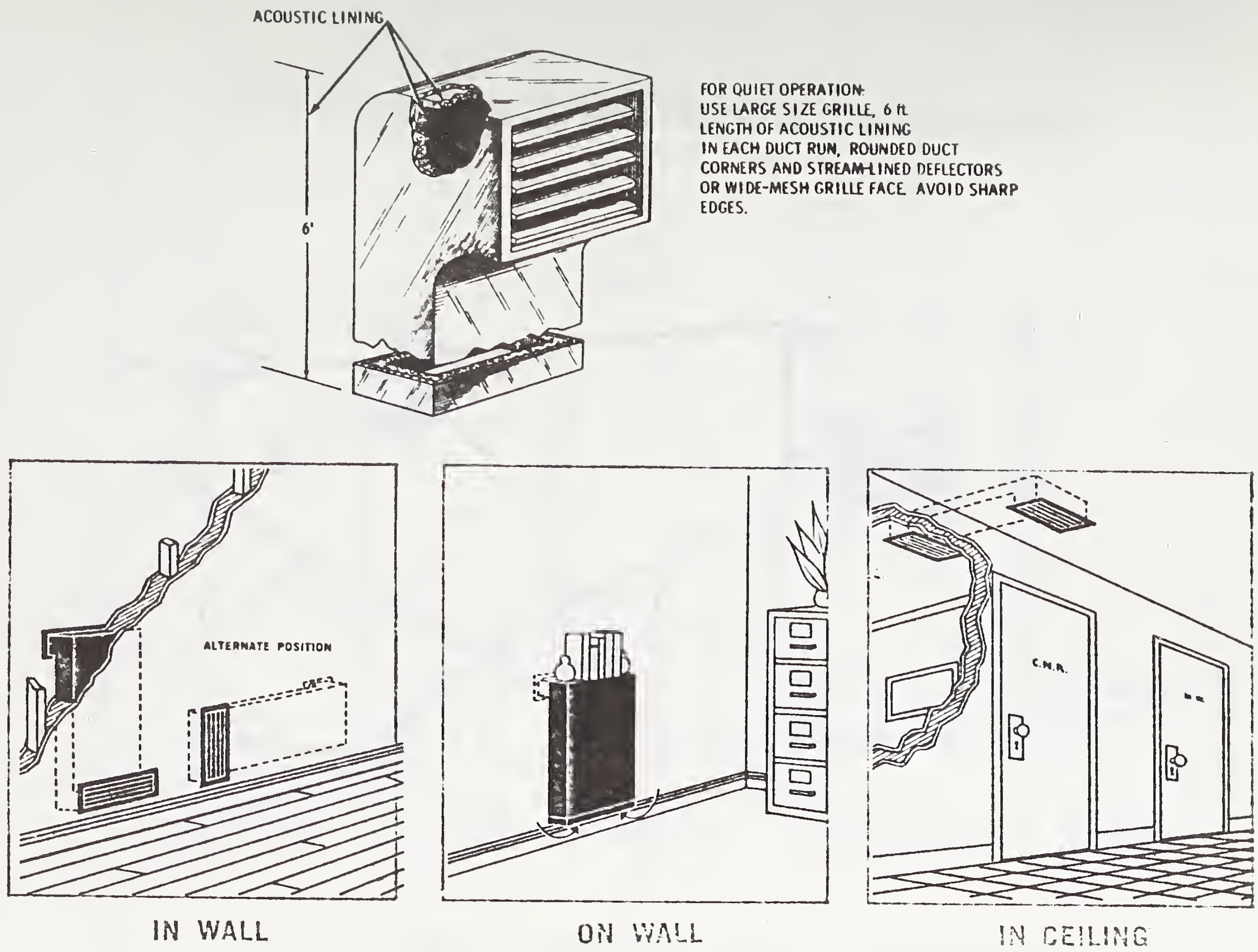


FIG. 4-11 DESIGN AND INSTALLATION OF A QUIET AIR RETURN DUCT.

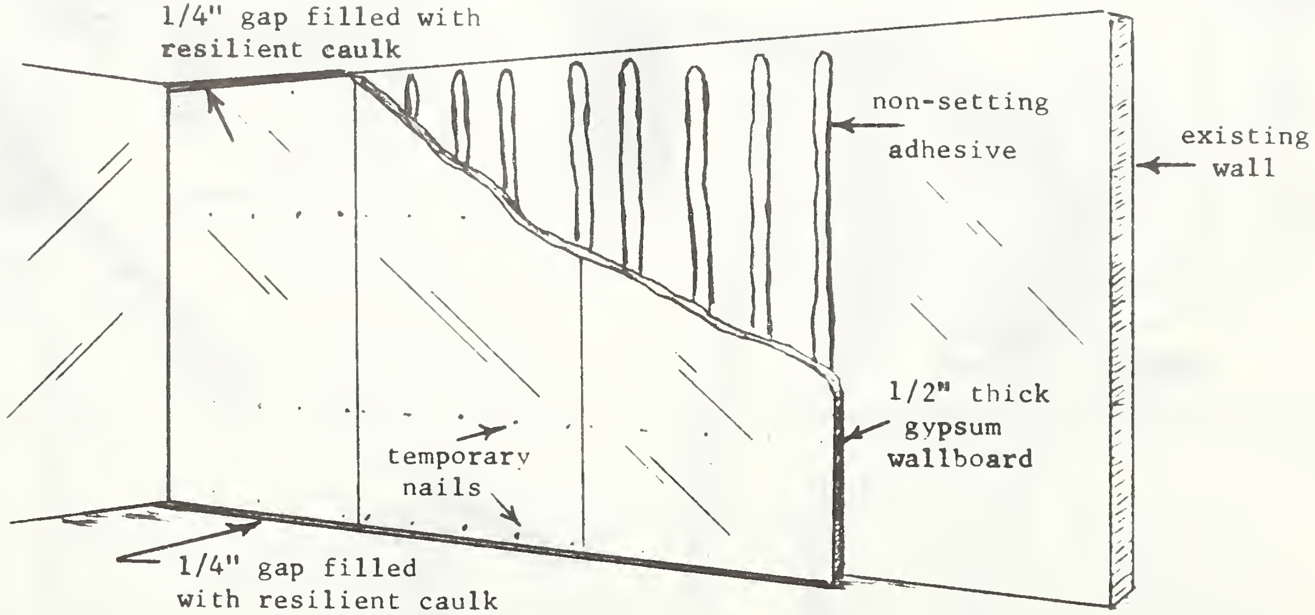
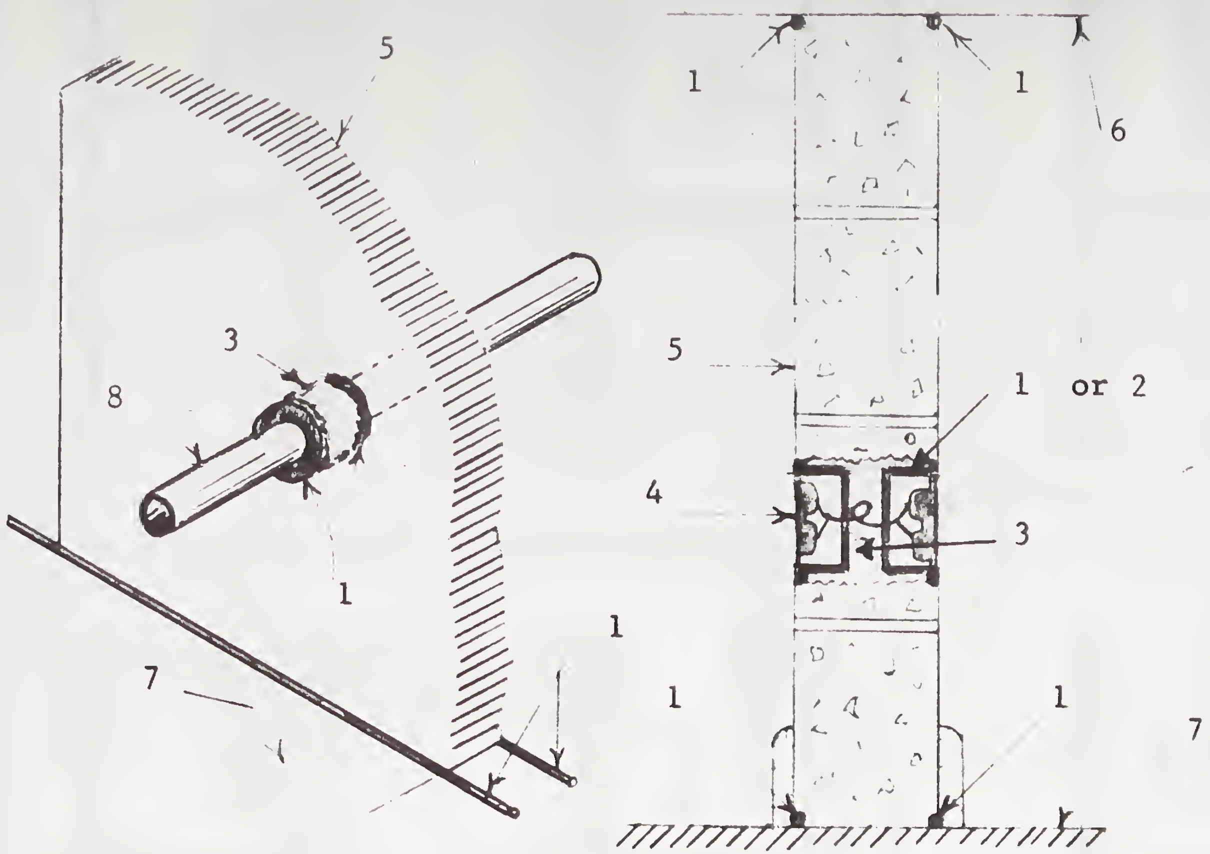


FIG. 4-12 IMPROVING THE SOUND INSULATION OF AN EXISTING WALL.



1. Caulk
2. Lead Wrap
3. Glass Fiber Packing
4. Electrical Outlets
5. Wall
6. Ceiling
7. Floor
8. Pipe

FIG. 4-13 SEALING COMMON NOISE LEAKS IN EXISTING WALLS.

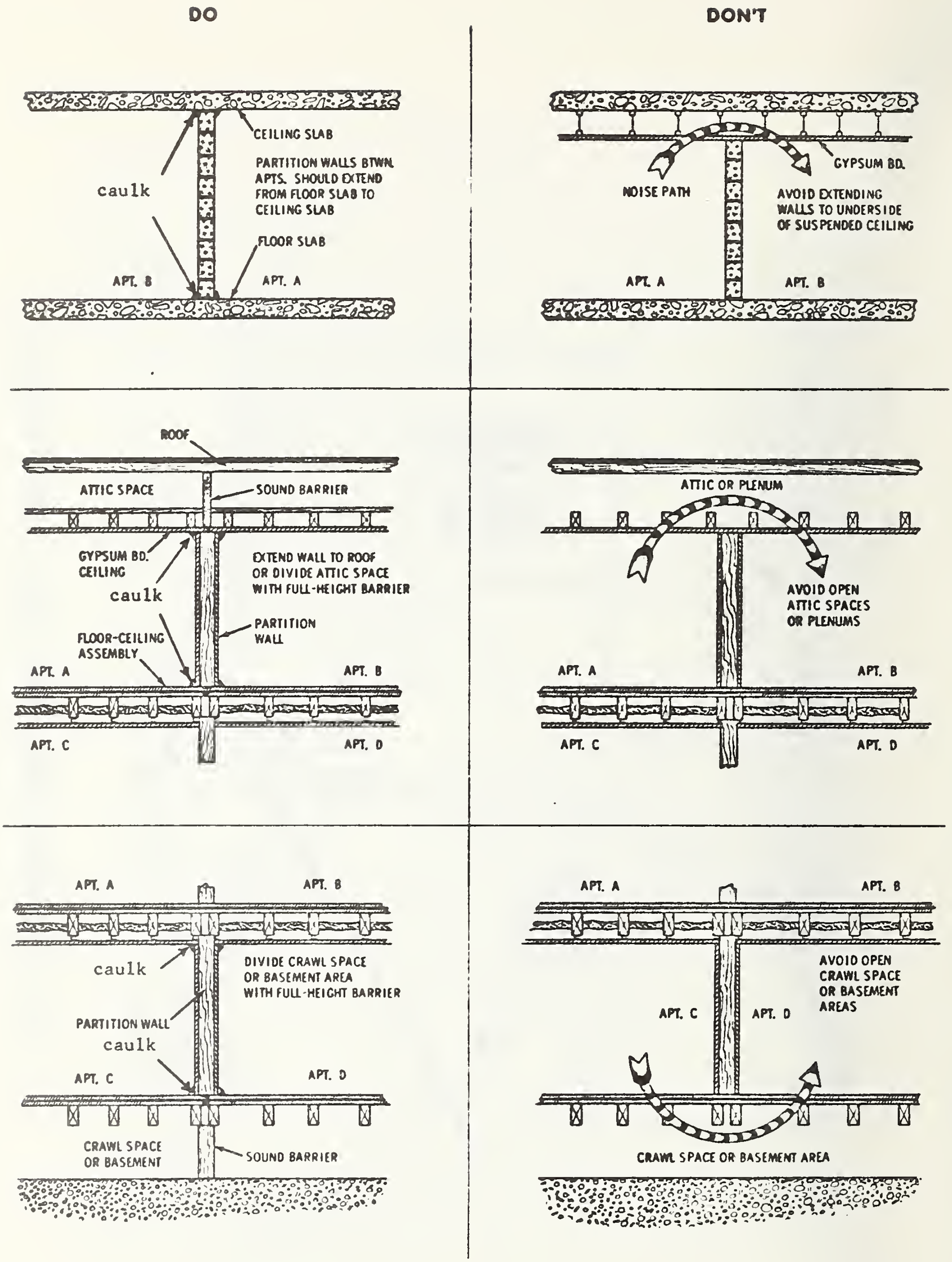


FIG. 4-14 METHODS OF CONTROLLING FLANKING SOUND TRANSMISSION PATHS.

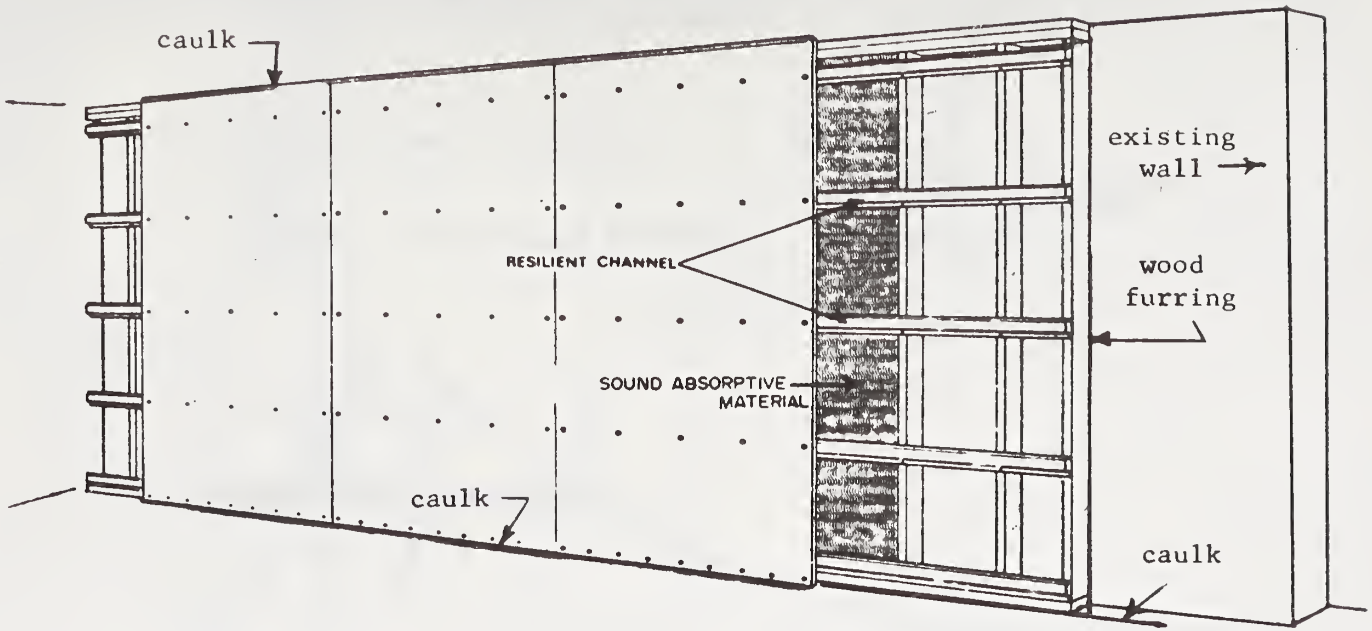
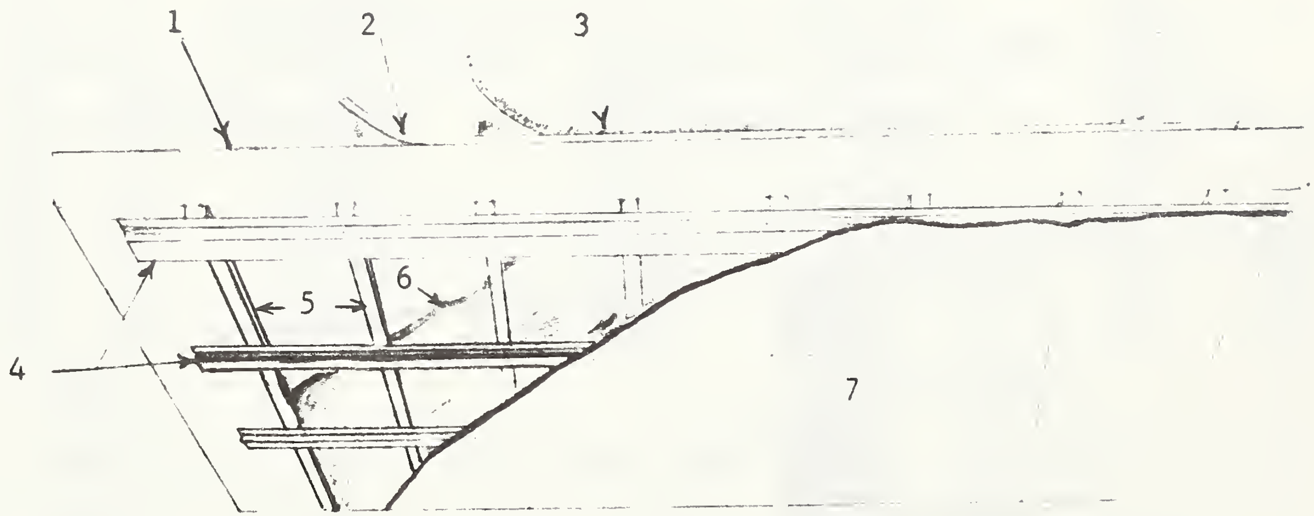
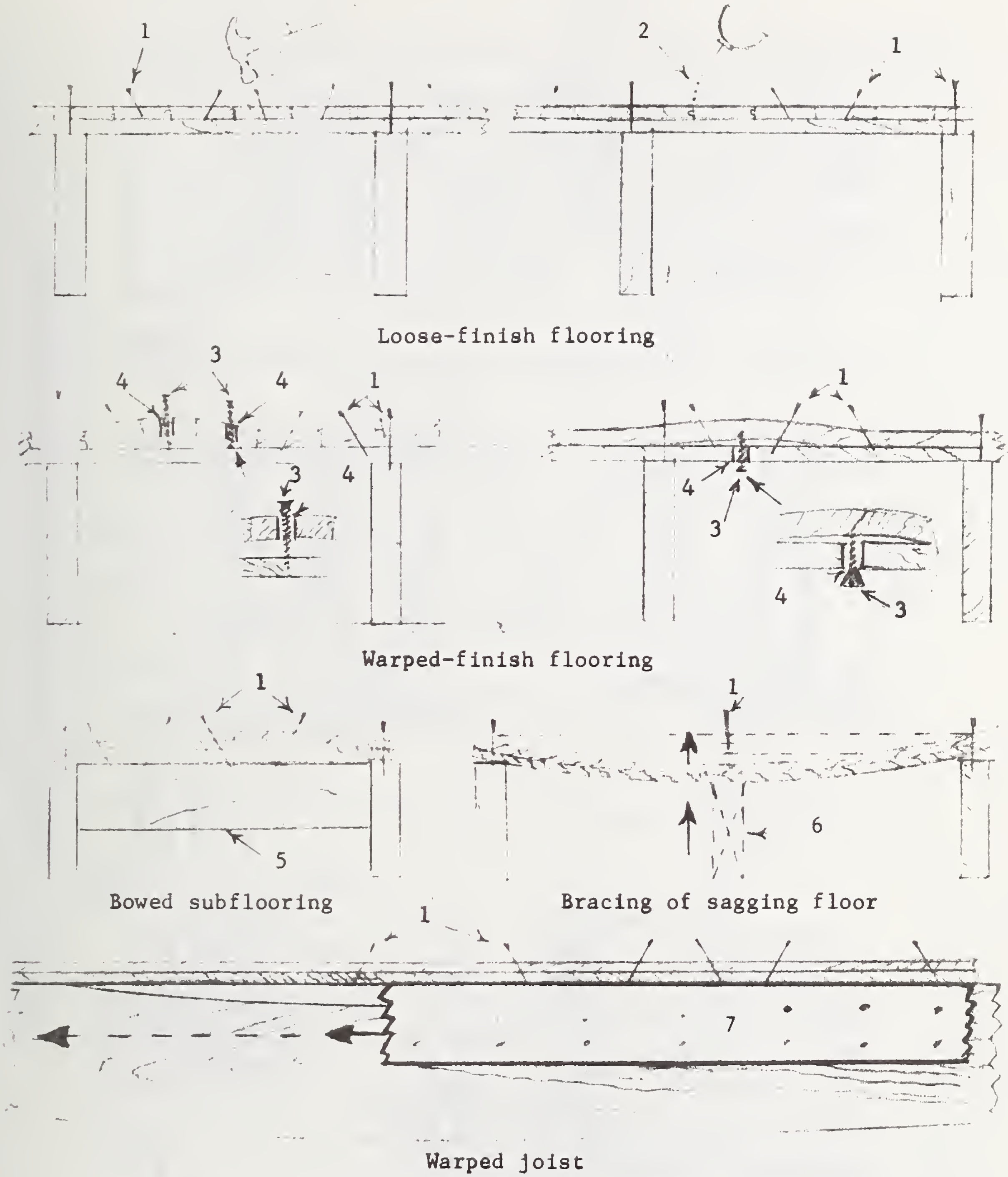


FIG. 4-15 METHOD OF OBTAINING A SUBSTANTIAL INCREASE IN SOUND INSULATION FROM AN EXISTING WALL.



1. Existing floor-ceiling structure
2. Pad
3. Carpet
4. Resilient metal channels
5. Wood furring
6. Glass fiber pad
7. Gypsum ceiling board

FIG. 4-16 METHOD OF INCREASING THE AIRBORNE AND IMPACT SOUND INSULATION OF AN EXISTING FLOOR-CEILING STRUCTURE.



(1) Serrated or ring-type nails
(2) Mineral oil in grooves
(3) Wood screws
(4) Clearance hole
(5) Cross brace inserted
(6) Extra joist inserted
(7) Full-length straight board nailed to joist

FIG. 4-17 TECHNIQUES FOR THE CONTROL OF SQUEAKING FLOORS.

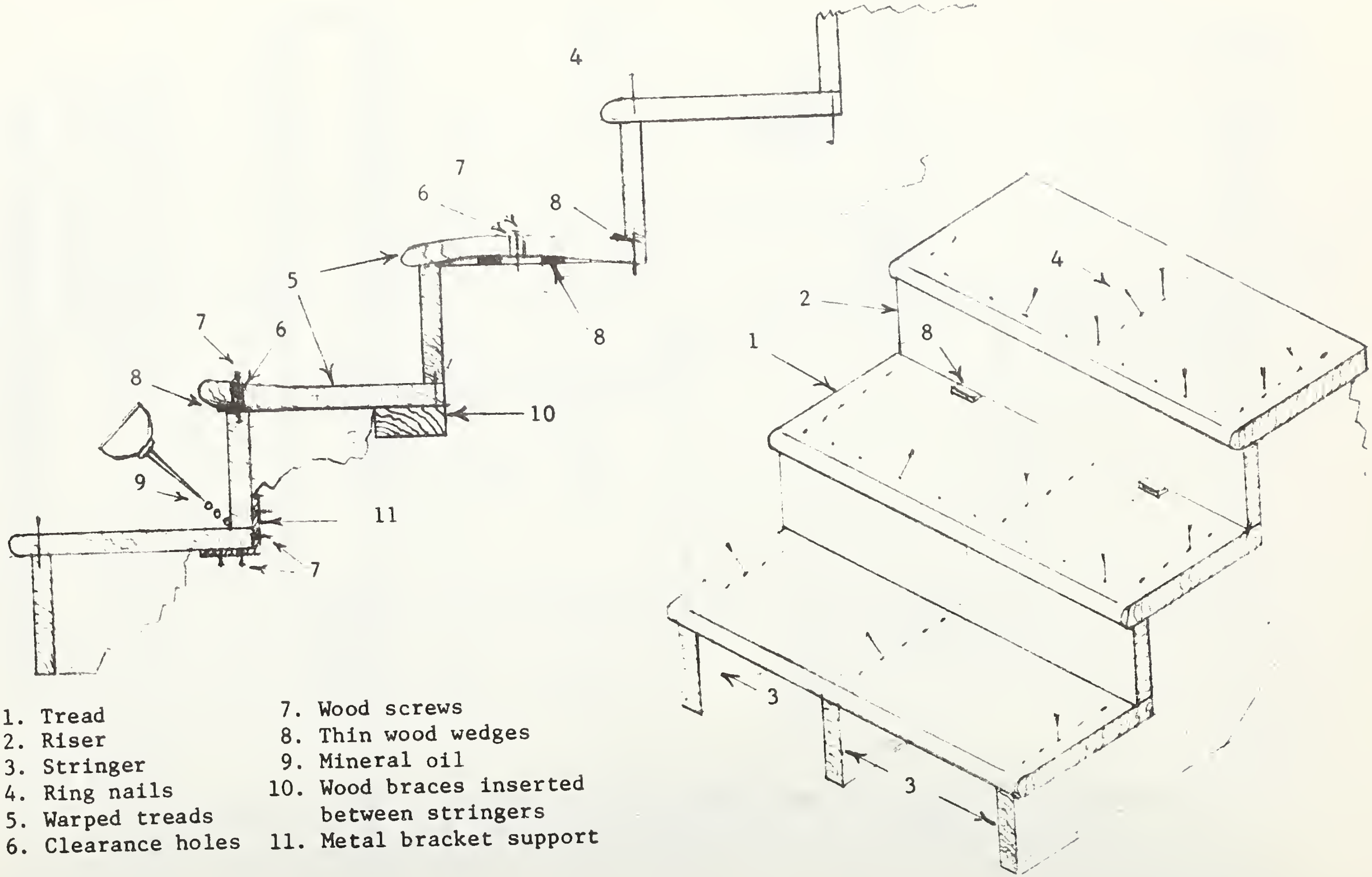
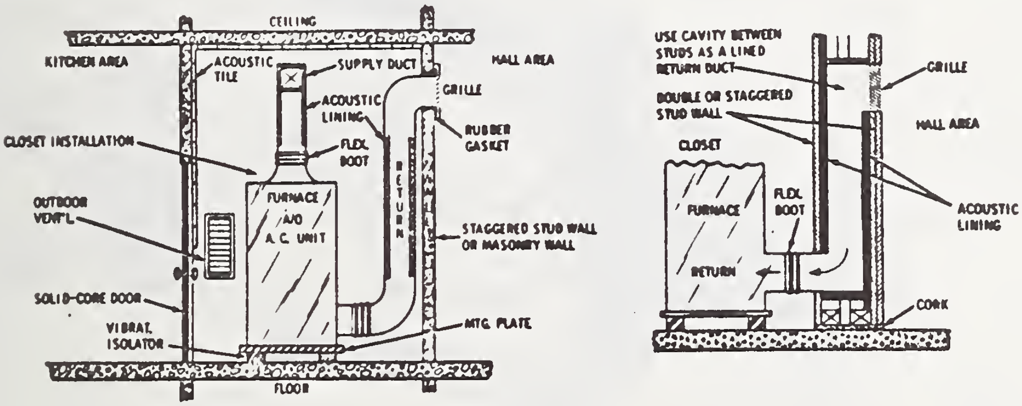


FIG. 4-18 TECHNIQUES FOR THE CONTROL OF STAIR SQUEAKING.

Selecting proper location of closet-installed furnace unit.



Recommended design of closet and installation of furnace unit.

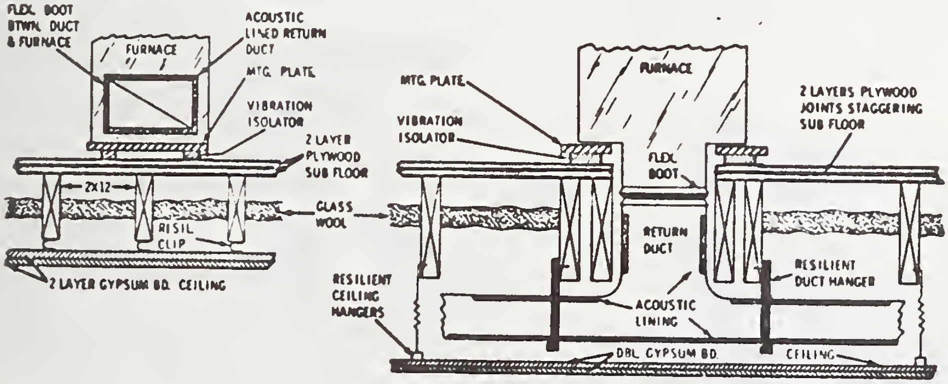
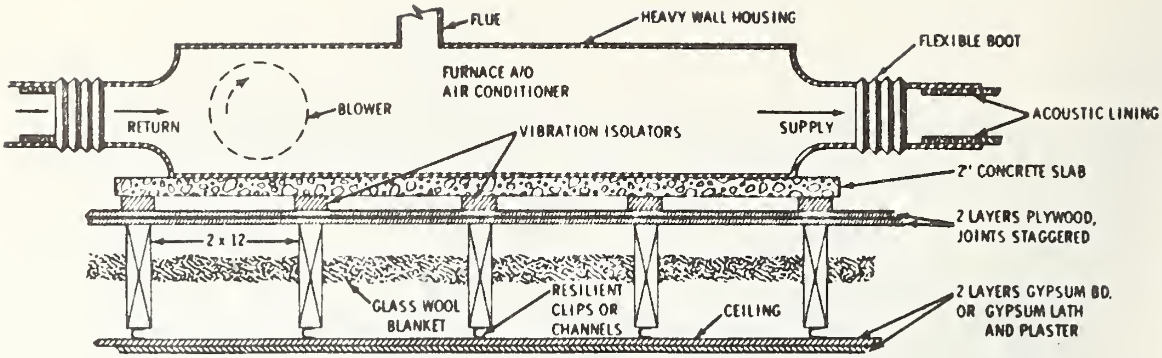
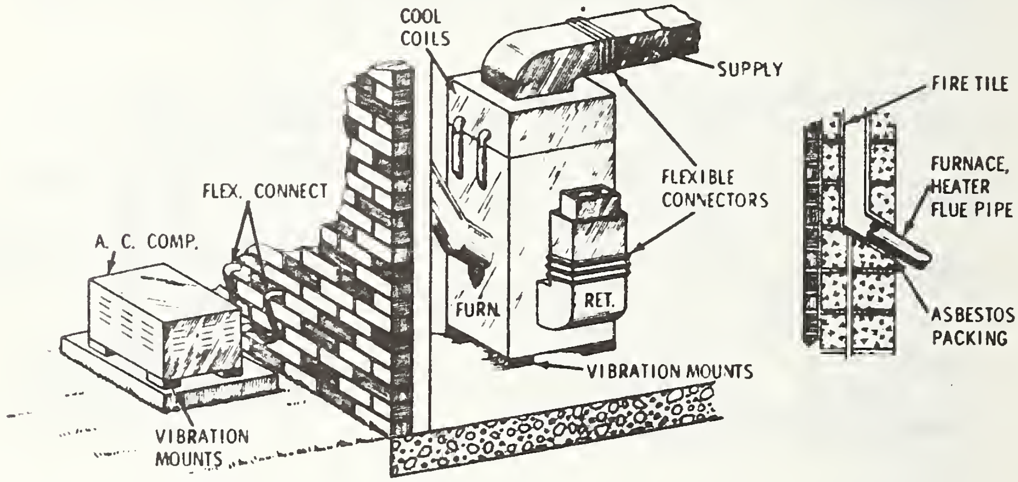


FIG. 4-19 RECOMMENDATIONS FOR NOISE CONTROL OF CLOSET-INSTALLED FURNACE AND AIR CONDITIONING UNITS.



