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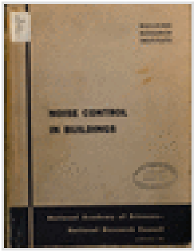

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NOISE CONTROL IN BUILDINGS

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UNSOLVED PROBLEMS IN SOUND TRANSMISSION AND NOISE CONTROL

FOREWORD

The increased use of lighter weight construction in modern buildings, new types of interior partitions, and the increased use of mechanical equipment of all kinds, have created a great number of new problems in the field of noise control within the building generally, and between separate rooms or areas. In order to more adequately cope with these problems, builders, architects, engineers and building owners have voiced a widespread desire to have more information about acoustics in buildings and the control of noise.

This Building Research Institute research correlation conference was therefore organized to examine noise control problems in buildings, stemming from the use of lighter weight exterior walls, floors and partitions, and from such mechanical equipment as high velocity air conditioning and ventilation systems, high frequency lighting, air duct terminal devices, communication systems and business machines.

The Building Research Institute acknowledges with gratitude the time and effort devoted to this conference by the speakers, the session chairmen and moderators, and the planning committee listed below which was responsible for the organization of this program.

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Abstracts of Conference Papers

BASIC CONCEPTS OF ENGINEERING DESIGN
Robert B. Newman, Bolt, Beranek and Newman

The increased use of lightweight materials and the modern demand for flexibility are mentioned as contributing to the problems of noise control. A number of problem situations in office buildings, involving ventilating systems, a particular fluorescent lighting system, a luminous ceiling and others are described, and the solutions of these particular problems explained. The mechanisms of noise control are stated as absorption of sound and isolation of sound, and the means of accomplishment are discussed in those terms.

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EFFECTS OF NOISE ON PEOPLE
Lewis S. Goodfriend, Lewis S. Goodfriend & Associates

The direct and indirect effects of noise on people are outlined and the mechanics of the individual's attempts to adapt to it. Design objectives are discussed in terms of acting as guides, rather than criteria. Tables show recommended noise criteria for various types of rooms and auditoriums; speech interference levels; and office noise conditions. The question of costs in relation to the quality of noise control is also discussed.

* * * * * * * * *

THE ARCHITECT'S PROBLEMS WITH NOISE CONTROL
Robert L. Geddes, Geddes-Brecher-Qualls, Architects

The author deplores the lack of attention in contemporary theory and building to the subject of noise control and points out the increasing difficulty of reconciling noise control with other ideas in art and technology. Citing the way the building "operates" to keep out water, he suggests that control of noise can be effected on an operational basis, with sound barriers serving as part of the expression of architecture. He therefore urges that "sound conditioning" be made more predictable so that the architect may deal with it in the same manner that he does air conditioning.

* * * * * * * * *

THE BUILDER'S PROBLEMS WITH NOISE CONTROL
Haydon T. Noyes, Turner Construction Co.

This paper takes note of the fact that the builder's problems are interwoven with those of the architect, and that the builder must also consider increased cost of noise control, delay in completion of the work, availability of the desired material, ease of installation, and permanence of the efficiency of the material. In addition to enumerating the building components and equipment which give the builder the most trouble, this paper points out the need for educating the construction industry in the field of sound control, and the need for a reliable schedule of sound transmission values as related to walls, floors, partitions, ducts, etc.

* * * * * * * * *

THE BUILDING USER'S PROBLEMS WITH NOISE CONTROL
Julius F. Weinhold, Cornell University

Based on a survey of universities and colleges in the U. S. and Canada which own almost every conceivable type of building, noise control problems seem to fall into five classifications: determining general levels of noise in areas of various occupancies; ascertaining that architect, engineer and owner understand what the requirements are and the design that will produce the desired results; being sure that materials and equipment meet all requirements; translating acoustical theory into practice so that the contractor can exercise the necessary in workmanship; and methods by which the owner may proceed to correct faulty acoustical conditions. This paper discusses each of these considerations in detail.

* * * * * * * * *

CONTROL OF TRANSMITTED SOUND OVER AND AROUND PARTITIONS
B. G. Watters, Bolt, Beranek & Newman, Inc.

Due to the high cost of remedial measures, many sound problems existing today in comparatively modern buildings are not being corrected, this paper point out, and the reasons why such problems problems prevail are examined for a number of specific cases. These are enumerated as: ignorance of what to specify; misuse of acoustical terminology; and inadequate laboratory testing used as a basis on which to predict field performance. A relative rating system for comparing one wall against another is presented, pointing out why low weight and high stiffness tend to be antagonistic to high transmission loss. A table is used to demonstrate the wide range of stiffness of materials used for partitions, as compared to the low range of surface weights normally encountered, and several graphs serve to help apply the rating system to existing conditions and materials in use.

* * * * * * * * *

SOUND TRANSMISSION THROUGH SUSPENDED CEILINGS AND OVER PART-HIGH PARTITIONS
Richard N. Hamme, Geiger and Hamme Laboratories

The author concludes from an examination of present data that: 1) The attenuation of ceiling-transmitted sound depends on the interaction resultant between sound transmission, sound absorption and plenum-duct propagation losses; 2) The attenuation of ceiling-transmitted sound cannot be deduced directly from sound-transmission-loss and sound-absorption-loss coefficient determinations without due regard for acoustical leakage between individual elements of ceiling and partition configurations; 3) The attenuation of ceiling-transmitted sound depends as crucially on the characteristics of the ceiling plenum as it does on those of the ceiling construction. Sections of the paper deal with formulation of the problem, experimental procedure, dependence on ceiling and on plenum characteristics, and some remarks on future study now being undertaken.

* * * * * * * * *

THE IMPORTANCE OF DETAIL
William A. Jack, Johns-Manville Research Center

This paper cites various experiences which have pointed up the inadequacy at the present time of data on the importance of various types of details in the control of sound. Details considered deal with movable partitions, floors, large open areas, perforated metal ceilings, plumbing systems, etc. Cautions are also voiced as to the proper use of acoustical measurements.

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Keynote Address

By John S. Parkinson*, Conference Chairman
Director of General Research and New Business Development,
Johns-Manville Corporation

The problems of noise control are so many and so varied that before undertaking this conference, your planning committee sent out a questionnaire to all Building Research Institute members who might be interested, asking what particular problems concerned them and suggesting various aspects of the noise control problem which might conceivably be covered.

The response to this questionnaire was gratifyingly complete. A tabulation of this response can be found in Appendix I. After analyzing the answers and the sources from which the questions came, your planning committee concluded that two specific areas of interest should be covered. One was the problems of sound transmission through buildings, either through or around partitions, or through the building structure itself. The other was the control of noise sources which occur in multi-occupancy buildings; this includes an examination of the nature of those sources and the kind of sounds which they produce. Obviously, there are many other related problems which might have been attacked, but within the scope of a two-day conference this program seemed to be as much as we could reasonably attempt.

The planning committee was divided into two groups. One group, composed of architects, builders, and building owners, undertook to collect the questions which their respective groups wanted to ask. The other group, which consisted of acoustical consultants and acoustical manufacturers' representatives, undertook to supply as many of the answers as possible. Many of these answers are provided in the formal papers and in the specific discussion panels of this conference.

We emphasized to our speakers that the basic objective of this meeting was an interchange of information, and that this interchange must occur between individuals of widely different backgrounds. We therefore asked them to keep their presentations as straightforward as possible and to try to cover each point presented thoroughly. We feel that they have done an excellent job in this respect.

*JOHN S. PARKINSON studied at the University of Wisconsin, Columbia, Rutgers and George Washington Universities. He represents his company as a member of the Building Research Institute and as an alternate representative to the Industrial Research Institute, is a member of the Chemists' Club, a Fellow of the Acoustical Society of America, and Honorary Treasurer of the Society of the Chemical Industry.

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FUNDAMENTALS
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Basic Concepts of Engineering Design

By Robert B. Newman*, Vice President
Bolt, Beranek and Newman

Acoustics involve both physics and psychology, and we can not separate the two. I have been assigned to handle the physics ends, but may touch on the psychological side, because the two are intimately tied together. The field of architectural acoustics is a reasonably well defined field of engineering. There is a lot we don't know, but there is a lot we do. We understand the basic mechanisms that control sound, both to make it and to suppress it. We've come out of the dark ages of merely hoping that acoustics would be good in finished buildings.

Noise control has two basic objectives: One, to establish a satisfactory environment, and the other to provide good hearing conditions. These are obvious. You will notice I have not used clear terms of definition. I have not defined "satisfactory", nor "good". We will try in the course of this two-day meeting to define just what is good, what is satisfactory and what is bad. It is important in discussing noise control not to confuse it with noise elimination. We must get away from the idea that quiet is the ideal. We know a great deal about the value of noise itself, and we know what is a satisfactory amount of noise in our buildings to make our buildings work. So, we will talk about the control of noise, of making it behave the way we want it to.

Most architects, engineers, builders and acoustical engineers realize that in many of our modern buildings we have entirely unsatisfactory acoustical conditions. With the increased use of lightweight materials and the demand for flexibility, and movability, we find many owners surprised when the building doesn't work acoustically, and being disgusted with the architects or engineers who designed this unusable building. We even begin to wonder if architects are purposely making mistakes. However, I don't think we can say that. Most of the mistakes made in buildings today come from just plain ignorance, neglect, or the lack of realization that every building has acoustical problems. Everyone knows that a music building presents acoustical problems, and a school auditorium must be given some acoustical thought, but how often do we think about acoustics in the office buildings, in the apartment house, in every, single building type?

Every aspect of the design of the building, including the mechanical equipment, the structure and the surface finish material, affects the acoustics. We can not isolate the acoustics as something that we put in when the building is finished. We must consider acoustics at the very outset, in the basic design consideration of what goes into the building, or we're going to have a lot of surprises.

The other day we had a desperate call from a contractor down in Florida who had just put up a new 10-story office building for doctors and lawyers. Doctors and lawyers have a way of demanding a certain amount of privacy in their offices. They don't want their conversations with their clients to be audible to others. In this particular case, the architect had become intrigued with a new system

*ROBERT B. NEWMAN received his B.A. and M.A. degrees in Physics from the University of Texas and his Master of Architecture degree from M.I.T. He is an associate professor of Architecture at M.I.T. and a visiting lecturer on acoustics at Harvard and Yale. He has done acoustics research and development at RCA, the Electroacoustic Laboratory at Harvard, and the Bureau of Aeronatics of the Navy. He is a Fellow of the Acoustical Society of America and former chairman of its Committee on Architectural Acoustics, and a member of the Board of Governors of the Building Research Institute.

