U.S. DEPARTMENT OF COMMERCE

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CIRCULAR OF THE BUREAU OF STANDARDS, No. 403

A DISCUSSION OF SOME OF THE PRINCIPLES OF ACOUSTICAL INSULATION

By

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[Issued June 23, 1933]

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D.C. - - - - Price 5 cents

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By V. L. Chrisler

ABSTRACT

A general discussion is given of the factors which control the transmission of sound through partitions. Impact noises, and methods of insulating against them receive special mention.

Attention is called to the fact that a small opening may almost completely destroy the sound insulating value of a wall.

It is shown that in the presence of noise a wall which is a poor sound insulator may appear to be fairly good.

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I. INTRODUCTION

Sound insulation should be one of the most important details considered when hotels, hospitals, apartment houses, and office buildings are planned. Unfortunately, in many cases little consideration is given to this very important feature, and as a result the interior of the building is noisy and there is not sufficient privacy between adjoining rooms. There is a growing demand for proper sound insulation and in many cases tenants move to another building in the hope that there will be less annoyance from noises originating outside of their rooms.

Up to the past 6 or 7 years there has been little reliable information available on the subject, but at the present time there are measurements available showing the sound-reduction factors for most of the ordinary types of construction. There still remains, however, the problem of designing a lightweight partition with a large sound-reduction factor.

To aid in obtaining the necessary data for the proper design of a wall to eliminate external noises the Bureau of Standards some 10 years ago built a series of concrete chambers in which measurements could be made of the numerical values for the sound insulation of

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different types of construction. About 175 different types of partitions have been tested, ranging in nature from a single sheet of wrapping paper to 8-inch brick walls and 13-inch tile walls. Many of these tests have been on modifications of customary types of wall and floor construction by which it was hoped that the sound insulation could be improved. A large portion of this work has been made possible by the cooperation of manufacturers of building materials.[1]

The problem as a whole is a very interesting one, as there are so many unknown quantities that it is generally impossible to predict with any degree of certainty whether or not a partition will be a better sound insulator if certain changes are made in it. Owing to the work which has now been done, it is possible to make a much better guess than 10 years ago, but there are still many elements of uncertainty.

II. FACTORS WHICH CONTROL THE TRANSMISSION OF SOUND THROUGH PARTITIONS

In trying to understand the problem of sound insulation, let us consider some of the factors which control the transmission of sound through a panel. To begin, suppose we consider how sound passes through a sheet of window glass. The sound energy is transmitted to one side of the glass by the air. The impact of the successive sound waves upon the glass causes it to be set in motion like a diaphragm, and because of this motion, energy is transmitted to the air on the opposite side. The amount of energy transmitted through the glass depends upon the amplitude of the vibration of the glass. This in turn depends primarily upon four things—the initial energy striking the glass, the mass of the glass, the stiffness of the glass, and the method of clamping. There is a fifth condition which is occasionally of importance. When the sound consists primarily of a single frequency there is a possibility that the diaphragm may be in resonance with this frequency. Under this condition a very large part of the sound energy is transmitted. Normally the resonance frequency of any part of a building is much lower than the frequencies of any of the ordinary sounds, hence this condition will be ignored in the following discussion.

III. HOMOGENEOUS WALLS

With homogeneous walls of any type it has been proved by both theory and experiment that the weight of the wall per unit area is the most important factor in determining the sound insulation. Of secondary importance is the nature of the material and the manner in which it is clamped at the edges. For instance, it has been found that a piece of sheet iron is a slightly better sound insulator than a sheet of lead or fiber board of the same weight per square foot, but the difference is not great enough to be of any practical importance. In small panels the manner of clamping the edges is of importance, but for a large panel the manner in which the edges are held makes but little difference in its value as a sound insulator.

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[1] Transmission and Absorption of Sound by Some Building Materials, B.S.Sci. Paper no. 526. Transmission of Sound Through Building Materials, B.S.Sci Paper no. 552. Transmission of Sound Through Wall and Floor Structures, Research Paper no. 48.

Attention should, however, be called to the fact that the sound-insulation factor for homogeneous walls is not directly proportional to the weight per unit area, but increases less rapidly than this factor, being in fact proportional to the logarithm of the weight per unit area. This means that a high degree of sound insulation cannot be obtained in this way alone unless the wall is exceedingly heavy.