Attic installation



Basement installation

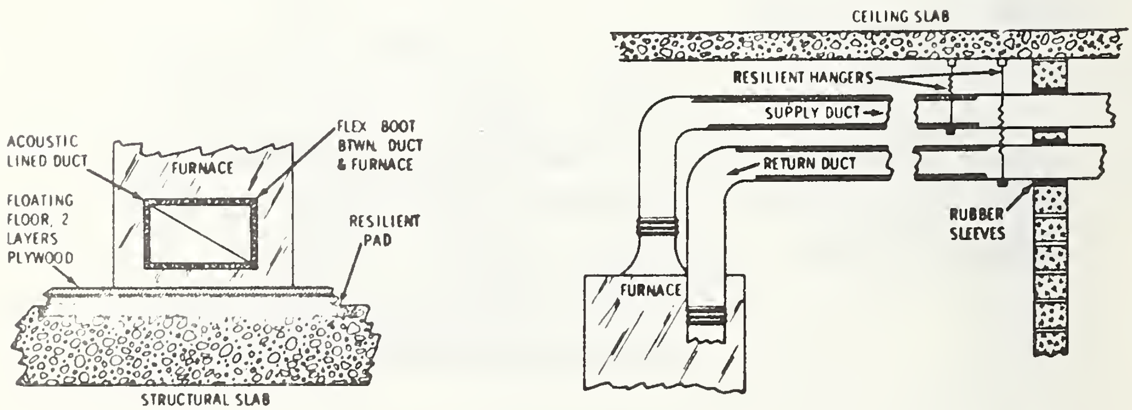
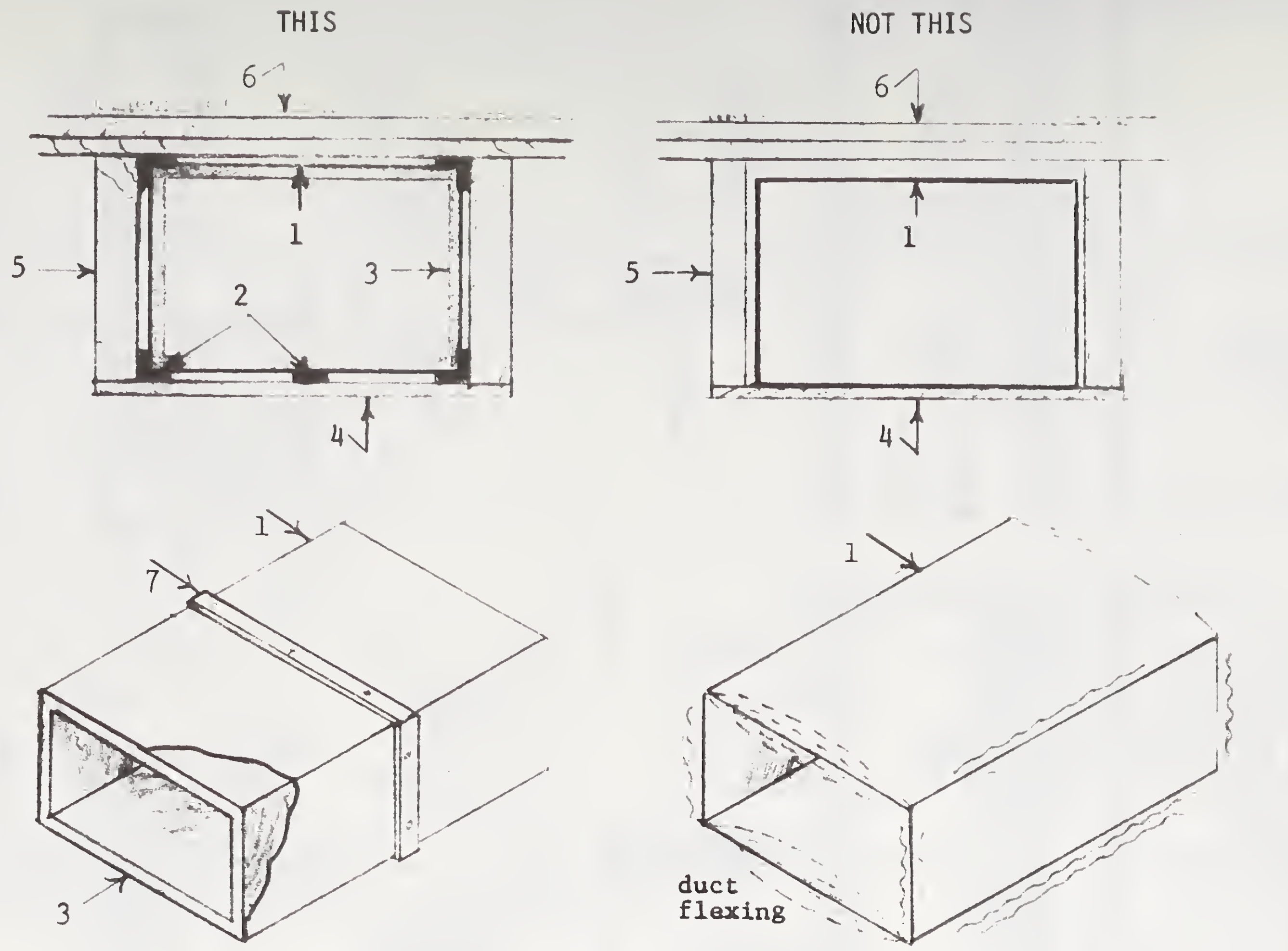


FIG. 4-20 TECHNIQUES FOR THE CONTROL OF NOISE FROM EXISTING ATTIC OR BASEMENT INSTALLATIONS OF FURNACES AND AIR-CONDITIONING UNITS.



(1) Metal duct
(2) Soft rubber spacers
(3) Sound absorbent duct lining
(4) Support bracket
(5) Wood joist
(6) Floor
(7) Metal brace

FIG. 4-21 METHODS OF REDUCING NOISE DUE TO AIR FLOW, EQUIPMENT, AND THE EXPANSION, CONTRACTION AND FLEXING OF METAL DUCTS.

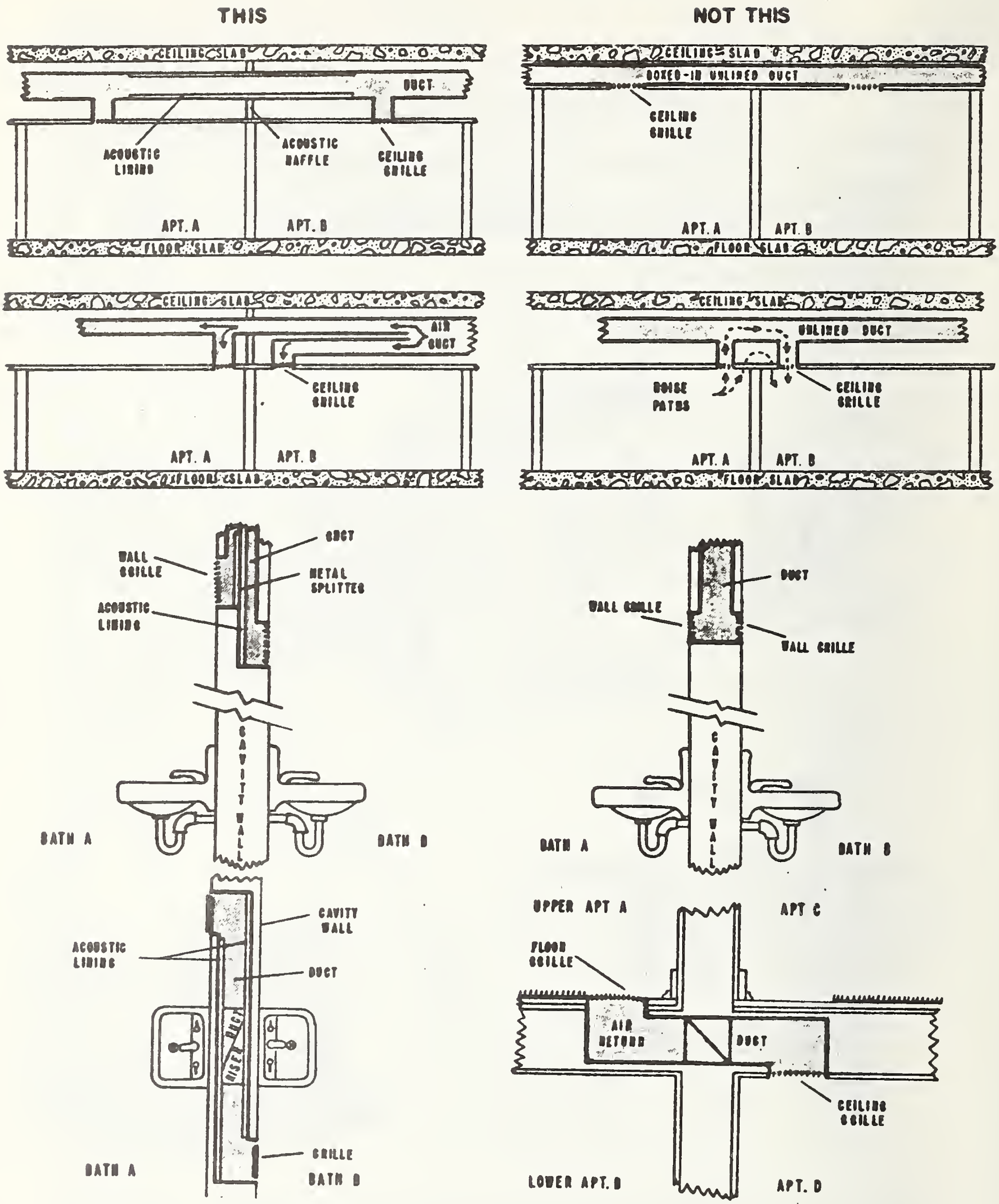


FIG. 4-22 METHODS OF CONTROLLING CROSS TALK AND THE TRANSMISSION OF FLANKING NOISE IN DUCTS.

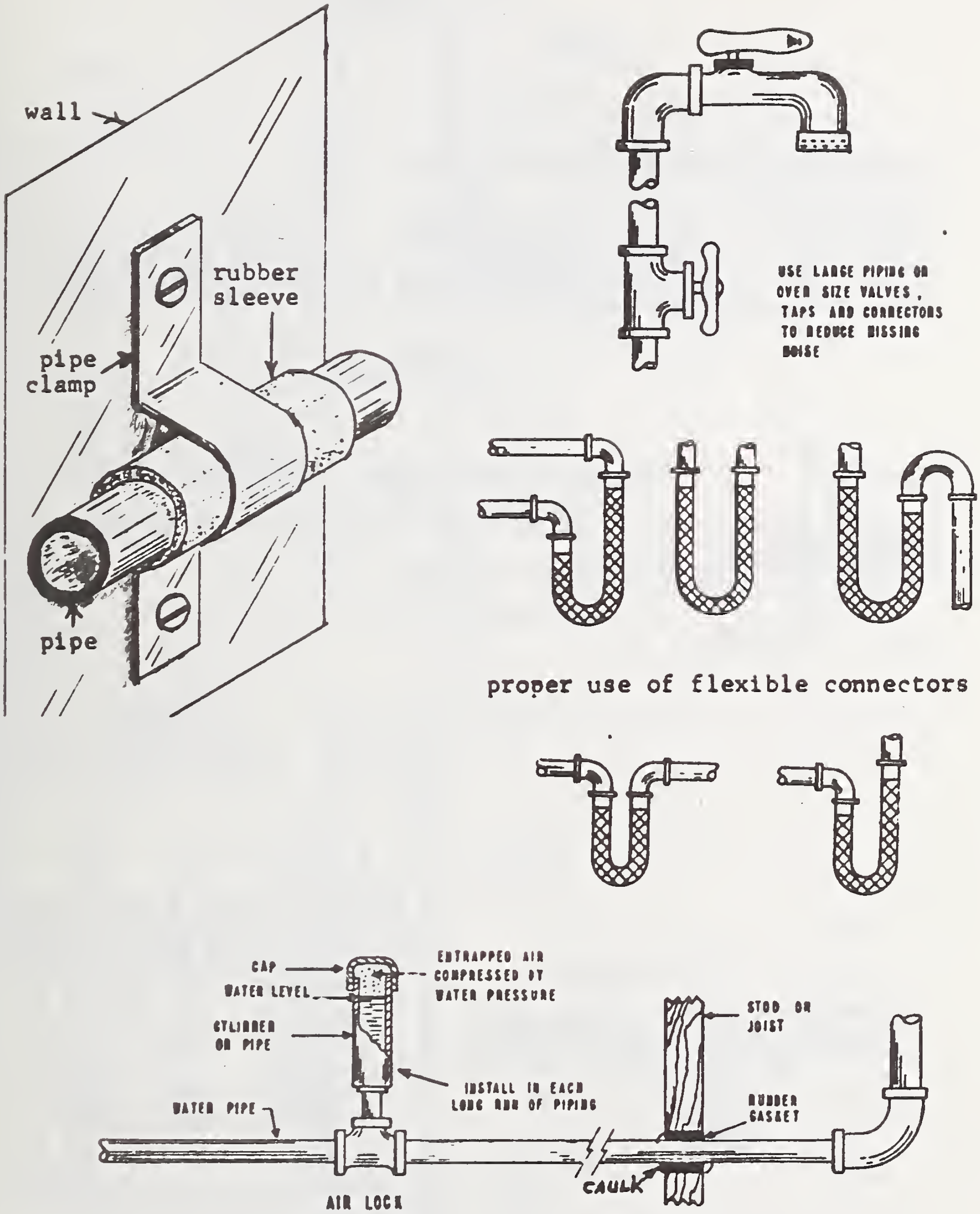


FIG. 4-23 TECHNIQUES FOR CONTROLLING NOISE IN PLUMBING SYSTEMS.

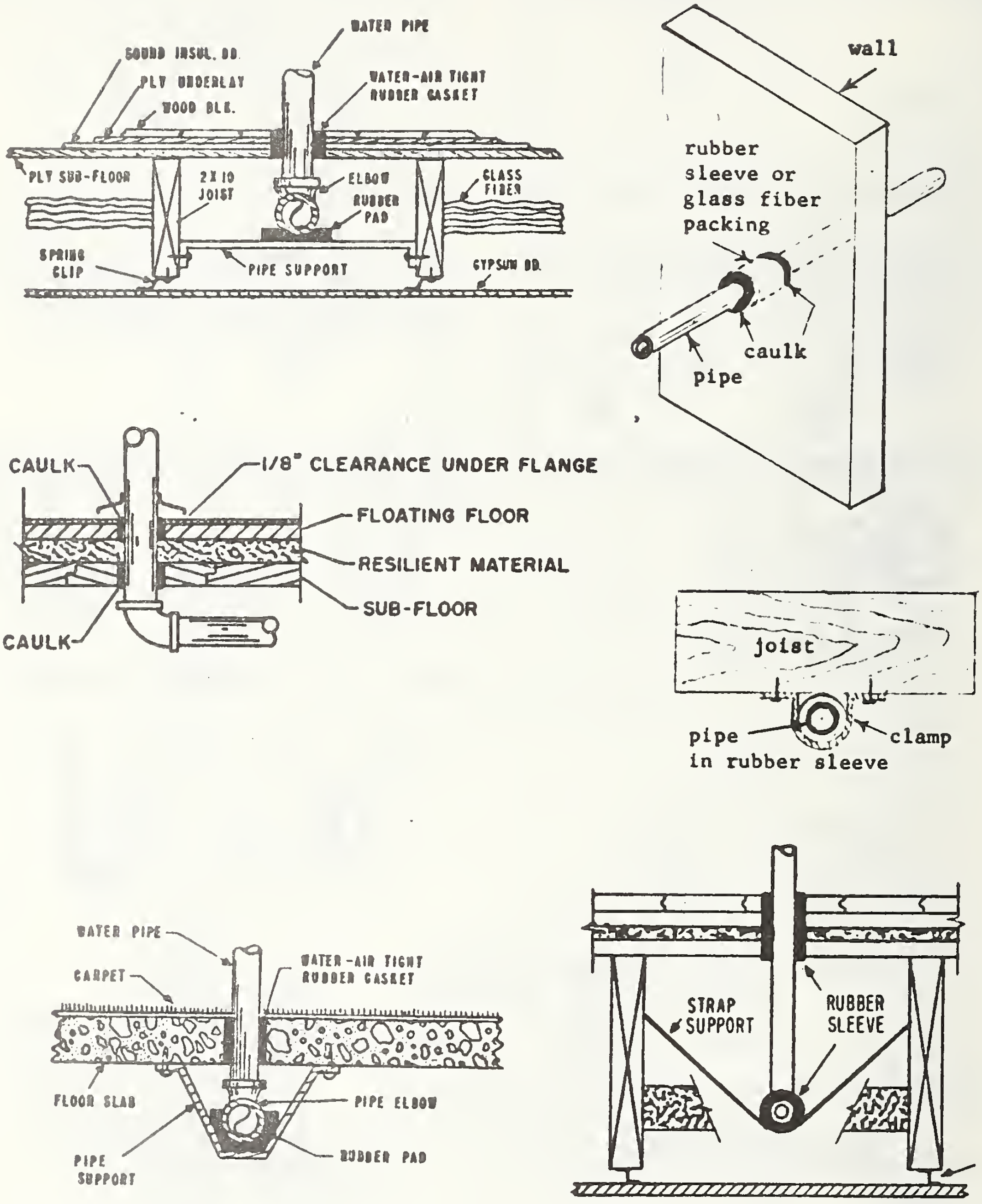
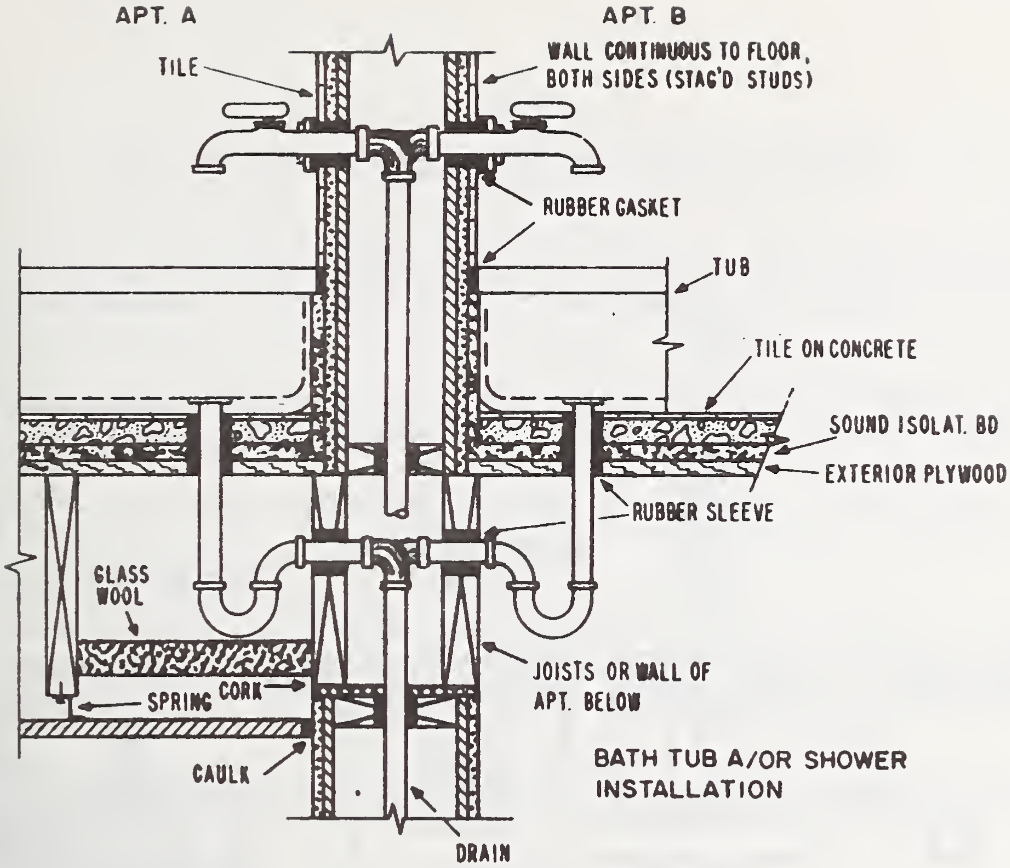


FIG. 4-24 METHODS OF INSTALLING PIPES FOR QUIET OPERATION.



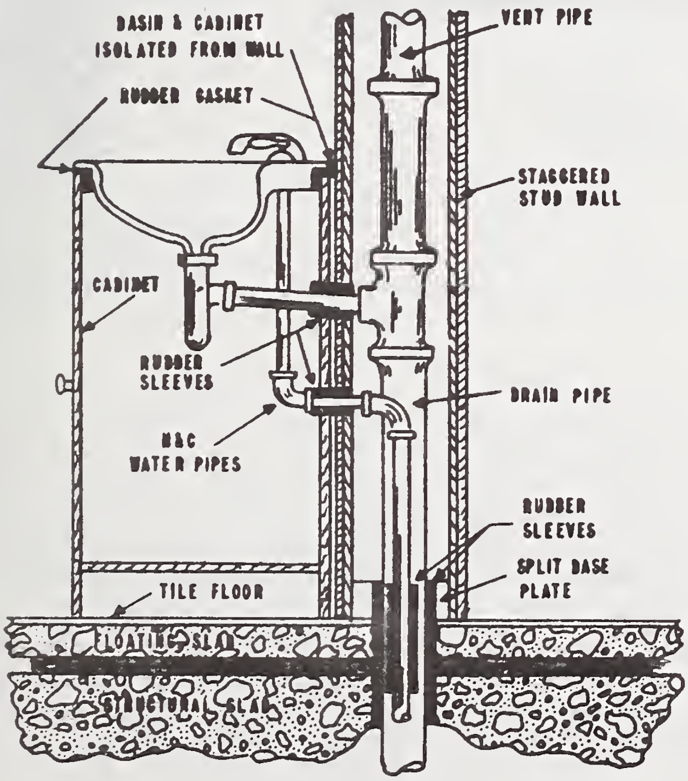


FIG. 4-25 PROPER INSTALLATION OF BATH TUBS AND WASH BASINS.

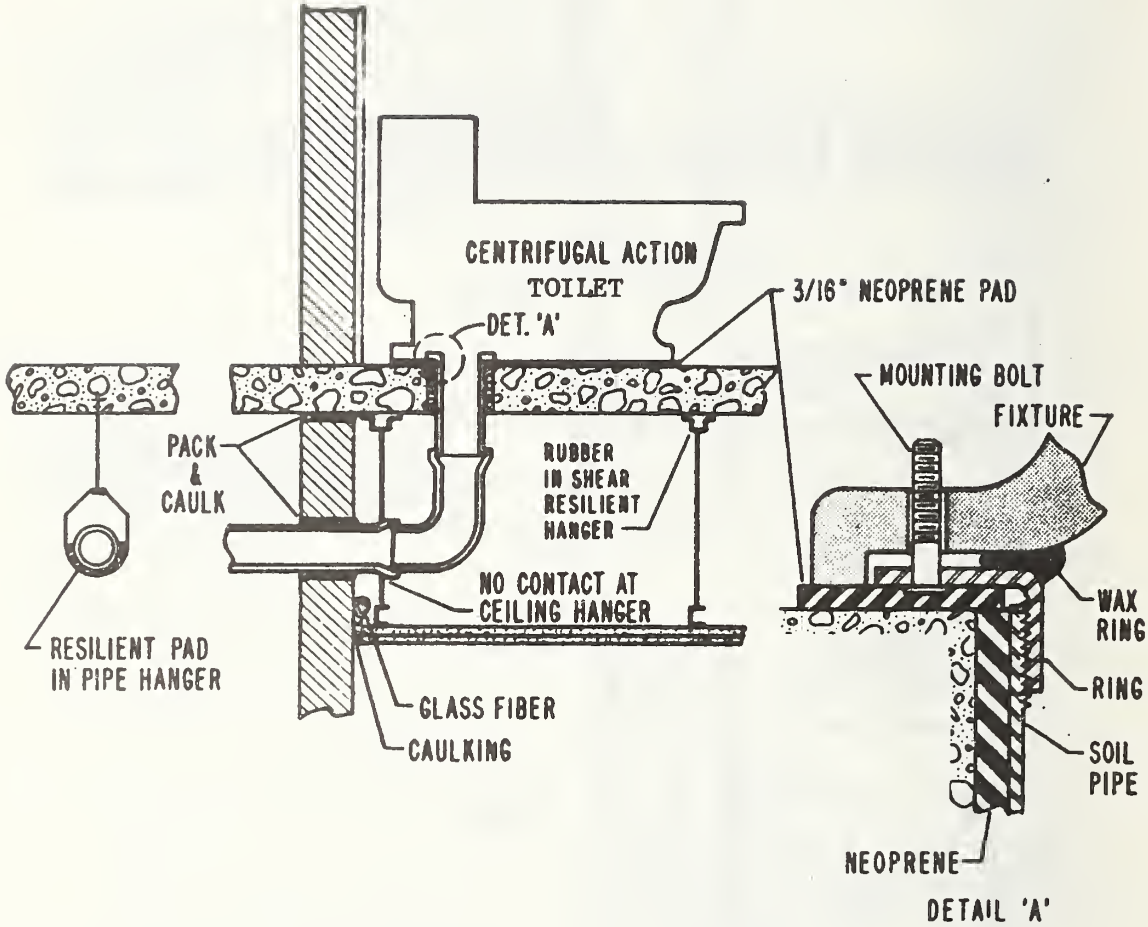


FIG. 4-26 PROPER INSTALLATION OF A TOILET FOR QUIET OPERATION.

Chapter 5

HOW TO INSULATE YOUR HOME AGAINST OUTDOOR NOISE

As we know from experience, residential areas that formerly were quiet and peaceful, frequently have become engulfed by highly disturbing sources of noise.

Changes in zoning ordinances often permit development of noisy industrial parks or shopping centers on the outskirts of residential areas.

Ordinary highways eventually become high-speed noisy expressways which invade the peace and privacy of quiet communities and suburban areas that often are encircled or flanked by the roadway.

In some cases, local neighborhood noise caused by community traffic, homeowners' use of outdoor power applicances such as lawn mowers, chain saws, or perhaps children at play, barking dogs, etc., may be the most disturbing problem.

In other cases, noise from community swimming pools, playgrounds, athletic fields, amusement parks or sport arenas may be the major source of annoyance.

The outdoor noise levels generated in neighborhood environments by the various sources cited above might be described as being in the moderate to high level range, or roughly 70 to 95 dB.

However, the greatest number of noise complaints come from home owners and apartment occupants living in residential areas near airports. The expansion of medium jet airports into international airports handling much larger and noisier aircraft has created noise problems affecting much larger communities and populated areas. The expansion of small private airports to handle the new breed of small business jet aircraft has created similar noise problems in small, relatively quiet communities.

Aircraft noise levels at the location of the home or apartment site will vary depending chiefly on its distance from the airport or flight path, and type and altitude of aircraft among other factors. In any event, dwellings near large airports or directly under flight paths may be subjected to rather intense levels of noise ranging from 90 to 110 dB or more.

We will discuss first the steps for improving the sound insulation of houses in moderately noisy neighborhood environments, and deal separately with the more difficult problem relative to aircraft noise intrusion at the end of this section. Illustrations of building modifications and sound-insulating construction discussed in this chapter are given at the end of the chapter.

Generally speaking, most single-family dwellings are an assemblege of light-frame interior partitions enclosed and supported by a light-frame exterior shell. If this shell were continuous and provided an air-tight seal for the enclosed space, it would provide at best only a fair amount of sound insulation. However, this shell not only is covered by a thin roof of even lighter-weight materials but also contains a number of windows and doors with their customary air and noise leaks. These structural assemblies tend to reduce substantially the sound-insulating capabilities of the dwelling. The following information will suggest ways of improving the sound insulation of the house to provide adequate privacy in typical noise environments.

Reducing the Intrusion of Neighborhood Noise

If you have a home in a noisy neighborhood and are disturbed by the exterior noise intrusion, the following recommendations may alleviate the problem.

(1) The first rule of thumb is to install a central heating and air conditioning system in the house. This will eliminate the need to open windows and doors for ventilation purposes and thus reduce considerably the intrusion of outdoor noise.

(2) Existing windows should be caulked or equipped with gaskets to provide an air-tight seal.

(3) If the noise source is high pitched and very directional, install storm windows with caulk or gasket seals on the side of the house facing the source. However, it is more beneficial to install storm windows, properly sealed, on all existing windows. This will provide additional insulation against low-pitch noise as well as noise approaching from other directions.

(4) Exterior doors should be provided with soft resilient gaskets and threshold seals. This applies to sliding doors as well.

(5) Install storm doors equipped with resilient gaskets and threshold seals. Sliding storm doors also should be installed.

(6) Seal or caulk all openings or penetrations through walls particularly around water or gas pipes, electrical cables, and refrigerant lines.

(7) Cover mail slots in doors; install hinged cover plates on clothes dryer heat vents, bathroom and kitchen exhaust ducts, and central vacuum system dust discharge chute.

(8) Close fire-place damper, clean-out cover plates and install a 1/2-inch (13 mm) thick plywood barrier in front of the fire-place opening.

Adoption of the above measures would improve the sound insulation of the exterior shell of the house about 6 dB for low-pitched sound and above 10 dB for high-pitched sounds; this would reduce the loudness of the intruding noise about 25 to 50 percent, respectively.

Reducing the Intrusion of Traffic Noise

Homes or apartments of conventional construction that are located very near to heavily traveled roadways or expressways are particularly vulnerable to the intrusion of excessively high levels of noise. Since the sound proofing of such dwellings would be costly and impractical, the occupants should choose those solutions which provide the most noise reduction at least cost. In addition to the recommendations described above, the homeowner should incorporate, on a step-by-step basis, the following noise control measures, until the noise has been reduced to a tolerable level.

(1) In existing windows, install glass panes of double thickness on the side of dwelling facing the noise source.

(2) Lifewise, install storm windows over the same windows. Select storm windows which have glass panes mounted or encased in rubber gaskets.

(3) Line perimeter surfaces between the existing windows and storm windows with acoustic tile or sound absorbent lining.

(4) Replace existing hollow-core entrance doors with solid-core, sound-proof doors provided with perimeter gaskets and drop closures.

(5) If intruding traffic noise disturbs your sleep and your bedroom faces the roadway, choosing a bedroom which is located on the opposite side of the house may reduce the loudness of intruding noise an additional 50 percent or about 10 dB or more. Selecting a bedroom on the side of the house that is partially shielded from the noise source should reduce the loudness of the intruding noise about 25 percent or 6 dB.

(6) Install a barrier wall or fence between your house and the roadway. To be effective, the fence should have a solid, continuous surface without any openings or holes. The fence should be relatively long and tall enough to shield, or hide, the entire roadway when viewed from the nearest side of the house. The barrier or fence can be made of relatively light material such as 1-inch (25 mm) thick boards, because in such circumstances a noise reduction of only 5 to 10 dB may be obtained.

Reducing the Intrusion of Aircraft Noise

If you are one of many home owners who now find themselves constantly exposed to intense and highly disturbing aircraft noise, you should consider carefully the fol-owing four basic facts before you decide on any course of action to resolve the problem.

(1) The cost of soundproofing an existing home against intense aircraft noise is exceedingly high.

(2) Although soundproofing your home will reduce your annoyance indoors, it does nothing to improve the noise environment outside the home. Therefore if you enjoy gardening, patio parties or backyard barbecues, you will have to tolerate the aircraft noise as before.

(3) The probability is rather low of gaining noticeable relief from the noise through the development of quieter aircraft or changes in aircraft landing or takeoff flight patterns. In fact, the noise environment near a large airport generally tends to grow worse in time, with the inevitable expansion in aircraft size and flight operations.

(4) The most effective solution is to move to a more quiet area, even though it might entail some financial loss in the sale or rental of your home.

The following is a discussion of the various sound insultating modifications that may be used to reduce the intrusion of intense aircraft noise into the home. Figures 5-1 through 5-12 illustrate the structural details of such modifications.*

Major Sound Insulating Modifications:

(a) Incorporate the noise-reduction recommendations given above relative to reducing the intrusion of neighborhood and traffic noise.