A manufacturer of roof decks ran an advertisement a while ago which claimed that because the steel deck was ribbed, it would break up the sound and give a noise reduction coefficient of .45. This isn't so. A ribbed deck or a waffle ribbed concrete ceiling or any kind of a complicated shape will give a certain diffusion of sound, or re-direct sound energy. It's like the difference between the reflection from a glossy mirror and from a matte piece of paper. It merely scatters the sound energy in all directions, but the energy is still there. The only way we can dissipate energy is with a porous, fuzzy material. I can't say that too many times. If we must dissipate it, we must dissipate it. To get rid of sound, we must reduce the energy to heat, and unless we heat something up, we're not going to get anywhere. The question is often asked, "What about skewing the room? Can't we just skew the room out of parallel, and won't that control the noise?" No, it won't. Redirection of sound energy by splaying walls and other forms of surface shaping is necessary in some kinds of spaces to control other problems like flutter echo, or to get what we call "sound diffusion" into listening spaces for speech or music. But, again, we've got to have the dissipating material present in the room.

Absorption is a very useful mechanism in controlling noise. In a given space it controls the spreading of sound. Sound absorbing material on the ceiling reduces the spreading of sound from one end to the other. In an auditorium we want to spread the sound, so we don't put sound absorbing material on the ceiling. In the noise control situation, we do want to control the sound so we do put sound absorbing material on the ceiling. It controls the feel of the space and makes the space feel furnished. A worker feels that if good sound absorbing material is used, the other man's noise stays over there and isn't surrounding him from everywhere. We like it better when the space feels a little bit dead and the other person's noise stays with him and doesn't come over to us.

We use absorbing materials for control of sound within a space, not by itself for controlling the transmission of sound from one space to the other. We can reduce the transmission of sound from one end of the building to the other, for example, in corridors by putting sound absorbing materials on the ceiling, thus reducing the speaking-tube effect. We also reduce the transmission of noise in ducts by introducing sound absorbing liners. All of these things are useful reducers of sound, and sound absorbers are useful in noise control, but more within the space than between.

Sound isolation, on the other hand, which is the control of the transmission of sound from Space A to Space B is governed almost entirely by the weight and other physical characteristics of the partitions. You may say, "We all know that," but quite recently we looked at a "soundproof partition" which had been constructed in a hospital in Boston. It was made with two layers of perforated hardboard with a glass fiber blanket hung in the middle. The architect had put it in there because this would be soundproof, which proves there still must be some misunderstanding of this very basic question. Isolation in useful quantity is given by virtue of the mass, by the weight of the partition component.

It's as simple as thinking about this piece of paper as a partition. These molecules in the air moving back and forth approaching it are trying to move the partition back and forth. If this partition has high weight and high inertia, it will resist this motion and won't re-radiate sound on the other side. It's just as simple as that. The heavier the partition, the more inertia it presents, and the less transmission we get through.

You will hear a number of speakers in subsequent presentations here discussing certain aspects of this question; that the stiffness of the partition, for example, influences its isolating characteristics, but basically the mass is the controlling factor. If we have a massive partition, it will resist the transmission of sound. We can not hope to get a high degree of sound isolation with a very lightweight partition. You may say, "I can't have heavy partitions in my building. I have to have partitions one man can pick up and move when the boss decides to rearrange the area." The answer is, if you have to have very lightweight partitions, then you will need a lot of noise in the space to make the environment a tolerable one with a reasonable degree of privacy. Leaks, cracks or holes, are the real depth of any partition system, no matter how good the isolator may be nor how heavy nor how much inertia it may have. If it is filled with cracks and leaks and holes or if it is surrounded with openings of all sorts, then it just can not perform as well as we would expect it to. We must put into the buildings details that will permit them to operate at their full potential.

We must remember that when we ask a partition to give us a noise reduction or a transmission loss of 40 decibels, we demand that it transmit only 1/10,000th of the incident energy, which is a very small fraction. This type of partition with a reasonable quiet background level might permit the audibility of raised voice conversations. The very tiny fraction of energy which can be transmitted means that any cracks or leaks, which have 100% transmission coefficient rather than a 1/10,000 or 1/100 of 1% can very quickly overtake and completely nullify the value of the good partition component which we had to start with. We can't overemphasize the importance of detail, of sealing up the cracks and leaks to realize the full potential of any partition system we eventually decide to use.

This business of ultrasonic screens actually was proposed by some architects on the West Coast as the new way to do schools. They visualized great left spaces, infinite space in all directions, with skylights to let in the light, and with ultrasonic screens used to divide the space into classrooms. You just can't go about sound control that way. We need actual physical sound barriers. If we can't get sound control with one barrier, then we may have to go to two or three in series, but there is no substitute for the physical control mechanisms. And, they must be used properly. They must be air-tight, and installed so they can behave as they really should. I don't think any of us working in this field thinks there is going to be any terribly new or different way developed to control the behavior of sound between spaces.

Often the question is asked, "What about partial height partitions? Can't we do something about them?" I saw an insurance building where partial height partitions had been used because the designer thought they looked better. The people involved in this particular situation were in personnel. Imagine a personnel department fuctioning with partial height partitions. In one case we know about, in the course of the first six months occupancy there were four major leaks of personnel information picked up by people walking by in the corridor. At least the people in the next offices were in the same business, in that they were all firing and hiring. However, even idle passersby could hear about someone about to be fired.

A partial height partition is never a good sound isolation partition. If we have similar activities all over the building, if people are doing the same sort of thing, we can get by with a minimum enclosure with partial height partitions. I think in schools we can sometimes use part-high enclosures if all of the students are going to be engaged in the same activity in adjoining spaces. However, if the French class is singing a song while the English class next to it is conjugating verbs or taking a quiz, we have complete distraction and confusion, and then it won't work.

I have a little black box (Fig. 1) with me, which I use to illustrate a few of the basic principles of noise control in buildings. This box is made of plywood and around the bottom is sponge rubber. Inside it, I have another box which is made out of old, used rug cushion. I use this hair felt because it is not a proprietary acoustical material, and no one can object when I show how badly it performs. This hair felt is a very good sound absorbing material. It is porous and fuzzy; it dissipates energy and if I put it over my face, you can probably still hear me. The high frequency sounds are cut off somewhat, but the low frequency sound comes through. This is a sound absorber, not a sound isolator.

I also have a device designed to make noise. For the purpose of this demonstration, we will presume that this is a noisy machine such as a compressor or fan. It vibrates, it shakes a little, and when I hold it up in the air you hear a certain kind of noise coming from it. When I put it down on the table, if the table is a good radiator, we get a lot more noise from it, as you hear. These is an increase in low frequency noise when we get it down on the table. When I set this noise maker on a resilient pad of

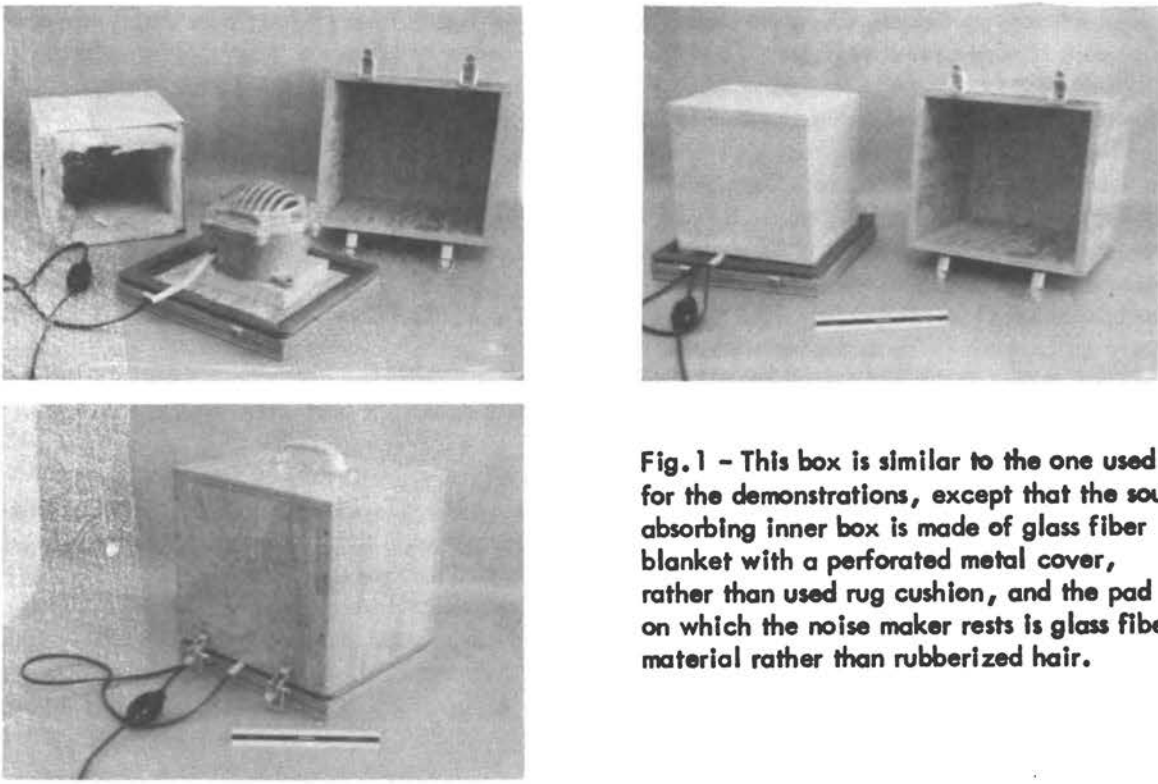

Fig. 1 - This box is similar to the one used for the demonstrations, except that the sound absorbing inner box is made of glass fiber blanket with a perforated metal cover, rather than used rug cushion, and the pad on which the noise maker rests is glass fiber material rather than rubberized hair.

rubberized hair, the noise level is measurably decreased. This demonstrates the first important principle in controlling mechanical noise. Remember the tuning fork in physics? When you hold it up, you don't hear it; when you put it down in contact with the sounding board, you do hear it.

Now, when we put it on the box made of sound absorbing material, there is some change, but not enough. We have just housed it with sound absorbing material. Obviously there is little noise reduction with this kind of housing. So, let's try housing it with half-inch plywood in the form of a simple box with a rubber gasket around it to seal it up air-tight. Used properly, inside the box, the sound absorbing material does a fine job, but as you can hear, the plywood box itself does the biggest part of the job. If we keep the cracks sealed, we could live with the remaining amount of noise. However, if we do all this properly; seal up the cracks, use sound absorbing material, etc., but forget to isolate the machine itself from the building, note that we still have not solved our problem. The basic conclusions are that mass is necessary for isolation, that porosity and fuzziness are needed for good sound absorption, and if we're going to isolate a piece of machinery we have to do it with resilient separation, in addition. An architect asked me about a problem recently. He had a concrete slab with a couple of big transformers on rubber pads, and between them was a big switchgear which was bolted to the floor. This, of course, completely short-circuited his resilient isolation of the transformers. Underneath the slab were meeting rooms of a hotel, and in the meeting rooms the noise was a continuous hum, because all of the vibration was going right through the slab. The architect asked "Don't you think it would do some good if we put 4" of sound absorbing material in the ceiling?" The answer is obvious, of course.