IV. NONHOMOGENEOUS WALLS

It is possible to increase the sound insulation considerably by breaking the wall up into two or more layers. As soon as a wall is thus broken up the problem becomes more complicated from a theoretical standpoint and it becomes impossible to predict what the sound insulation value will be.

1. LATH AND PLASTER WALLS

A wood stud partition with either wood or metal lath is an example of this uncertainty of prediction. Many considerations enter into the sound insulation of such a structure. With walls of ordinary nonstaggered stud construction we have two plaster diaphragms which are on the opposite sides of the partition and have common supports at the edges, where they are attached to the studs. Sound energy then can be transferred by two different paths from one side of the partition to the other. The energy of vibration of the plaster on one side can be transferred either to the studs and then across to the plaster on the other side by solid conduction, or it can be transferred to the air between the two plaster surfaces and then from the air to the second plaster surface. By experiment it has been shown, for the ordinary plaster construction on nonstaggered wood studs, that most of the energy is transferred through the studs and only a very small proportion through the air. Keeping this in mind we may draw a few general conclusions. First, the stiffer the stud, which is the common support for the two surfaces, the smaller the amplitude of vibration, hence the structure will be a better sound insulator. Second, if the plaster is rather weak and flabby and has considerable internal friction it will be set in vibration easily by the sound waves striking it, but a considerable portion of this energy will be absorbed by internal friction and only a small portion will be transferred to the stud and hence to the other side. Hence the stronger the plaster the poorer it will be as a sound insulator. The practical difficulty that arises here is that in the attempt to secure good sound insulation by weak plaster, the plaster may be made too weak to withstand the abuse that a wall generally receives.

As most of the sound in ordinary wood stud construction is transmitted through the stud, attempts have been made to improve such a partition by using separate studding for the two sides. This type of construction always shows some improvement over a single stud, but not so much as one might expect, as considerable energy is transmitted around through the common connections at the ceiling and floor. The same principle applies here as the previous case; namely, that it is desirable to have the surface as flabby as possible. This can be partly accomplished, even when there is a good job of plastering, by making the studs in this case as weak as possible consistent with holding up the plaster surface.

A filling material is sometimes placed in the interior of a stud wall. While such a filler is usually advantageous as a heat insulator, the same cannot always be said of it as a sound insulator. With a heavy wall (where each plaster layer weighs over 10 or 15 pounds per square foot) an empty air space is acoustically the best construction. For lighter partitions, a filler may be of advantage, but even here much depends upon its nature and properties. If it packs down so that it becomes rather solid it will act as a tie between the two surfaces and generally do more harm than good. If it is a material which is fairly elastic so that it always stays in contact with the plaster and exerts some pressure, and if it has considerable internal friction it may materially damp the vibration of the surface and thus improve the sound insulation of the panel.

With the properties just mentioned one filler may be more efficient than another, depending upon the type of surfaces between which the filler is placed. To illustrate this let us consider two different types of panels which have been tested at the Bureau of Standards. One panel had surfaces of thin sheet aluminum. In this case the maximum amount of damping seemed to be secured when a Kapoc blanket was placed rather loosely between the two surfaces. The other panel consisted of metal lath and plaster attached to 1½-inch steel channels. The sound insulation was improved quite materially by filling the space between the plaster with rock wool. If Kapoc fiber had been used in this second case packed as loosely as in the first panel, it would have been of little value, as it would have been too light to have exerted sufficient force against the heavier diaphragms. In other words, this semielastic filling material must exert a certain amount of pressure against the surface to aid in damping out the vibrations, but if it is packed in too tightly and becomes too dense it may act as a tie to transmit sound.

Unfortunately, we have not sufficient data at present to enable us to determine without measurement exactly what kind of a material should be used as a filler and how tightly it should be packed between given surfaces so as to obtain the maximum sound insulation.

In the construction of airplane cabins this problem is of considerable importance, as here it is necessary to obtain the maximum sound insulation with a minimum of weight. There is also another special feature of importance in airplane construction—the material should not be hygroscopic, else in damp or rainy weather the weight of the panel may be considerably increased.

2. MASONRY WALLS

For heavy building construction, such as load-bearing walls, a double wall will increase the sound insulation, but any of the fillers which have been tried seem to be of little value. However, with a masonry wall satisfactory sound insulation can be obtained in other ways which often give better results than a double wall.