(b) Windows

Windows are the weakest acoustical barrier in the exterior shell or surfaces in most homes.

Ordinary double-hung, locked windows generally provide an average noise reduction of about 18 dB; the addition of a storm window will increase the sound insulation about 6 dB. Caulking of both windows improves the sound insulation about 3 dB at the higher frequencies. However, if the aircraft noise still seems to be coming through the windows, despite the fact that they were equipped with storm windows and sealed air tight, then the existing window installation will have to be replaced with fixed, non-operable, double windows throughout the house.

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*Figures 5-1 through 5-12 are courtesey of the Department of Housing and Urban Development.

The window installation would consist of two 1/4-inch (6 mm) thick panes of glass, each encased in a "U" shaped soft, resilient gasket with a 4-inch (10 cm) air space between panes. Line perimeter surfaces between panes with acoustic tile or other sound absorbent material.

This double-window installation would increase the sound insulation approximately 10 dB above that provided by ordinary windows protected by storm windows.

(c) Exterior Doors

If the noise now seems to be coming through the doors, remove the moulding from the door frame to see if there are any air gaps or noise leaks between the door frame and the wall. The conventional practice of installing prefabricated door kits, in which the doors are premounted in a door-frame assembly, often causes serious sound transmission problems. Builders generally provide an oversized opening to receive the preassembled door and fasten the assembly into place with a few wedges and nails, and completely ignore any resulting air gaps or leaks. These are conveniently covered and hidden from view by the thin finish moulding. However, such leaks must be sealed if any improvement in sound insulation is to be expected, and certainly before any existing doors are replaced with soundproof doors or equipped with gaskets.

Replace existing doors with 1-3/4 inch (4.5 cm) thick solid-core doors with soft, resilient, perimeter gaskets and threshold seals. Install storm doors with 1/4-inch (6 mm) thick glass and weather stripping. It is estimated that the noise reduction provided by this combination of doors would be about 20 dB greater than that of a conventional exterior door.

(d) Exterior Walls

Generally speaking, exterior walls constructed of poured concrete, cinder block, brick or other masonry materials provide sufficient sound insulation against aircraft noise, if all penetrations through the walls have been properly treated and sealed. For example, ventilation ducts and exhaust vents must be lined with sound absorbent material or equipped with sound silencers; holes around penetrations of gas or water pipes, electrical conduits and refrigerant lines must be sealed airtight with a resilient, non-setting caulking compound. Settlement cracks in the walls or gaps around framing of windows and doors should be caulked or sealed in the same manner.

No structural changes or modifications should be made to the exterior walls until you are sure that the noise is not entering the house through the basement, crawl space or attic areas.

Exterior walls of light-frame construction consisting of wood studding faced on the inside with gypsum board and on the outside with insulation board and wood, metal or stucco siding, are inherently incapable of providing adequate sound insulation against moderately high levels of noise, much less intense levels of aircraft noise intrusion. Such walls would have to be capped on the outside with a 4-inch (10 cm) thick wall of brick veneer before the aircraft noise could be reduced to a tolerable level inside the house.

(e) Roof and Ceiling Modifications

<u>Ventilated attic space</u>

If the attic is to be used as a wlak-in storage area, install subflooring on top of the ceiling joists and cover with 5/8-inch (16 mm) thick gypsum board. Tape and seal the edges and joints of the gypsum board layer. Otherwise, the gypsum board may be installed directly on top of the ceiling joists.

Install a metal duct with 1-inch (2.5 cm) thick glass fiber liner at all air-circulation vents or openings.

<u>Plank and beam vaulted ceiling or flat roof</u>

Attach wood furring or preferably metal resilient channels to the existing ceiling. With self-tapping screws, fasten 5/8-inch (16 mm) thick gypsum board to the furring or metal channels. Tape and finish joints and edges of the gypsum board in the conventional manner.

(f) Basement Areas

Caulk or weatherstrip existing windows and install storm windows.

Weather-strip existing hinged or sliding doors and install storm doors.

(g) Crawl Spaces

Install a metal duct with 1-inch (2.5 cm) thick glass fiber liner at all air-circulation vents or openings.

Install 5/8-inch (16 mm) thick exterior plywood or moisture-proofed gypsum board to the underside of the floor joists.

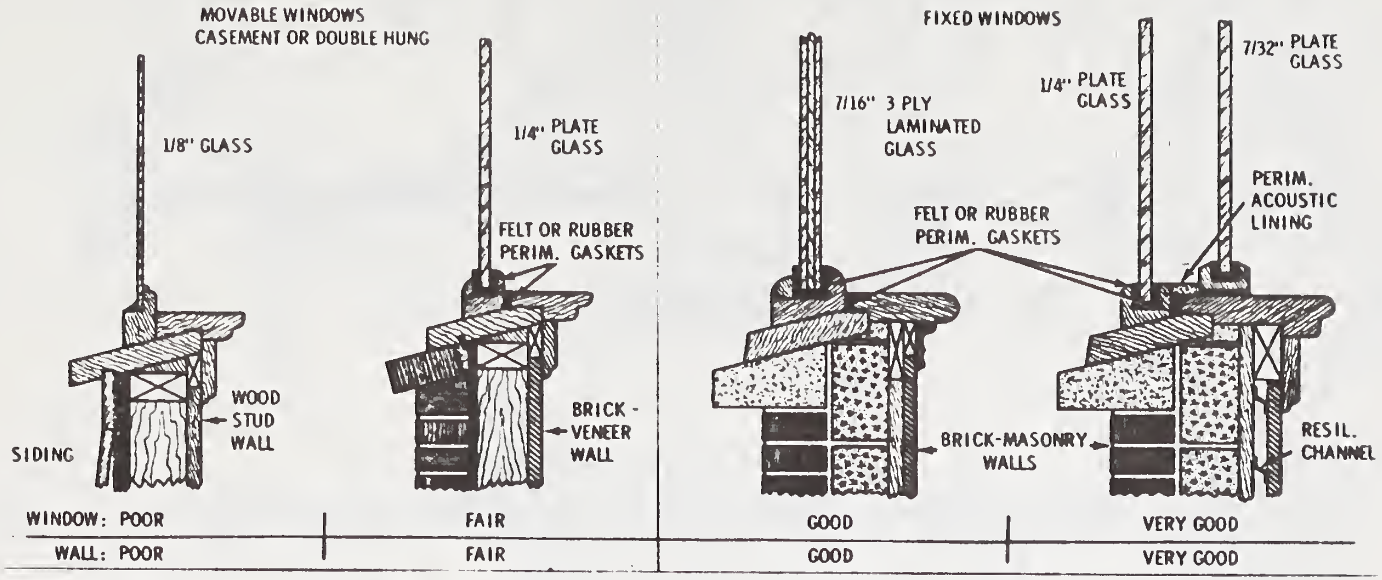


FIG. 5-1 SOUND INSULATION EFFECTIVENESS OF VARIOUS WINDOW-WALL ASSEMBLIES.

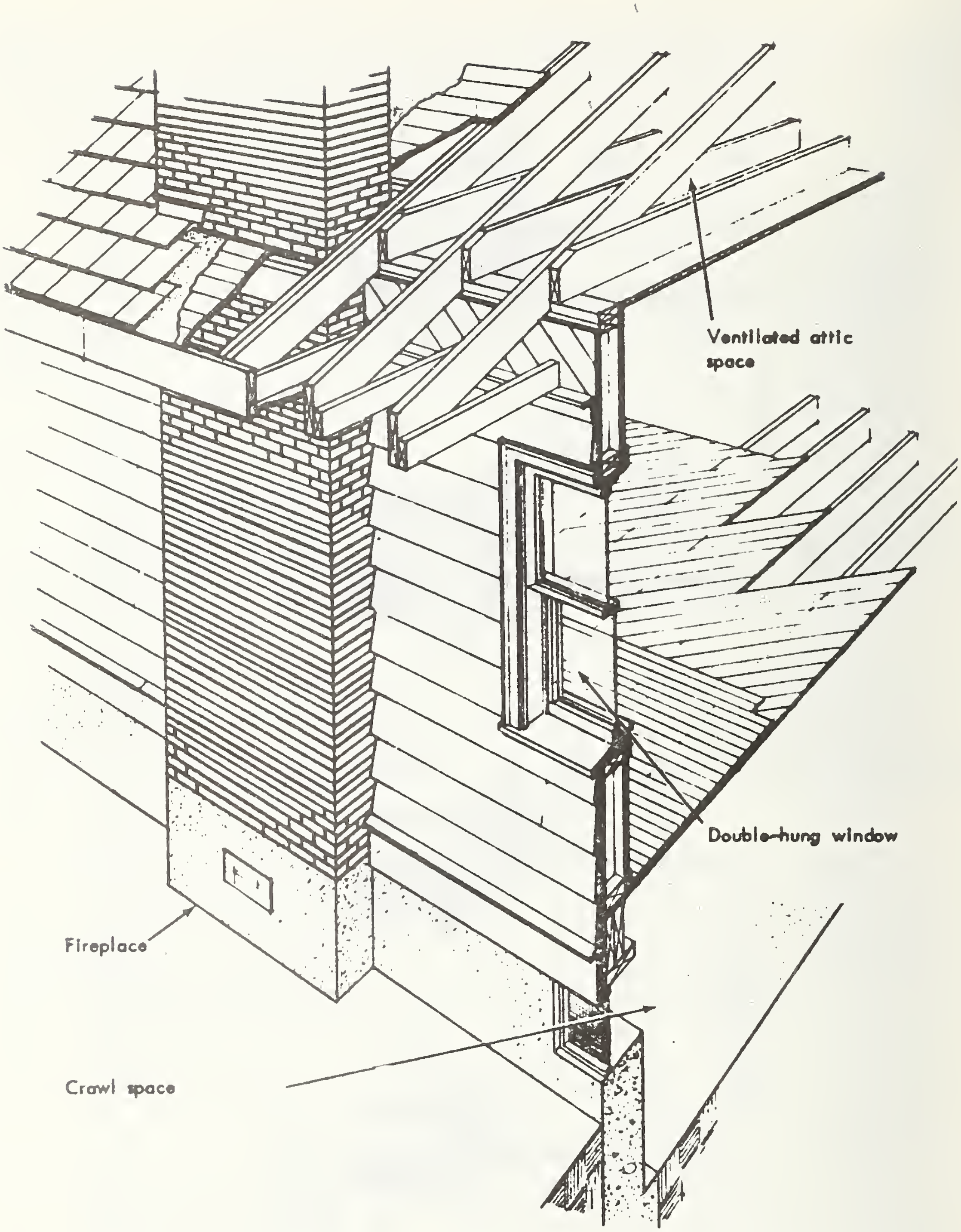


FIG. 5-2 HOUSE WITH A CRAWL SPACE AND VENTILATED ATTIC.

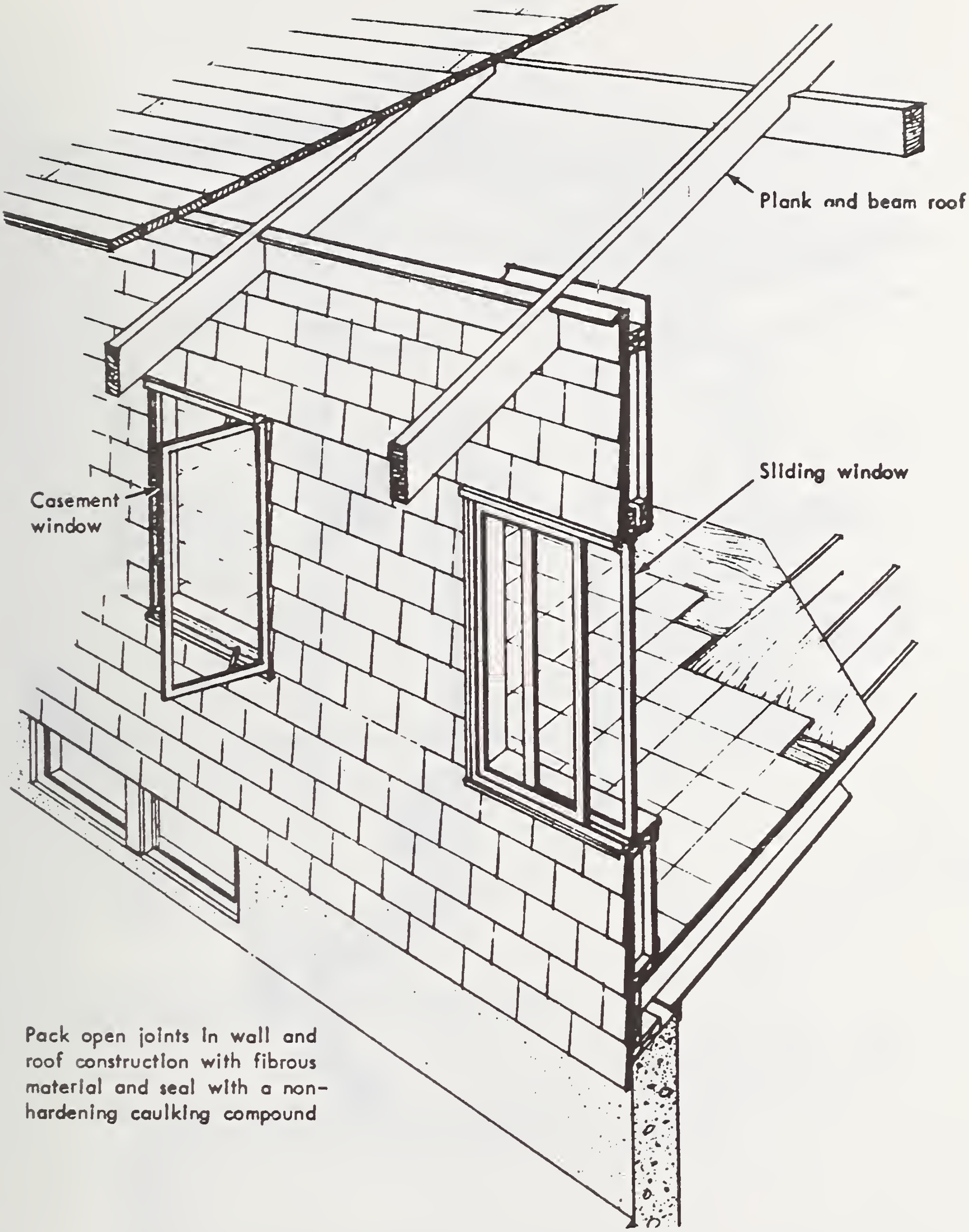


FIG 5-3 HOUSE WITH BASEMENT AND PLANK AND BEAM ROOF.

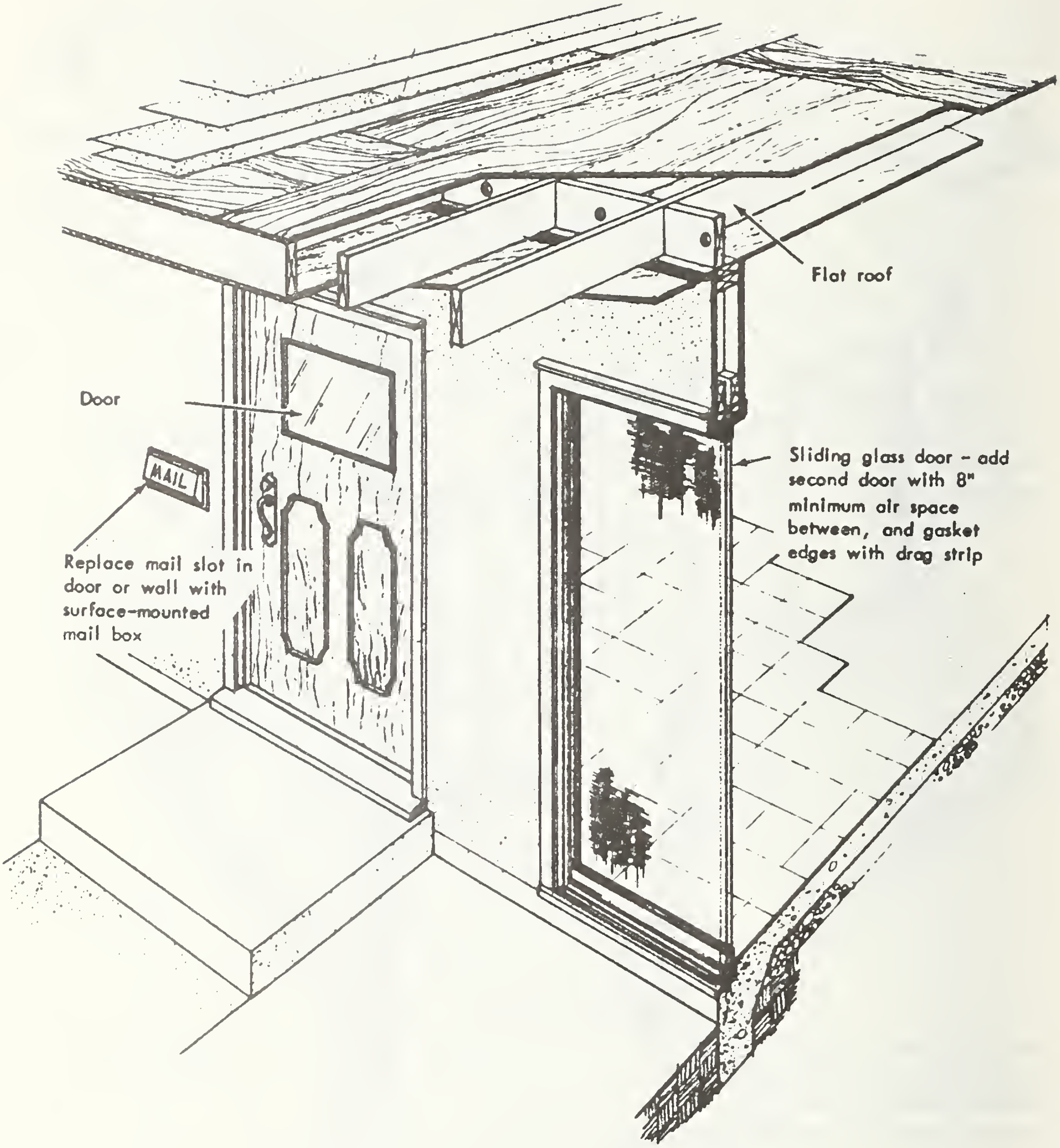
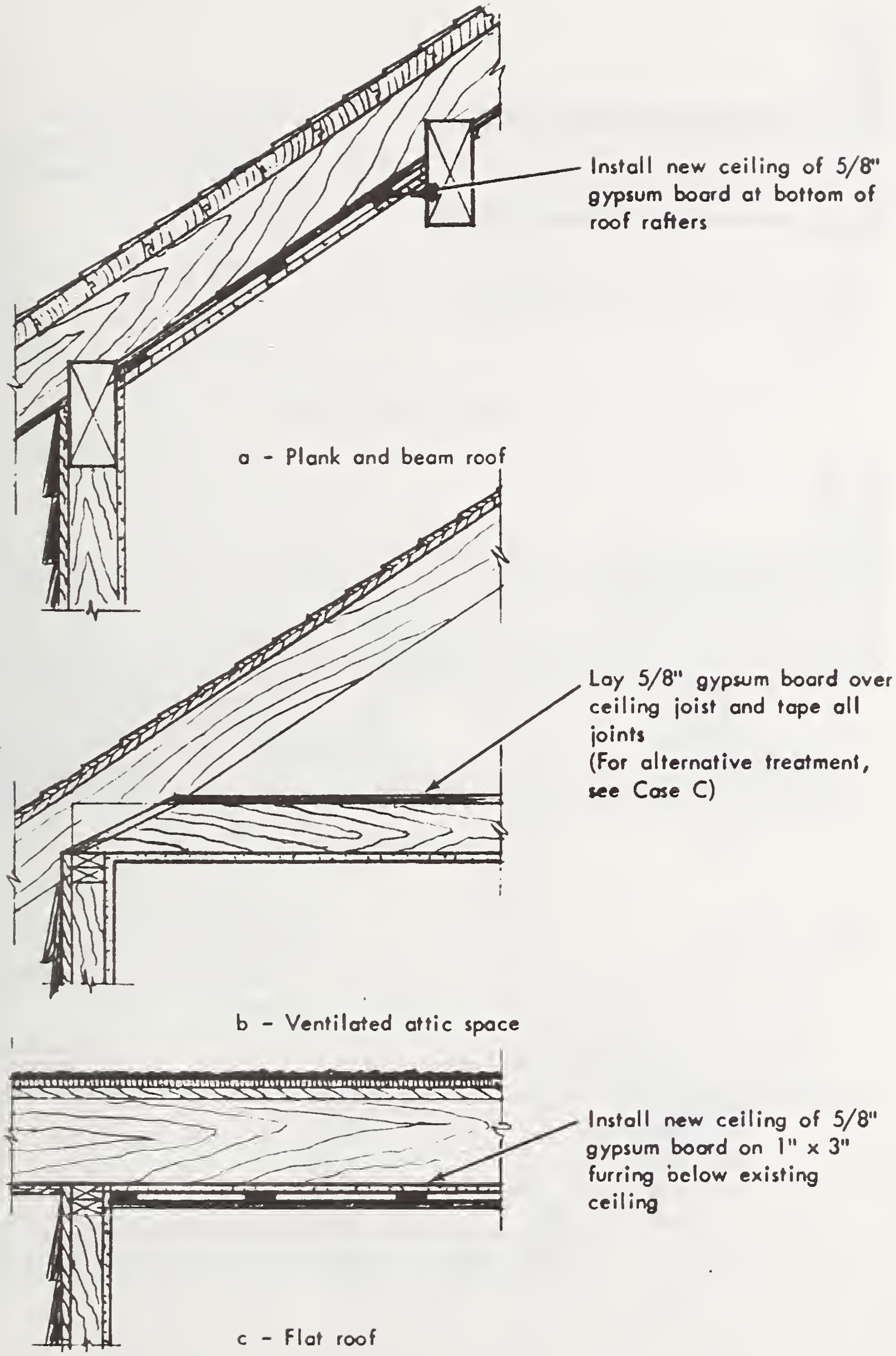


FIG. 5-4 HOUSE WITH SLAB ON GRADE AND FLAT ROOF.

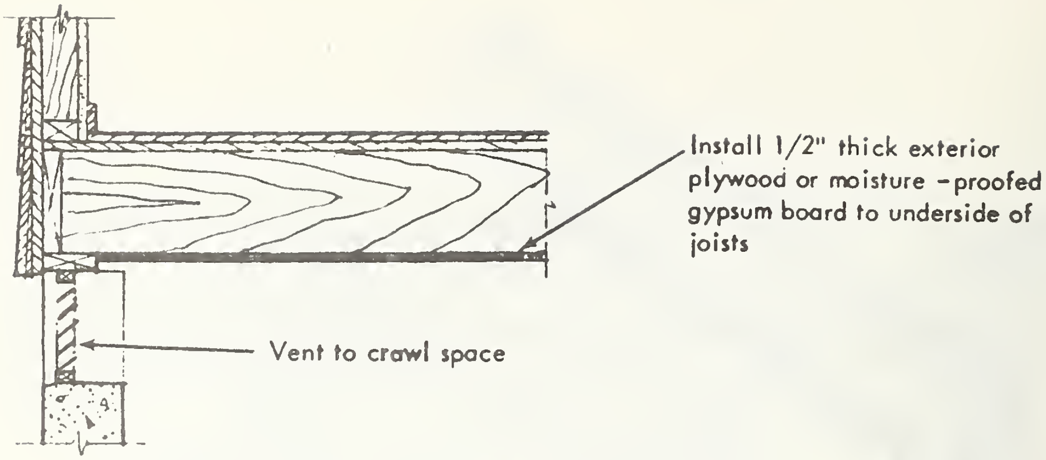


a - Plank and beam roof

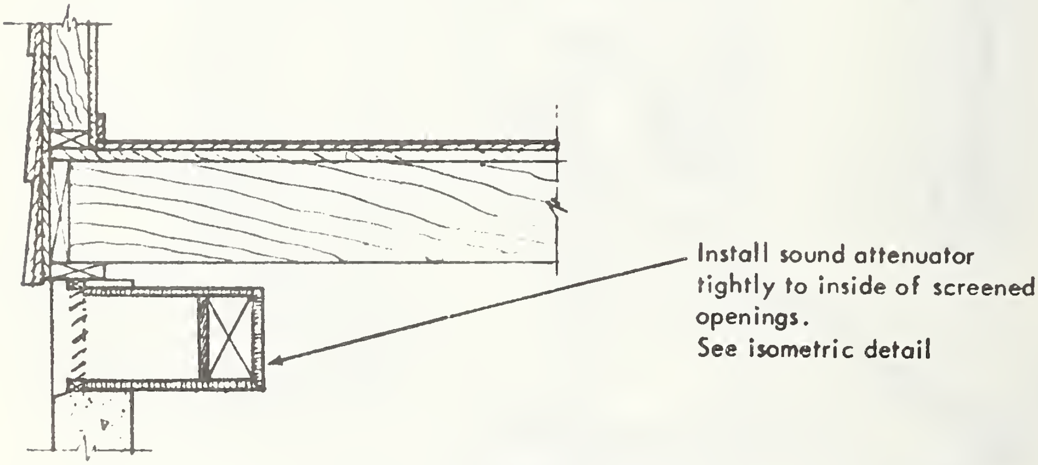
b - Ventilated attic space

c - Flat roof

FIG. 5-5 ROOF AND CEILING MODIFICATIONS.



a - Added floor construction



b - Vent attenuators

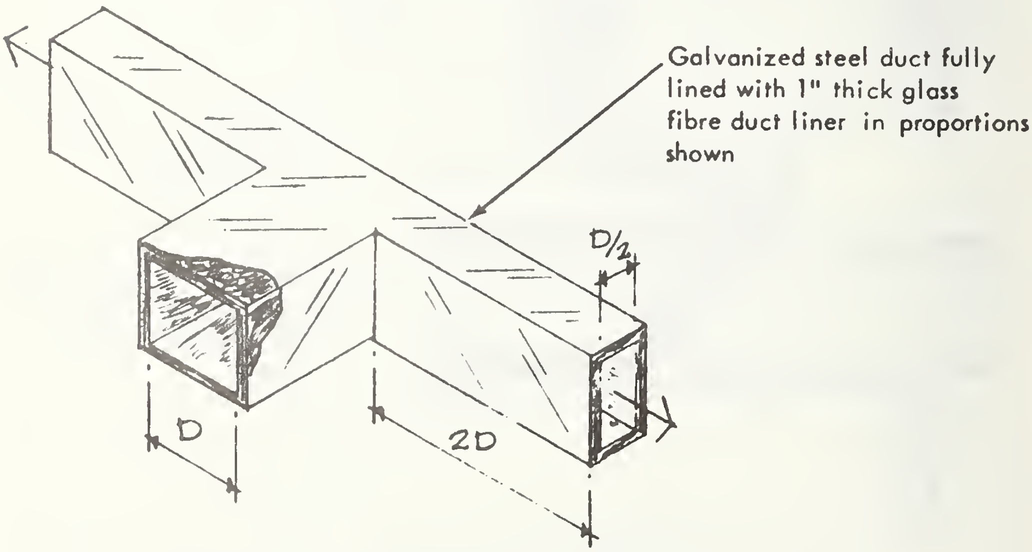


FIG. 5-6 CRAWL SPACE MODIFICATIONS.

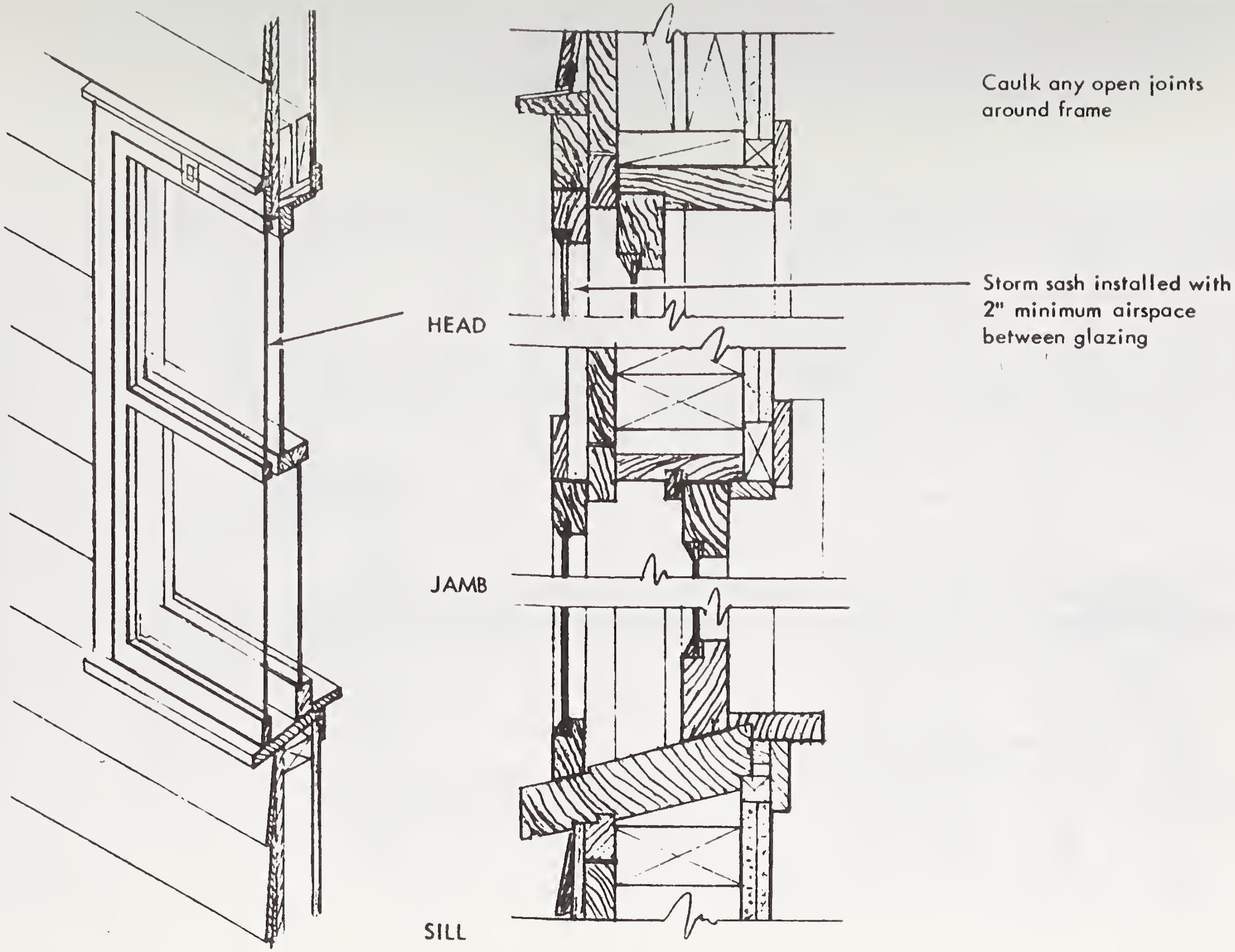


FIG. 5-7 DETAILS OF A DOUBLE-HUNG WINDOW WITH A STORM SASH.