Recently, I went out to the Mid-West to talk with some architects about an apartment house they were designing. It had apartments on 10 floors including the first floor. Underneath the first floor was a basement given over to mechanical equipment including refrigerant compressors, not only for the apartment house, but for an adjoining ice skating rink, several steam reducing valves and all the air handling equipment for the apartment house. They said "We want it quiet in the bedrooms overhead." My first recommendation was that all piping be hung on resilient isolators and a resiliently supported one-inch plaster ceiling be installed without any holes, leaks, or cracks. After considerable debate, I also told them they should think about putting this equipment in another building, and leave the basement for trunk storage. They did a careful investigation and found out that, in truth, it was a good deal cheaper to put the equipment in another building which didn't need any special provisions for acoustics.

We can engineer and make anything quiet you want, if you are willing to pay the cost of doing it, but we can often solve acoustical problems by putting mechanical equipment somewhere else. A case in point is a building in the Southwest where all the mechanical equipment had to be on the top floor. Directly underneath was the executive office area with the best view, and company officials occupying this area wanted it especially quiet. The architect was planning to use a 2" slab on a metal deck and we recommended an 8" slab. In addition the plans called for a 3" layer of glass fiber blanket and then four inches more of concrete, with the slab, thickened to a foot wherever there was a machine. This meant 8" plus a foot, plus the sandwich layer in the middle, and they wanted a very good job of resilient isolation of the machinery. This called for a complete structural redesign of the building. It cost money both to redesign and to build, but it works. The owner of the building won't give us any money and go back and make measurements. He says he can't hear the machinery and he won't pay money for an acoustical engineer to make measurements on it. I agree with him. It's very quiet, it's fine, but it cost a lot of money. How much cheaper and easier it would have been to put this equipment in another building or in the basement, I don't know. But you who are responsible for the design of buildings can often save a lot of trouble and realize better buildings in the end by putting things somewhere else. When you must put noisy things next to quiet things, then you must apply the basic principles we have discussed above.

Effects of Noise on People

By Lewis S. Goodfriend*,
Lewis S. Goodfriend & Associates

Noise is a by-product of many beneficial devices and processes produced and used by modern civilization. Noise, by definition, is unwanted sound. The continued exposure of any person or group to this unwanted auditory insult causes irritation of and annoyance to the auditor or auditors. The resulting effects are many and varied, but all negative. It is to the nature and extent of these effects that I shall direct my attention this morning.

There are both direct and indirect effects of noise on people. Among the direct effects are interference with the auditors' activities, general annoyance, retaliatory or remedial action, and finally, if nothing else causes the noise to stop, legal action against the owner or operator of the noise source. The indirect effects include behavioral changes under the stress of noise, adaptation to the noisy environment, and apprehension. These indirect effects may occur simultaneously with and interact with each other and with the direct effects to produce a complex group or individual response.

These indirect effects require a few words of explanation before proceeding to any discussion of criteria. Behavioral changes often occur in individuals at such slow rates that neither they nor their close associates are clearly aware of the magnitude of the change. I have seen such changes occur in noise exposed communities where some people are tagged with such terms as "crank" or "troublemaker" when it comes to noise. These people, in a few cases, have reasons not related to the noise exposure for their extreme reaction to the noise source or its operator. However, in a majority of cases noise exposure over a long period of time has given these people the feeling that their fight is a crusade, a strategic operation, to which they devote considerable energy. They feel, and often rightly so, that their rights have been invaded. It is difficult to interview these people in an effort to determine facts such as the duration of the noise, because they frequently exaggerate in their descriptions of both duration and comparative loudness of the noise in question.

The process of adaptation permits office workers to maintain their levels of work output with little or no degradation of quality even while working under extraordinary noise conditions. I have seen conditions where the employee consumption of headache pills and aspirin amazed me, and where continuous representations were being made by employees to their employers and to the owners of the noise source, which was a printing plant recently installed on the floor above the office in question. In fact, legal action was in progress. However, no reduction in work output was noted. Some by-products of this unfortunate environment were: (1) more end of the day fatigue on the part of the employees and (2) a feeling of apprehension on the part of individual employees for their own future health and peace of mind.

Although psychologists have determined that noise does not interfere directly with many kinds of work,

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* LEWIS S. GOODFRIEND heads his own company of consulting engineers in acoustics. He received a degree in Mechanical Engineering at Stevens Institute of Technology, where he became a Staff Engineer in their Sound Research Department, and a Master's in Electrical Engineering at Brooklyn Polytechnic Institute. He is a Fellow of the Acoustical Society of America, a Senior Member of the Institute of Radio Engineers, and a Fellow of the Audio Engineering Society.

they have not been able to measure all of the systemic changes that take place in the individual under the stress of loud noise. Apprehension, which was mentioned in regard to health, has a more important aspect in regard to architecture and community planning. Residents of communities at the ends of airport runways and those near highway intersections where fatalities have occurred are made apprehensive by the acoustical reminder of the presence of the danger. These are the major indirect effects of noise on people. These are the effects that we have not been able to describe by numbers.

If you will remember these effects and the kind of influence they may have on the verbalization of an individual's response to noise, we can proceed to the examination of noises and criteria for noise in architectural spaces.

There are many sounds which are music to the ears of one person which, at almost any sound level, will be annoying noises to other people or groups of people within our society. Among these are the sounds made by children playing, model airplane engines, racing sports cars, a sports event heard on someone else's radio or television receiver. Each one of these sounds provides a pleasing response for some, and often violent reaction on the part of others. The proud father of a future concert violinist may find his child's practicing a musical treat while his neighbors contemplate a call to the police.

As you have already heard, the ear is not as sensitive at low frequencies as it is at high frequencies. Thus sounds which have only low frequency components are often quite acceptable. They include distant automobiles and piston engine airplane traffic, in fact, any sound which through natural means or by control devices has had most of its high frequency energy removed or reduced.

There are some relatively quiet sounds which will be annoying no matter how quiet they are. These include conversation from another room heard indistinctly, somebody else's barking dog, flushed water heard in your living room filled with guests. These sounds are really members of classes of noises, but they illustrate the noises that are either acceptable or unacceptable on the basis of the relationship of the noise and its source to the auditor.

Design Objectives Are Guides, Not Criteria

There have been set up over a period of many years a number of tabulations showing in one column a room function and in an adjacent column the corresponding sound level recommended for that space. In some cases these levels are those measured in existing spaces, in other cases they are the design objective sound levels for ideal living or listening conditions, and in still other cases they are the levels which will probably be tolerated by the expected occupants of the space. If the occupancy changes these formerly tolerable levels may be intolerable. Unfortunately, different writers have used the same terms, "the weighted sound level," "speech interference level," or "NC level" to label their selections, but they seldom state whether this is what they would like to achieve or what they estimate as just tolerable.

The most comprehensive guide to acceptable noise levels is based on work by Rosenblith, Stevens and Bolt,[1] in a study prepared for the United States Air Force and later refined by Beranek[2, 3] for industrial, commercial and residential use. This guide is in the form of two charts showing the NC and NCA curves. The charts have been superimposed and are shown as a single illustration in Fig. 1. I should like to point out here that these are the same as the earlier curves called the SC curves except that the SC curves have been drawn through integral decibel values.

In using these curves a list or table (Table 1) indicates which of the NC curves is recommended for a given space. The noise control procedures are then planned to achieve the design levels selected, or any value below the design objective. Berenel and his colleagues have selected a number of values as design objective noise levels. These levels are to be measured in the space when it is not

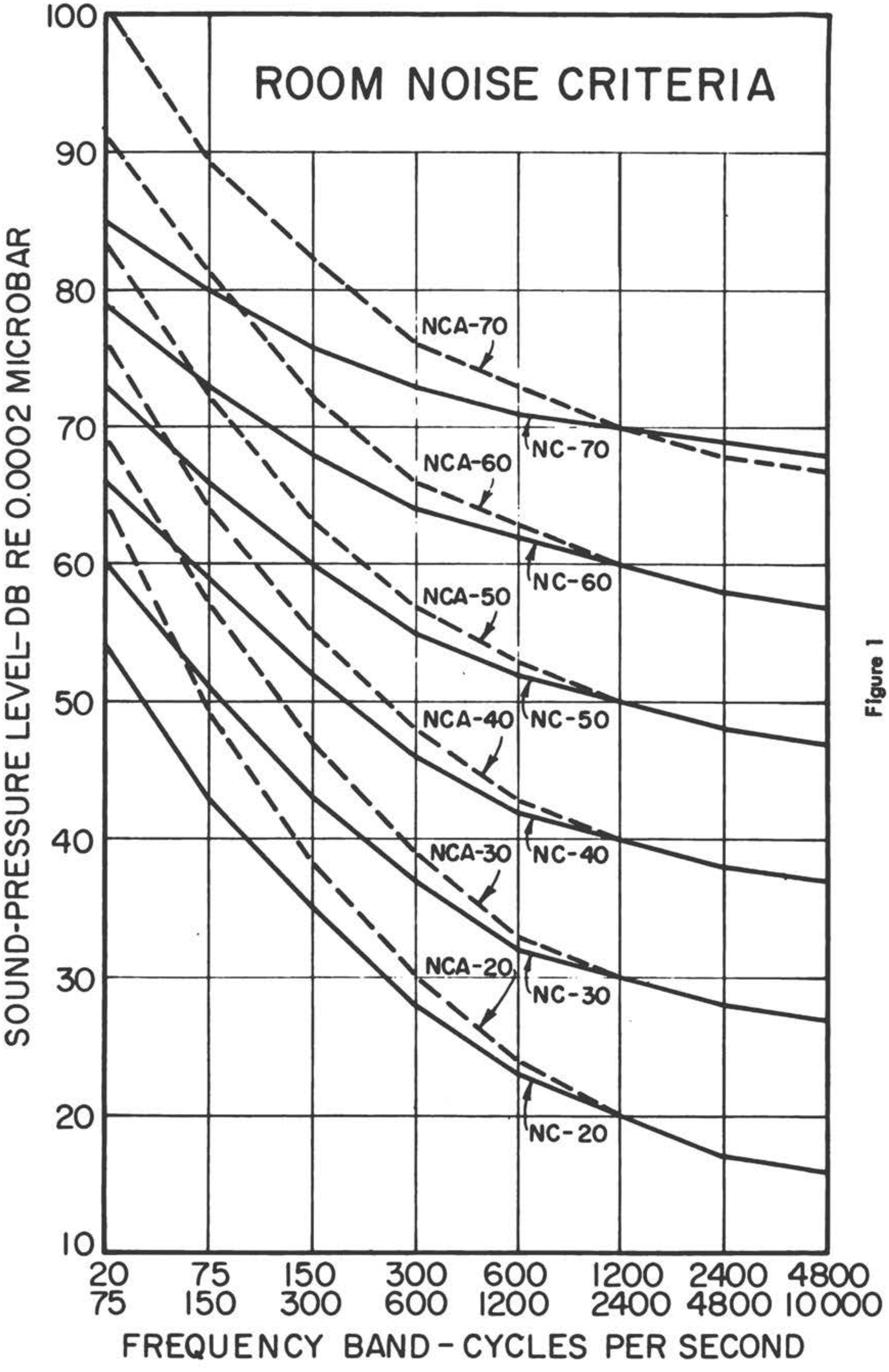
ROOM NOISE CRITERIA
SOUND-PRESSURE LEVEL-DB RE 0.0002 MICROBAR
100
90
80
70
60
50
40
30
20
10
NCA-70
NC-70
NCA-60
NC-60
NCA-50
NC-50
NCA-40
NC-40
NCA-30
NC-30
NCA-20
NC-20
20 75
75 150
150 300
300 600
600 1200
1200 2400
2400 4800
4800 10000
FREQUENCY BAND - CYCLES PER SECOND

Figure 1

TABLE 1

RECOMMENDED NOISE CRITERIA FOR ROOMS [3]

Noise levels to be measured in unoccupied rooms. Each noise criterion curve is a code for specifying permissible sound-pressure levels in eight octave bands. It is intended that in no one frequency band should the specified level be exceeded. Ventilating systems should be operating, and the outside noise sources, traffic conditions, etc. should be normal when measurements are made.