In most cases it is customary to apply the plaster directly to the masonry. In this case the wall becomes a solid unit and its weight is the most important factor. If only 3-inch or 4-inch tiles are used there is not sufficient weight to give satisfactory sound insulation in most cases. The problem then is one of attaching the plaster surfaces to the masonry core so as to secure as much sound insulation as possible.

To obtain some idea of the effect of keeping the plaster surface as independent of the masonry as possible, wood furring strips were tied to a 4-inch tile wall with wires which had been imbedded in the mortar joints. Waterproofed paper was nailed to these furring strips, then metal lath and plaster were applied (fig. 1). The object of the paper was to prevent the plaster from pushing through the metal lath and bonding to the masonry core. It was found that this type of wall was a trifle better than an 8-inch brick wall although it weighed approximately one-third as much. When this was first tried out it was believed that the method of attaching the furring strips might make considerable difference in the sound transmission. The measurements which have been taken indicate that this feature is of minor importance. There are 2 or 3 patented methods of attaching furring strips, but it is believed that for this type of wall construction there is little difference in the sound-insulation values of these systems as long as the plaster surface is held away from the masonry, not making direct contact at any point.

When these furred-out masonry panels were in position conversational tests were made as well as the usual sound-transmission measurements. In every case it was found that the sound of a conversation carried on in an ordinary tone of voice was barely audible to a listener

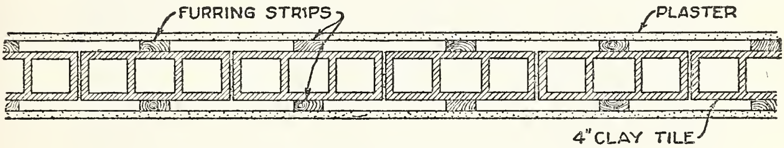

FIGURE 1.—*Masonry wall with furred-out plaster.*

on the other side, provided he was listening intently, but that he was unable to understand anything that was said. In addition, if there was the slightest noise in the listener's room, he failed to detect any sound of the conversation on the other side of the panel. It should be borne in mind that the rooms in which these tests were made had bare concrete walls and were so situated that no distracting noises entered from the outside. If these rooms had contained draperies and furniture to absorb part of the sound, and if there had been some noise due to traffic or other causes, the panel would apparently have given better results.

V. IMPACT NOISES AND METHODS OF ISOLATING THEM

Up to the present we have considered only air-borne noises. Noises caused by impact, such as walking or moving furniture, or due to a direct transfer of vibration as from machines, musical instruments, such as pianos, radios, etc., form another class of noises which are more difficult to insulate than air-borne noise. From experience we all know that a machine often sounds almost as noisy in the room below as in the room where it is located. For experiments with impact noises, a special machine (fig. 2) was built. It consists of a set of five rods which are raised in succession by a set of cams. The speed of the cams is such that one rod is allowed to fall every fifth of a second. On a wood floor it is quite noisy—so much so that it is rather difficult to hold a conversation with anyone in the room. With a floor built with wood joists there was some reduction of the noise transmitted through the floor panel, but it was still decidedly annoying. Some contractors build a so-called "floating floor" by laying a rough flooring upon the joists, upon this a layer of fiber board, and upon the fiber board the finish floor, which is nailed through the fiber board to the rough floor. This form of construction was tested by the impact machine to determine if such a structure was an improvement, but it was found that the same percentage of sound was transmitted (within experimental error) as without the layer of fiber board.

In another experiment a rough subflooring was laid, upon which was placed the fiber board. On the fiber board were laid nailing strips to which the finish floor was nailed. This may be described as a real "floating floor." It is believed that the method of fastening these nailing strips is not of great importance. They can be nailed every 3 or 4 feet or held in position by various arrangements of straps. This same result can be accomplished by the use of springs or small metal chairs containing felt. For air-borne noises such structures are quite satisfactory. Under usual conditions a conversation carried on in an ordinary tone of voice is not audible through them. For impact noises, however, such structures are rather disappointing. They are somewhat of an improvement over the usual wood structure, but footsteps can be easily heard through them.