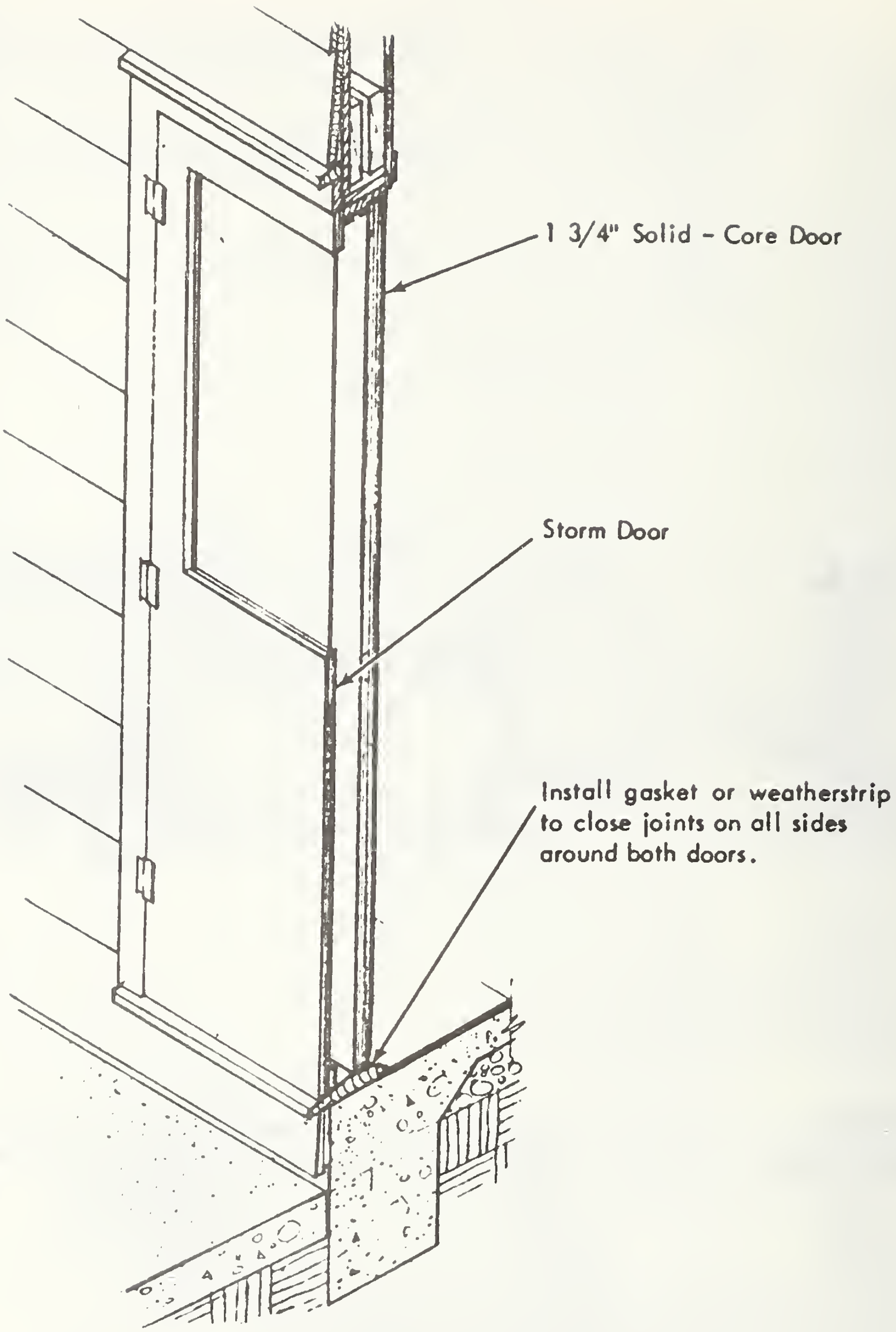


FIG. 5-8 DOOR MODIFICATIONS.

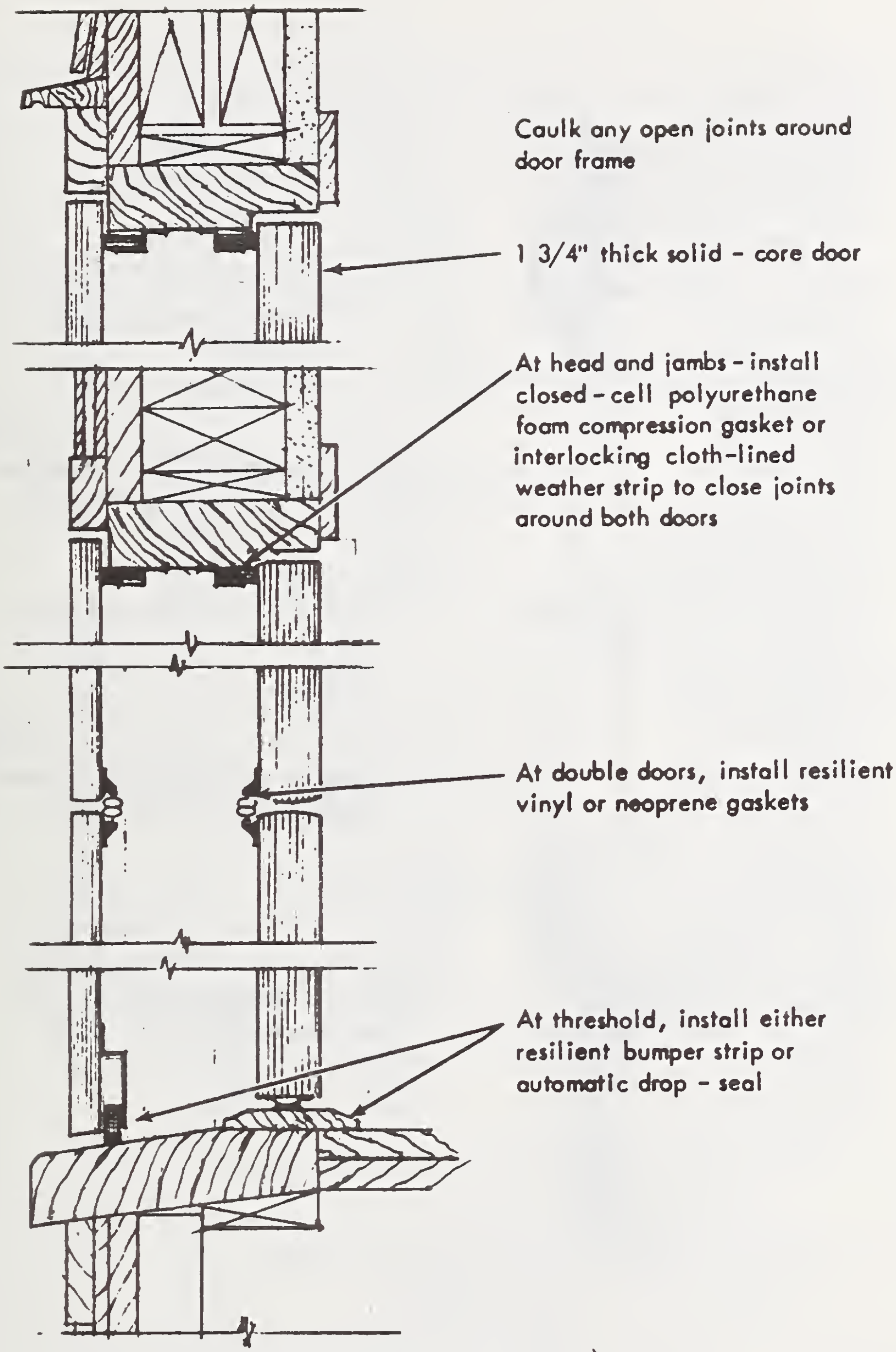


FIG. 5-9 DETAILS OF DOOR MODIFICATIONS.

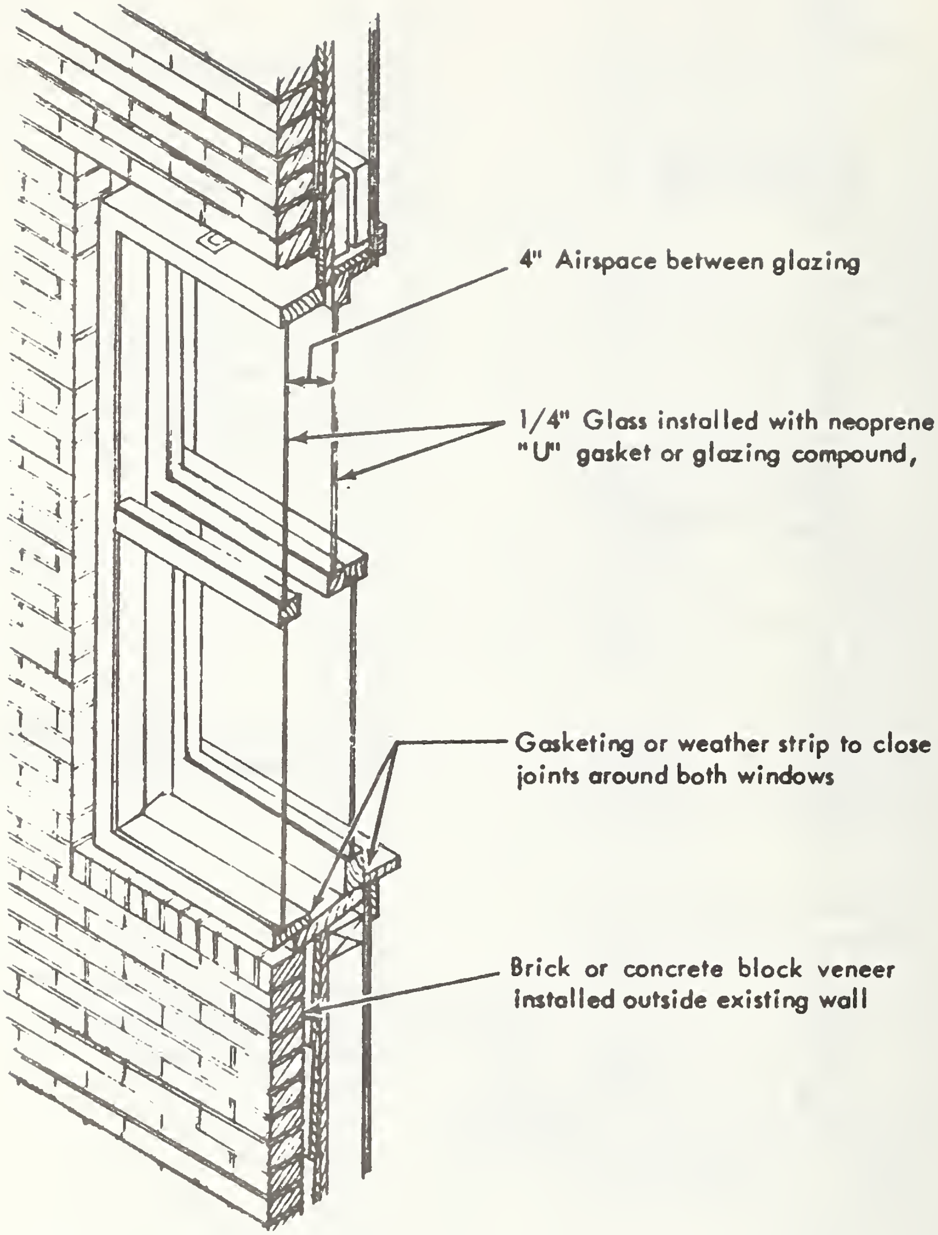
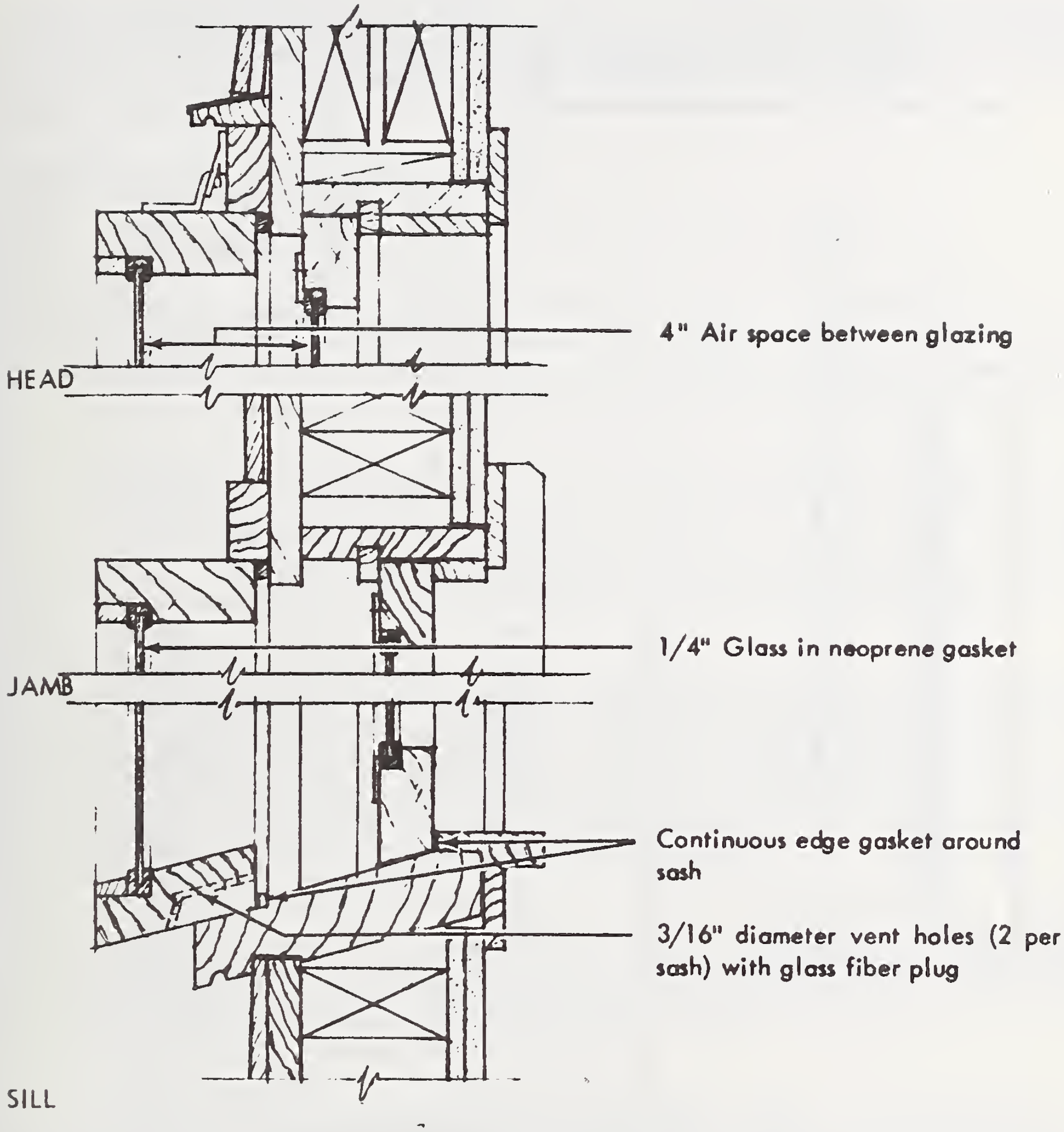


FIG. 5-10 INSTALLATION OF BRICK VENEER AND DOUBLE 1/4-INCH WINDOW GLAZING.



Step B - 1/4" Glass in separate sash added to form 4" Airspace between the two windows.

FIG. 5-11 DETAILS OF DOUBLE 1/4-INCH WINDOW GLAZING.

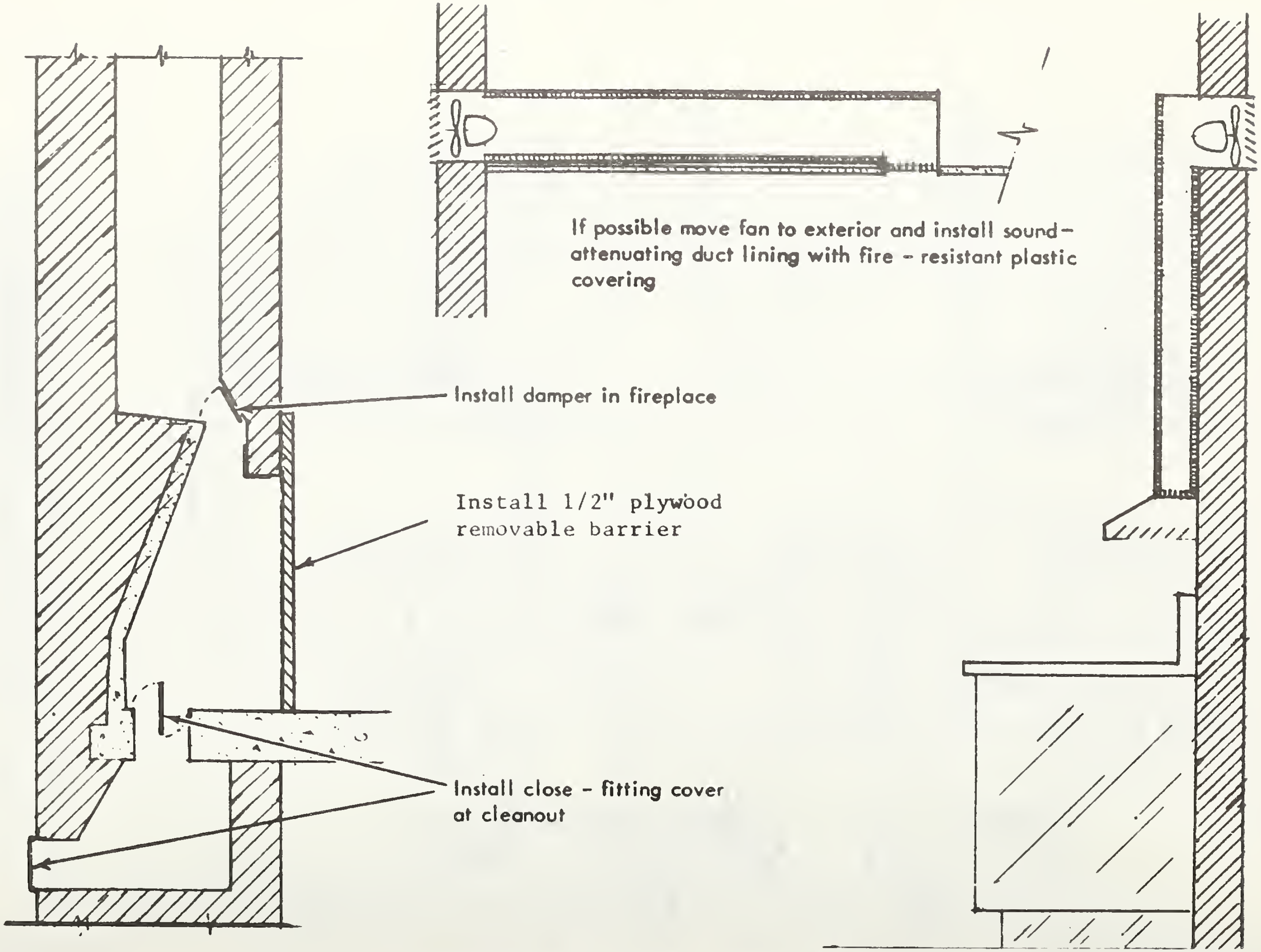


FIG. 5-12 FIREPLACE AND KITCHEN EXHAUST FAN MODIFICATIONS.

Chapter 6

SELECTING A QUIET HOME OR APARTMENT SITE
(or how to avoid making the same mistake twice)

If you are planning to move to a new home or apartment and desire more peace and privacy than you have at present, the following recommendations can help you to select a quiet location.

1. SELECTING A QUIET RESIDENTIAL AREA

(a) Obtain Maps of the Area

Obtain a recent edition of a detailed map of the area that you propose to live in and study it carefully for the location of major sources of noise. Look, particularly, for such major sources of noise as airports, railroads, expressways, and industrial areas.

Airports: If possible get a sectional aeronautical chart of the area to determine the location of all airports and their respective flight patterns and air routes relative to the proposed building site. Such charts may be obtained from local airport authorities or the Aircraft Owners and Pilot Association, Washington, D. C. 20014.

Sites near large commercial, international or military airports should be avoided completely. Residential buildings directly in line with prescribed runways, take-off and landing patterns or flight paths would have to be located at least 15, and preferably 20 miles (24 to 32 km) away from the airport before the noise from jet aircraft fly-overs would be tolerable to the occupants, as illustrated in Fig. 6-1.

Near an airport, but off to the side of the runways, buildings would need to be a lateral distance of about 3 to 4 miles (5 to 6 km) from the flight path before the noise would drop to a level tolerable at the building location.

(Railroads, Expressways and Industrial Areas): If annoyance or disturbance from these excessively noise sources is to to be avoided, residential buildings should be located at a distance of at least one mile and preferably two miles (1.5 to 3 km) from the sources.

(b) Check With City Zoning or Planning Authorities

Consult with local city or county planning authorities regarding future development plans for the area. As a result of future rezoning action, quiet residential areas frequently are boardered by noisy industrial parks or huge shopping malls.

(c) Consult With City or County Transportation Authorities

Such authorities should be consulted relative to the status and location of existing and proposed expressways, mass transit systems and changes in aircraft flight paths, procedures and operation.

(d) Conduct An On-Site Examination:

Conduct several on-site examinations of the area during daylight and especially also after midnight to assess the outdoor noise environment. Be especially alert for the location of fire and police stations, schools and athletic fields, hospitals, sport arenas, race tracks, shopping centers and amusement parks. Although ordinarily these civic centers and activities may be considered secondary sources of noise, they could well become, depending on their proximity to your location, the major source of noise and disturbance for you.

(e) Consult With Residents Living In The Area

It often pays to talk to people living in the area to determine whether or not they are disturbed by noise, especially at night.

2. SELECTING A QUIET LOCATION WITHIN A HOUSING OR APARTMENT DEVELOPMENT

(a) Select and inspect an apartment development which advertises "soundproof" wall and floor construction, quiet, efficient central airconditioning systems and fully carpeted interiors, including entrance foyers, corridors and hallways. Such construction and furnishings usually provide a quiet indoor environment, adequate privacy and negligible noise intrusion or disturbance from neighboring dwelling units or other areas within the building. The intrusion of outdoor noise also may be substantially reduced, especially if the building is equipped with heavy glass windows that are fixed or non-operable and which are installed with weatherproof, airtight seals.

(b) Avoid home or apartment sites which are along main traffic arteries or bus routes through the development. Early morning traffic noise may be a source of annoyance, as illustrated in Fig. 6-2.

(c) Select buildings which face wide open spaces such as parks, golf courses, rivers, lakes and seashores. Such areas usually are very quiet, especially at night.

(d) Select a building site which is located as far as possible or is acoustically shielded from a major source of noise by other buildings, natural landscaping or wooded areas, as illustrated in Figs. 6-3, 6-4.

3. SELECTING A QUIET APARTMENT UNIT WITHIN THE BUILDING

(a) Avoid apartment units which are adjacent to elevators, mechanical equipment rooms, laundry rooms, or indoor garages, roof-mounted ventilation equipment, such as chiller pumps, compressors or cooling towers. Rarely are such powerful sources of low-frequency noise and vibration properly isolated in sound-insulating enclosures or vibration-isolated from the building structure by means of resilient mounts. As a consequence dwelling units adjoining such sources may be subjected to intermittent round-the-clock intrusion of excessively high noise levels. These dwellings can readily become an acoustically intolerable environment.

(b) Avoid apartments that overlook parking lots, thoroughfares or through streets, play grounds and swimming pools. Noises caused by automobile operation such as starting of engines and door slamming, particularly during the early morning hours, can be a source of annoyance. Likewise, the voices or shouting of children at play throughout the day and evening may be disturbing.

The best way of avoiding such problems is to select an apartment unit on the "quiet" side of the building; that is, one which faces away from such noise sources.

(c) Avoid apartments which face "U" shaped courtyards. Such areas tend to be quiet reverberent and noisy, particularly if they are used as recreation or play areas or face traffic through streets.

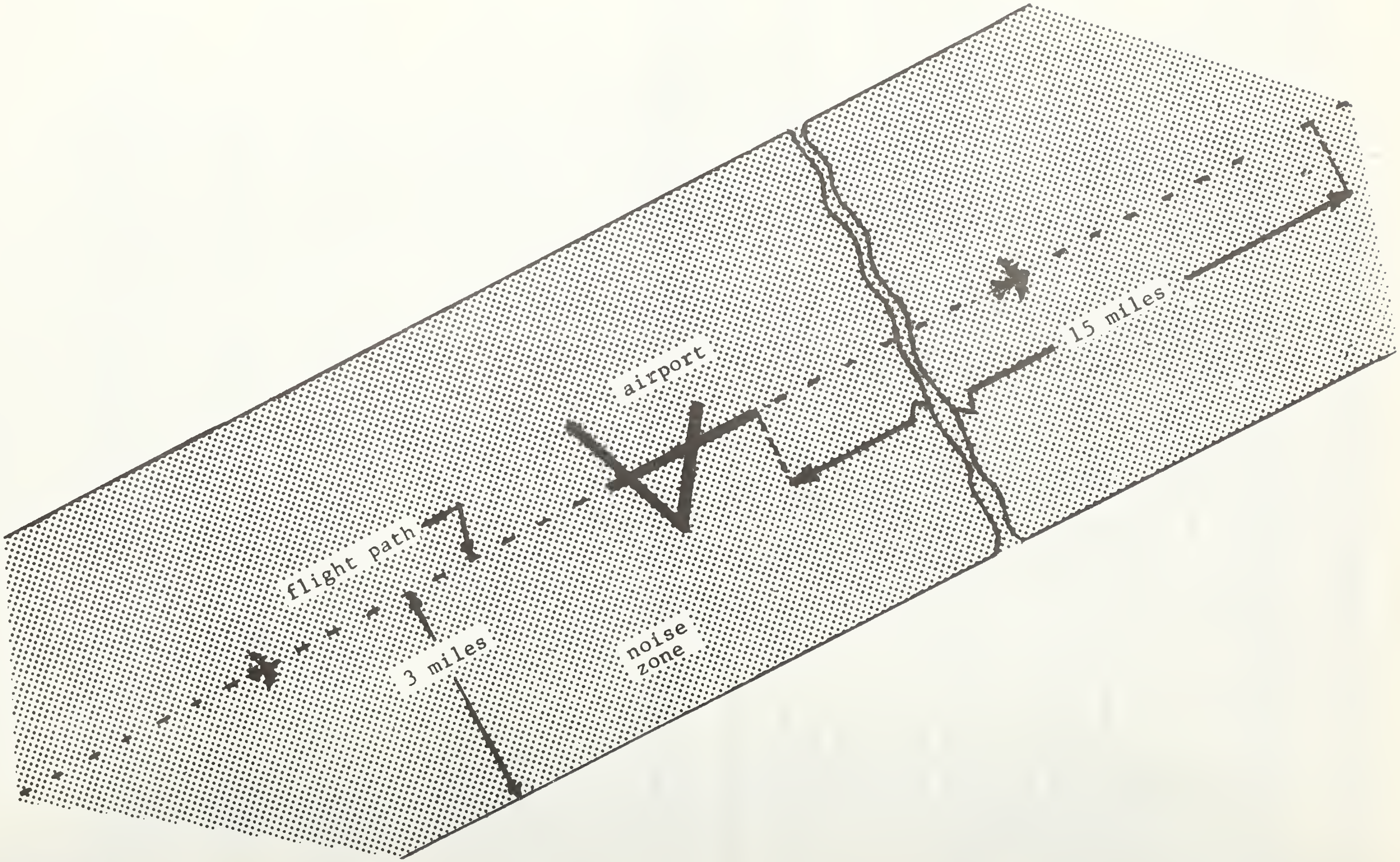
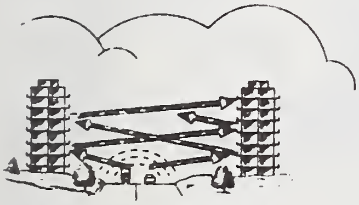


FIG. 6-1 TO AVOID AIRCRAFT NOISE DISTURBANCE, SELECT HOMES OR APARTMENTS OUTSIDE THE SHADED AREAS.

AVOID BUILDING SITES AT INTERSECTIONS OF MAJOR TRAFFIC ARTERIES. SUCH SITES ARE EXTREMELY NOISY DUE TO ACCELERATING, DECELERATING, AND BRAKING VEHICLES.

BUILDING SITES IN OPEN AREAS ARE LESS NOISY THAN SITES IN CONGESTED BUILDING AREAS.



TRAFFIC ARTERIES BETWEEN TALL BUILDINGS ARE QUITE NOISY. AVOID BUILDING SITES OPPOSITE TALL BUILDINGS IN SUCH CASES.

UPWIND BUILDING SITE IS LESS NOISY THAN A DOWNWIND SITE.

AVOID BUILDING SITES ON THE CRESTS OF HILLY TRAFFIC ARTERIES. SUCH SITES ARE VERY NOISY DUE TO LOW GEAR ACCELERATION NOISE.

AVOID HOLLOWS OR DEPRESSIONS THEY ARE GENERALLY NOISIER THAN FLAT OPEN LAND

FIG. 6-2 EXAMPLES OF APARTMENT SITES THAT SHOULD BE AVOIDED.

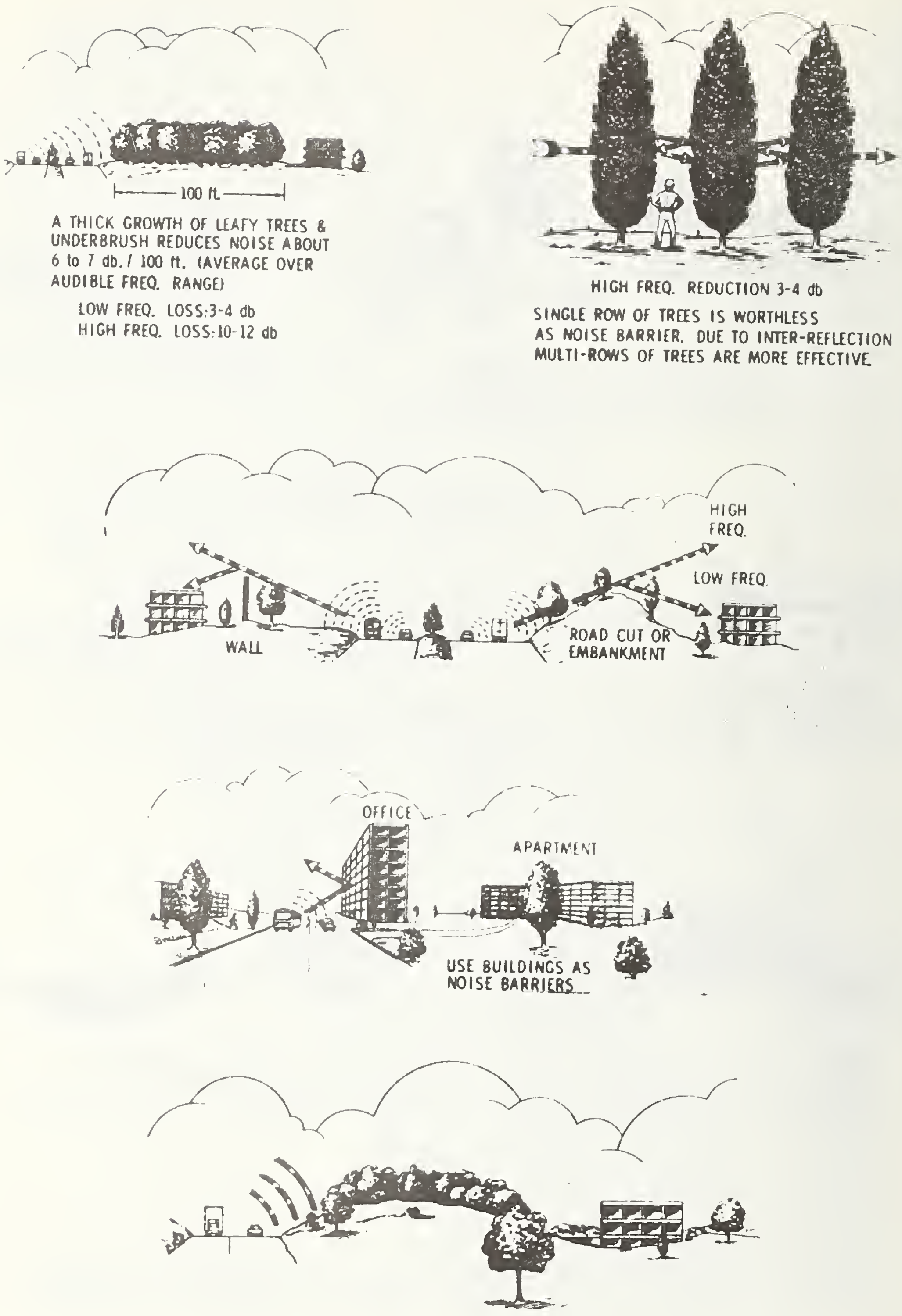


FIG. 6-3 ACOUSTICAL SHIELDING PROVIDED BY LANDSCAPE AND NATURAL AND MAN-MADE BARRIERS.