Type of Space	Recommended Noise Criterion Curve
Broadcast studios	NC 15-20
Concert Halls	NC 15-20
Legitimate theatres (500 seats, no amplification)	NC 20-25
Music Rooms	NC 25
Schoolrooms (no amplification)	NC 25
TV Studios	NC 25
Apartments and hotels	NC 25-30
Assembly halls (amplification)	NC 25-30
Homes (sleeping areas)	NC 25-35
Motion picture theatres	NC 30
Hospitals	NC 30
Churches	NC 30
Courtrooms	NC 30
Libraries	NC 30
Restaurants	NC 45
Coliseums for sports only (amplification)	NC 50

occupied. The occupants may or may not make noises of their own. That is under their own control. It should be noted that the sound level must not exceed the NC curve selected as a design objective in any band in order to meet that objective.

All earlier criteria for noise control design can in a general way be related to these NC curves. The weighted sound level in decibels which has been in use for many years is very close to the shape of the NC curve at the low levels usually recommended for home and office spaces, and the curves of loudness levels in phons used in Europe are also close to the NC curves. Beranek himself had this to say about the application of the NC and NCA curves, "The architect or consultant will have to use his own judgement is selecting a curve for a particular specification because of the wide range of attitudes toward noise and because of local customs and expectations in different locations. In some cases lack of funds for quieting may require that a calculated risk be taken."

Where does this leave us? It leaves the architect and consulting engineer with some good guides to design. As you will learn, if you do not already know, noise control measures provide large increments in noise reduction through specific design techniques. It is difficult to obtain just a little sound control. For example, adding 1/4" of additional plaster to a 3/4" thick plaster and steel-stud wall does not add even one decibel to its sound isolation. The addition of resilient clips to the wall system can add 10 decibels of isolation in the speech range. Similarly a few bends in an unlined ventilating duct do little to limit the fan and motor noise. Adding a proprietary trap, or lining an existing plenum, will probably make the fan and motor noise inaudible.

In almost all types of building noise problems, the acoustical engineer can spot the noise sources and can advise the architect where control is simple and will be adequate for even the most stringent design objective. He can also outline the critical areas where changes in planning will be less costly than trying sound control by materials and by mechanical isolation. These design criteria, which I prefer to call design objectives, must be applied with understanding, on the part of both the acoustical engineer and the architect and his client.

There are two major points still left for discussion. One is the matter of the cost of noise control. The other is the effect of noise duration on the design. There are many psychological factors involved in the noise control design. If the design objectives are relaxed by 10 decibels, the owner may be able to save 10% on his construction cost, but may be unable to keep all his space occupied. On the other hand, safety factors in the design and rating of duct silencing devices usually result in quieter ventilating systems than calculated. Decisions regarding these matters affect the acoustical design. Once made they commit the owner to a fixed course. If he settles for less sound isolation he should not try to convince his tenants they are cranks when they complain about noise from adjacent spaces.

It is equally foolhardy to provide excellent architectural sound isolation between apartment or office units and connect them together with poorly isolated air conditioning ducts. A similar situation exists where a heating plant for garden apartments or a hospital is placed in a building of its own, separate from the main buildings, to eliminate noise problems and the steam is then noisily exhausted to the atmosphere, creating high noise levels.

There is one condition under which higher noise levels than those recommended as design objectives may be tolerated. This is when the duration of the noise is short and it occurs only during the day or early evening. A neighbor's kitchen fan running at breakfast and supper hours will not in general be an annoyance even to close neighbors. However, a summer ventilating fan or air conditioning unit that makes about the same noise all day and all night will very likely be considered a nuisance. Similarly, a laundry which shuts down and exhausts its steam lines at 6:15 each weekday evening will not be too annoying even to nearby neighbors, but just let them try a night shift with shut-down taking place at 12:15 AM. There are other sounds for which time is an important factor. One currently receiving considerable attention is the noise from airports. Here the techniques designed to determine noise tolerance of the community are keyed to the duration as well as the sound level and its spectrum.

To estimate correctly the effects of noise on people, it is necessary to study both the noise and the people. The noise experience of the noise exposed population, whether they are office workers or apartment dwellers, should be determined if possible. The engineer must study their sociological history, if it is residential construction, or their tasks and communications requirements if it is commercial or industrial construction. Then the margins, the safety factors, may be estimated and the NC design objectives applied.

To demonstrate the NC curves and their use, Figs. 2-6 present the octave band charts of both the background and the intruding noises.

I am sure that you see the point. If you don't like birds on a summer morning shut the window and air condition the house. If you have a noisy background, a window air conditioner doesn't make any difference. Actually, the architect must keep all but Figs. 3 and 4 in mind when he is designing. The owner will have to make the decision about the birds and the crickets before commissioning the building.

Speech Interference Levels

Earlier, I mentioned speech interference levels. These levels were defined by Rosenblith, Stevens

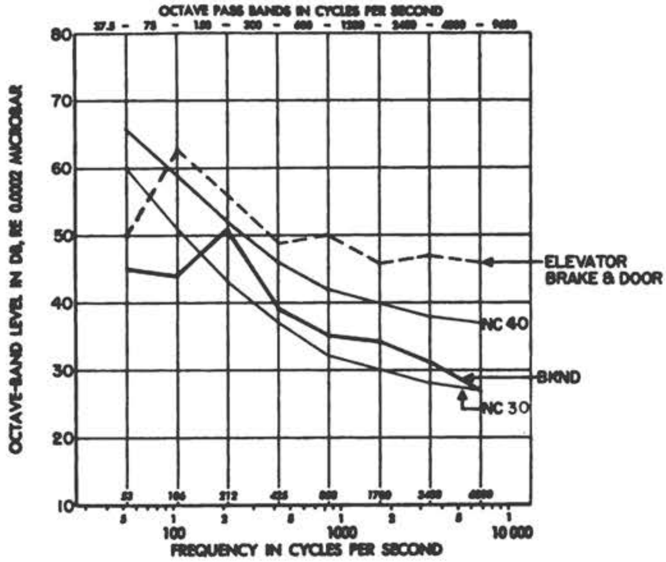

Fig. 2 - Hospital Elevator noise heard in patient's room.