The next attempt to improve such structures consisted in separating the ceiling and floor joists. This gave about the same result as the single set of joists and floating floor, although not quite as good. A floating floor was then added. This combination gave the best results that were obtained with wood joists and was very satisfactory as far as air-borne noises were concerned. It still needed improvement in regard to insulating against impact noises. In fact, at this point of the investigation the conclusion was almost reached that the most practicable way to prevent noise coming through from the floor above was to minimize the noise being produced. For noises produced by walking, throwing shoes on the floor, etc., this can be accomplished by the use of carpets or rugs. Considerable sound energy may be transmitted through the legs of a piano or radio into the floor. This can be partly eliminated by putting the legs of the piano or radio in caster cups and then putting rubber between the floor and caster cups. Transmission of noise through the floor from machinery may be largely eliminated by a properly designed machine base. In other words, for most stuctures it is necessary to prevent most of the sound energy being carried into the structure if a good job of sound insulation is desired.

The other type of floor which was studied was masonry. When impacts were allowed to fall directly on the masonry, the noise in the room below was practically as loud as in the room where the machine was situated. A floating floor was then built, with decided improvement. Finally a suspended ceiling was added and this gave the best result which had been obtained (fig. 3). For one of the listening tests a radio loudspeaker was used. The loudspeaker was driven somewhat harder than is customary for home use, and even then when listening through the panel the sounds were so faint that it is doubtful whether a person could have been sure that the radio was going. It is certain that if the test had been made anywhere except in a room which was absolutely quiet, the radio could not have been heard.

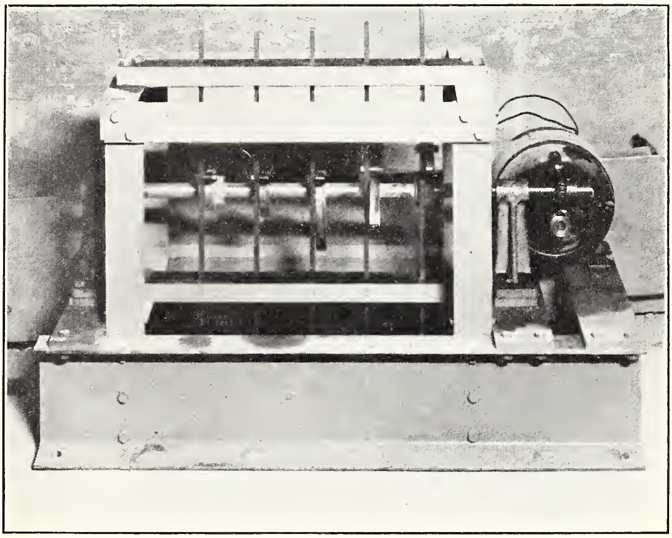

FIGURE 2.—*Machine for producing impact sounds.*

For impact noises this construction was not as good, but was a decided improvement over a masonry slab. The noise from the impact machine was distinctly audible, but not loud enough to be very noticeable if two people were talking in the room. The results in this case were better than for wood joists, but it is still desirable that the vibrations be checked at their source as far as possible.

The method of attaching the nailing strips is probably of secondary importance as in the case of furring strips attached to masonry walls. For the suspended ceiling rigid hangers should not be used. Any flexible supports, such as springs or wires which do not give a rigid connection, should be satisfactory.

From the above discussion it is evident that the best form of sound insulation for masonry would be constructed in the following way: What might be called the "core" of the building would be built in the customary manner; that is, with walls and floors of masonry. From this point the procedure would be different. Each room has been formed by this rough masonry and inside of this the finished surfaces are to be built. Instead of plastering on the masonry to form the wall and ceiling surfaces, this part should be furred out so that the finished plaster surfaces are not in direct contact with the masonry.

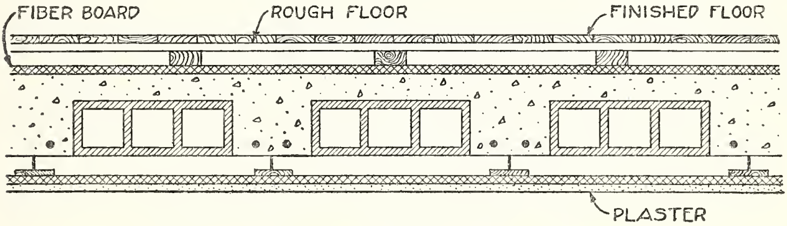

FIGURE 3.—*Floating floor and suspended ceiling.*

In the same way the floor should be of the floating type. In other words, we might picture it as a box within a box, the inner box being attached to the outer one at as few points as possible, and these connections should not be any more rigid than is absolutely necessary.