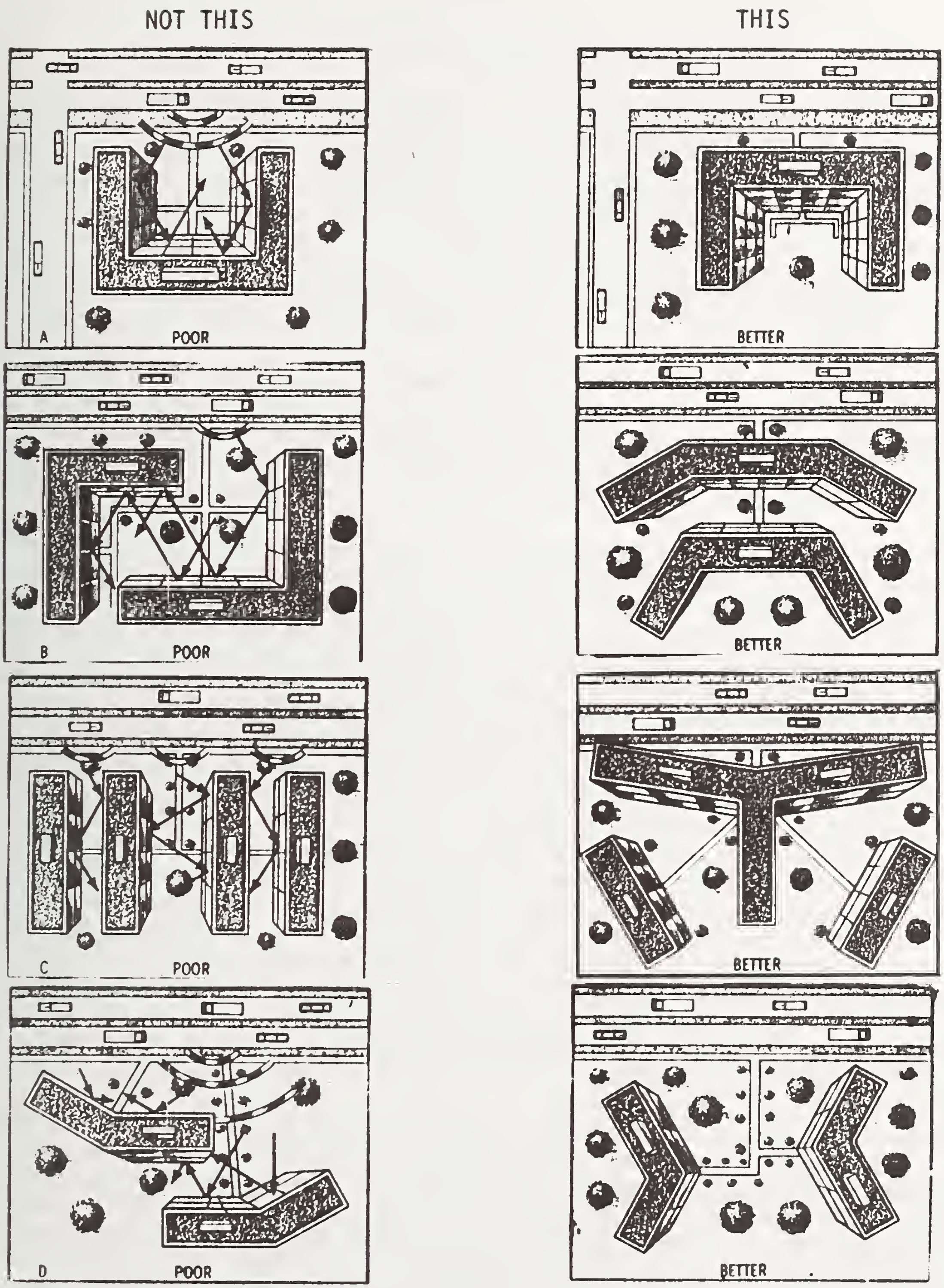


FIG. 6-4 ORIENTATION OF APARTMENT BUILDINGS FOR OPTIMUM ACOUSTICAL SHIELDING.

Chapter 7

A TROUBLE-SHOOTING GUIDE

In solving noise control problems, it is best to employ the SOURCE - PATH - RECEIVER concept introduced in Chapter 3. You can trace the travel of the offending noise back to its source with some very simple equipment if you pay attention to what you hear. Working in this manner, you will be following the footsteps of a renowned acoustical engineer - Lord Rayleigh - who did some of his best research with only the materials he had in his posession: his ears, a duck call, tennis and croquet balls. Having located the source of noise and its path, you can use this guide for help in eliminating the annoyance. For your convenience, we have a detailed index at the end of this chapter.

First of all: Do you have a problem that is hazardous to hearing, or does the noise merely bother you? You can use your own ears for a sound- level meter. We have already mentioned the first step: Do you find conversation possible? From just one further step you can estimate the sound level in your vicinity: Over what distance is conversation possible?

Figure 7-1 shows the experimental relationship that has been found between the recognition of spoken words and the typical dB(A) reading of a sound-level meter. As an example of the use of this graph, suppose you are standing talking to another person at a customary distance of from 3-5 feet (1 - 1.5 m) from him. If you are comfortably able to carry on your conversation - no unusual effort to hear him, no feeling that you are pushing your voice to a higher level - then it's likely that the sound level doesn't exceed 67 dB(A) where you are standing [point (1), Figure 7-1]. Suppose, now, you are at a stand-up dinner or a cocktail party, where a typical level shortly after the beginning of the party might be 74 dB(A) both of you may have to raise your voices [point (2)], but you could still expect to understand one another. However, to attract the attention of someone at the other end of the living room (20 feet or 6 meters) you would have to shout [point (3)]. However, since shouting raises only the voice sounds, but contributes almost nothing to the power of the consonant sounds upon which the meaning of speech so often depends, you would also have to confine your remarks to the simplest subjects: scarcely more than "Hi!" could get across. At about 80 dB(A), a level reached by some guests and some parties, even the normal conversational distance becomes impossible for conversation; at this level, continued exposure for many hours might offer some risk to hearing, and it's advisable to leave.

To use Figure 7-1 as a guide to sound levels, you can start a conversation with a companion, and then back slowly away. You can signal one another the moment you feel that extra effort is involved, either in speaking or listening. At this point, if neither of you has a hearing loss, the distance between you can be noted on the horizontal scale on the chart. From the solid line on the chart you can read off the effective sound level in dB(A) along the vertical scale. This will work even when you are in a fairly reverberant space; only a very long echo time, as in a concert hall or church, will cause you to overestimate the sound level.

The reason that this process works rather well is that the A-weighting network of the sound-level meter parallels quite closely the sound distribution in conversational speech. Speech has another great advantage: we all are expert listeners. You can use your recognition of speech sounds to tell you more about the noise source, itself. To allow you to translate your recognition into the terms used by acoustical engineers, we have shown some of the characteristics of speech sounds in Figure 7-2. If you listen closely to the noise, you may be able not only to recognize the source, but may be able to recognize the principal pathway through which the noise is reaching you.

For example, suppose you live in an apartment building, and the sounds from neighboring apartments annoy you. Are they coming through the air, or via the structure? If footsteps sound more clearly than voices, and you can hear the voices but can't make out what is said, the chances are that the sound is traveling as vibrations along the floor, or through the walls and ceiling. High-frequency sounds, such as those of the consonants that carry most of the meaning of English speech, do not pass as readily through structures as do the low-frequency sounds of footsteps and the voice melodies and vowel sounds of speech. If speech comes through as though it were passing down a "speaking tube", you should expect to find airborne sound paths - actual sound leaks.

Sometimes, however, the character of the sound is so altered that you can't recognize its origin. A floor lamp may "sing" if you set it at some points on the floor, but be quiet in other positions. There you are dealing with a resonance in the structure of the lamp that permits it to resonate when excited by a vibration from the floor that would otherwise be inaudible. A possible source of this vibration might be the compressor of your refrigerator; in that case the lamp would sing only when the compressor is working. Simply changing the bulb in the lamp might eliminate the trouble, or tightening up the screw on the base of lampshade. Here, the chart in Figure 7-2 can prove helpful. You can shout various words at the lamp and see whether some words will set it singing. The chart in Figure 7-2 will then allow you to estimate the frequency of the vibration that is triggering off the singing of the lamp.

Armed with these charts for analyzing the problem, you now need some simple tools. Most of these are at hand, in almost any household. For example, you can look for sound leaks with a flashlight. Light coming through the edges of a closed door is following a path that sounds can travel along as well. Another place to look for a light leak is along the edge of the doorway molding. Sometimes the opening cut for a doorframe has been larger than needed, and inadequately filled in.

Of course, sounds can worm their way around corners too abrupt for light beams. To locate these, you need a sound probe. A very useful device for conducting sounds to your ears from a definite location is a stethoscope. The child's toy sold in some "educational" kits is good enough. In a pinch , you can follow the lead of the originator of the stethoscope, and use a hollow tube. You can use the central tube from a roll of paper towels, or a mailing tube of about that diameter. This is just about the right size to accommodate one ear, and is long enough to enable you to move about freely while you look for sound leaks. With a small lump of caulking compound, modeling clay, or putty at hand, you can make temporary closures of the leaks you find, thus making it easier to locate secondary leaks.

For any extensive search, you need devices for generating sounds and vibrations of relatively high intensity. The noise source that bothers you may not be obliging about generating enough noise just when you are in a position to look for it. Even with a continuous noise, it is sometimes useful to recognize that the noise path is reversible. If sound is reaching you through a leak from outside, you can make a noise inside the room, and look for that noise on the outside.

A portable transistor radio makes a convenient sound source. Several ordinary appliances make convenient vibrators. If you remember that it is designed for brief spurts of service, and can overheat if operated too long, a household blender makes a good source of vibration running under a mixing load. A mixer on a stand, working on a moderate load, is less intense as a rule, but also useful. Other devices you might have about the house make fairly good vibration sources: a vacuum sweeper with a rug beater, an electric shaver, a scroll saw, a portable drill.

Your stethoscope will help you locate vibrations as well as sounds. Another sensitive vibration detector that you can use is the sound conduction path through your forehead, just by resting it against a wall. Another somewhat more sensitive area for picking up sounds is the mastoid bone behind your ear. (You can lean it directly up against a door frame, for instance.) For low-frequency vibrations, your fingertips are a sensitive pickup when held lightly against the vibrating surface.

HOW TO LOOK FOR LEAKS

First of all, try to estimate whether the intruding sound is arriving by structural vibration or directly through the air. Compare the loudness when you are in direct contact with the wall with what happens if you pull your head just slightly away.

If the sound seems to be coming through the air, explore wall cracks, window-frame openings and door frames. You will find that the tube or the stethoscope will allow you to locate specific leaks. You can mark them with chalk, or, even better, plug them temporarily with whatever plug or caulk material you have conveniently at hand. Since you have to find the dominant leak before the general noise level changes very much, it may take a little time to find the worst leak. That is why plugging leaks as you go along is a great help. If you have access to both surfaces of a room wall, it is also practical to explore for suspected leaks with your flashlight, having both spaces darkened. For remote corners or inconvenient places, a hand mirror is useful. You may find that a surprising amount of sound can leak through a little hole.

The stethoscope will also allow you to find the particular wall surface through which vibrations are being radiated into the room. You can perhaps determine whether you have any hope of removing the noise yourself, or whether you may have to ask the upstairs neighbor to lay down a rug in his living room.

If you are searching for leaks during a period when the source is quiet, you may have to make some noise yourself. Remember, for convenience, that it is possible to reverse the source and the receiver in searching for a noise path. You may be able to persuade someone to help you by pounding on an adjacent wall, or you may want to resort to one of the noisemakers we have suggested. You can set a radio on a table, and then explore the exterior of the room for sound leaks. If you think sounds may be coming through by vibration, you can set the radio on a pillow, and notice whether this makes the sound coming through less intense. If the pillow reduces the sound, you can resort to one of the vibration sources suggested, and then explore with your stethoscope for the paths by which the vibrations travel.

You can explore for leaks using any simple device that generates air pressure, such as a small hand-held hair dryer or a vacuum cleaner with a long narrow crevice tool fitted at the end of the hose. You can aim them at the places where you suspect noise leaks, and explore for drafts on the far side. You can use a wetted finger, or a candle flame (if you are cautious about the fire hazard) to locate and trace out the pattern of the leak.

Your problem may be that both airborne and structure borne sounds are coming through. In that case, you have to make a trial estimate of which path is dominant, for you have always to quiet the most potent source of noise before you can proceed to the next remedy with any hope of success.

Table 7-1 shows the way in which a listener may describe an irritating noise problem, and lists the environmental qualities that lead to his complaint. Notice that some of the complaints are based upon secondary effects of the interference, such as the "liveness" of a room and its noisy character.

REMEDIES

Often the remedies for quieting noise sources are as simple and accessible as the tools we have suggested for locating the troubles. You do have to keep in mind the difference between absorbing sounds (to reduce echoes) and keeping sounds away. It's like the difference between blotting paper and a slate roof. You do have use for sound absorbers to reduce room resonances, making for a quieter, less echoing environment. Often they do much to reduce the annoyance from high-frequency sounds, although they are much less effective over the entire sound range than removal of the source of noise.

Just to give a general idea of the strategies involved in removing the difficulties from noise, we present a table of noise abatement techniques in Table 7-2. Because we pay most attention to the loudest noise sources in our environment, the order in this table is also approximately the order in which remedies need to be applied for maximum effectiveness. It may seem to you that some of these efforts are quite extensive, and yet may reduce the sound level by "only" 6 dB. If you recall what the decibel scale means, however, you will see that a reduction of 6 dB means that you have succeeded in removing 75% of the noise power. No wonder it is important to select the remedies for noise problems in the order of their likelihood for success. As you can see from the arrangement of this bulletin, and from Table 7-2, you start by removing resonances, reducing the probability of generating noises such as turbulence and vibration, try to remove pure-tone components, and end by "decoupling" the source from the path -- either by enclosing it in a sound-resistant box or by introducing sound or vibration attenuators, such as mufflers or resilient mounts.

Most of the suggested remedies deal with breaking the path. As a result, most of the techniques are those of sealing off and shock-mounting noise sources. The materials for these processes are often readily at hand.

Old automobile tires and inner tubes make excellent shock mounts for fairly large appliances, such as freezer chests or large compressor units for air conditioners. Sections of automobile tire can be mounted as bumper strips on the bottom of overhead garage doors. Discs cut out of old tire casings can be used under casters on pianos, to reduce transmission of vibration to the floor. (They also will spread the load over a wider area of a thick rug, forming a protective surface as well as a resilient mount.)

Refrigerator supply stores and plumbing supply shops have various styles of gasketing that can be used to seal door closures, making it easier to seal off noise that is reaching an apartment from the outside corridor when the leaks come through the doorway.

Household supply stores and plumbing supply shops stock various types of non-hardening caulking compound. In addition to cutting down thermal losses and reducing cold drafts, various sorts of weather stripping remove the rattle from windows and help to cut down the conduction of sound from out-of-doors. "Safety-glass" laminated window panes can be made up for replacement in window frames to replace large areas of overly-thin glass, where the windows of a house must also cut down the intrusion of outdoor noise. Automobile glass shops stock these sandwich glasses in large sizes, from which they may be cut to fit your window frames.

Bathtub mats and floor mats made of sponge or foam materials make area shock mounts that can be placed under lighter appliances. You can make most effective use of these mounts by choosing materials that are only partially compressed by the load. Once the material has become greatly compressed, its value as an isolator may be lost. The choice of padding depends upon the weight of the load.

Some of the "closed cell" foam materials sold for upholstery and padding make good gasketing when cut into strips. For instance, you can use a thin strip of foam under the lower part of a double-hung window set between the lower edge of the window and the top of a window air-conditioner unit. Not only will it serve as weatherstripping, but because of its resilience, if properly installed it will keep the air conditioner from rattling the windowpanes. You do have to be careful to choose fire-resistant foam material if you mount a window ventilation fan near a cookstove. Some types of upholstery padding are not sufficiently heat-resistant for this service.

For a kitchen appliance shelf, consider setting down a slab of marble or other heavy material over a pad of soft rubber, and operating such appliances as the blender on it. This treatment will reduce the "drumming" transmitted to the rest of the cabinet, and can be cleaned fairly easily. The principle here is that the marble is massive, the rubber is resilient, and only the lowest-frequency vibrations can be transmitted to the rest of the cabinet. Since the marble is heavy, the power needed to set it into motion would be great; it tends to be moved only slightly by the unbalance of the blender load, and that little motion is absorbed by the rubber. Detailed remedies for specific noise problems are given in an indexed catalog at the end of Chapter 7, which presents an alphabetized list of common noise sources, and suggests ways for reducing their impact upon your senses. Where a remedy has been discussed in the text, you will find a page reference. If you find only a number following the entry, it means that there has been a detailed discussion on that page in the text. Finally, you have another opportunity to look up quieting in general within the final index, which includes a comprehensive list of the topics discussed, arranged alphabetically and interleaved with the page references for the alphabetic index of common noise sources and their abatement.

LAST RESORTS

When the source of noise is beyond your control and you have done all that is possible to break the transmission path, you have to do whatever is possible to protect the listener if the noise level is still high enough to present a hearing risk or serious disturbance. In the next chapter, we will take up community action, but on a more individual basis you have still the following remedies at hand: Use noise appliances only at particularly insensitive times of day, and provide numerous respites from the sound. Protect the user of the appliance by ear plugs if possible. If the noise source is relatively mild, but distracting, consider some favorable masking sounds, such as a splashing fountain or a source of quiet music.

Brief intrusions of high-level sounds are among the most troublesome to remedy. A recent study of aircraft flyover noise showed that reports of annoyance tended to increase by a factor of only two when the flyover rate increased by a factor of eight. Read optimistically, this means that if you can tolerate one intrusion, you probably can tolerate two. From the standpoint of an acoustical engineer who must quiet an airport area, and the community that must live within the area, the situation must be viewed pessimistically. Reducing the number of landings and departures per hour to one-half their original number may leave a large number of delayed and disgruntled passengers in remote airports that they did not wish to see, but still produce only an insignificant dent in the number of complaints from the residents. For a householder, this statistic is also important. If you must operate a noisy tool, even though very briefly, it is important to try to stop the noise at the source. Otherwise, you may find yourself the recipient of a number of complaints despite the limited duration of the noise involved.

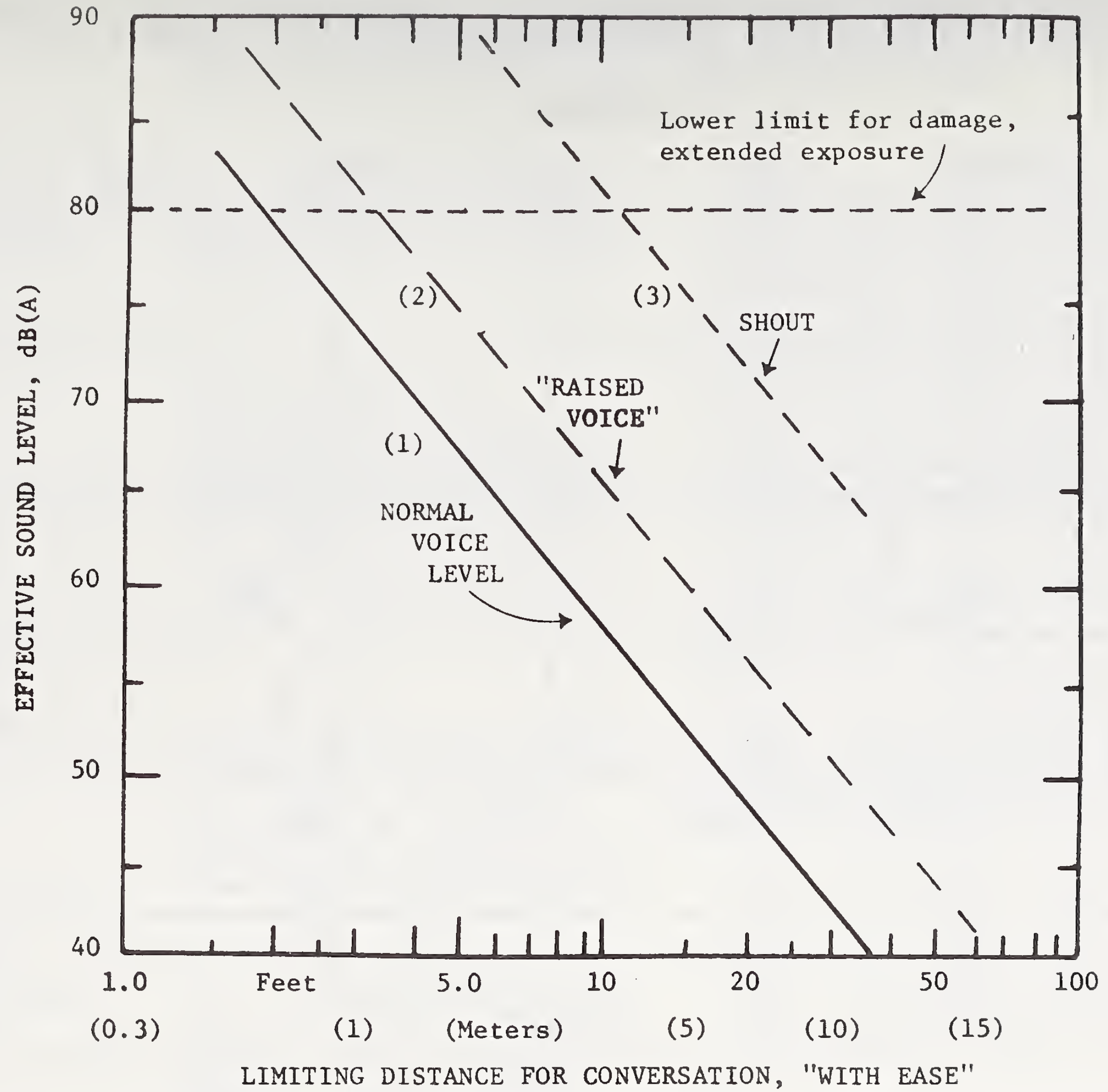


FIG. 7-1 THE "A" WEIGHTED SOUND LEVELS OF SPEECH AT VARIOUS DISTANCES UNDER ORDINARY CIRCUMSTANCES.

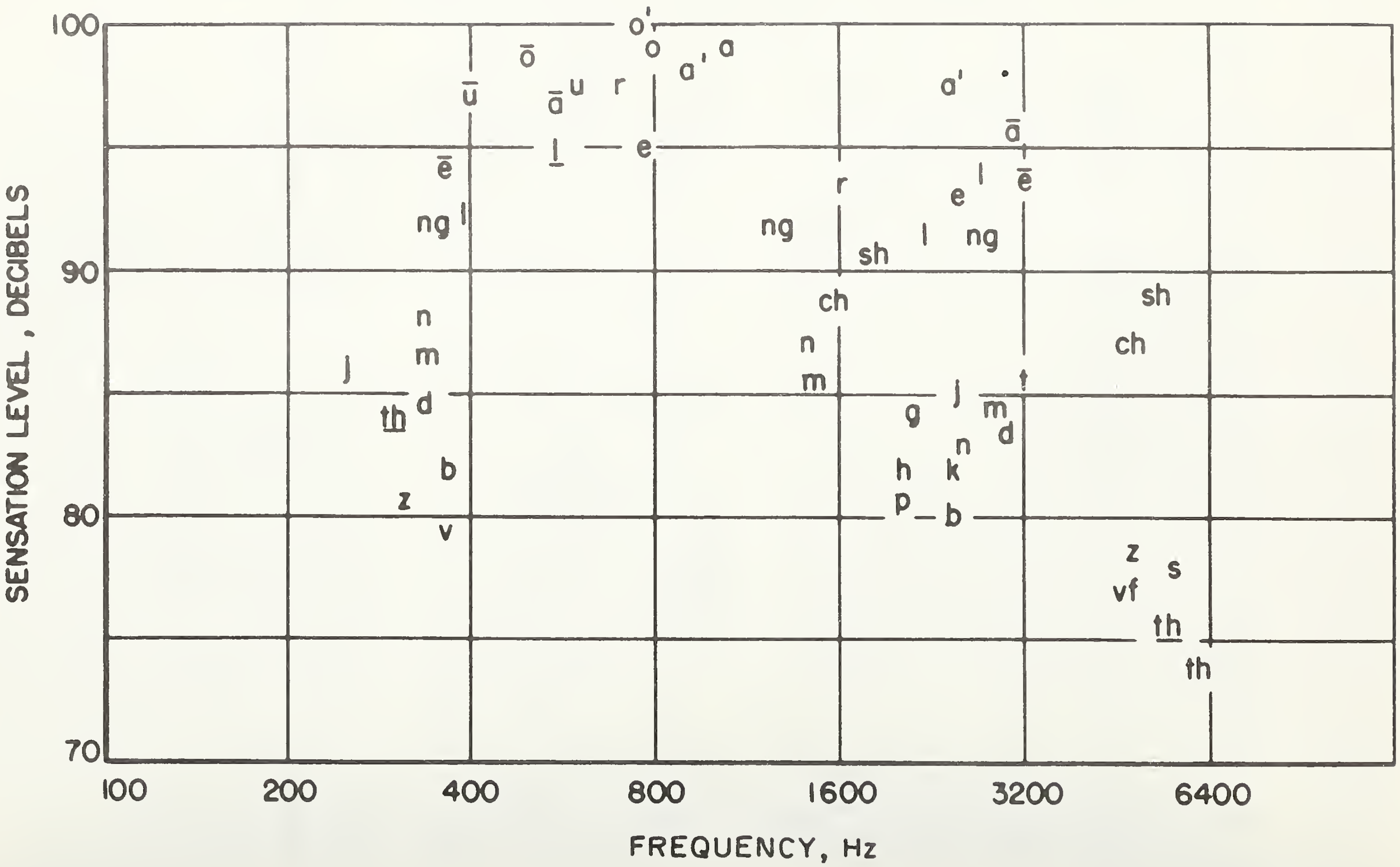


FIG. 7-2 INTENSITY AND FREQUENCY DISTRIBUTION OF COMMON SOUNDS IN ENGLISH SPEECH.

Table 7-1

COMMON NOISE COMPLAINTS, LIKELY CAUSES AND SOLUTIONS

Complaint	Probable Causes	Remedies
A. "This room is noisy"	Noisy appliances, ventilation system.	Reduce noise output of source: install vibration mounts; isolate source in sound-insulating enclosure. Ventilation noise: reduce blower speed; install acoustic lining and flexible connectors in ducts.
	Room is excessively reverberant; if the sound of a person's handclap persists longer than a second or two, the room is too reverberant.	Install sound absorbing materials, e.g. carpets and pads, drapery, upholstered furniture, acoustical ceiling. Total surface area of absorbent material should be at least one-fourth of total room surface area.
	Outdoor noise instrusion.	Install gaskets around existing windows and doors; install storm windows and doors; replace hollow core or paneled entrance doors with solid core doors.
B. "It is difficult to concentrate"	If conversation at an ordinary distance of 3-5 feet (1-1.5 m) is difficult, the ambient noise level is too high [greater than 70 dB(A)]. Excessive noise may be due to causes described above.	If the remedies outlined above do not alleviate the problem, install a prefabricated, sound-insulated engineer's booth or field office enclosure.
C. "It's stuffy and oppressive in here"	If there is adequate ventilation, the room is acoustically "dead." There is too much absorption, i.e., excessive drapery, rugs and pads and upholstered furniture.	Remove at least 50% of every drapery, thick carpet and padding; or replace existing furnishings with lighter-weight material.

Table 7-1 (Cont'd)

Complaint	Probable Causes	Remedies
D. "You can hear voices, but they are unintelligible"	The sound transmission through a partition, ductwork and ventilation noise in the mid-frequency range.	Caulk or seal all visible cracks at ceiling and floor edges of party wall. Remove cover plates of all electrical outlets in party walls to check for back-to-back installation; in such cases pack cavities with glass fiber wadding and seal with a resilient caulk. If additional sound attenuation is required, acoustical modification of the party wall may be necessary (see text).
E. "I hear whistling noise"	High-pitched sound usually is generated by ventilators and grilles; worn or defective washers, and valve seals in plumbing, heating and refrigerant systems. High velocity gas flow through furnace burner jets or nozzles cause similar noises.	Set dampers at most quiet setting; place ear at grille, if noise is louder remove grille. If noise vanishes with grille removed, reduce blower speed or install new grille with larger and more streamlined openings and deflectors. Reduce pressure in plumbing system and isolate pipes and valves from supporting wall and floor structures with resilient sleeves or collars. Replace worn or defective faucet washers or valve seals.
F. "I hear my neighbor's TV and stereo"	Acoustically-weak partition wall due to inadequate construction, noise leakage through cracks at floor and ceiling edges or through back-to-back electrical outlets. Neighbor's TV set may be too close to party wall.	Use same methods as in D. above. Suggest that neighbor place resilient pads under his TV and stereo sets and relocate them away from the party wall.

Table 7-1 (Cont'd)

Complaint	Probable Causes	Remedies
G. "Footstep noises from the apartment above annoy me"	Rigid, light-frame construction of floor assembly; solid concrete floor slab covered with tile; lack of carpeting and padding.	Suggest that carpet and padding be installed on the floor above. If additional footstep isolation is desired, test both ceiling and the walls in your room with a stethescope to determine which is radiating most noise. If noise radiation from ceiling is greater, install a gypsum board ceiling mounted on resilient hangers, place fiber glass blanket in void between ceilings. In some cases, wall panelling mounted on resilient furring members may be required in addition.

TABLE 7-2

GENERAL NOISE ABATEMENT TECHNIQUES
(Arranged in order of effectiveness)

Procedure	Reduction in Sound level, dB	Estimated Decrease in Loudness	Relative Reduction in Sound Power
Break-up resonances.	20 dB or more	Almost 75%, possible more. Resonances yield pure tones perceived as louder than mixed sounds of equal total intensity.	99% or more.
Reduce flow velocity to half.	18 dB	Almost 73%	Almost 97%
Break pure tones into random spectrum, same power.	May be negligible as read on a sound-level meter	Depending upon composition, loudness may be reduced more than 50%. (Equivalent to about 15 dB SPL.)	None
Reduce dominant frequency by a factor of two, as by halving fan speed.	6 dB	Lowered dominant pitch reduces loudness equivalent of additional 6 dB SPL. Total loudness can be reduced about 50%.	Reduces sound radiation efficiency by a factor of about four.
Reduce radiating surface area by a factor of two.	6 dB	Noticeable reduction in loudness (about 25%).	Reduces sound radiation efficiency by a factor of about four.
Increase mass of sound barrier by a factor of two.	6 dB	Noticeable reduction in loudness (about 25%).	Reduces sound radiation efficiency by a factor of about four.

TABLE 7-2 (Cont'd)

Procedure	Reduction in Sound level, dB	Estimated Decrease in Loudness	Relative Reduction in Sound Power
Double distance from a source of sound.	Up to 6 dB, (small source), up to 3 dB (line source).	Loudness reduction up to 25%	Reduces sound power to 1/4, if sound source is small and in open space; to 1/2 if long line source; by nil if large source or echoing space.
Install sound-absorbent materials.	Up to 6 dB, mostly at high frequencies.	Noticeable reduction in echoes and high-frequency noise, usually noticeable effect on loudness.	Usually reduces sound power to as little as 1/4.
Increase dominant frequency by a factor	Up to 6 dB.	Can reduce audibility for sounds if original is above 6 kHz. Higher-frequency sounds are more readily absorbed by air and weakened or deflected by barriers. A last resort.	May be none. Likelihood of efficient sound radiation <u>increased</u>, but can reduce sound transmitted through enclosures or barriers by a factor of four.

ABSORBERS, SOUND

Materials: Acoustic tile, prefabricated silencers, fiber glass, carpets, drapes, upholstered furniture. See Chapter 3.

Application: On ceilings and walls of noisy rooms, inside noisy ductwork, appliances. See Chapter 4.

Function: To reduce noise buildup and reflection of sound, not transmission, See Chapter 4.

AIR CONDITIONER, Central (See Chapter 4)

Compressor: Select low noise-rating number, shock mount.

Grilles, Diffusers and Convector: Select streamline units with smooth, wide openings and low-spread discharge.

Fan: Choose slow-speed large diameter bearings and balance.

Motor: Choose symmetrical belt drive, large diameter pulleys, shock-mount.

Ducts: Treat ducts and dampers with sound-absorbent material; use slow, large volume air-flow in preference to small, high-speed flow.

AIR CONDITIONER, Room or Window (See Chapter 4)

Compressor: Select power adequate for job. Oversized compressor more noisy than needed.

Fan: Large diameter, squirrel-cage type.

Gasket: Install perimeter gasket of soft rubber.

Mounting: Mount on resilient pads.

Thermostat: Starting and stopping noise more troublesome than steady running: avoid over-power unit.

Air Filter: If the air filter in the unit becomes loaded with dust, condensate may freeze on expander tubing and cause whistling noise. Clean filters weekly during season to retain free air flow.

AIRCRAFT NOISE

Note alignment of main runways and flight patterns of commercial or military airports.

Methods of avoiding: see Chapter 5.