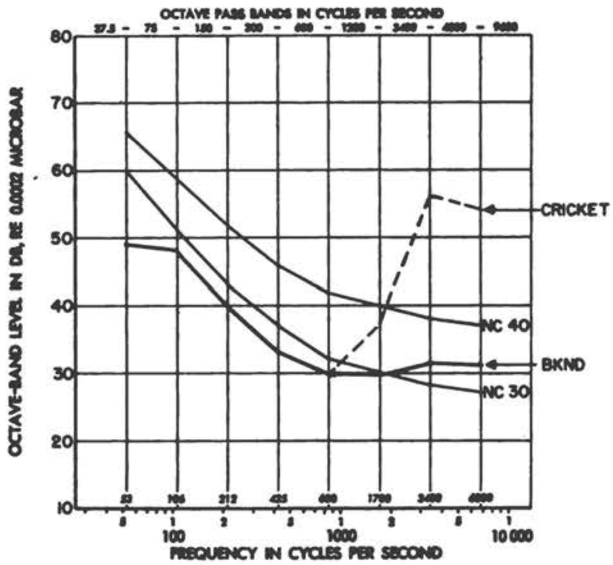

Fig. 3 - Cricket recorded in apartment interior

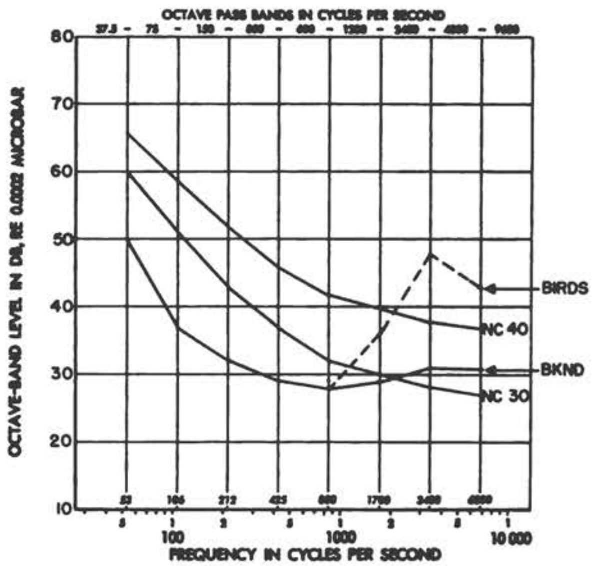

Fig. 4 - Birds recorded inside in the early morning

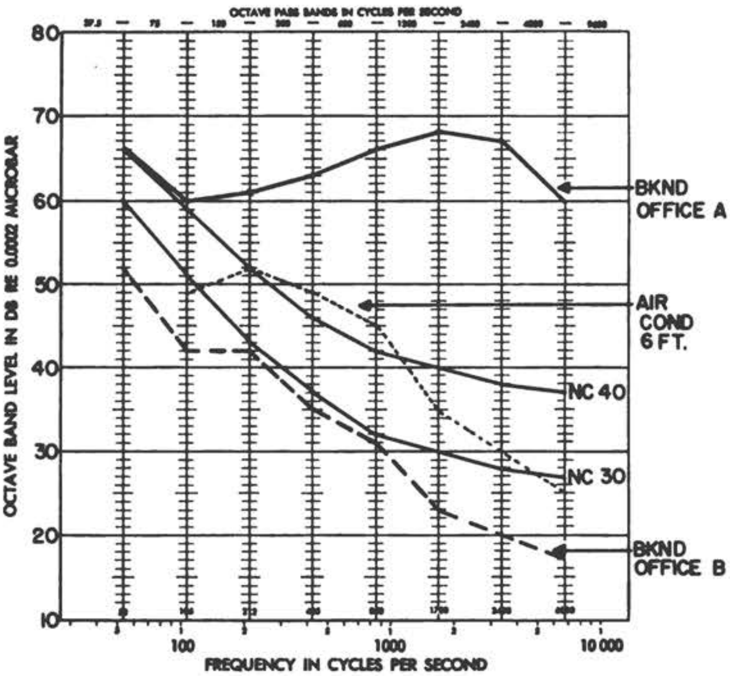

Fig. 5 - Window air conditioner noise

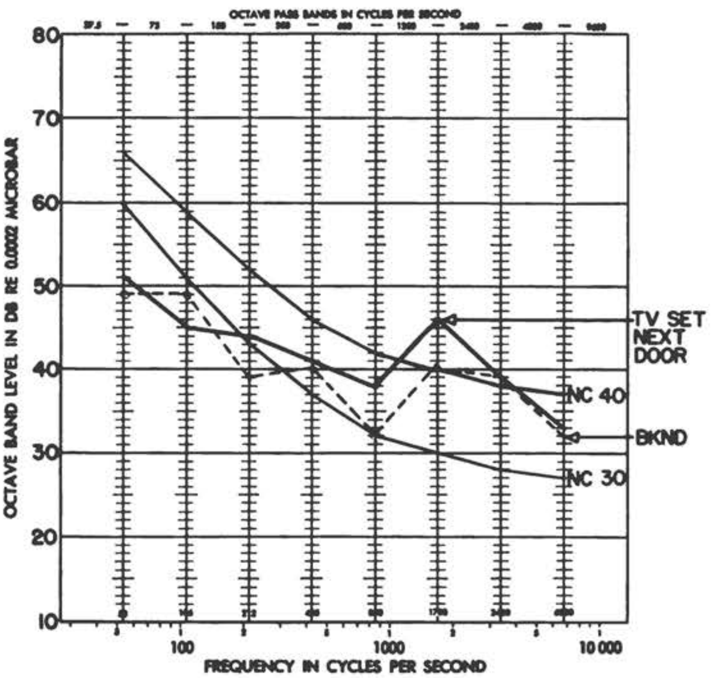

Fig. 6 - Television in the next apartment

and Bolt[1] as the average of the decibel levels in the octave bands 600-1200 cps, 1200-2400 cps and 2400-4800 cps. You may note that the Speech Interference Levels of sounds that follow the NC curves have the same value as the NC curves. The Speech Interference Levels may be used to predict the ability of people to communicate over certain distances using standard vocabularies and various degrees of speaking effort. Table II shows the distances over which reliable speech communications may be maintained with the sounds having various speech interference levels.

TABLE II

SPEECH INTERFERENCE LEVELS (IN DECIBELS RE 0.0002 DYNE/CM^2) WHICH BARELY PERMIT RELIABLE CONVERSATION AT THE DISTANCE AND VOICE LEVELS INDICATED

Voice Level Distance (ft)	Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

Beranek has prepared a table based on the SIL levels (Table III) to show office communications conditions at various SIL and NC levels.

It is not easy to relate these octave band charts and even our own experiences in noisy environments to the requirements for noise reduction. It is not so simple as thermal insulation nor as precise as illumination control. On the other hand, it is as important in the design of buildings as either of the other two.

Unfortunately, noise will continue to be a by-product of the many labor saving, beneficial products of our modern world. Notwithstanding its continued presence, it will still be unwanted. Nobody wants to live in an icily cold, dark house. Why should they be willing to live or work in a noisy one? Thus the effects of noise will continue to be negative. Engineers can design quieter products and architects can provide better sound isolation, select the quieter products, and meet the most desirable design objective values for building noise levels.

TABLE III

OFFICE NOISE CONDITIONS [3]

Noise measurements made for the purpose of judging the satisfactoriness of the noise in an office by comparison with these criteria should be performed with the office in normal operation, but with no one talking at the particular desk or conference table where speech communication is desired (i.e., where the measurement is being made.) Background noise with the office unoccupied should be lower, say by 5 to 10 units.

SIL or NC Curve	Communication Environment	Typical Applications
NC-20 to NC-30	Very quiet office-telephone use satisfactory-suitable for large conferences.	Executive offices and conference room for 50 people.
NC-30 to NC-35	"Quiet" office; satisfactory for conferences at a 15-ft table; normal voice 10 to 30 ft; telephone use satisfactory.	Private or semi-private offices, reception rooms, and small conference rooms for 20 people.
NC-35 to NC-40	Satisfactory for conferences at a 6- to 8-ft. table; telepho ne use satisfactory; normal voice 6 to 12 ft.	Medium-sized offices and industrial business offices.
NC-40 to NC-50	Satisfactory for conference at a 4- to 5-ft. table; telephone use occasionally slightly difficult; normal voice 3 to 6 ft; raised voice 6 to 12 ft.	Large engineering and drafting rooms, etc.
NC-50 to NC-55	Unsatisfactory for conferences of more than two or three people; telephone use slightly difficult; normal noice 1 to 2 ft; raised voice 3 to 6 ft.	Secretarial areas (typing), accounting areas (business rooms, etc.
Above NC-55	"Very noisy"; office environment unsatisfactory; telephone use difficult.	Not recommended for any any type of office.

REFERENCES

1. W. A. Rosenblith and K. N. Stevens, "Handbook of acoustic noise control, Vol. II, Noise and man", Wright Air Development Center, June 1953. (WADC TR 2-204, PB 111274)

2. L. L. Beranek, "Criteria for office quieting based on questionnaire rating studies," J. Acoust. Soc. Am. 28 833-852 (September 1956)

3. L. L. Beranek, "Revised criteria for noise in buildings," NOISE Control 3, Vol., 19-27 (January 1957)

The Architect's Problems

By Robert L. Geddes*, Partner
Geddes-Brecher-Qualls, Architects

Architects are always redefining architecture: introducing new ideas, and reconsidering old ideas. Design is really the synthesis of important ideas. The priorities given these ideas, the hierarchy of their importance one to another, are apparent in what an architect builds, and sometimes in what he says. Unfortunately for the purposes of this conference, much contemporary theory and building either ignores noise control, or treats it as only a surface aesthetic.

One wonders what priority is given to noise control within the following approach: "Architecture is an art and hardly anything else. The aim of architecture is the creation of beautiful spaces, and everything else is so subordinate to it that it just doesn't exist." (Philip Johnson) History is on the author's side. Architecture is essentially an art: a visual art, a plastic art, a spatial art. But one must realize that the experience of architecture is received by all of our senses, not by the eyes alone. "The quality of a space is measured by its temperature, by its light, by its ring," (Louis Kahn) and how a space is served with light, air, and sound must be embodied in the concept of the space itself. How do we make the "ring of the space" part of the concept of the space?

It is ironic that the modern movement is called "functionalist." Some of the highest priority ideas in our architecture are not based on function but on poetry. The painters also have had great influence. A modern architect says, "Transparency is definitely one of our objectives. It is one of the most fascinating new technological possibilities. We can do it with the means we have, with our materials, with our heating systems, with everything." (Marcel Breuer) But can we do it and also control noise? The problems posed by transparency are many. Structure becomes light and thin. Space is not isolated, but apparently continues without a barrier through glass, grilles, and gardens.

It is increasingly difficult to reconcile noise control with other ideas in art and technology. For example, "continuity" is an important idea that underlies much contemporary architecture: the flow of space and the open plan that means continuity of space; and the flow of structural forces that leads to a continuous structure. The leaders of the modern movement, from Wright to Le Corbusier, have practiced and preached the importance of "continuity" as an architectural idea. How can we achieve it, and still control noise?

It is important to remember that architecture is always changing its set of priorities. Neither the architect of the next century nor the architect of the Renaissance would set the same emphases or priorities as we do. The Renaissance conception of space and structure, for example, was more static, isolated and cellular; it would have solved some of our man-made noise problems. But, that opens the door to new possibilities again, doesn't it? Is there any hope for concepts that will admit noise control, if not into the center ring, at least into the same circus tent?

Ever since man first crawled into a cave or made an enclosure, there has been a sense of the "operational" basis of architecture. The aesthetic of structure has always been based upon the elegant

*ROBERT L. GEDDES graduated from the Harvard School of Design and was formerly Associate Professor of Architecture at the University of Pennsylvania. He is a member of American Institute of Architects and the Building Research Institute.

solution and expression of an operation: the carrying of a load, the resisting of a force, the resolution of thrusts. A modern architect says that "a space in architecture shows how it is made. Nothing must intrude to blur the statement of how a space is made. The joint is the beginning of ornament in architecture." (Louis Kahn)

In a similar way, one can consider the way the building "operates" to keep out water: the way water is made to drip from mouldings, the way exterior materials join to be waterproof, the way water-stops are put in all joints. Water control is part of the.basic space order of architecture, and it is part of the detailing of all joints. The way in which water is controlled has become a basis for expression and enrichment in architecture.

These two examples - structure, and the control of water - indicate the possibilities that can be found in an "operational" basis for architecture. They indicate the possibility that the control of noise might also enter fully into a theoretical basis, as well as the practical needs of architecture.

Ten years ago, an excellent presentation of this viewpoint was made by James Fitch in his book, "American Building." Fitch said that "the function of American building must be the maintenance of those optimal environmental conditions essential to the health and happiness of the individual and to the peaceful, efficient development of American society."

In defense of our architects, I must point out that until recent years, a simple sound environment was the natural state of man. Our ancestors heard a few sounds and most of them were pleasant: the song of a bird, or the wind in the pines, the cry of a baby. Although some of these sounds might have been dangerous by implication (as warning signals) they were not themselves dangerous to health. All the more ironic, then, that today the man-made sound environment constitutes a real threat to the well being of urban America. For it is modern industrial society that has created new sound to the point where sound levels in many plants and offices are at the threshold of pair, and where most urban areas have an average loudness level that makes protection against it necessary. We have polluted our naturally quiet environment.

Architecture must develop more fully as an "environmental art." One purpose of a building should be to operate as a selective filter and barrier, taking the loads of the natural and man-made environment off man's body. One purpose of a building should be to contribute to a humane environment.

The control of the environment is not the totality of architecture, but it must be part of the basic order of design. The architect must make sound control his own problem.

Sound barriers can become part of the expression of architecture. They can be put around the source of the noise, or around the victim, or both. They can be incorporated in the first thoughts about the nature of spaces. Like the water barriers, the sound barriers can contribute to the richness of expression in architecture. Sound absorbent and reflective materials can be given a life of their own, and traditional materials can be reconsidered in terms of their sound qualities. This could happen, but it hasn't happened, because sound conditioning does not yet have the status of air conditioning in our building program.