VI. EFFECT OF OPENINGS AND METHOD OF COMPUTING RESULTS

In the foregoing discussion the fact that all rooms have either doors or windows or both has been ignored. A window or door cut in a partition will frequently transmit more sound than the rest of the partition; hence it may be useless to do anything to the partition to improve its sound insulation.

To bring out this point it will be necessary to discuss rather briefly how to compute the total sound transmitted through a wall composed of several elements having different coefficients of transmission and the manner in which these results are usually expressed.

First let us consider the usual manner of expressing results and why they are expressed in that way. In most cases we are interested in the effect of the sound upon the human ear, hence an attempt has been made to express the results in such a form that they are proportional to what the ear hears. It has been found that the ear does not respond according to the physical intensity of the sound. As the intensity of a sound increases steadily on the physical scale, the response of the ear fails to keep pace with it. There appears to be in the ear a regulating or protective mechanism, which, like the well-known mechanism of the eye, protects the organ against excessive stimulation. Experiment shows that the response of the ear is approximately proportional to the logarithm of the physical intensity; that is, intensities proportional to 10, 100, and 1,000 would produce in the ear effect proportional to 1, 2, and 3, respectively.

A slight modification of this scale has come into general use to measure sound intensities and the amount of noise reduction. It is called the decibel scale. This scale merely multiplies the numbers of the logarithmic scale by 10. The unit of this scale, the decibel, is a rather convenient unit as it is approximately the smallest change in intensity that the average ear can detect. For this reason this unit has frequently been called a sensation unit.

To understand a little more clearly what is meant by different intensities in decibels, and how much this intensity may be reduced by a structure with a given reduction factor, figure 4 should be referred to. This has been made up from the results of various noise measurements and gives an approximate idea of the value of different decibel noise levels in familiar terms. The reduction factor as referred to in this paper is the difference in intensity expressed in decibels, due to the presence of the wall or panel between the sound and hearer.

It can be shown that if I_1 is the physical intensity of the noise outside of a room, and I_2 the intensity in the room

$$\frac{I_1}{I_2}=\frac{a}{\tau_1 A_1+\tau_2 A_2+\tau_3 A_3 \ldots\ldots} \tag{1}$$

where a is the total absorption in the room, A_1, A_2, A_3, etc., are the areas of the various portions of the walls, such as walls, doors, windows, etc., and τ_1, τ_2, τ_2 are their respective coefficients of sound transmission; that is, the fraction of the incident sound energy that is transmitted through the panel. The denominator ($\tau_1 A_1+\tau_2 A_2+\ldots$) is termed the total transmittance, and will be represented by T. Formula (1) can be rewritten

$$\frac{I_1}{I_2}=\frac{a}{T} \tag{2}$$

The noise reduction factor, in decibels, which is the difference between the noise level (as heard by the ear) outside of a room and the noise level in the room, is equal to

$$10\ (\log_{10} I_1-\log_{10} I_2)=10\ \log_{10}\frac{I_1}{I_2}=10\ \log_{10}\frac{a}{T} \tag{3}$$

and the quantity $10 \log_{10}\frac{1}{T}$ is called the transmission loss in decibels.

To illustrate the use of these formulas assume a simple case of a brick building containing a single room. The walls are of 8-inch brick and the roof a 6-inch reinforced concrete slab. The total absorption in the room is assumed to be 600 units. It is assumed also that the foundations and floor are built in such a manner that the