Recommended dwelling locations: see Chapter 6.

Sound insulation requirements of dwellings: see Chapter 5.

Recommended seat location for passenger: see Chapter 9.

AIR HAMMERS

Select units with exhaust silencer and sound insulating jacket. Choose minimum stroke needed to perform work. See Chapter 3.

ALARMS

Emergencey vehicles: see Chapter 2.

Noise levels: see Chapter 2.

Startle effects: see Chapter 2.

Traveling: see Chapter 2.

APPLIANCES (See Chapter 3 and 4)

Choose low noise-rating number where given.

Install properly: Use vibration mounts, resilient pads, flexible connectors, vibration damping coatings.

Look under individual appliances by type.

BIRDS

(See Chapter 5.)

Reducing noise intrusion: Caulk or gasket existing windows; install storm windows. (This will also conserve energy by minimizing temperature variation in the home.

BLENDERS

Select unit with low noise rating; see Chapter 4.

Container: prefer glass.

Housing or base: choose metal instead of plastic.

Mounting: place on resilient pads.

Use as a vibration source for troubleshooting noise problems; see Chapter 7.

BLOWERS

Choose slow speed, large diameter fan with wide blades or squirrel-cage design; prefer belt-drive to direct drive. See Chapters 3 and 4.

BOWLING ALLEY (See Chapters 3 and 4)

Reduce noise buildup and reverberation by sound-absorbent treatment of walls and ceiling. Avoid areas where conversation can be done only by shouting.

Alley must be vibration-isolated from building structure by means of resilient mounting.

BUSSES

Avoid residences near major bus routes. Motors should be well tuned, well muffled (see Chapter 6).

Tires should be selected for quiet treads; see Chapter 9.

Brakes should be adjusted and properly maintained to avoid squealing.

Choose seats near center; see Chapter 9.

CABINETS

Choose solid, well-damped door material; see Chapter 4.

Apply mastic to inner panels; see Chapters 3 and 4.

Tighten loose strike plates.

Line shelves and backs of cabinets with cork or rubber tile to absorb impact noise; see Chapter 4.

CAN OPENER

Place on soft rubber pad. See Chapter 4.

CAT FIGHTS, CATERWAULING

(See Chapter 5.)

Reduce noise intrusion: caulk or gasket existing windows, install storm windows.

CHAIN SAW

Select quiet unit with adequate power; see Chapters 3, 4, and 5.

Wear ear protection; see Chapter 2.

CHILDREN, VOICES AND PLAY NOISES (See Chapters 4 and 5)

Avoid play in reverberant spaces; reduce noise buildup by sound-absorbent treatment of playrooms and classrooms, close off sleeping quarters with well-fitted windows, gasketed doors; treat ventilation inlets with sound-abosrbing lining

CLOCKS, Alarm (See Chapter 4)

Give preference to the types of alarms that chime or turn on radios, if you live in a multiple dwelling. Place alarm clock on a padded surface. Be especially careful not to set the alarm on a surface leaned against a party wall between your apartment and the one next door, or on a wall adjoining another sleeping room.

CLOTHES DRYER AND WASHER (See Chapter 4)

Select units with low noise ratings. Vent clothes dryer where noise will give minimum disturbance. Isolate laundry room as much as possible from other living space.

Install units on resilient pads or mounts.

Use sound-absorbing and vibration damping materials on inside surfaces.

COMBUSTION NOISE - FURNACE (See Chapter 4)

Have fuel-nozzle adjusted for minimum noise (this can be done with no loss of burning efficiency). Separate furnace room from rest of residence with fireproof partition, if possible. Air intake in most residential furnaces is direct from cellar; replacement with duct from outdoors can reduce noise entry into rest of house, also might reduce need for humidifying heated air in the house.

Flexible connector and sound-absorbing lining in air ducts can reduce transmission of combustion noise from the furnace to room areas.

COMPACTOR

Vibration isolate the unit from enclosing cabinet and floor by means of resilient mounts and gaskets; see Chapter 4.

COMPRESSED AIR LINE

Select quiet blower nozzle; install silencer on exhaust port; keep tight couplings (see Chapter 3).

Maintain uniform diameter; avoid abrupt changes in cross-section. Avoid rigid connection between pipe and wall, to prevent "soundingboard" effect. (See Chapter 3.)

COMPRESSORS

Use muffler on air intake to reduce radiation of whistling noises, see Chapter 3.

Choose rotary pump rather than reciprocating pump; balance carefully. Vibration isolate unit from surrounding structures by resilient mounting; install flexible connectors in lines. Place unit in sound-insulated enclosure. (See Chapter 3.)

CORRIDOR NOISE

Treat corridor floor with carpeting, ceiling with sound-absorbent acoustic tile. Install sound insulating doors with gaskets to reduce sound leakage into corridor space. Walls of apartments that are common with corridor walls should be of sound-insulating construction. (See Chapter 4.)

COURTYARD NOISE

Courtyards tend to be reverberant and noisy.

Seal windows (see Chapt. 5 & 6), draw ventilation from other exposures. If necessary, increase weight of glazing in windowpanes.

Some reduction of noise level can be obtained in a large courtyard by planting trees and shrubs.

Avoid installation of air conditioners in areas with courtyard exposures.

CREAKING

Common causes of creaking in a house are loose wood joints. For floors, see a separate entry under "floors", also see Chapter 4.

For creaking door hinges and blinds, lubricate hinge pins. Weatherstripping improves the door seal and also restricts its freedom to move and generate creaking sounds. Refit latches and locks.

Creaking of ductwork is caused by thermal expansion and contraction. Mount ductwork on flexible hangers. Flexible expansion joints may help relieve the problem.

"CROSSTALK"

Install acoustic barriers in ceiling plenums, crawl spaces, and ventilation ducts. (See Chapter 4.)

Flanking transmission (see Chapter 4) and small acoustic leaks are common causes of sound conduction from supposedly isolated adjoining spaces. See Chapter 7 and general discussion of "Troubleshooting" for leak-finding techniques.

DAMPER NOISE

Dampers are the vanes used to control the flow of air in ventilation and heating ducts. Damper noise is typically a whistling or hissing sound, and may be reduced by slowing air flow, see Chapter 4. Some improvement can be obtained by coating the damper with a sound-absorbent coating (this, however, may impede the flow).

Some flutter noise may be generated in a flexible damper; substitution of more rigid, heavier, or better-shaped dampers may help.

DIFFUSER NOISE

Diffuser outlets in ventilating systems are frequent sources of whistling or hissing. Reduction of air flow velocity is the most effective remedy. Replace existing diffuser with a large-diameter, low-spread, better-streamlined unit. In a pinch, removing the diffuser altogether and replacing it with a "spreading plate", i.e. a panel - treated with sound-absorbing material on the sie toward the duct opening - suspended 4-6 inches below the opening, can be used to diffuse the air flow without whistling. See Chapter 4.

DISHWASHER

Generally, choose a dishwasher after a demonstration for quiet operation. Built-in dishwashers should be quieter because of the limited surface for radiating sound. However, rigid pipe coupling and drain coupling can transmit noise to the household plumbing. Install flexible connector in pipe and drain lines to interfere with the vibration conduction path. Load dishes so that they are not free to flap in the washing stream. Tighten loose fittings, especially door latches and shelf supports. See Chapter 4.

DOG BARKING (See Chapters 5 and 10)

Voice your complaint to the neighbor. Dogs likely to bark should not be left out in the yard at night, out of consideration for the neighbors. Your own dog makes a fine burglar or fire alarm <u>in</u> your house.

Caulk or gasket windows; install storm windows.

DOOR KNOCKER (See Chapter 4)

Replace device with a door chime. Door knockers that strike too heavily may be relieved by putting a small resilient felt or rubber pad at the point where it contacts the strike plate. The knocker itself may be replaced by a lighter-weight part.

DOOR SLAMMING (See Chapter 4)

Install door closure dampers on all spring-loaded self-closing doors, such as screen doors. A resilient strip (or weatherstrip) surrounding the door closure will reduce the impace noise, as well as help seal the door against acoustic leaks. Substituting a solid-core door for a hollow-core door may help to relieve door-slamming and door-rattling noise.

DRAIN PIPES

The principal generator of noise in drain pipes is turbulence from rapid and unsteady flow. The noise, however, generally becomes annoying because the drain pipe is fastened rigidly to some surfaces capable of serving as sounding boards. Insertion of resilient pads in the pipe supports should reduce noise, as should spacing the pipe from floor supports by means of resilient padding. Where a choice is available, use the largest diameter of pipe, to maintain relatively slow, smooth flow; see Chapter 4. Use heavy-walled pipe such as ceramic or metal pipe rather than plastic pipe.

DRILLS, PNEUMATIC

Drills with exhause silencers and sound-insulating jackets are available.

Sounds of road-making machinery are difficult to eliminate. Repairs on city streets using pneumatic drills should not be carried out during sleeping hours; see Chapter 10. In many cities, ordinances forbid such noise during night hours.

Caulk or gasket existing windows facing source; install storm windows.

DRUMMING, BELT (See Chapter 3)

Looseness makes belt drumming and slapping more likely. Adjust tension for minimum noise. If necessary, a damping idler wheel may be installed to maintain belt tension while reducing belt vibration.

DUCT NOISE

The principle causes of duct noise are creaking, rubbing and snapping noises due to expansion and contraction. See Chapter 4. Turbulent flow through ducts causes roaring sounds; see Chapter 4. Sound conducted through the ductwork as though it were a speaking tube can be minimized by installing sound-absorbing material and sound baffles.
Dampers in ducts cause whistling noises for high-speed flow, see entry under "dampers". Whistling generated at duch orifices and dampers can be transmitted through the ductwork.

Use of sound-absorbent lining, flexible connectors and stiffeners or bracing in ductwork generally alleviates duch problems.

ELECTRICAL EQUIPMENT (See Chapters 3 and 4)

Common sources of noise are loose laminations on transformers (which can sometimes be tightened), sparking (indicated by a hissing, frying sound), and, occasionally, "singing" of loosely-supported filaments in lamp bulbs. Sparking can be prevented by tightening electrical contacts, and by making sure that switch contacts are clean. Lamp bulbs that "sing" should be replaced. Loose laminations sometimes develop on the ballasts used with fluorescent lamps; these should be replaced, preferably with more conservatively-rated ballasts. Fluorescent lamps yield more light per watt of power than do incandescent lamps, but they tend to be noisier than the latter. Noisy wall switches that are likely to be turned on in the middle of the night - as in bathrooms - can usually be replaced by "silent" mercury switches of the appropriate rating.

See individual entries for specific electrical appliances.

ELEVATORS (See Chapter 6)

An elevator shaft acts as a speaking tube to transmit sounds from the drive motors and elevator doors. Proper mounting of the motors and doors can reduce the noise produced. Sound-absorbing material can be installed in the elevator shaft, though this is seldom done. Bedrooms should not be placed adjacent to elevator shafts.

Especially in tall buildings, where high-speed elevators are used, the air overpressure and rarefactions caused by the piston action of the elevator have to be vented somewhere; provision of alternative vents for this pressure may be feasible, and can prevent the whistling of air past the safety strips on elevator doors.

EXPANSION AND CONTRACTION (See Chapters 3 and 4)

Long sections of sheet metal supported at infrequent intervals along their major dimensions are likely to make "clacker" type noises as they expand and contract with temperature. This is a serious source of noise in air-handling ductwork. Separating the duct into segments which are supported independently and connected together with resilient or compliant joints can reduce sound from this cause considerably. Sheet-metal roofing can be sealed with mastic placed at frequent intervals where it is laid on the roof. This can be used to minimize rattling in the wind. Careful attention to the edge of roofing can prevent the rattling (and tearing) produced when strong gusts of wind penetrate under the roofing and lift it.

In "vee-groove" roofing, nails should be applied through a spot of mastic applied at the spring section at the peak of the vee. Motion of the roof relative to the nail will then tend to clinch the roofing material around the nails.

FANS, EXHAUST

See Chapters 3 & 4. Remember the useful rhyming conditions "slow and low". Use as slow a fan speed as can be obtained. Exit louvers should be of easily-cleanable material and massive enough to prevent rattling. In choosing a kitchen hood filter, give preference to a longer section of more highly porous material (i.e., greater thickness); this choice will tend to maintain smooth air flow. Of course, for ease of cleaning the filter should be interposed between the hood and the fan.

FAUCETS

For quiet valves see Chapter 4. The greatest nuisance is a dripping faucet with no immediate chance of fixing it (late at night); simply placing a sponge or a facecloth under the drip may reduce the sound appreciably. The traditional quick remedy is to tie a string or shoelace to the faucet so that the drip is channeled as a miniature stream down the string.

"Singing" of a faucet is almost always a sign of a deteriorating washer, which should be replaced.

FLOOR NOISES

Squeaking floors and stairways: see Chapter 4. Squeaking floors often can be silenced by inserting oil in grooves or edges of flooring, renailing, inserting wedges under warped board, installing additional support or bracing to sagging floors.

A curious slapping noise on tiled floors, such as parquet and the various linoleum, rubber and asphalt tiles can be heard if a tile becomes loose. The loose unit can be located by walking briskly across the floor and noting which tile emits the sound. To prevent tile or linoleum from cracking, apply heat from hand-type hairdryer or pans of hot water to soften surface. Even if partly secured, tiles may be partially bent or lifted, allowing mastic to be inserted under the loose edges. A weight placed over the tile will hold it in place until the cement sets.

GARAGE DOOR (See Chapter 4)

The noise generated by the opening and closing of roll-up type doors of garages attached to the home can be reduced substantially by mounting the track on resilient isolators and placing a rubber gasket at the bottom edge of the door to absorb the impact shock of closing the door.

GARBAGE COLLECTION (See Chapters 4 and 5)

Vibration-damped, laminated metal trashcans, which are relatively quiet are commercially available. Cans made of heavy-gage, resilient plastic make less noise when dropped or struck than do ordinary metal cans.

If collection takes place at hours when it interferes with sleep, there may be a case for community action; see Chapter 10.

GARBAGE DISPOSER

If possible, select a unit for quiet operation. Sink units feature resilient mounts, flexible pipe connectors and a sound-insulating outer shell. Coating the underside of sink basin with vibration damping compound will improve the noise reduction. Installing acoustic tile inside cabinet enclosure will reduce noise buildup.

GARDEN TOOLS

The major noisemakers are lawn mowers and chain saws. Mowers can be selected for quiet operation. Reel mowers tend to be quieter (and often somewhat safer) than rotating-blade mowers. Ear protection should be worn if needed (see Chapter 2), and attention should be paid to the community's needs for reasonable quiet.

Since chain saws are hard to shield against noise, they should be used only where power tools are indispensible, and attention to adequate rest periods should be stressed.

If it is possible to extend a power cord to the working site, electrically-operated tools may eliminate a large degree of the noise.

GRILLS

The ventilator grilles on forced-air heating and cooling systems are a major source of noise. The most common cause of noise is excessive air velocity through the grilles and duct; choice of a more streamline grille with large openings will reduce constrictions which cause whistling. See Chapter 4.

GRINDERS

Except when it is directly engaged in grinding, any rotary grinding tool should be so well-shielded and well balanced that it is essentially quiet. This can be improved by careful mounting of the grinder on resilient pads. See Chapter 3.

A portable grinder can be operated quietly when set upon a vibration-isolating mount. See Chapter 4.

HEATING SYSTEMS (See Chapter 4)

These are among the major sources of annoyance. See also entries under fans, steam radiators, furnaces.

One advantage of lowering the thermostat at night during the heating season is that it minimizes the number of times the heating system goes into operation during sleeping hours.

Flame noise can be minimized by proper choice of combustion nozzles and proper adjustment. The quietest system is hot-water heat, if care is taken to vibration isolate the system from wall and floor structures by means of resilient mounts throughout the house. A noisy impeller can be replaced with a quieter one, or the rate of flow can be reduced, which will lower the noise output. Steam systems generate noise through air vents, which whistle and hiss every time the steam is circulated; a two-pipe steam system is much to be preferred to the one-pipe steam system. Steam radiators also "hammer" if water gets trapped in the circulatory system, a particularly serious fault of the one-pipe steam system.

Many modern heating systems use forced air circulation because it permits air conditioning and humidification to be supplied through the same ducts. This is potentially one of the noisiest systems unless special care is taken in its design and installation. See entries under fans, ventilation, heating and air-conditioning equipment.

HEATING SYSTEMS, CENTRAL AND CLOSET INSTALLATIONS

Noise associated with forced-air heating systems is due to a combination of sources, such as mechanical noise of the motor/blower, blower-blade passage frequency, turbulence, air-flow noise, combustion or burner noise, thermal expansion and contraction of ductwork and pulsation and vibration of the ducts.

Substantial reductions in noise output can be made by designing systems for low-velocity and low pressure operation. Use of resilient mounts under the motor/blower; resilient hangers, flexible connectors and acoustic lining in ducts will alleviate the noise problem.

Closet installations will require in addition soundproof walls, doors and an acoustic-lined return duct.

HUM

Most household appliances have some magnetic parts in them, such as the armatures on motors and the reactors in fluorescent lamps. The magnetic sheets will vibrate against one another, and generate hum at multiples of the power line frequency. Where the frames are bolted, as in transformers, tightening the bolts may help to eliminate the hum. On reactors for fluorescent lights, replacement of the "potted" unit may be the only remedy available. Radiation of the hum by other parts of the fluorescent lamp may be decreased by shock-mounting the reactor (ballast); see Chapters 3 and 4.

HUMIDIFIERS

The noise is largely from the fan or impeller. Atomizer-type humidification may generate a noise from the spray nozzle, which may be adjusted or replaced with a quieter unit. Since the spray noise is relatively high in pitch, acoustic baffles may help; see Chapter 4.

HYDRAULIC CONTROLS

The most common cause of trouble is valve noise, which is discussed under that entry. Also see Chapter 3.

As a rule, hydraulic and pneumatic controls are simple and rugged, but generally more noisy than electrical controls, with which they can sometimes be replaced.

ICE CRUSHER

See general discussion for kitchen appliances in Chapter 4.

Like a blender, it can be made quieter by using a heavy container for the crushing compartment, and mounting the crusher on a shock-absorbing surface.

IMPACT NOISE

See Chapters 3 and 4 , for general principles of reduction of impact noise in machinery, kitchen cabinets, and floors in homes and apartments.

IMPACTOR

These devices should be operated at times that do not interfere with sleep among the neighbors. Shock mounting helps, as does care in selecting an appliance that is designed upon good acoustic principles. A hydraulic device can be made quiet more easily than can a device depending upon mechanical impacts to compress the trash. See Chapters 3 and 4.

INCINERATOR CHUTES (See Chapters 3 and 4)

Frequently these are made of relatively thin sheet metal, and the sound made is rattling of the trash against the flexible metal surface. Again, reason suggests that this is something not to be used during normal sleeping hours.

The metal chute should be structurally isolated from the building walls by means of resilient mounts. The exterior surfaces of the chute should be coated with a vibration damping compound to reduce the drumming resonance of the chutes caused by the impact of trash or refuse.

JACK HAMMER

Workmen should wear hearing protection. Work with these implements should be confined to normal waking hours. Avoid long, continued use of the jack hammer, allowing recovery periods. See Chapter 2.

These may be a case for community regulation; see Chapter 10. Frequently, an additional source of noise is the compressor supplying air power to the jack hammer. Adequate muffling is available, and should be required.

See discussion under compressors and compressed air line in this index.

KITCHEN APPLIANCES

With the exception of washers and dryers, most kitchen appliances are used for brief periods of time. However, several appliances may be in use simultaneously such as clothes washer, dryer, dishwasher, garbage disposer, etc., which can generate a rather high level of noise.

For methods of selecting appliances and proper installation see Chapter 4.

KNIFE SHARPENER

Place the appliance on a soft resilient pad to isolate it from the kitchen counter top or working surface. See Chapter 4.

LAUNDRY ROOMS

The principal sources of noise are clothes dryers and clothes washers; refer to these entries. These rooms tend to have hard surfaces and are likely to be very reverberant. Noise buildup can be reduced by installing sound absorbing material such as perforated metal tiles backed with glass-fiber pads, which will withstand the moisture. Resilient mounts should be placed under all machines; see Chapters 4 and 6.

For gas-operated dryers and water heaters, consider using an exterior-opening duct to draw outside air for combustion. This will reduce radiation of combustion and burner noise.

LAWN EDGERS

These tend to be as noisy as gasoline engine-operated lawnmowers but have a high-speed blade, which emits a somewhat louder and more irritating high-pitched noise. This is a case for selecting a quieter appliance. Ear plugs should be worn; they are especially effective against high-pitched noise.

LAWN MOWERS

Rotary Power Type: Select model with low noise rating, preferably with under-deck exhaust. Replace the conventional muffler with a new, somewhat more expensive, but highly effective model. Sharpen cutting edges of blade and balance blade. Tune engine and reduce speed; tighten loose and rattling parts. The above measures should provide about a 6-dB or about a 25-percent reduction in loudness. Generally speaking, noise levels at the user's position frequently exceed 90 dB(A), although this does not pose a hearing hazard because of the brief use of the mower, once every week or two. However, it may prove very hazardous to workers whose daily occupation is the mowing of lawns, park lands or the grounds of large institutions. Parents should consider this point very carefully before allowing their children to mow lawns to earn money on weekends or during summer vacations. In any event, ear protection should be worn by all workers exposed to such noise for extended periods. Refer to Chapter 2 for a discussion regarding noise-induced hearing damage. Rell-type power mowers, because of their smaller radiating surface, are somewhat less noisy than the rotary type. Properly designed electric-motor type mowers generally are the least noisy. Mower manufacturers can make substantial reductions in the noise out of their machines by adopting the following recommendations.

(a) Install the most effective, not the cheapest, muffler available.

(b) Vibration isolate engine from the mower deck.

(c) Except for the cutting edge, design a blade with rounded corners and a serrated or feathered trailing edge.

(d) Underdeck should be designed for smooth streamline air flow passage ways devoid of any obstacles or sharp corners.

(e) Coat the deck of the mower with a laminated composite virbation damping or undercoating material.

(f) Enclose engine compartment in a sound-insulating jacket or cover.

LAWN THATCHERS

Fortunately, these are used infrequently on any given lawn. The noise problems are common to those of lawn mowers and edgers, i.e. the motive power for them is a potent source of noise. Select units with well-muffled engines. See related entries. The operator should wear ear protection.

LEAF BLOWERS

Choose a model with a well-muffled engine, large air-inlet apeture, a squirrel-cage blower, and a streamlined discharge nozzle. Select attachment hoses that have smooth inner surfaces. Operate blower at slowest speed that will perform the chore.

LEAF SWEEPERS AND MULCHERS

Select machinery with well-muffled engines. Leaf sweepers are available in two types - the vacuum sweeper and the rotating brush types. Requirements for quiet operation of the vacuum-type sweeper are similar to those for a leaf blower. Canvas hoppers should be selected rather than metal to absorb the noise produced by the impacts of stones, acorns or debris. Metal hoppers should be coated with a vibration damping compound. The cutting and blowing action of a mulcher also can be reduced somewhat by coating the inside surfaces of the metal housing with vibration damping material.

LIGHT SWITCHES

Silent light and thermostat mercury-type switches are available. Rotary-disc type switches also are relatively quiet in operation compared to the spring-operated type switches.

MASKING NOISE

See discussion under "acoustic perfume."

MECHANICAL EQUIPMENT

See individual entries in this section and in Chapter 3 for methods of reducing the noise output of various types of machinery and mechanical equipment.

MOTORS

On electrical motors, unbalanced loads and worn bearings are potent sources of vibration and thumping noises; dry bearings screech.

Stray electromagnetic field from motors can set steel housings into vibration; replacing steel housings by brass or other non-magnetic material may alleviate this noise problem.

Motors should be set up on resilient mounts and vibration isolators.

MOTORBOATS

Relatively quiet outboard motors are available. They come equipped with vibration isolating mounts, sound insulating jackets, and under-water exhaust systems. Inboard motors with basically the same features can be installed in an acoustically-lined, sound-insulated enclosure to provide a greater amount of noise reduction. Electrical, battery-powered motors which operate quietly are available for light use, such as trolling or fishing. In addition they do not pollute the water.

MOTORCYCLES

Quiet mufflers are available. Except for delayed adolescence, there is no reason to use a poorly-muffled vehicle. With a properly designed muffler, power from the engine will be more smoothly developed, and greater fuel efficiency can be expected.

MUFFLERS

In general, these are sound-absorbing chambers placed on the exhaust of internal combustion engines to prevent the discharge of noise from the combustion process. As a temporary measure, additional muffler action can be improvised by lining a large-diameter metal can with a pad of glass fiber and inserting a slotted, smaller-diameter can. This double wall muffler should be attached to the end of the exhaust pipe.

To work properly, a muffler must be designed for a given noise spectrum, sealed carefully to the exhaust pipe, and must itself have substantial, non-rattling walls, and snd sound baffles.

MUSIC

Unwanted music becomes noise. Two rival sources of music generate cacophony. Rock bands approach sound levels hazardous to hearing (see Chapter 2). Similar levels can occur with some "Hi-Fi" systems.

Avoid places that feature such loud music. Warn your children about the hearing hazard. See Chapter, 4, Recreation Rooms, for methods of sound-proofing rooms against loud noise or music.

NAIL GUNS

Relatively quiet models are now commercially available. Avoid prolonged use of the device on a daily basis unless hearing protection is worn.

NEEDLE VALVES

The characteristic noise emitted by a needle valve is a high-pitched hiss. Examine valve and replace it if it is defective. Vibration isolate valve and associated piping from large radiating surfaces by means of resilient pads or sleeves. Enclose valve in glass fiber padding with an outer jacket of leaded vinyl.

OFFICE EQUIPMENT

See Chapter 8 for methods of quieting office machines and equipment.

OUTBOARD MOTORS

See discussion under MOTORBOATS.

PIPES

See Chapter 3 for design of quiet flow systems, and Chapter 4 for control of plumbing noise.

PLUMBING NOISE

See Chapter 4, Control of Plumbing Noise.

POLISHERS

Quiet models are available. These feature slow-speed, large diameter rotating discs which can be fitted with brushes or buffing pads.

POWER TOOLS

Variable speed tools like drills and scroll saws are less noisy than the high speed/torque models. Operate the tool at lowest speed capable of doing the job. See entries under specific type of tool.

PUMPS

Sump pumps and automatic-leveling water pumps are serious noise offenders, particularly if a quantity of water is drawn late at night. Vibration isolate the pump from the building and connect it to the plumbing via flexible tubing. Seal connectors carefully for maximum pumping efficiency (briefest operating time).

Pumps for compressed air systems are exceptionally noisy devices. See Chapter 3, Section 5 and Chapter 4, Control of Plumbing Noise.

RADIATORS

Steam radiators are inherently noisier than hot-water radiators; one-pipe steam systems are noisiest because of air-venting requirements and the frequent onset of vapor lock (water condensed from cool steam blocks the access of new steam in the pipes which causes intermi-tent hammering). Select a hot-water system which features large diameter pipes and low velocity flow. Vibration isolate the impeller pump from the building structure. Separate the pump from the pipe system by means of flexible connectors. "Bleed" dissolved air out of hot-water system at regular intervals to avoid hammering sounds from trapped air bubbles. See Chapter 4 relative to steam and hot water heating systems.

RADIO

Adjust volume control of the radio so that the sound level of commercials (which usually are about 5 dB higher than program material) is at a confortable conversational level.

RAILROAD

A railroad is a source of vibration as wll as airborne noise. Select dwellings that are at least one mile, preferably two miles, from a railroad line. See Chapter 6, selecting a quiet home or apartment site.

If you live near a railroad see Chapter 5 for recommendations regarding insulating your house against outdoor noise.

RAIN GUTTERS AND SPOUTS

A major noise source is the turbulent flow and irritating dripping of rainwater in the gutters and down spouts.

Select rain gutters of heavy gage metal, rounded bends and coated with vibration damping material. Avoid installing vertical drains outside of bedroom areas; isolate drains from the building structure by using soft rubber sleeves at pipe clamps and gutter spouts. Replace conventional metal elbow duct at base of down spout with a soft rubber boot or plastic hose.

REFRIGERATORS

Select units for silent operation. Frost-free refrigerators are operated with numerous fans, all more-or-less contributing to a noisy kitchen. Any refrigerator will be less noisy if it is mounted on resilient pads on a solid floor. See Chapter 4, Kitchen Noise, item 12.

RISERS

Vertical ducts or ventilation risers mounted on the exterior of buildings frequently are the cause of noise complaints. Such devices often rattle in windy areas or snap, crackle and pop, owing to thermal expansion and contraction with outdoor temperature variation. Further, the outdoor noise of aircraft, traffic, etc., are easily transmitted by the thin-wall duct and carried into the building interior. All exterior ductwork should be of double-wall construction with acoustic lining and silencers. Risers should be vibration isolated from exterior walls by means of resilient mounts at all points of support.

ROCK AND ROLL

Just possibly, this term may become obsolete before this publication, but anyone who has been exposed to amplified music has heard the noisiest part of "Rock and Roll." The sound levels generated can be high enough to damage the hearing of audience, performers, and bystanders. See Chapter 2.

If you <u>must</u> have a rock-and-roll session at your house, and if you <u>must</u> play the music so loud that you experience the pleasurably giddy sensation that high sound levels seem to produce in some people, the only way to avert noise complaints is to give a block party and invite all the neighbors in.

Obviously, shutting all windows and doors will reduce the amount of noise escaping outdoors.

ROOFING

"Rain on a tin roof" is a proverbial source of noise. Metal roofing can be quieted to some extent by mounting it over a layer of mastic. Slate roofing is strong and relatively quiet, though liable to breakage by hail and repeated freezing and thawing, but can only be applied to a roof structure capable of withstanding its great weight. Asbestos roofing is quietest, but most likely to tear in high winds. Massive roof materials like lead, copper, and slate serve best as barriers against exterior noise; sound insulation of the roof of a house is just as important as it is for the walls.

ROTOR TILLERS

The noise generated by a rotor tiller is comparable to that from a motor lawn mower; see entries under LAWN MOWERS.

SANDERS

Since most noise is generated at the contact between the disc or belt and the work, little can be done to prevent noise from being produced. At the factory wear ear protection. Provide for adequate rest periods away from the noise. Work in well-ventilated areas, preferably treated with sound-absorbing baffles or acoustic tile ceilings.

SAWS; BAND, CHAIN AND CIRCULAR

Noise reduction at the source is difficult. In the case of chain saws, a good muffler can make a substantial reduction in noise output.

Wear ear protection and provide for adequate rest periods away from the noise during the working day.

SEWING MACHINES

The reciprocating motion of the machine generates considerable impact noise. Place rubber pads under the legs of the machine cabinet or under the machine itself if it is a portable table-top model. Resilient mounting of the machine in the cabinet will result in a noticeable reduction of noise.

SHAVERS, ELECTRICAL

Motor-driven models are less noisy than vibrator types.

SHOWER STALLS

Shower stall should be mounted on a resilient pad or underlayment. Plumbing fixtures and drains should likewise be resiliently mounted. Metal or fiber glass stalls should be coated with vibration damping materials. See Chapter 4 on control of plumbing noise and Chapter 3 on vibration damping materials.

SIRENS

Audibility is a natural requirement, useful except for those who live near an emergency facility such as a fire station or hospital. Fortunately, the spectral distribution of sirens clusters within the 500-2000 Hz frequency range, which can be excluded to a considerable degree by closing off living quarters from outside noise, just as one tries to do for highway noise. See Chapter 5 for reducing the intrusion of outdoor noise into the home. See Chapter 2 relative to detection of sirens.

SNOW MOBILES

Many communities are beginning to regulate the noise emission that will be tolerated from snow mobiles and other all-terrain vehicles.

Select machine on basis of low noise output. Such machines feature effective mufflers, acoustical lining and vibration damping treatment. As a precautionary measure, ear protection should be worn, particularly during periods of extended or prolonged use.

SOLENOIDS

Many automatic household machines such as dishwashers and washing machines use electrically-operated solenoids to open and close input and drain valves. The basic mechanism is a rod of magnetic material operated by a coil. Usually, a fairly heavy impact occurs when the solenoid is actuated. Shock-mounting the device may help to confine the noise to the machine and its immediate vicinity. Sometimes, a solenoid held back by a spring will vibrate when the slot in which it travels becomes worn, and replacement will cut down the hum level significantly.

STAIR CASES

The impact from footsteps can be minimized by placing carpets or resilient pads on the treads. Stair halls are often needlessly "live", and can be quieted considerably by the use of fireproof, sound-absorbing material on the upper walls.