It is essential that sound be presented to architects in terms of operations, rather than as soundproof materials. After all, we understand heating and air conditioning in terms of insulation, ducts, cycles, humidity, and so forth. It seems incredible to me that most architects, and most manufacturers' literature, are so inarticulate about the basic operations of sound: transmission and absorption.

It is also essential that sound conditioning be predictable, within reasonable limits of accuracy and economy of effort, while the building is still being planned. I understand that any noise is acceptable as long as it does not annoy the occupants of the building. Can this point of annoyance be predicted ahead of time? The architect can rightfully claim that noise is not the problem; annoyance is the problem.

What would the architect like to know about sound? For example, how can we predict the quality of sound, the "ring" of a space? How can we make a space feel more noble, or more gay, or more intimate, or more climactic, or more private?

What is the difference in sound control techniques between large and small spaces? Can the quality of sound relieve the monotony of corridors? How can the quality of sound contribute to a sequence of spaces, a rythm of spaces?

What does a wall need to be? What does a floor need to be? We understand these questions very well in terms of structure; why not in terms of sounds, impacts, vibrations?

It is ironic that the spatial ideas of our time have dealt so eloquently with structure and light, but so poorly with sound. If the problem of noise control is clearly stated, so that it can be given a high priority among the ideas to be incorporated in design, one can predict that new spatial concepts will arise.

And the other side of the coin, whereas the structure of building has become an expressive element (Nervi, Le Corbusier, etc.), the provisions for sound control have generally remained inexpressive. Hung ceilings and other false work are the most common images that come to mind when one considers sound control. But most false ceilings deny the structure and mechanical services of the building. False ceilings tend to "homogenize" architecture. The future direction of architecture lies elsewhere. How a space is made, and how it is served by light, heat, power, sound: this is the integration of technique we seek in architecture.

But we must remember that technique is a means to an end, not an end in itself. Architecture is a social art and a spatial art: its essential function is to help solve man's problems and to enrich his spirit.

The Builder's Problems

By H. T. Noyes*, Chief Engineer
Turner Construction Company

Initial consideration of the problems of noise control in buildings from the builder's standpoint makes evident the fact that it is practically impossible to separate our problems from those of the architect and occupant.

The architect must balance the numerous factors confronting him, including noise control, in his designs, details and specifications, and the builder follows these designs in the construction work.

The following points and their effect upon the building operation are of particular interest to the builder:

1. Increased cost.
2. Delay in completion of the work.
3. Availability of the desired material.
4. Ease of installation.
5. Permanence of the efficiency of the material.

It is the owner or occupant who must live with the results. Frequently, an unanticipated noise condition shows up as being of very serious importance to the occupant. When this happens the architect and builder are quickly brought into the problem and must make an effort to solve it, sometimes at considerable added expense.

The best time to correct a bad noise problem is to anticipate it during the planning and specification stages of the work, and to plan corrective measures from the beginning. It is very important that the builder and his subcontractors be alert to the problem during the shop drawing and construction periods. Contractors who are conscious of noise problems can do much to reduce unsatisfactory noise conditions.

Inasmuch as the design of a new building is generally a balance between good architectural, structural and mechanical practices and the dollars which the owner is willing to pay, it is very important that the matter of noise be clearly discussed with the owner during the design stages, and that the owner be kept aware of the effect upon sound transmissions of any decisions with respect to economies which he may make or approve. Recent projects changes were made which indicated savings at the time, but which eventually raised the final cost to the owner or tenants because alterations to finished construction were necessary to reduce sound transmission to an acceptable level.

It is recognized that mass is best for reducing the transmission of sound. Recent conversations with architects, engineers and builders indicate that many in the industry do not know the basic principles of sound transmission, and many think that acoustical celings or soft coverings on walls will stop its transmission. Education on this problem is essential.

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*HAYDON T. NOYES is chief engineer with the Turner Construction Co. of this city. He received his B.S. and civil engineering degrees from the City College of New York. His memberships include the American Society of Civil Engineers, the American Concrete Institute, ASTM and the Building Research Institute.

Before the war most partitions in buildings were of masonry which extended from floor to floor, or at least to a substantially plastered ceiling. Most floors were of concrete with a thick fill and finish, and most partitions were of masonry plastered on both sides. These conditions were accepted as the standard, and when the designer and the builder lightened the construction the public usually thought of it as being a poor job because the transmission of sound was noticeably increased.

Today the architect desires clean lines, thinness and light weight in both partitions and floors. The owner desires flexibility in partition arrangement, and the contractor desires some form of dry unit construction. These desires have brought us to designing and building low-mass structures which 25 years ago would have been considered far too light and therefore of poor construction.

The general problem of noise transmission is accentuated, of course, by the increase in the use of machines and telephones in offices and radios, television and hi-fi sets in apartments and hotels. When we consider the mechanical and electrical features of a building, we find many new items have been added since the war. The mechanical and electrical work in a modern air conditioned office building now amounts to about 40% to 45% of the total cost of the building, whereas these items in a prewar non-air conditioned office building ran about 19% to 22%. Much of this increased cost is for machinery and equipment from which noise originates, and for ventilating ducts and similar items which may conduct sound.

Our principal problems of sound transmission are:

1. - The transmission of sound from one room to an adjacent one through or over partitions has become serious in many buildings, usually because appearance, flexibility and economics have dictated the use of partitions having acoustical faults. A plastered masonry partition is far better from the standpoint of direct transmission of sound, but today most partitions, regardless of type, are carried up to and stopped at a suspended acoustical ceiling. Economy has usually dictated this, but also, in some buildings, the air conditioning system is designed to use the space above the hung ceiling as a plenum chamber. In any case, under such conditions a sound originating in one room can readily carry through the acoustical ceiling, and even into an office at some distance, if the sound paths are favorable.

2. - Transmission of sound through floors has always been somewhat of a problem, but today there is a strong tendency to lighten the construction of floors in a manner which reduces mass and, therefore, increases sound transmission. A cellular steel floor construction with a 2-1/2 inch fill and finish and a light-weight plaster or gun-applied fireproofing contains far less mass than the old concrete slab with a four- to five-inch fill and finish. Bar truss type floors are even lighter. Too often the structural designer gives little or no consideration to acoustics when considering the various factors in selecting the structural system to be used. On several tall office buildings we have recommended stone concrete construction for floors of machine rooms as well as the floors immediately above them. These floors also have a substantial fill and finish.

3. - Street and other outside noises are still a problem to the designer. The reduction of masonry and the increased use of glass and metal has greatly reduced the mass of the exterior walls and therefore has eased the path of outside sounds into the building. In many buildings this has not become serious because, with air conditioning, the windows are kept closed, and also because the buildings are being kept farther away from serious street noises through country locations or increased set-back locations. Exterior noise is still a problem, particularly for buildings erected at street intersections, and therefore it needs caredul consideration in the design stages.

4.- Air conditioning and various mechanical and electrical installations have introduced many sources of noise and vibration not formerly present in appreciable magnitude. This problem calls for the close consideration of the designer, the builder and the various subcontractors. Fans, compressors, pumps, high frequency motor generators and similar equipment all need careful design of their foundations and mountings. Sometimes the structure of the building must be changed to give more mass for the deadening of these noises. The walls of fan and machine rooms need particular attention, and frequently special soundproof doors are required, particularly if the fan rooms are near executive offices or other space which demands quietness. In one instance, a telephone switchboard room was located adjacent to a fan room in which a large fan rested on a platform some eight feet above the floor. The noise level was so high that the switchboard operators could not hear the long distance operators and a check indicated that the noise level was about 75 decibels. It was difficult and expensive to correct this condition to bring the sound within acceptable limits.

Frequently, senior executives desire offices on the top floors or in penthouses which are adjacent to or directly under fan and equipment rooms. This is always a troublesome problem unless the design has been well thought through and well executed. An effort should be made to separate such areas; if this is not possible, then great care must be taken in sound isolating them.

5.- Ventilating ducts act as speaking tubes in the transmission of noise from one area to another, and in practically all buildings some effort is made to deaden the sound of fans and other equipment so as to prevent its being transmitted through the duct system. With modern sound isolation this is not too diffucult if plannned in advance. The transmission of conversation from one office to another, or from one toilet room to another, is far more serious as it introduces the need for expensive sound isolators in ducts at numerous locations. We have had to make costly changes to correct this problem which exists also in apartments and hotels.

6. - We have had complaints of noise being conducted from one office to another as far as 100' away through under-floor electric ducts, usually the low tension ducts which have open fittings for telephone or signal wires in each office. These ducts frequently transmit typewriter and similar noises when the openings are located under secretarial desks.

7. - In addition, we have had many instances of special problems, such as the isolation of an elevator machine room which was placed next to a meeting room; and numerous problems in a newspaper printing plant situated adjacent to a railroad freight yard. This required careful design of both the interior portions of the building to isolate printing press noise from the office portions, and also to prevent penetration of the railroad noises.

8. - One problem peculiar to tall buildings is the creaking made by the building frame on very windy days. In several buildings this noise has been of such intensity that the tenants have complained, and in one case, some girls became so frightened that they wanted to leave the building. Investigation attributed the noise to the minor workings of the joints in the frame and determined that they were of no structural significance. The floors and masonry walls tend to carry these sounds some distance from the columns.

We need a means of educating the construction industry in the reduction of sound problems insofar as it is within the builder's province. We would like a means of evaluating the sound transmission properties of walls, floors, partitions, ducts, etc., and a reliable schedule of sound transmission values would be helpful.

The Building User's Problems

By Julius F. Weinhold*, Director of the
Physical Plant, Cornell University

My assignment is to try to present to you some of the problems confronting the building owner and user in matters related to noise control. Since he is the one who has to pay the bills and has to live with the building, be it good or poor, his interest in this subject is most sincere.

Lest I concentrate on those things which have troubled me individually, I asked one group of owners, the universities and colleges in the U. S. and in Canada, what their problems are. They apparently own almost every conceivable type of building: classrooms and laboratories, libraries, auditoriums, dormitories, apartments, hospitals, offices, restaurants, churches, gymnasiums, and almost anything else you could think of. One hundred such institutions presently have over $1 billion worth of new construction either under way or being planned. It would, therefore, seem that this group is representative of owners' and users' problems.

The problems they raised seem to fall into five general classifications.

1) What are the general levels of noise that can be permitted in areas of various occupancies? Obviously there is quite a variation.

2) How can the owner be certain that he, the architect, and the engineer understand what the requirements are and that the design will produce the desired results?

3) How can we be sure that the materials and equipment selected will not only meet economically the requirements of appearance, strength, capacity, and the like but will also have the needed acoustic properties?

4) How can design theory be translated into practice, and the contractor be made to realize the need for the careful workmanship necessary to obtain the degree of noise control for which the structure has been designed?

5) What does the owner do when he finds the noise level above or below that which he had anticipated?