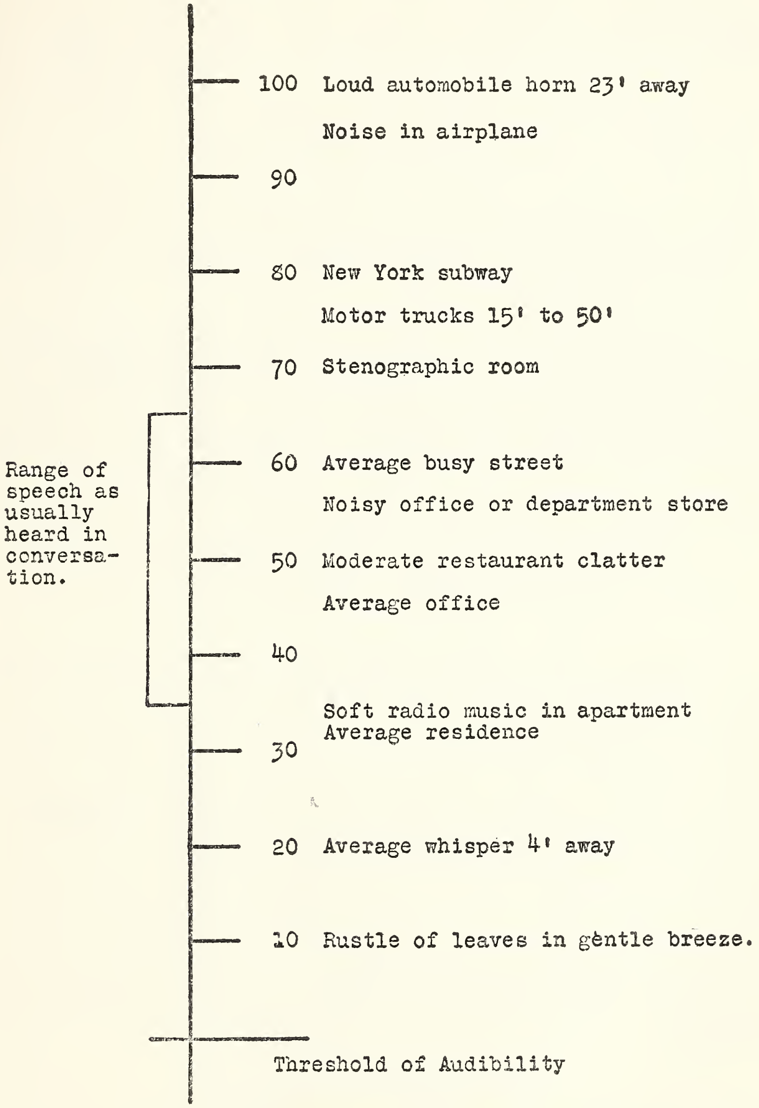

FIGURE 4.—*Decibel scale of sound intensities.*

amount of sound which enters the room through the floor is negligible. Assuming usual values for the transmission losses through the various parts, we may tabulate the separate items as follows.

Material	Areas A	Transmission loss	τ	τA
	Square feet	*Decibels*		
8-inch brick walls plus plaster	1,200	54	0.0000040	0.0048
6-inch cement roof slab plus plaster	600	50	.000010	.0060
Windows	150	28	.0016	.24
Door	21	35	.00032	.0067
Total transmittance T equals				.2575

Noise reduction factor (in decibels) $=10 \log_{10}\frac{a}{T}=10 \log_{10}\frac{600}{.258}=33.7$ decibels.

From the last column in the above table it may be seen that the windows admit several times the amount of sound admitted by all of the wall and ceiling structures and that the door admits more noise than either the walls or ceiling.

Suppose one window were opened so there was 1 square foot of open window. The transmission loss through an opening like this is zero, hence $\tau=1$ and $\tau A=1$. In other words, an opening of 1 square foot would transmit four times the sound energy that is transmitted by the entire structure with closed windows. The noise reduction factor with the partly opened windows is diminished to 26.8 decibels.

The values given for transmission losses are approximate for doors and windows, and are used simply to illustrate the fact that with a door or window in a wall there may be little use in trying to make the rest of the wall a good sound insulator, as a small opening, such as the crack under a door, will greatly reduce the sound insulation. The same is true of ducts or any other opening which may connect two rooms.

In formula (3) the total absorption comes in the numerator, hence the noise level can be reduced by increasing the total absorption in the room. Generally, however, this reduction is not large, being of the order of about 5 decibels as between a treated and an untreated room. This means that the introduction of absorbent material to reduce the noise level due to noises originating outside of the room is of small value, as a much greater reduction can generally be obtained at less cost by increasing the sound insulation of the boundaries of the room. This does not mean that sound-absorbent materials are of no value, for they are necessary to keep down the noise level due to noises originating in the room. In corridors absorbent material prevents the corridors acting as speaking tubes transmitting sound from one room to another when the doors are open. Other illustrations could be given of the value of sound absorption, but the fact should be emphasized that sound absorption cannot take the place of sound insulation.