In apartment buildings, staircases that are sealed off with fire-proof doors equipped with quiet closures minimize not only the fire hazard but, also noise interference.

STEAM AND PRESSURE-REDUCING VALVES

Such valves are exceedingly noisy. Replacing existing valve with a number of smaller units to affect a gradual reduction in pressure will lower noise output considerably. Enclosing valves in a gypsum board or plywood box, or duct packed with fiber glass is an effective means of reducing the noise level.

SWIMMING POOLS

The hard tile surfaces surrounding swimming pools cause the area to be highly reverberant and thus buildup noise made by persons at play within the pool. Various types of sound absorbers can be used within indoor pools to reduce echoes, but seldom are. Of course, the water surface is a reflector.

Pumps and circulating water are additional sources of noise. A rooftop swimming pool is a nearly insoluble source of noise to the residents beneath. Such installations require vibration isolation of the pool, plumbing and filtration system from the building structure.

SHOCK WAVES

Also see entries under THUNDER.

By the time these reach your house, they usually will have spread out, been echoed off many surfaces, and lost some high-frequency sounds by absorption.

House structures that exclude traffic noise will also do rather well with shock waves, but in their infrequent occurrence, they offer problems with startle and short-term interference that are more like aircraft flyover noise. This involves a community decision with respect to supersonic aircraft, and also with helicopters, which generate a minor shock wave in their near vicinity - "blade slap". See Chapter 9.

STEREO SETS

See entries under MUSIC.

SUMP PUMPS

See discussion under PUMPS.

TELEPHONE

Most telephones are equipped with a volume control to adjust the noise level of the bell.

If you need only to know when there is a call for you, and don't wish to have an audible signal, you can arrange to have the ringing signal replaced by a flashing light. This is done routinely by the telephone company for hard-of-hearing clients, and is available in most systems.

If you are hard-of-hearing, and the telephone is in a noisy environment, you can improve your chances of hearing the conversation by having your hearing aid fitted with a telephone pickup coil, which picks up the electrical signal from the earphone of the telephone. This will reduce markedly the competition from the room noise.

TELEVISION

Many problems with television receivers are like those from "Hi-Fi" sound systems and rock bands; i.e., people play them at a level objectionable to the neighbors. However, another source of objectionable sounds is the high-pitched noise of a poorly-adjusted television receiver. Persons with normal hearing can find this noise quite troublesome; however, it can be removed by having the receiver readjusted.

In apartment buildings TV noise disturbance can be reduced by requesting tenants to locate their sets away from party walls, and to place resilient pads under the legs of the cabinet.

THERMOSTATS

See discussion under LIGHT SWITCHES.

TIRE NOISE

See Chapter 9, Automobiles.

TOILETS

See Chapter 4 on control of plumbing noise.

Water flow in the drains is a major source of noise. "Silent flushing" toilets are available.

Syphon-jet toilets with flush-tank fixtures equipped with adjustable flow valves are considerably less noisy than conventional models. A high-pitched noise which occurs when the flush tank is being refilled usually is a sign of defective seals. Replacement of the seals eliminates the problem.

TOOLS

See entries for individual tools such as "Saws", "Lawn Mowers", "Grinders", etc.

TOYS

Toys perform useful functions for children, but their use does not justify risking a child's hearing.

Explosive devices such as cap and air pistols are a serious hazard, now subject to regulation in many states (see Chapters 2 and 10).

The regulations do not protect against the use of noisy toys in rooms with hard, reflecting walls that will permit the noise to build up. It is likely to be a good idea to restrict noisy toys to out-of-doors, where the chances of reflections and reverberation are lessened.

Musical instruments, such as trumpets, should not be put into the hands of children who might carelessly blow them in the near vicinity of another child's ear.

Noisy firecrackers are banned in many places, primarily as a fire and explosion hazard, but occasionally a child may be deafened permanently by another child's pramk. This loss, though less visible, is a very serious problem.

TRANSFORMERS

A transformer carrying a fairly large amount of power can be a serious noise problem. The core of the transformer is made up of layers of magnetic iron alloys. Occasionally these layers ("laminations") work loose and vibrate with the frequency of the alternating current passing through the transformer. On large transformers, there is often a provision for tightening the bolts holding the laminations together. On cheaper appliances, such as the fluorescent lamps and high-intensity lamps, the laminations are "potted" in a tarry mixture, which may become heated and leak out, permitting the laminations to vibrate. These must be replaced.

TRAFFIC NOISE

For reducing invasion of traffic noise into your living quarters, see Chapter 5, Reducing the Intrusion of Expressway Traffic Noise.

TRAIN NOISE

Airborne noise from a train can be treated like traffic noise, see Chapters 5 and 6.

For selection of quiet accomodations while travelling in trains, see Chapter 9.

TRUCK NOISE

For tire noise, see Chapter 9.

For protection of dwellings from truck noise, see Chapters 5 and 6.

VACUUM CLEANERS

Relatively quiet models are now available. Such cleaners feature improved blower and air passage design, vibration isolation of the motor from the housing, and use of sound absorbent and vibration damping materials within the housing or cannister. In cannister-type cleaners, replacing corrugated hoses with smooth-wall hoses may eliminate pure-tone whistling noises caused by air flow turbulence in the hose.

VALVES

Quiet valves are now available. Since a valve involves the constriction of fluid flow, it is always a potential source of noise.

A smooth flow path for the fluid should be provided at the entrance and exits of the valve. See Chapter 3 for design of quiet flow systems. A valve that gradually becomes noisier, generally has worn gaskets, seals or valve seats. Replacement of the defective part usually alleviates the noise problem.

Reduction of water or fluid pressure frequently lowers the noise output substantially.

To prevent valve noise from being carried all over the house, consider the following measures: isolate the valve from the rest of the system by mechanically flexible couplings; avoid rigid clamping fluid-flow systems to such sound boards as floors and walls; run the piping through sound-treated ducts.

See Chapter 4, Control of Plumbing Noise.

VEHICLE NOISE

See entries under Traffic Noise and under individual types of vehicles, such as automobiles, trains, etc.

VENTILATION SYSTEMS

See Chapter 4, Control of Heating, Ventilating and Air-Conditioning Noise.

VIBRATION

See discussions in Chapters 3 and 4 relative to vibration isolation and control of structure-borne noise.

WALLS

See Chapter 4, Improving the Sound Insulation of Walls.

WATER COOLERS

These have major noise sources in the refrigeration equipment and in the plumbing connections. See entries under Compressor, Plumbing Noise, Valve Noise, Refrigerators, and Valves.

See Chapter 4, Quieting of Large Appliances, for methods for shock-mounting appliances.

WASHING MACHINES

See entries under Plumbing Noise, Valves, Solenoids, and Drain Pipes. See Chapter 4, Quieting of Large Appliances.

WATER NOISES

See Chapter 4, Control of Plumbing Noise.

WATER HAMMER

See Chapter 4, Control of Plumbing Noise.

Water is a heavy fluid; when its flow is interrupted, its inertia will produce a sharp rise in pressure at the shutoff valve. Starting and stopping the flow of water gives rise to "water hammer", unless some means of prevention is applied. In plumbing systems, an air cushion is used to absorb some of the shock. A defective washer in a tap, by producing a sharpley intermittent flow of water, can be a potent source of water hammer, easily remedied by putting in a new and better-fitting washer. Gate valves are more likely to produce water hammer than are needle and globe valves.

Water hammer can also occur when piping systems are poorly supported on "V" shaped wire hangers. Placing a rubber sleeve around the pipe and clamping it to some solid structure will resolve the problem.

WINDOWS

If loose window panes rattle, look for breaks in the putty. If the entire frame rattles, check the adjustment of springs or weatherstripping. Double-hung windows in aluminum guides can have the guide spacings adjusted for good fit. Sliding and casement windows are harder to quiet because they are harder to seal or weatherstrip properly.

In a pinch, you can make a temporary stop to window rattling by forcing a wedge of wood between the panel and the window frame, or by wedging the space between the panels of double-hung windows. A more satisfactory and durable repair is to refit the window sashes and install adequate weatherstripping.

Storm windows provide acoustic insulation as well as thermal insulation, and in the interest of quiet, can be left on windows that need not be open.

WHISTLING NOISES

Turbulence generated by air flow past the edge of an obstacle at high speed generates a whistling note.

This is, of course, made use of in flutes, whistles and pipe organs, but it occurs where it isn't wanted, in wires, air ducts, dampers, air-conditioner and heating grilles, and on the blades of fans, usually around obstacles that have sharp or rugged edges or narrow restrictions.

Turbulence is a very strong function of flow velocity, and lowering the fluid flow by a relatively small factor can get rid of many whistling noises immediately.

See Chapter 3 on design of quiet flow systems and Chapter 4, Control of Plumbing Noise.

Chapter 8

NOISE CONTROL AT THE OFFICE

Noises at the office often can reach levels high enough to interfere with a person's ability to do his work. Interference in communication, disruption in concentration, and invasion of privacy are among the chief complaints.

NOISE SOURCES

The main sources of noise in most offices are:

conversation among workers and on the telephone,

noise from typewriters,

ringing telephones,

noise from office machinery, such as copiers, teletypers, etc.,

noise from ventilation systems,

and intrusion of outdoor noise, such as traffic and aircraft.

REDUCING THE NOISE

In order to control the noise the first thing to do is to examine the office environment. If the wall, ceiling, and floor surfaces are hard and smooth the space will be excessively reverberant and will tend to amplify the noise to disturbing levels. Installing an acoustical ceiling, draperies, and good quality carpeting will lower the noise level approximately 5 to 8 dB (or approximately 1/4 to 1/2 in loudness).

Typewriter noise may be reduced by placing soft rubber pads under the machine to prevent vibration of the desk top. Applying vibration damping material to the underside of the desk top or typewriter stand, particularly if it is made of metal, will tend to reduce the sounding board effect and the usual noise buildup.

The noise of ringing telephones may be reduced almost to inaudibility. There is a control in the base of the telephone that adjusts the ringing volume. The control can be reset to lower this volume. In fact, the bells can be replaced with flashing lights in most instances.

Office equipment like copiers, teletypes, computers, card punches and printers often are excessivly noisy. If at all possible, such equipment should be installed in a separate room, such as a storage area. Otherwise, they should be located in an area as far as possible from office personnel. Acoustically lined barriers or partial enclosures should be placed around the machines to confine the noise. Any other noise control measures usually require making modifications to the equipment itself as illustrated in Fig. 8-1. This should be done when the machine is idle or awaiting repairs, and preferably by a skilled technician or repair man. In most cases, the machine noise can be reduced by adopting the following recommendations in the order listed. This order is chosen on the basis that noise from the major source must be attenuated before reduction of the noise from subsidiary sources will have any significant effect.

1. Cover all ports or openings around card punches, copiers, readers and printers with 1/4 inch (6 mm) thick clear plastic shields edged with soft rubber gaskets to make an airtight seal.

2. Wherever possible, vibration-mount all drive motors and cooling fans on rubber pads, or use rubber grommet-type sleeves on mounting bolts.

3. Treat all console panels with viscoelastic-type e.g., gum mastic, vibration damping material.

4. Install 3/4 inch (19 mm) thick fiberglass board liners on the inside surfaces of console paneling to reduce the noise build-up in the hollow reverberant cavities.

5. Install acoustically lined ducts at intake and discharge sides of cooling fans.

6. Install resilient pads or vibration isolators under all equipment to reduce low frequency vibratory transmission to the supporting false floor.

7. Install acoustically-lined U-shaped partial enclosures around individual card punches, readers and printers.

8. If a choice is available, give preference to many-bladed slow speed fans and wide ducts in providing for the cooling of equipment.

The above measures should be attempted a step at a time in the order listed until the noise level in the office is reduced to acceptable limits. However, the most effective way of quieting office equipment is to incorporate good noise control techniques early in the design stage. In many cases, objectionable amounts of noise are generated at the supply and return grilles of the ventilation systems. This is especially true where such systems are of the high velocity-high pressure types. If the noise at a grille is high-pitched, it is more than likely generated by the high velocity air flow striking the grille deflectors. A quick test to determine the cause of noise is to remove the grille. If there is a marked reduction in the noise output with the grille removed, it is evident that either the grille is at fault and should therefore be replaced with one with better design (that is, more streamlined and with wider spaced deflectors) or if practicable the air speed in the duct should be reduced by 10 to 15 percent. A slight reduction in fan speed will often result in a noticeable reduction in noise. If there is no appreciable reduction in the noise output without the grille, the noise may be due to other sources farther back in the duct system. Measures for controlling noise in ventilation and duct systems are discussed in Chapter 4.

EXTRANEOUS NOISE

The intrusion of noise from outside sources such as automotive traffic or aircraft flyovers can be minimized by improving the sound insulation of the windows, which usually are the weakest acoustical barrier against outdoor noise. Seal existing windows tightly with non-hardening caulk; if additional sound reduction is required, try installing a storm window, preferably encased in a rubber gasket. See Chapter 4 for more detailed instructions for minimizing the intrusion of outdoor noise.

PRIVACY BETWEEN OFFICES

If lack of privacy between offices, as for example, between an executive's office and the outer office, is of major concern, you should examine walls, doors, and ventilation ducts separating the two spaces to determine their sound insulating capabilities as well as the presence of noise leaks. In most cases, the door separating the office areas is the weakest barrier against indoor noise transmission. More than likely it is a hollow core door, constructed of thin veneer panels and with an open air space of 1/2 inch (13 mm) or more at the base. Such a door at best will provide a noise reduction of only 10 to 15 dB. Replacing the door with a solid core, sound proof door with gasket seals at the top and sides and a drop closure at the base will correct the problem.

However, if the partition wall separating the two offices extends only to the underside of a suspended ceiling, noise from one office can easily travel through the ceiling plenum over the walls and emerge into the space on the other side. Measures to correct this problem involve installing an acoustical barrier of lead sheet and fiber glass blanket in the plenum space immediately above the wall. Noise leakage at the base of the wall can controlled by caulking the bottom edge on both sides of the wall with a resilient, non-setting compound.

Ventilation ducts serving both spaces should be acoustically lined or equipped with baffles to prevent them from acting as speaking tubes. If additional sound insulation is required after the above measures have been adopted then an additional wall or resilient attachment of a layer of gypsum board to the existing wall will be required. This would involve attaching furring strips to the existing wall, fastening resilient metal channels horizontally across the furring strips, and with self-tapping screws, screwing the layer of wallboard to the channels.

A relatively simple and moderately effective measure for improving the privacy between two offices is to locate personnel, desks, office machines, file cabinets, etc. in both offices as far as possible from the intervening wall, and especially the door, as illustrated in Fig. 8-2.

PRIVACY IN OPEN-PLAN OFFICES

In large open-plan offices with many employees, acoustical privacy is difficult to achieve between the work zones. Where privacy of a confidential nature is important in various work zones, speech originating in any one zone must be made either unintelligible or non-distracting when heard in adjacent zones. In order to achieve satisfactory privacy, a highly sound absorbent environment throughout the entire office area is mandatory. This can best be done by installing acoustical ceiling with a very high sound absorbent rating, erecting acoustical barriers around work zones, introducing an unobtrusive broadband "masking noise", (similar to the sound of a splashing fountain or air diffuser noise) and decorating with carpeting and draperies. The work zones should be situated no less than 15 feet (4.6 m) apart. The factors controlling privacy in open plan offices are illustrated in Fig. 8-3.

The acoustical ceiling should be installed at a height of 9 feet (a little less than 3 m) or less. For best results the ceiling should be suspended to provide a plenum of at least 30 inches (76 cm). The ceiling tile or panels should have a NRC, Noise Reduction Coefficient, of between 0.70 and 0.80. The NRC ratings usually appear on the labels of the cartons containing the tile.

The acoustical barriers should be at least 5 feet in height, (1.5 m) 8 feet (2.5 m) in length with a sound absorbing layer 2 to 4 inches thick (5 to 10 cm). Acoustical barriers encased in metal frames and faced with fabric are commercially available. Such barriers should be placed directly on the floor and positioned so that they will shield the employee from any line-of-sight sources of noise or reflecting surfaces. In other words, the barriers should be arranged so that they break-up all direct paths of sound travel from one work area to another. The larger and taller the barrier the greater is its effectiveness.

Sound systems which produce specially designed "masking" noise are commercially available. Such systems include a number of loudspeakers which generally are installed above the suspended acoustical ceiling. The level of masking noise should be high enough to over-ride distracting noise sources in the office, but yet must be low enough not to interfere with conversation in a given work area. This points out one of the limitations or risks of using masking noise, even if it specially shaped, to improve speech privacy. If the level of masking is too high, people will tend to talk louder, in order to maintain intelligibility. Consequently, their conversation will be more easily understood in other areas. Thus, instead of improvement there is actually a reduction in the degree of privacy provided by the masking.

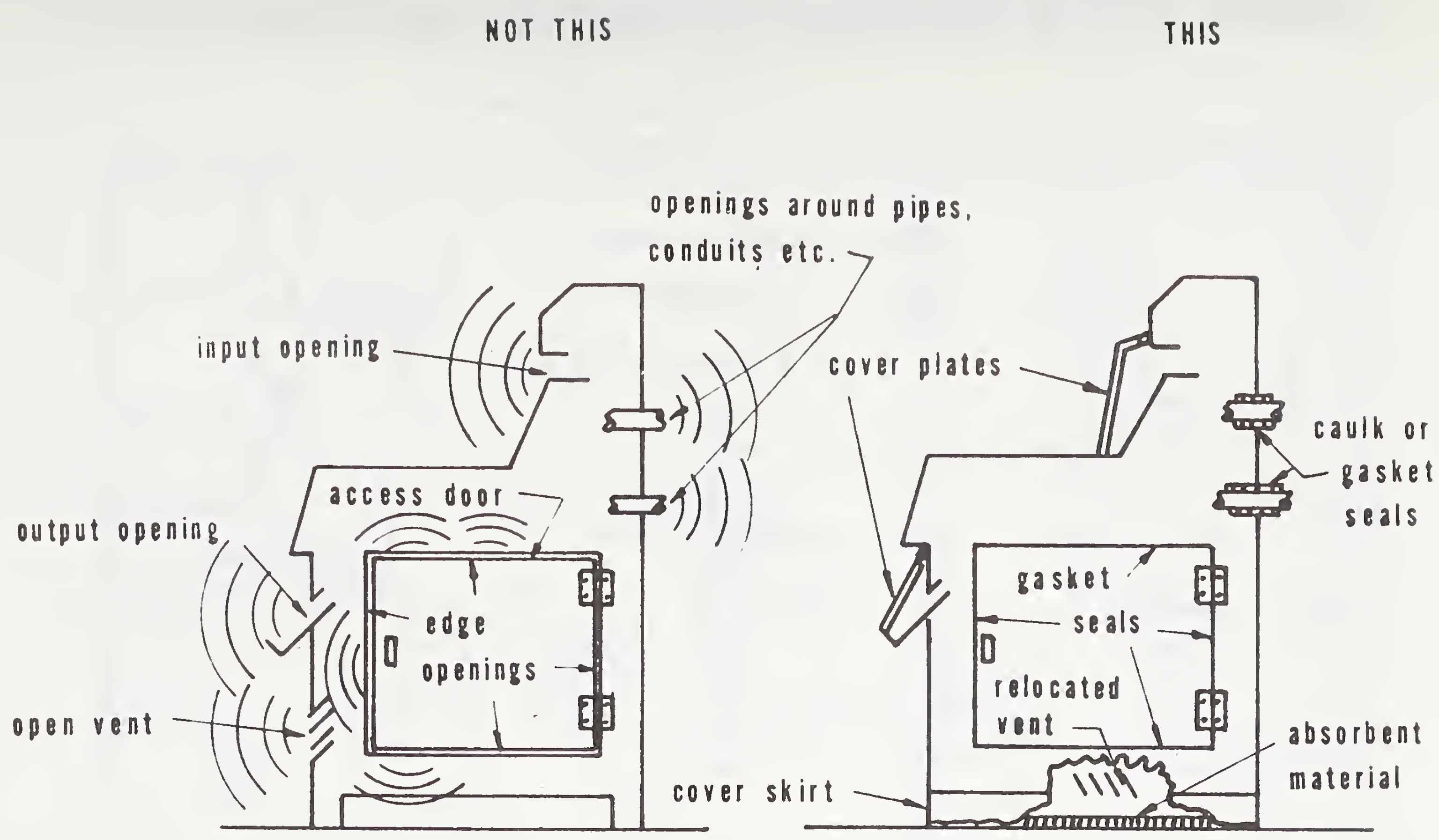


FIG. 8-1 MINOR DESIGN CHANGES FOR QUIETING OF OFFICE MACHINES.

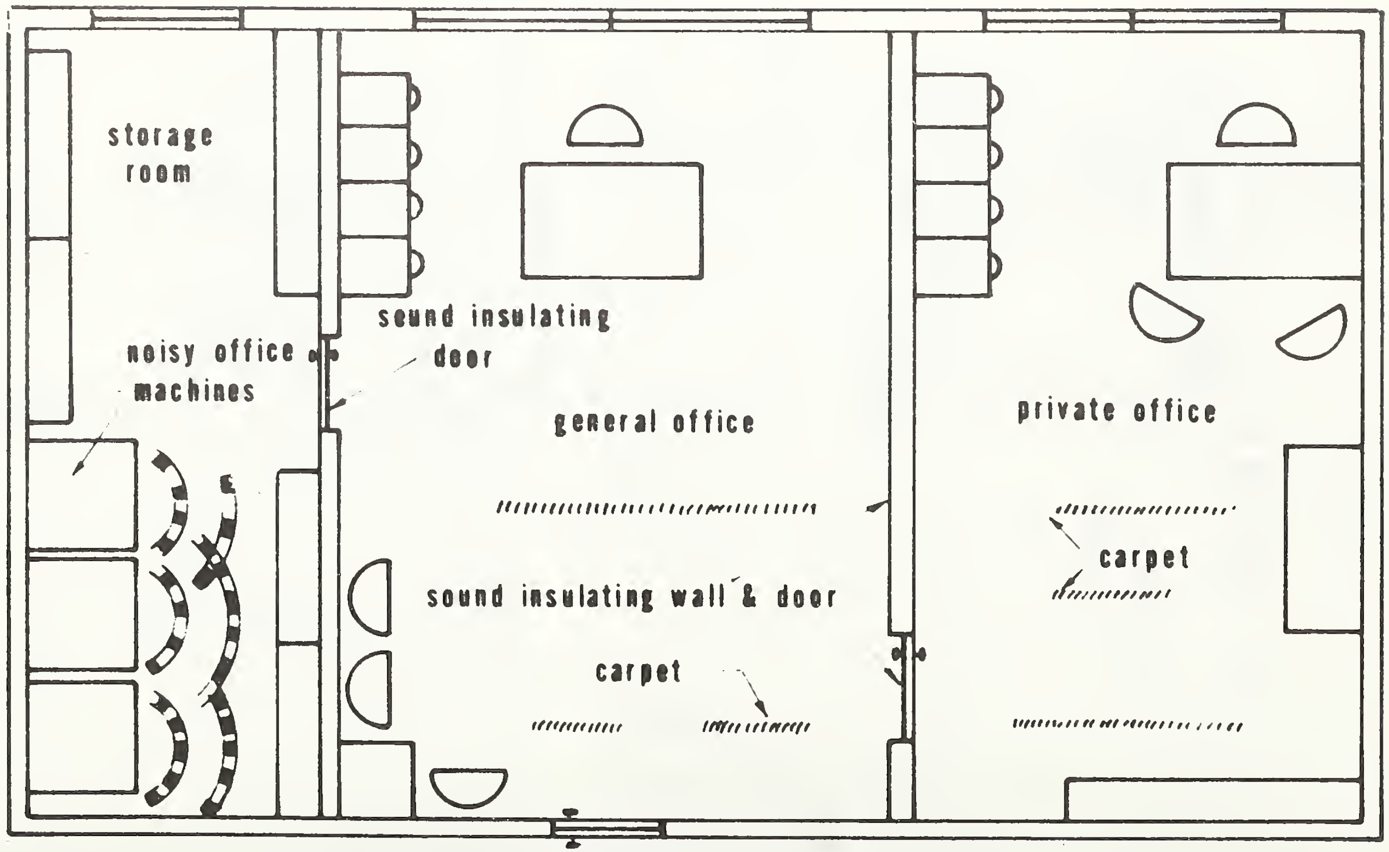


FIG. 8-2 A WELL-PLANNED OFFICE COMPLEX WHICH AFFORDS PRIVACY AND A QUIET ENVIRONMENT.

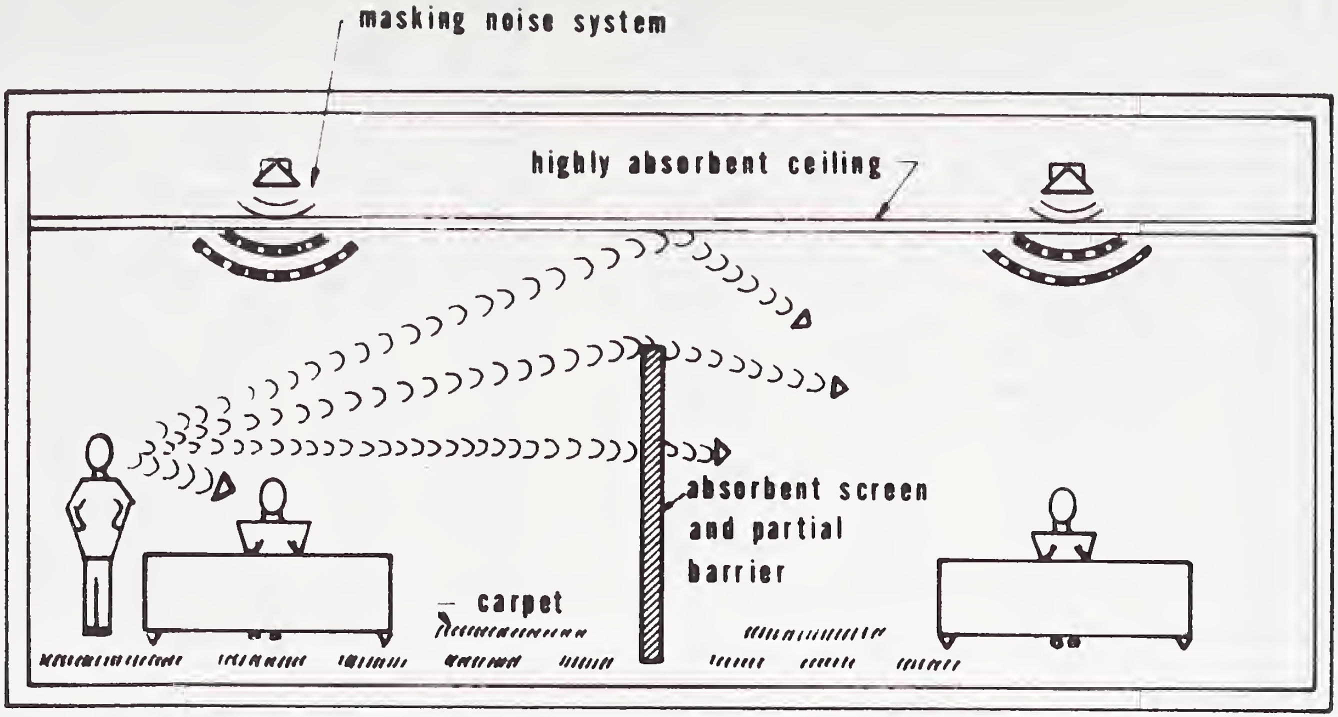


FIG. 8-3 FACTORS CONTROLLING SPEECH PRIVACY IN OPEN-PLAN OFFICES: ACOUSTICAL CEILING, SCREEN AND CARPET MINIMIZE SOUND REFLECTION. PARTIAL BARRIER ATTENUATES AND DEFLECTS DIRECT SOUND. MASKING NOISE RENDERS SPEECH TRANSMISSION UNINTELLIGIBLE.

Chapter 9

NOISE CONTROL WHILE TRAVELING

Prolonged exposure to noise and vibration, even at moderate levels, produces a certain amount of fatigue and irritation. This explains why most of us usually have experienced a feeling of exhaustion and irritability following a day-long automobile or bus trip or a cross-country jet plane flight, even though we were supposedly resting comfortably in our seats or simply relaxing while reading, conversing or watching the scenery roll by.

According to a recent survey many cars and trucks traveling at expressway speeds generate such intense infrasonic sound (i.e., sound below the threshold of human hearing) and such vibration levels within the vehicle that drivers are adversely affected by them. They experience symptoms brought on by stress including fatigue, irritability, recklessness, euphoria, dizziness and lowered efficiency and vigilance.

Noise levels of about 100 dB in the infrasonic range have been measured in these vehicles, with windows closed. When windows were opened the noise levels increased to 110-120 dB. Infrasonic sounds, although they cannot be heard, are felt or sensed as separate pulsations.

An individual person has no control of the noise levels while he is traveling in public transportation vehicles such as buses, trains, or airplanes. He has at his disposal several techniques, however, which can be used to make a substantial reduction in noise level in the automobile he drives.

AUTOMOBILES

1. Select A "Quiet" Automobile: The first course of action is to purchase or rent cars which are specifically designed to be quiet. As a rule they are considerably less noisy than other cars.

2. Drive at Slower Speeds: Driving at slower speeds results in less wind noise, engine noise, transmission noise, road or tire noise and reduces the low frequency noise and vibrations described above.

3. Drive with Windows Closed: Driving with car windows closed may reduce the interior noise level including infrasonic noise, by 10 to 20 dB. The roar of rush hour traffic is likewise greatly reduced. Unfortunately, siren noise is equally diminished, therefore the driver has to be especially alert for approaching emergency vehicles. Turning off the radio and cooling fan would help to lower the interior noise level and thus make emergency signals more audible.

4. Use Air Ventilators: If air ventilation is required in the car, as on a hot summer day, the driver should use the car's air conditioning or ventilation system rather than open windows. In the event a car window must be opened to provide ventilation, opening the rear window -

preferably farthest from the driver - usually exposes him to the least noise. The worst condition, and unfortunately the one most commonly chosen by the driver, is to open the window nearest him. Especially at expressway speeds, this places his ear virtually within the source of very intense wind noise and air turbulence. The common driving habit of resting an elbow on the window ledge and sticking it out into the wind stream usually intensifies the noise and vibration levels. It is no wonder that a driver completing a sustained, high-speed trip under these conditions might feel exhausted, dizzy and short-tempered.

5. Use Slow Fan Speed: With rare exception, air conditioning, ventilation and defroster fans in most automobiles are excessively noisy at their high speed settings. Since fan noise is highly related to the speed of the blades, even small reductions in fan speed often result in noticeable reductions in noise output. It follows that to minimize noise, you should try to achieve adequate ventilation for the lowest possible fan speed.

6. Turn Off the Radio: It is seldom recognized that sustained exposure to moderately loud radio noise causes some acoustic fatigue. To demonstrate this fact to those who ordinarily drive with their radios blaring, may we suggest that they drive home from work some evening with the radio turned off. They might discover to their surprise that they arrive home less tired. Try it - you might like it!

7. Select Quiet Tires: Some types of passenger car tires are noisier than others. Some make a singing or whining noise, while other - like snow tires - produce a low-pitched rumbling or humming noise. Generally speaking, the noise output of a tire is influenced by tread design. The buyer has a choice of three basic types of tread designs: continuous rib; block; and cross-bar, as shown in Fig. 9-1. Tires using the continuous rib pattern are relatively quiet. Furthermore, the buyer should select a continuous rib tire with a randomized or nonsymmetrical design; that is, one in which the design of each individual rib is different and the number of transverse grooves or slots between each pair of ribs is different. Such tread designs tend to smooth out pure-tone hum into a less objectional broadband noise. The noisiest tires are those utilizing the cross-bar designs; these are generally found on snow tires.

8. Balance Car Wheels: Automobile wheels or tires even slightly out of balance can generate a substantial amount of vibration and low-pitched noise - often with annoying pure tone humming. Good wheel balance generally results in a smoother, quieter and less tiring ride. It also reduces tire wear.

9. Reduce Windshield Wiper Noise: Driving an automobile in rainy weather can be rather tiresome, but if one is forced to listen to the incessant noise of a chattering and groaning windshield wiper the trip can be nerve wracking. Usually, a noticeable increase in wiper noise is a sign that the rubber in the wiper blades has aged and has become stiffer and harder. An expedient though temporary measure to control such noise is to file the edges of the wiper blades with an emory board of the type found in most

ladies' handbags. This will remove the hard rubber edges and expose the soft resilient rubber underneath; this will result not only in a reduction of noise but improved wiper action as well. The long term solution, of course, is to replace worn or dried-out wiper blades as soon as they become noisy or streaky.