Some illustrations may help you to visualize our problems. When you discuss sound requirements with future occupants of a building, you are usually confronted with a statement that monastic quietness is needed. From a practical and economical viewpoint, this seems almost unachievable and undesirable. Various levels of noise are not only tolerable but necessary. For example, in the auditorium or lecture room it is essential that you can hear the proverbial pin drop. Yet, we can all recall auditoriums in which the ventilating system has to be turned off so that the speaker can be heard. In other instances, outside noises disturb the audience. In areas such as libraries, a certain back-

*JULIUS F. WEINHOLD received his M.E. from Stevens Institute of Technology and is a licensed professional engineer in New York and Connecticut. He is a member of the American Society of Mechanical Engineers, the Society of American Military Engineers, and the Building Research Institute.

ground noise level is desirable. Recently, a dormitory has come to my attention where the noise level was so low that privacy was lacking.

Classrooms need to be so constructed that sounds from other areas do not disturb the students and teacher. In offices, the noise from business machinery, clicking heels and the like, becomes most distressing. Yet obviously, some noises can be tolerated. In living quarters, certain noises can be beneficial, and others become disturbing. Music and dramatic art buildings present other problems.

This, then, becomes one of the first vexing problems the owner faces. What range of noise level can he tell the architect must be maintained for the various occupancies? The owner would welcome a code or specifications defining the allowable noise level in various areas based on actual experience.

How can we get our architects and engineers to realize that noise control is as important to us as, for example, proper floor strength or room lighting? That the owner has not been able to be convincing, or that the architect and engineer have failed to grasp the problem, is illustrated by numerous examples. I know of several auditoriums built very recently where the ventilating system is so noisy, because of duct sizes or equipment location, that it must be shut off when the room is used. Many classrooms have been built where the student can hear the lecturer in the next room or across the hall as clearly as though he were standing before him.

In the psychiatric clinic of a medical school, sounds of an ordinary voice are transmitted from one room through the ceiling and over the top of room partitions into the adjacent room. You can appreciate the difficulties here. In the neurological laboratories in this building, noises coming through the doors and windows are very disturbing to the patient upon whom the work is being performed. Other examples of similar difficulties could be cited. From the reports received, many architects unfortunately do not realize the seriousness of this problem. In one instance where a small music building had to be designed, the owner reports that the architect, upon being requested to hire an acoustical engineer, said, "Why do we need to do that? This is only a small building." Obviously, even in a small building, disturbances from one area to another could render the building useless.

How can we be sure that the materials which we would like to use possess those acoustical qualities which will help us to get the proper degree of noise control? Since there seems to be a very strong trend, for economic reasons, to construct buildings with exposed masonry block partitions, many of our problems are in connection with that type of design.

Aside from work done by the Riverbank Acoustical Laboratory of Armour Institute and the National Concrete Association, there seems to be very little scientific data on absorption and transmission loss of masonry blocks. Recently a consultant, investigating the acoustical characteristics claimed by a large manufacturer of cement blocks for his product, found that this company had made no tests and the figures were arrived at by taking a good look at published data for similar products, and then estimating what might be fair coefficients for its own product. In a publication of the lightweight concrete products industry I found this statement: "Walls of this material absorb sound. The acoustics of large rooms are substantially improved by the reduction of sound reverberation. Privacy is insured by practically eliminating transmission of sound." I am sure that a large number of us would not agree with the accuracy of that statement.

Another baffling problem reported is that of plumbing noises. While noises that occur in ventilating systems are more or less understandable and the practicing engineer has enough data on hand to solve them, this does not seem to be so with plumbing equipment. Major manufacturers of such equipment do not seem to be doing any work on correcting plumbing noises, although one of the larger companies is reported to be starting research on this subject. The flush tank which can be heard from one end of a building to another is quite familiar. The chap taking a shower or filling the bathtub in the adjacent hotel room has disturbed many of us. Since considerable work is being done by manufacturers of some building products to obtain reliable data on the acoustical properties of their products, the suggestion is made that it would be highly desirable for all manufacturers to produce similar, reliable scientific data on acoustical characteristics of their various products.

How can we translate design theory into practice? How can we impress upon the contractor the need for attention to detail? From what I have seen and heard, in many cases our acoustical engineers and architects have assumed that the contractor, with ordinary workmanship, can produce the seemingly impossible economically. We are greatly concerned with air leaks in walls and partitions, around doors, between partitions and ceilings, etc. In many cases we have had difficulties because cracks existed or developed due to careless workmanship. Openings were not filled, partitions were not carried to their required height, doors and windows were carelessly fitted, fans were run at too high a speed, machinery ducts and pipes were not properly supported.

How do we get a design that is practical, allowing for certain human failures in construction, and how do we get that class of workmanship which is so essential to obtain those results envisioned in our design? What does the owner do about those areas where the noise level turns out to be beyond endurance? How does he correct:

The light block which transmits too much noise.

The movable partition which does not exclude sound.

The partition which has not been carried to the roof.

The door or window which offers little resistance to sound transmission.

The ventilating duct which is too small to handle air at low velocities.

The air conditioning equipment placed so that its noise cannot be contained.

The floor covering which reflects the sound of all footsteps.

The apartment in which the neighbor's conversation is no secret.

Disturbances from typewriters, accounting machines, dishwashers, jet planes, street noises, etc.?

The building owner and user have serious problems. We hope that out of this conference will come some solutions and at least a better understanding of our needs.

Noise Control in Buildings
http://www.nap.edu/catalog.php?record_id=21391

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Control of Transmitted Sound over and around Partitions

By B. G. Watters*, Engineer
Bolt, Beranek & Newman, Inc.

The acoustical consultant is in a good position to see trends in building construction. We see the plans for a lot of buildings each year. Often we select wall constructions for new buildings or recommend remedial treatments for buildings where the walls proved to be inadequate. In many of these buildings, things work out very well. For example, we did a suite of psychiatrists' offices for a Boston hospital. These were designed to permit a patient to speak freely, even to become excited and raise his voice, without being overheard by other patients waiting just outside. The offices were completed last year. We found that conversational speech in the examination rooms was undetectable outside, that shouted speech was just barely detectable but not really intelligible.

Some other case histories are not so good. For example, there are some university dormitories in Cambridge and a similar group in Baltimore whose occupants were up in arms. In both cases, the students found that the masonry block partitions did not provide privacy. This was especially noticeable in the evening when some of the students were trying to sleep, others were still studying, some were playing radios, and still others were involved in bull-sessions. In the evening quiet, a conversational voice was clearly understandable through the partition.

I also remember inspecting some new and very beautiful insurance company home offices in Hartford with partitions constructed much like hollow-core doors. The sound isolation is so small that you can almost whisper and be understood next door, even in the presence of the appreciable background noises of a busy office building. And, I could cite many similar cases where partitions failed to provide the acoustic privacy which had been expected of them. We have been called in to try to patch up building after building where the occupants were getting in each other's hair and consequently on the building owner's neck.

To me, the saddest aspect of these buildings is not the high remedial cost. It is the fact that, in nine instances out of ten, the situation will not be remedied. In the Cambridge dormitories, for example, the University decided it would be altogether too expensive to beef up the walls. Instead, they appealed to the students to live with the poor acoustics. I suppose that the students have learned to sleep with cotton in their ears, to listen to their radios with earphones, and to speak kindly of the fellow next door for fear he might be listening. People in other countries have learned to live with even less privacy, with paper walls, in fact, but somehow it seems that we can afford a higher standard than this; in truth, have always had a higher standard. And I feel that American architecture is missing the mark unless it finds a way to satisfy this need for acoustical privacy, along with all of the other needs in today's buildings.

It is worth looking at the reasons these buildings turned out poorly. None of them, as far as I know, was purposely built to have poor acoustical privacy. One of the reasons that we sometimes get poor privacy is that we don't know what to ask for. For example, we frequently see such specifications as, "The walls between private offices should have 40 db transmission loss." Well, sometimes they should, but at other times you may need more, even 50 or 60 db in order to meet an especially tough

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*B. G. WATTERS received his B.S. from Oklahoma State University and his Master of Science from M.I.T. He is an associate member of the Acoustical Society of America, a member of ASTM, and his company is a member of the Building Research Institute.

acoustic situation. In other instances, only 20 db may be perfectly adequate.

Another reason why buildings are built with substandard acoustics is that even when we know what to ask for, we often don't use the right words. The numbers 50 db, 40 db and 20 db usually refer to average transmission loss values. To get an average value, we lump together the wall's performance at the low sound frequencies, the mid frequencies, and the very high frequencies. Richard Waterhouse of the Natl. Bureau of Standards has stated, "The arithmetic average of the decibel Sound Transmission Loss values at the different frequencies is often used, but it is generally agreed to be far from perfect." Dr. Waterhouse is right. The average TL is an inadequate measure of a wall.

A third reason for acoustical privacy complaints is that, even when we know what wall performance we want and know how to describe it, we may not be able to get accurate test data. The basic trouble with laboratory panel tests is that some walls behave differently when installed in a laboratory than when installed in the field. Usually, for walls of this type, the laboratory performance will be superior to the field performance. The difference in performance will depend on how closely the laboratory conditions simulate field conditions. As the laboratory test panel is made smaller than a full-size wall, and as the laboratory edge mounting details are made different from the typical field details, the laboratory results will differ from the field performance.

Although the testing laboratories are aware of these problems, the solutions are yet to be worked out. Until they are, our advice is to be wary of the test values for relatively stiff partitions, especially when the test panel is small. Certainly the results for some of the smaller test panels (3' x 3' or so) will be of interest only if you are building windows or trap doors.

While the previous factors are important, probably the most important reason that today's buildings have more privacy problems is that the architect and builder are asking more and more from partitions. An 8" solid brick wall is no longer accepted for a between-office partition. What is desired is a panel light enough to be moved by one man, and stiff enough to make a good diving board. Now, I must admist that these are not unreasonable desires and that science is working to develop the materials to fulfill these desires. However, it is probable that science will put a man on the moon before that day comes.

I would like to spend some time discussing why low weight and high stiffness tend to be antagonistic to high transmission loss, at least at the present time, but before we can sensibly compare one wall construction with another, we must have a convenient, accurate rating system for their performance. Our problem is complicated by the different kinds of sound which we want to isolate. There are music, typewriter noise, speech, bathroom use noises, and many more. Unfortunately, a wall which is a star performer at stopping typewriter noise may provide almost no speech privacy, for example. We really should have a different rating system for each kind of sound we want to isolate.

One of the most important of these sounds is speech, and this is the problem of which we have the most understanding. In a recent program for a building product manufacturer, we studied the various factors which appear to be important in achieving good speech privacy. A number of things, such as the size and shape of the rooms, the usage of the rooms, etc., were found to be important. However, the key factor is the intelligibility of the transmitted speech. A person will generally tolerate weak sounds which he can recognize as speech, mixed in with the other noises in his office or hotel room. But when the speech rises enough above the background noise so that the occupant can understand the words, then he will probably complain.