VII. MASKING EFFECTS

Having discussed the various factors which determine the degree of sound insulation there remains one other important point and that is, what should be the reduction factor of a given partition to give satisfactory results and how can this be determined?

It has often been stated that when a certain type of structure has been built in one place it has proved perfectly satisfactory, yet when the same type of structure is used in another place it has not been satisfactory. It is believed that in these cases the conditions of local noise are entirely different, hence the apparent failure of the structure in one case. Whether a partition is satisfactory or not depends on what is heard through it. What one hears through a partition depends upon the amount of general noise in the locality as well as upon the intensity of the noise in the adjacent room, and the reduction factor of the partition.

For instance, in the country or any place where the general noise level is very low it might be possible to hear almost everything that occurred in an adjoining room, but if this same building were in a downtown district where the noise level is high, comparatively little would be heard of what occurred in the adjoining room. In other words, there is a masking effect due to the presence of other noises and this should be taken into account. This masking effect of noise is much the same as if the listener were partially deaf, as his threshold of hearing is shifted slightly upwards.

In what ordinarily passes for a quiet room this masking effect may raise the threshold of hearing as much as 5 or 10 decibels, and in an ordinary business office 10 to 20 decibels. In a busy place, such as a department store, the masking effect may be as much as 30 decibels and in a room containing a number of typewriters or telegraph instruments it may reach 50 decibels.

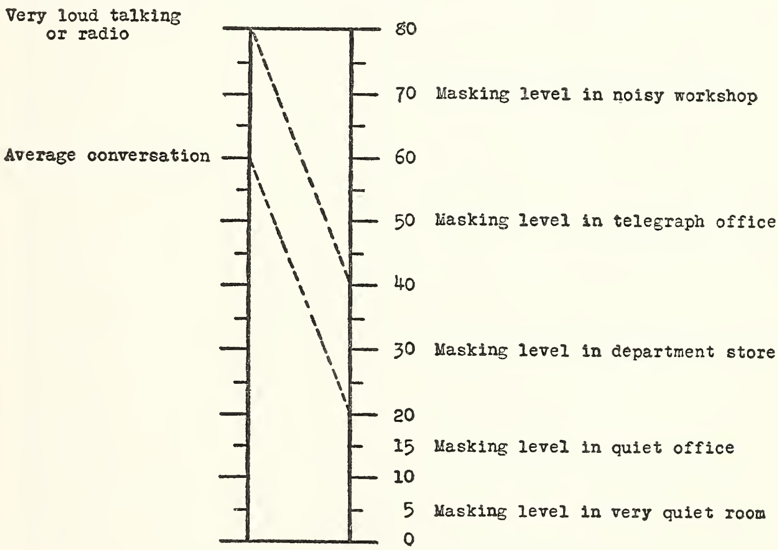

FIGURE 5.—*Masking levels for noise.*

Figure 5 shows the results that may be expected from a wall with a reduction factor of 40 decibels. Very loud talking on the left side is reduced on the right, as indicated by the dotted line, from a level of 80 decibels to 40. Ordinary conversation is similarly reduced from 60 to 20. Such a wall would be satisfactory for a telegraph office, and perhaps for a department store, but not for a quiet office or living room.

The foregoing is given merely as an illustration and while the values assigned may not accurately represent any actual condition, it shows the factors that should be known when designing a structure. It also shows why a partition that is satisfactory in a noisy down-town district is unsatisfactory in an apartment house in a quiet suburb.

Unfortunately we have not enough definite information as to the masking effect of various types of noises. The loudness of various noises has been measured by different observers, and the results are published in City Noise, published by the New York City Noise Abatement Commission and in Architectural Acoustics, by Knudsen. The transmission loss of numerous types of construction from which the reduction factors can be computed can be found in Knudsen's Architectural Acoustics and in the publications of the Bureau of Standards cited in the footnote on page 2.

With this information it should be possible to design a floor or partition which will give satisfactory sound insulation for most conditions.

WASHINGTON, February 1, 1933.

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