If it is a question of mechanical noise, lubricating the wiper motor and linkage mechanism usually will result in somewhat quieter operation. If noisy operation still persists, look for loose or worn parts, or for rubber motor mounts or gaskets that have become brittle and hard. Replacement of the defective parts often will restore quiet operation.

BUSES AND TRAINS

Passengers generally will find that seats in the center of the vehicle provide the smoothest and quietest ride, as illustrated in Fig. 9-2. In buses, seats located above the wheels and near the rear engine are the noisiest and usually have the greates vibratory motion.

AIRPLANES

Generally speaking, seats farthest removed from the windows - for example, aisle seats and those located near the center of the passenger cabin - are the quietest and provide the smoothest ride, as shown in Fig. 9-3. Window seats, as a rule, are noticeably noisier because of the windstream noise and the closer proximity to the noisy engines. Seats located in the rear or tail section of a jet plane are uaually the noisiest, regardless of whether the plane has wing-mounted or tail-mounted engines.

SELECTING A "QUIET" MOTEL OR HOTEL

Having once experienced the exasperation and frustration of spending a sleepless night in some noisy motel or hotel, the weary traveler hopes that he will have better luck in picking "quiet" lodgings in future travels. He can reduce the element of chance substantially in selecting a "quiet" motel by observing a few cardinal rules, as illustrated in Fig. 9-4 and listed below.

(a) Avoid all motels or hotels within sight of traffic expressways, railroads or airports. With regard to expressways and railroads, select motels that are at least 1/2 mile (800 m) away. If you are traveling by car, you can use the odometer to measure the mileage or distance.

(b) Avoid all motels or hotels located in the path of direct overhead aircraft flyovers. Unfortunately, finding a motel which is free of annoyance from nighttime jet flights may be difficult because of the intensity of the noise and the great distances that are required to attenuate it to acceptable levels simply by air absorption alone. Ordinarily, the traveler faced with the problem of determining whether or not jet aircraft flying in the vicinity of a given motel might disturb his rest can resolve it in one of three ways.

(i) If he is a trusting soul, he can ask the registration clerk whether or not aircraft noise is a source of disturbance at night.

(ii) He can conduct a simple "talk test" outside the motel. If it is possible to converse normally with a person three to five feet away without difficulty or disruption during a typical aircraft fly-by, he need not worry.

(iii) He should request a trial demonstration inside a given room to determine for himself whether or not aircraft noise is audible and possibly annoying.

(c) Avoid motels or hotels with window or wall-mounted air conditioners. Window or wall-mounted air conditioners are inherently and excessively noisy devices, especially models that are five or more years old. The noise levels produced by such units will in most cases disturb one's sleep. Furthermore, the air intake and exhaust ports of such units act as speaking tubes or noise leaks, thereby allowing the transmission of exterior noise into the room. As a consequence, even if you choose not to operate the unit because of the noise, you may well be disturbed by the noise radiating from air conditioners in adjoining rooms or other areas, not to mention noise associated with the late arrival or early departures of motel guests.

(d) Avoid motels or hotels with louvered windows or doors. Although open louvers are often desired for fresh air ventilation, they unfortunately constitute an open path for the intrusion of outdoor noise. Further, because of notoriously poor seals, closed louvers provide very little protection from outdoor noise.

(e) Avoid motels of wood frame construction. Unless dwelling units or rooms are spatially separated from each other, such as individual cottages or cabins, the intrusion of noise generated by the occupants in adjoining rooms can be a serious source of disturbance. Party walls in wood frame motels rarely, if ever, provide adequate privacy between rooms. In response to numerous complaints from guests about the lack of privacy between rooms, owners of such motels often install acoustical treatment in the rooms in a hasty though thoroughly misguided and futile attempt to correct the problem.

The traveler should not be deceived into believing that the presence of acoustic tile on the ceiling or walls of a particular motel is an automatic guarantee that the room is "soundproofed". While such treatment effectively reduces the buildup of noise within the room, it is totally ineffectual in preventing the intrusion of noise from outdoor sources or from adjoining rooms or other areas within the building.

Generally speaking, most motel or hotel rooms do not require any acoustical treatment on ceilings or walls; the ordinary room furnishings of carpeting, drapery, bedspreads and mattresses and other furniture are good sound absorbers and prevent the room from becoming too reverberant and noisy. Have you every wondered why your bedroom is so much more quiet than, say, your kitchen or bathroom? The sound-absorbing furnishings in the bedroom make the difference. It also explains why the "Bathroom Baritone" rarely sings in the bedroom - there his voice would sound weak and flat.

(f) Select motels of brick, concrete or masonry construction. Such motels generally have reasonably massive party walls and floors, good quality carpeting and drapery, relatively quiet air conditioning and ventilation systems, well-fitted solid-core doors, and sealed non-operable plate glass windows. These features combined tend to provide a quiet, restful, interior environment free from the intrusion of outdoor noise, or noise from adjoining rooms or other areas within the building.

SELECTING A "QUIET" ROOM

<u>Select a room on the "Quiet" side of the motel</u> (See Fig. 9-5). Since buildings are relatively large and massive structures, they can effectively reflect, block, or deflect (diffract) sound or noise. As a consequence, they are exceptionally good noise barriers. The larger the building, the greater its effectiveness as a noise barrier. When a sound wave strikes a building, some of the sound energy penetrates into the building and is absorbed; the remaining energy is reflected or deflected by the building in other directions. That side of the building receiving the full force of the sound wave will, of course, be relatively noisier than the opposite or shielded side.

Therefore, when selecting a motel, the traveler should remember that rooms on the side of a motel that faces a major source of noise, such as an expressway or railroad, may be objectionably noisy; whereas, rooms on the opposite side in the acoustic shadow of the building may be relatively quiet.

In addition, rooms on the "quiet" side of the motel ordinarily are disturbed less frequently by noise generated on the motel premises, such as noises caused by swimming pool activities, patio parties, or the traffic associated with guest registration.

<u>Other tips on selecting a "Quiet" motel or hotel room:</u>

(a) Avoid rooms which are adjacent to or near stairways, elevators, or areas containing vending machines, cooling towers, fans, or air conditioning equipment. The noise radiation from such equipment or from people using the vending machines may be quite disturbing. See Fig. 9-6.

(b) Avoid rooms located on the ground floor level, if noises from footsteps, parking lots or plumbing are particularly annoying to you. Rooms located on the top floor provide the most privacy from such disturbances.

(c) In large hotels in downtown locations, rooms facing an inner court-yard are usually much less noisy than rooms overlooking the street.

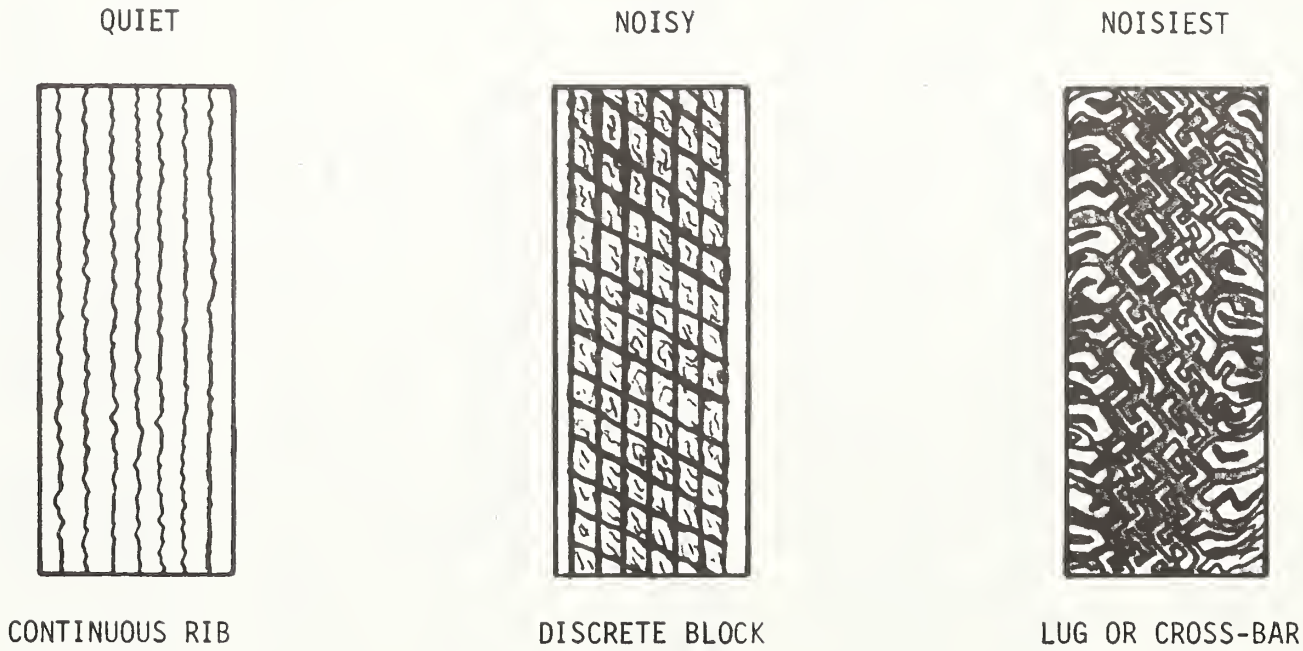


FIG. 9-1 BASIC TIRE TREAD DESIGNS.

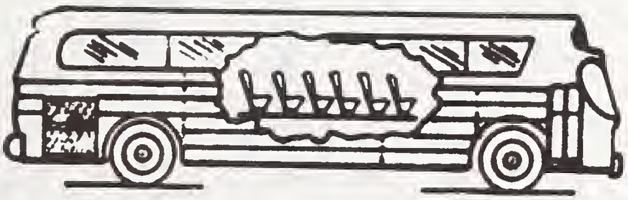


FIG. 9-2 SEATS LOCATED IN CENTER OF BUSES PROVIDE SMOOTHEST AND QUIETEST RIDE.

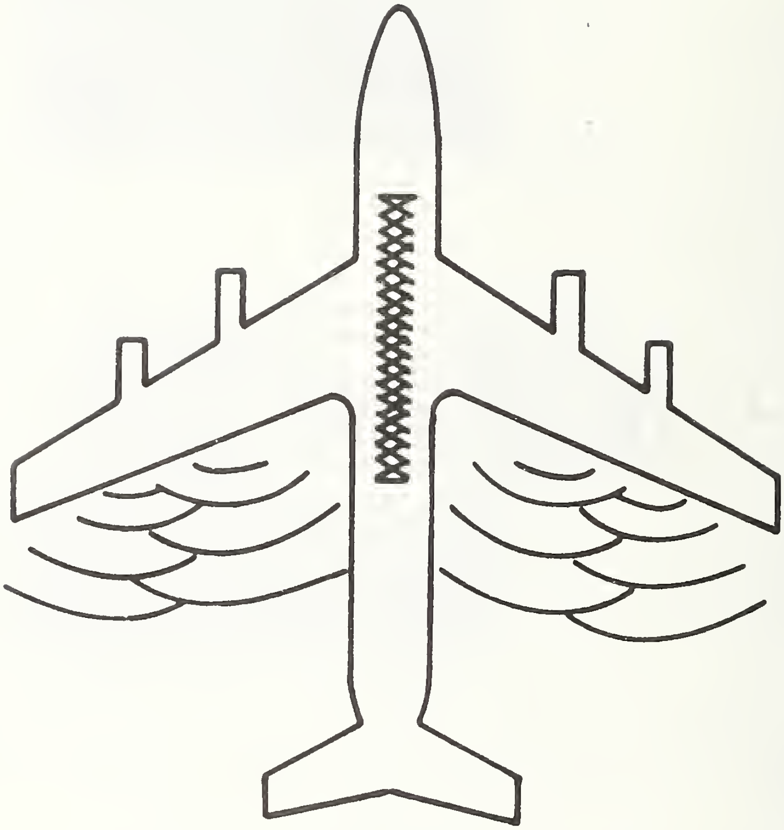


FIG. 9-3 SEATS LOCATED IN SHADED PORTION OF JET PLANE PASSENGER COMPARTMENT PROVIDE QUIETEST AND SMOOTHEST RIDE.

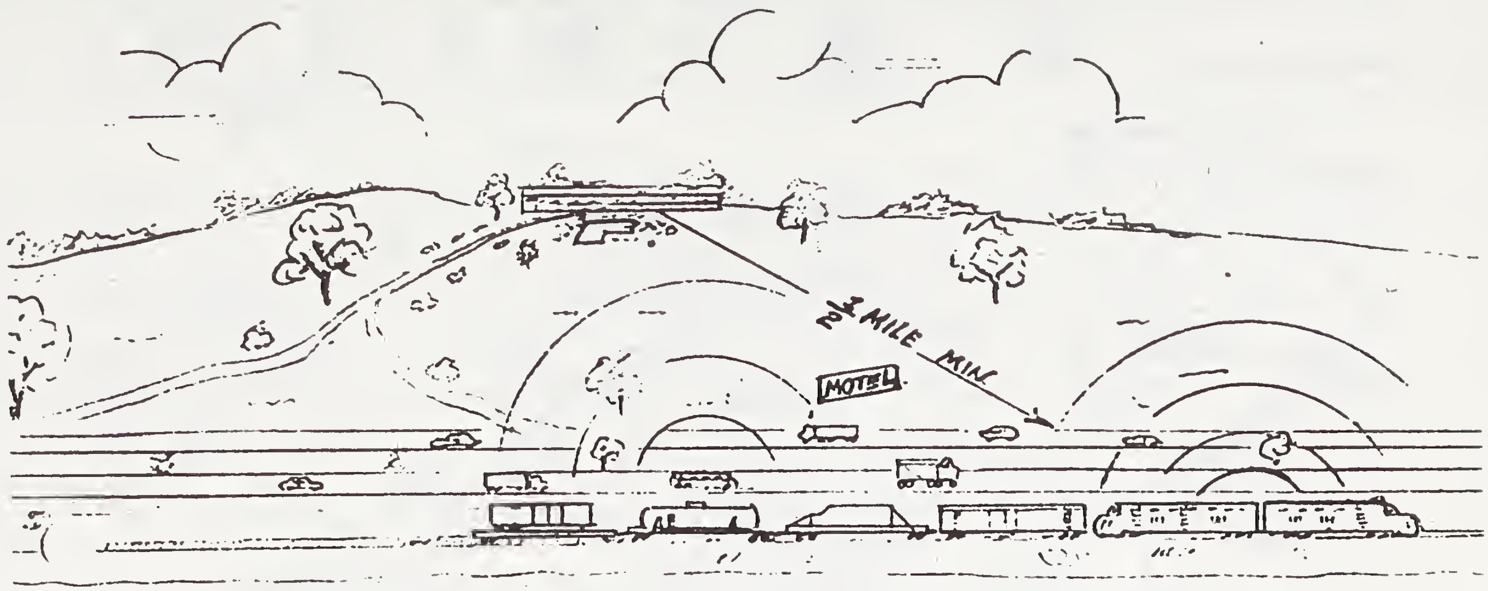


FIG. 9-4 FOR PRIVACY SELECT MOTELS AT LEAST 1/2 MILE FROM EXPRESSWAYS AND RAILWAYS.

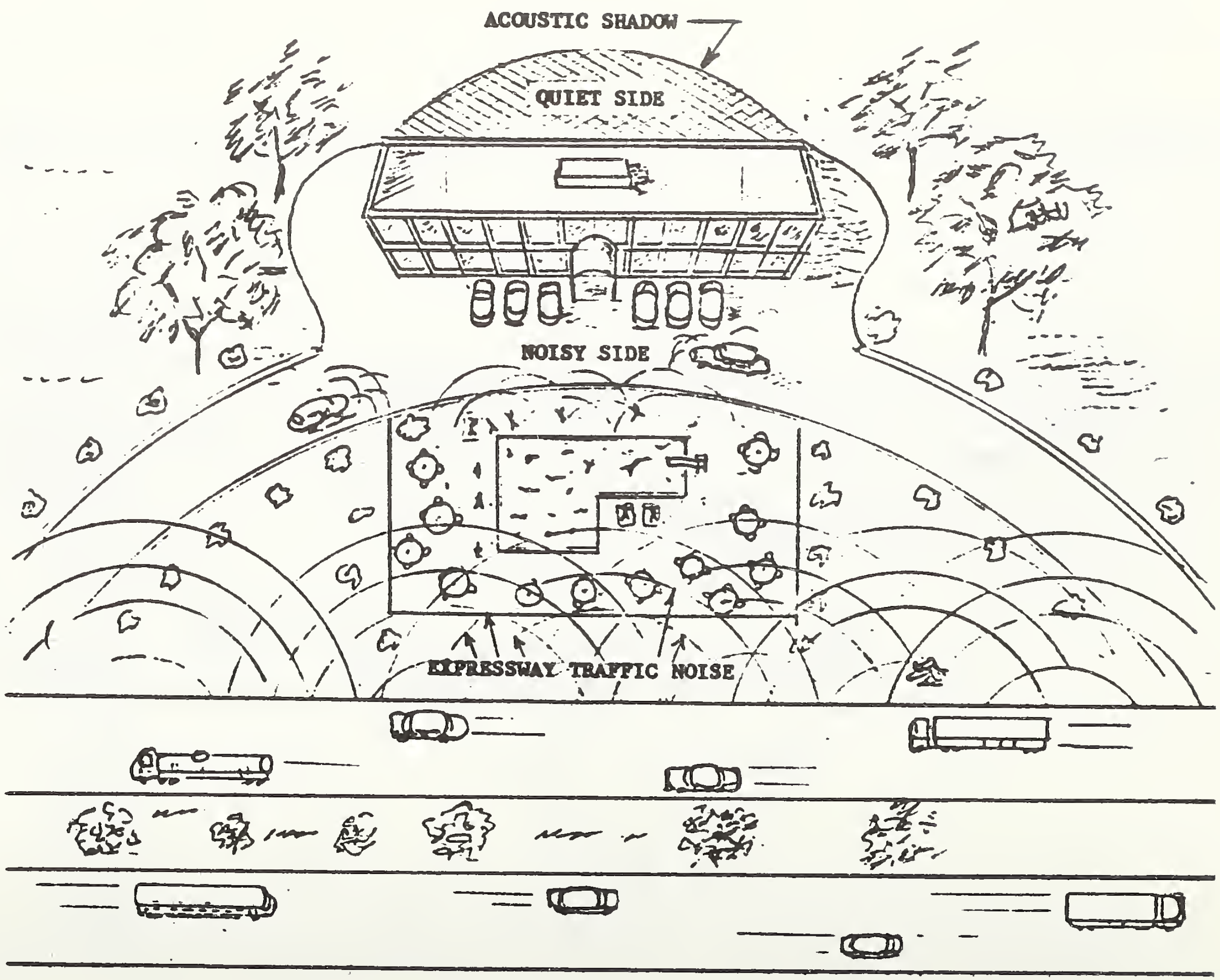
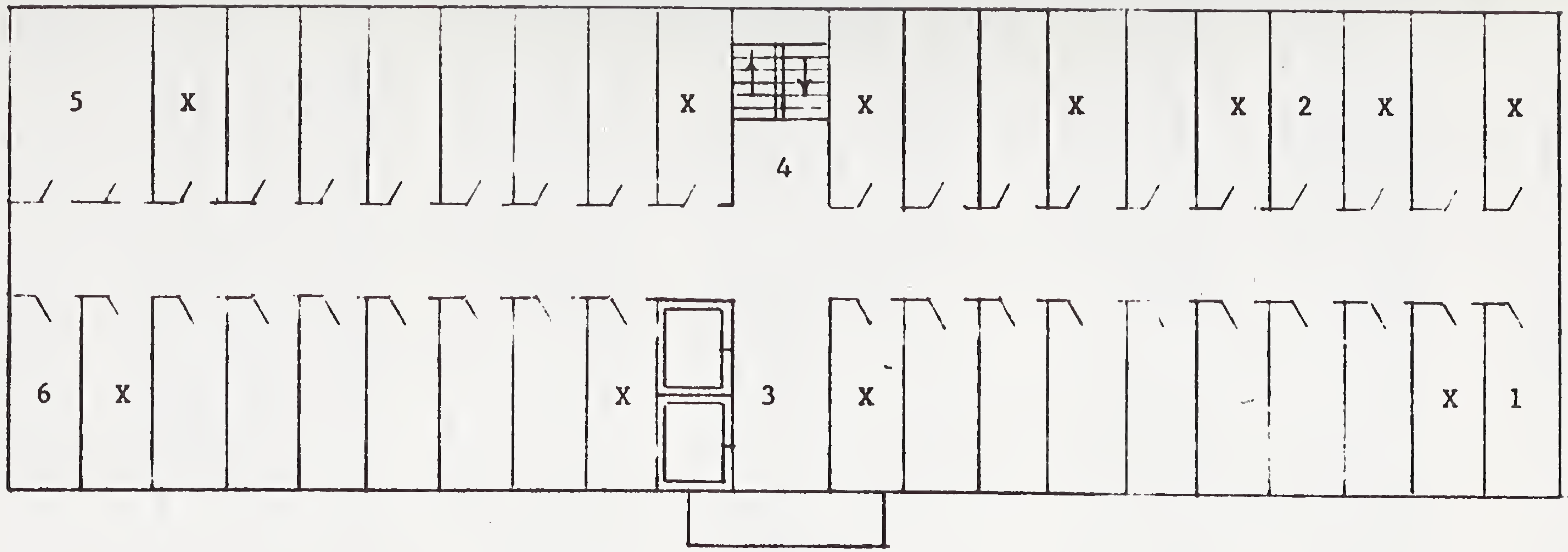


FIG. 9-5 FOR PRIVACY SELECT ROOMS ON "QUIET" SIDE OF MOTEL.



X marks the location of potentially noisy guest rooms.

1. Mechanical equipment room
2. Vending and ice machine room
3. Elevators
4. Staircase
5. Conference room
6. Telephone room

FIG. 9-6 FOR PRIVACY AVOID HOTEL OR MOTEL ROOMS THAT ARE ADJACENT TO OR NEAR NOISY AREAS OR EQUIPMENT ROOMS.

Chapter 10

POLITICAL AND LEGAL ACTION - WHEN ALL ELSE FAILS

INTRODUCTION

As an individual you can apply the principles of noise control given in the previous chapters. By doing so, you can protect yourself from the harmful and irritating effects of noise from many sources. Yet, there are some sources of noise which affect you, and over which you have no direct control. What can you do in such cases?

What one person did is forcefully described in a pioneering book he wrote entitled, The Tyranny of Noise*. Robert A. Baron woke up one April morning in 1964 to "a symphony of insanity" opposite the windows of his apartment. A construction company had started five diesel-driven air compressors to operate jackhammers and rock drills being used in a construction project for the New York City Transit Authority.

Mr. Baron wrote:

> "What happened to the residents of my neighborhood, as I was to learn, is already happening or will soon happen to millions of human and animal receivers of noise. The clatter of a jet or helicopter flight path; the incessant hum of a thruway; 'temporary' construction sounds; the multi-level buzz of a dozen modern kitchen appliances; conversations of neighbors in the next apartment; automated office equipment; the roar of an air conditioner; power lawn mowers, chain saws and mechanized farm implements - you don't have to live near a subway project to suffer from noise."

First, naively, Mr. Baron complained to the neighborhood policeman; then he contacted the Transit Authority, the contractor, his city councilman, the Commissioner of Health, a doctor on the Board of Health, the police department, the governor of the state, the Division of Occupational Health of the U. S. Public Health Service, and private acoustic consultants. As a result of all this, he found himself back at the beginning - the noise continued unabated.

In May 1965, Mr. Baron called for a neighborhood meeting at which a hundred people showed up to establish the Upper Sixth Avenue Noise Abatement Association. Even this organized group lost the battle against noise; but this led to the formation of a larger group in New York City, named Citizens for a Quiet City, Inc. (CQC), which began operating in January 1967. CQC encouraged the mayor to authorize a task force on noise control and endorsed the birth of New York City's Bureau of Noise Abatement. Also, Mr. Baron, as executive vice president of CQC, was appointed to the Commerce Technical Advisory Board Noise

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* Baron, Robert A., The Tyranny of Noise, St. Martin's Press, Inc., New York, 1970.

Abatement Panel of the U. S. Department of Commerce in 1968. A report of the Board* recommended the establishment of an Office of Noise Abatement and Control (ONAC) within the U. S. Environmental Protection Agency (EPA); and, indeed, legislation enacted in 1970 did establish ONAC as an operating entity of EPA.

FEDERAL NOISE REGULATION

The Noise Control Act of 1972 represents the first major Federal legislation in the field of noise control. The Act requires the U. S. Environmental Protection Agency to develop and publish information concerning noise levels that may be hazardous, and to set standards defining permissible noise levels for products that have been identified as major noise sources. These may include such products as power lawn mowers, mufflers, and room air conditioners.

Although EPA has primary responsibility for most Federal efforts to control noise, other agencies are also concerned with special areas of noise control.

Department of Transportation: The Federal Aviation Administration (FAA) sets criteria and standards for controlling aircraft noise. EPA advises the FAA in fulfilling its responsibilities, while much of the research and experimental testing for aircraft noise abatement is performed for FAA by the National Aeronautics and Space Administration and by the U. S. Air Force. The Federal Highway Administration, also within the Department of Transportation, has adopted Noise Control Standards and Procedures for use in planning and design of highways to assure that measures are taken to hold highway noise to levels that are compatible with various land uses.

Department of Labor: The Occupational Safety and Health Administration sets and enforces regulations under the Occupational Safety and Health Act of 1970, designed to protect the hearing of workers. Authority is limited to regulation of companies engaged in interstate commerce. Under this Act, the Department of Health, Education and Welfare performs research to define occupational noise limits needed to safeguard the hearing of workers. The Labor Department relies upon results of this research in setting noise standards.

Department of Health, Education and Welfare; Department of the Interior: Under the authority of the Federal Coal Mine Health and Safety Act of 1969, the National Institute for Occupational Safety and Health, Department of Health, Education and Welfare is responsible for the development of noise standards to protect the hearing of miners. The enforcement of these standards is the responsibility of the Mining Enforcement and Safety Administration, Department of the Interior.

The Department of Housing and Urban Development: The Department of Housing and Urban Development (HUD) has developed criteria for the sound insulation characteristics of walls and floors in row houses, nursing homes, and multi-family housing units. These criteria must be met by housing of this type in order to qualify for HUD mortgage insurance.

*"The Noise Around Us: Including Technical Backup," Report of the Panel on Noise Abatement to the Commerce Technical Advisory Board, CTAB-71-1, September 1970.

Many other Federal agencies, such as the National Bureau of Standards and the National Science Foundation, are concerned with research in noise control and abatement in factories, homes, offices, and commercial work areas.

STATE AND LOCAL REGULATION

For almost a century and a half the control of noise by regulation within the United States has been a matter of concern for city governments. It is only within the last decade that some states have seriously entered the field of noise regulation. Over 400 municipalities (representing a combined population in excess of 60 million people - 30 percent of the U. S. population) have enacted noise regulations; however, until recently, there has been very little leadership at the state level except for the enactment of regulations requiring mufflers on motor vehicles. An up-to-date compilation of various city and state noise control ordnances is maintained by EPA (Washington, D. C. 20460)

Both local and state noise control laws are usually classed as general nuisance laws which include a prohibition of "unnecessary," "excessive," or "unreasonable" noise. These criteria are often too subjective to be effectively enforced. When vigorously challenged, this type of noise control law tends to be struck down by the courts because they are too broadly worded for objective enforcement. What is "unnecessary" or "unreasonable" for one person may be "acceptable" to another.

Noise control laws which are based upon performance standards appear to be far superior to nuisance laws if they are properly written and correctly applied. Performance standards typically specify the maximum allowable noise level at a given point; and this requires monitoring equipment and trained personnel for enforcement.

A promising trend has been the adoption of noise control laws with performance standards (such as specified in the model ordinance prepared by the National Institute of Municipal Law Officers, Washington, D. C. 20006) and the establishment of offices of noise abatement to supervise enforcement. The advantages of such legislation and of establishing a regulatory agency are several:

1. An Office of Noise Abatement can act as a focal point for activities in noise control regulation, enforcement, and public education.

2. A staff can be assembled that is specifically trained to respond to complaints and monitor noise levels.

3. Authority would exist for the Office of Noise Abatement to use initiative in seeking out the worst offenders.

4. An Office of Noise Abatement would have legal authority to advise zoning commissions on the noise impact of different zoning plans under consideration.

The main disadvantage is the cost of such a program. Although this cost is not high relative to other kinds of pollution controls, it represents yet another demand on city, county and state budgets.

CORRECTIVE ACTION PROGRAMS

To be effective in solving community-wide noise problems the average citizen must make himself heard -- as in Chicago where an organization called Citizens Against Noise persuaded the City Council to pass an effective anti-noise ordinance in 1971; and as in New York City where Robert Baron and Citizens for a Quiet City, Inc., succeeded in establishing a Bureau of Noise Abatement.

Obviously, it is first necessary to familiarize yourself with the various regulations (Federal, state, and local) which affect your "noise environment." This familiarization need not be a close and detailed reading of all the applicable laws. At the local level, a telephone call to the police department and the city or county council is a starting point for determining what laws exist, if any, relating to noise control and their applicability to your particular case. The matter of noise in a community could also be brought up at a local civic association meeting - many voices can be more effective than one!

At the state level, you may write or call your elected officials in the legislature to inquire what they are doing about an effective noise control law in the state. The governor's office should also be contacted. Again, it is a matter of being heard. If enough organizations and private citizens ask probing questions about noise pollution, elected officials will take notice of this interest and corrective action will be forthcoming.

Although the activities of many Federal agencies have some bearing on noise control, it is the U. S. Environmental Protection Agency that takes the lead in coordinating these activities and initiating others. Write to the EPA Office of Public Affairs (Washington, D. C. 20460) for publications, general information, and answers to specific questions on noise control. Your voice, individually and collectively, can be heard at the Federal level through many channels of communication - by making your concern known to your representative and two senators in Congress, and to the President of the United States. You can also exert influence by urging EPA and other Federal agencies to develop and enforce noise control standards.

A corrective action program, to be effective, must involve powerful political groups in the community. Since both government and industry ultimately respond to public demands, the only real solution to the overall noise problem is a rising public awareness of the dangers of noise and a persistent demand for effective noise control.

LOCAL NEIGHBORHOOD NOISE PROBLEMS

Some noise problems may be quite local in character and are best solved on a neighbor-to-neighbor basis. For example, while nuisance laws might be invoked to engage the police in quieting a neighbor's dog, such tactics may do little to promote friendly neighborhood relations! Perhaps a better approach to solving problems of this kind might be to raise the issue of noise at a meeting of your local neighborhood association, or at a block party, attended by your neighbors. You might suggest appointment of a "noise warden" whose duty it would be to register complaints to those causing a disturbance. If such complaints were brought to the attention of the offender in a diplomatic way, and perhaps in indirect fashion through an appointed neighborhood representative, sensibilities may be spared - and more positive affect achieved!

Note: Persons interested in assuming an activist role in community noise control will find the following publication especially valuable: Gatley, W.S., and Frye, E.E., Regulation of Noise in Urban Areas - A Manual Prepared for Public Officials, Managers and Environmental Engineers, available from the Extension Division, University of Missouri, Rolla, Missouri 65401, price $21.00 postpaid. Although the publication is designed for administrators and professional engineers, the interested layman would benefit from discussion of the technical, medical, sociological, political, and legal aspects of noise and noise control. Suggestions are given for specific steps that can be taken to develop a realistic program of noise regulation at the state and local levels.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This publication is a guide offering practical solutions for the ordinary noise problems that a person is likely to meet in his home, while traveling, and at work. The discussion describes the ways in which sounds are generated, travel to the listener, and affect his hearing and well being. Recommendations are given for controlling noise at the source and along its path of travel, and for protecting the listener. The guide instructs the reader by way of "Warning signs" on ways and means of determining whether prolonged exposure to a noisy environment may be hazardous to his hearing. General principles for selecting quiet appliances are given. The remedies for noise problems deal both with prevention and with selection of quiet alternatives to existing noise sources. Ways of searching for the sources of noise and the paths over which they travel to the listener are described. A detailed index is given for individual noise sources and the solutions to the problems they present. General ways of looking for inherently quiet homes and travel accomodations are described. In a final chapter, there are suggestions for enlisting community help where large external sources of noise must be quieted, such as those arising from public transportation and public utilities.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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