Now, what we want to know about a wall is whether or not the occupants of the rooms on either side of it will be satisfied with the privacy it provides. And since some people will never be satisfied, we are really asking for the probability or "odds" on satisfaction. Therefore, we will use the calculated probability of satisfaction, based on the above mentioned study, as our rating scale for wall performance. Please understand that what we will present is intended only as a relative rating system, to compare one wall against another without considering whether or not either wall is suitable for a given situation. The over-all problem of picking the least expensive wall which will give satisfaction is a bit more complicated.

Our rating system simply gives the odds that an occupant will be satisfied with the privacy. Using this rating system, we can now look at the factors that influence the acoustical performance of walls. It deals only with single, relatively solid walls, primarily because we understand these better, but also because single walls are quite important. By using single walls, we rule out all of the double, resilient clip, and staggered stud constructions. By relatively solid walls, we mean those which vibrate essentially all together. Most stud walls are not relatively solid. However, most hollow masonry block walls are.

Two physical properties of walls are most important in determining the transmission loss, one is the mass or weight of the wall, the other is the stiffness of the wall material. Weight is important because an impervious wall transmits sound energy by vibrating in response to the sound pressure. When the sound is a loud one, you can actually feel the wall move with your fingertips. The function of the weight is to act as an inertia against this motion. When we double the weight of a massive wall, the motion is cut in half and the radiated sound is only about half as loud.

As to the stiffness of the wall, when the wall vibrates, it must also bend, and in bending behaves as a spring. Intuitively, one might guess that a high stiffness makes the wall harder to bend and improves the transmission loss. This is true at the very low sound frequencies. However, at the intermediate sound frequencies, the stiffness reaction tends to cancel out the reaction of the weight of the wall, and a serious reduction of the transmission loss occurs. In most cases, high stiffness is detrimental to high sound isolation. What we desire is a heavy, relatively limp wall.

I have had clients ask me at this particular point in the explanation, "What do you mean by 'limp wall' -- like a dishrag?" Fortunately, the answer is, "No, not quite like a dishrag." While a dishrag wall would provide more measurable transmission loss, most of it would not be very usable, especially by human beings. (This may not be true for dogs, cats or bats who have, I am told, hi-fi hearing.) The fact is that for any particular weight of wall, there is a corresponding value of stiffness which will permit the full potential of speech privacy to be realized. Any lesser value of stiffness will not improve acoustical privacy in the typical situation. Any value of stiffness which is greater than this critical value will reduce the effectiveness of the wall.

In order to give you something more useful than broad generalities, we must assign some numbers to the quantities of stiffness and weight. Weight is conveniently measured in lbs. per sq. ft. Bending stiffness can be measured in exactly the same way that a structural engineer would measure it in order to calculate the deflection of the wall due to a static load.

Figure 1 shows the coordinate system which we will use. The bottom of the chart is marked off in lbs. per sq. ft., the surface weight of the wall. The vertical scale measures the bending stiffness of the wall. This is the product of Young's modulus and the moment of inertia. We will use psi as the unit for the modulus and in.^{4} per inch width of the wall as the unit of measurement for the moment of inertia. As you may recall, the moment of inertia of a solid bar is given by $I = \frac{bh^3}{12}$ where b is the width of the bar and h is its thickness. Also, typical values of Young's modulus are shown in Table I

Upon looking more closely at the coordinates of this graph, one is struck by the tremendous range in the stiffness of materials used for partitions. While there is only about a 100 to 1 range in the surface weights which are normally encountered, there is more than 1 million to 1 range in the stiffnesses. I think it is safe to infer that either the most limp of these materials is much too limp or that the stiffest of them is altogether too stiff, from an architectural point of view. Certainly, all of this range of

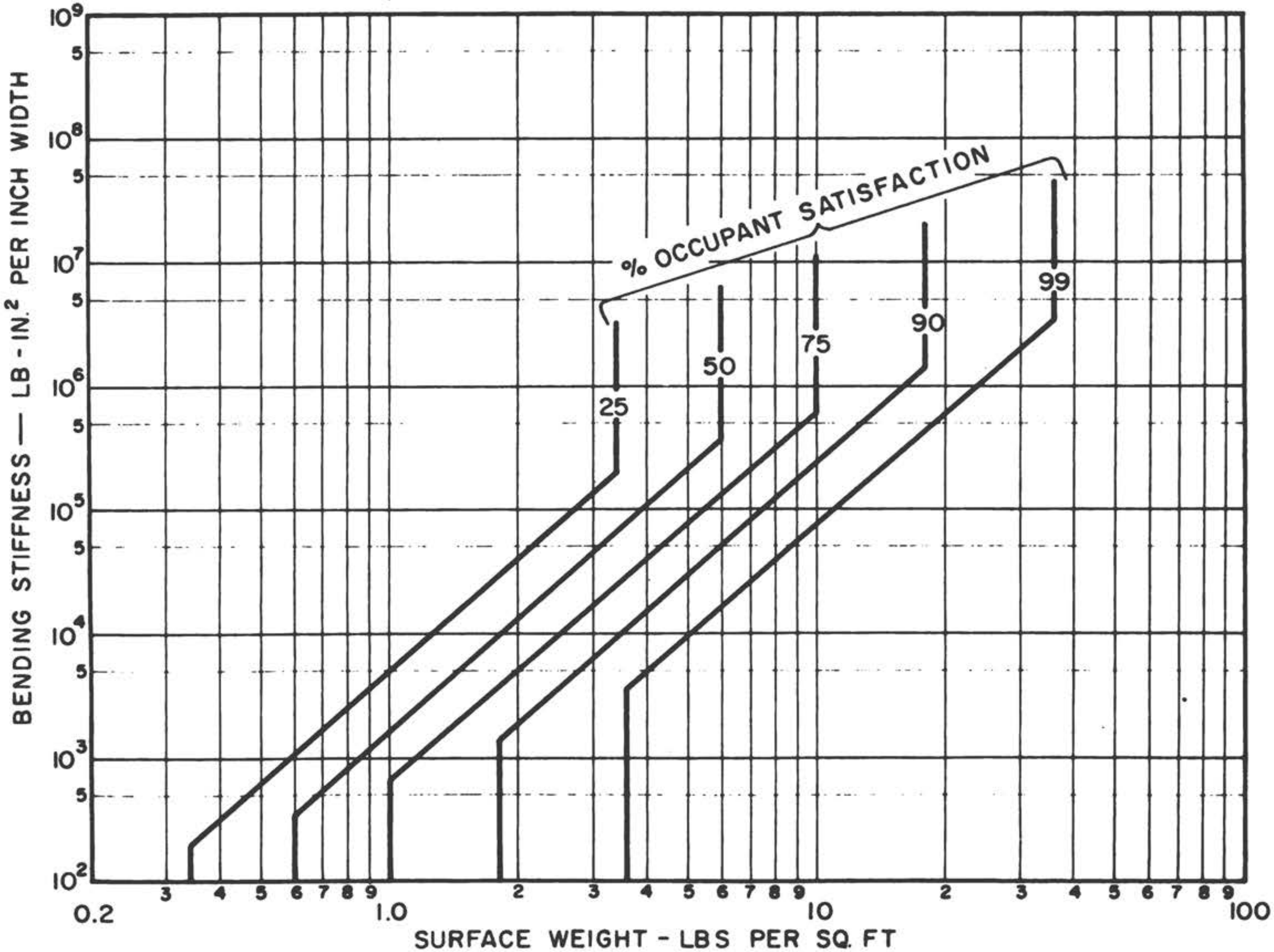

Fig. 1 - Approximate degree of speech privacy for walls with the indicated surface weight and bending stiffness, for one, typical, between-office situation.

Table I

Material	E
Steel	$3 \cdot 10^7$ psi
Aluminum	10^7
Glass	10^7
Dense concrete	$4 \cdot 10^6$
Cinder aggregate concrete	$1.5 \cdot 10^6$
Fir plywood	$7 \cdot 10^5$

stiffness cannot be justified.

Before plotting any data on this chart, I should emphasize that these are primarily theoretical results and that we are neglecting some the minor aspects of the theory. However, we have had fairly good agreement between this theory and our measurements of field installations. I believe that while the following discussion may be inexact in detail, it does lead to some useful, general truths.

The figure also shows some contours of constant privacy. The fourth contour, for example, means that for our particular speech privacy situation, 90% of the occupants of the two rooms will be satisfied with a very limp wall weighing 1-3/4 lbs. per sq. ft. or with a very stiff wall of about 18 lbs. In-between values of stiffness must be compensated for by some intermediate value of weight. In fact, we see that, once we are above this critical value of stiffness, each 10-fold increase in stiffness must be counter-balanced with a doubling of weight if the degree of privacy is to remain constant. Or, from another point of view, we can take a limp, 3-1/2 lb. partition that would satisfy 99 out of every 100 office occupants, and by making it about 100 times as stiff, have a partition which would satisfy only one out of every four occupants. This is what I had in mind when I said that high stiffness is detrimental to high sound isolation.

When you combine our degree-of-speech-privacy criterion with this chart, it tends to divide the chart into three ranges. First, that area of the chart in its lower, right hand corner describes the heavy, limp materials. These materials give very good speech isolation. Second, there is a diagonal strip of the chart extending from lower left to upper right which describes both the light-but-limp and heavy-but-stiff materials. These materials tend to be roughly equivalent in their ability to provide speech privacy and are less effective than the first group. Finally, the upper left hand region of the chart describes the light-and-stiff materials. This combination is practically useless.

Most if us have a pretty good feel for the significance of the weight of a partition. We know that a hollow-core, wood-faced panel may weight 3/4 lb. per sq. ft.; many movable partitions weigh about 4 or 5 lbs.; a 4-inch hollow cinder block will weigh about 25 lbs. and 8 inches of brick will weigh about 90 or 100 lbs. By constant, the ordinate, lb-in^2, probably doesn't have "seat-of-the-pants" significance at all. To bring the stiffness scale into focus, let us look at Fig. 2 where the stiffnesses of a number of solid, homogeneous materials have been plotted. The numbers along the curves give the thickness of the material. For example, a 1/2-inch sheet of glass will weight about 6 or 7 lbs. per sq. ft., will have a bending stiffness of about 10^5 lb-in^2 per inch of width, and would satisfy between 75 and 90% of the occupants of the particular rooms which we have assumed.

Steel has both a higher modulus and a higher density than glass so that a 1/2-inch plate will be three times as stiff and will weigh 20 lbs. per sq. ft. The steel wall would satisfy almost every occupant. A 1/2-inch sheet of fir plywood would be 1/10 as stiff as the glass, would weigh only 1-1/2 lbs. per sq. ft., and would satisfy only between 25 and 50% of the occupants. Lead is seen to be the most

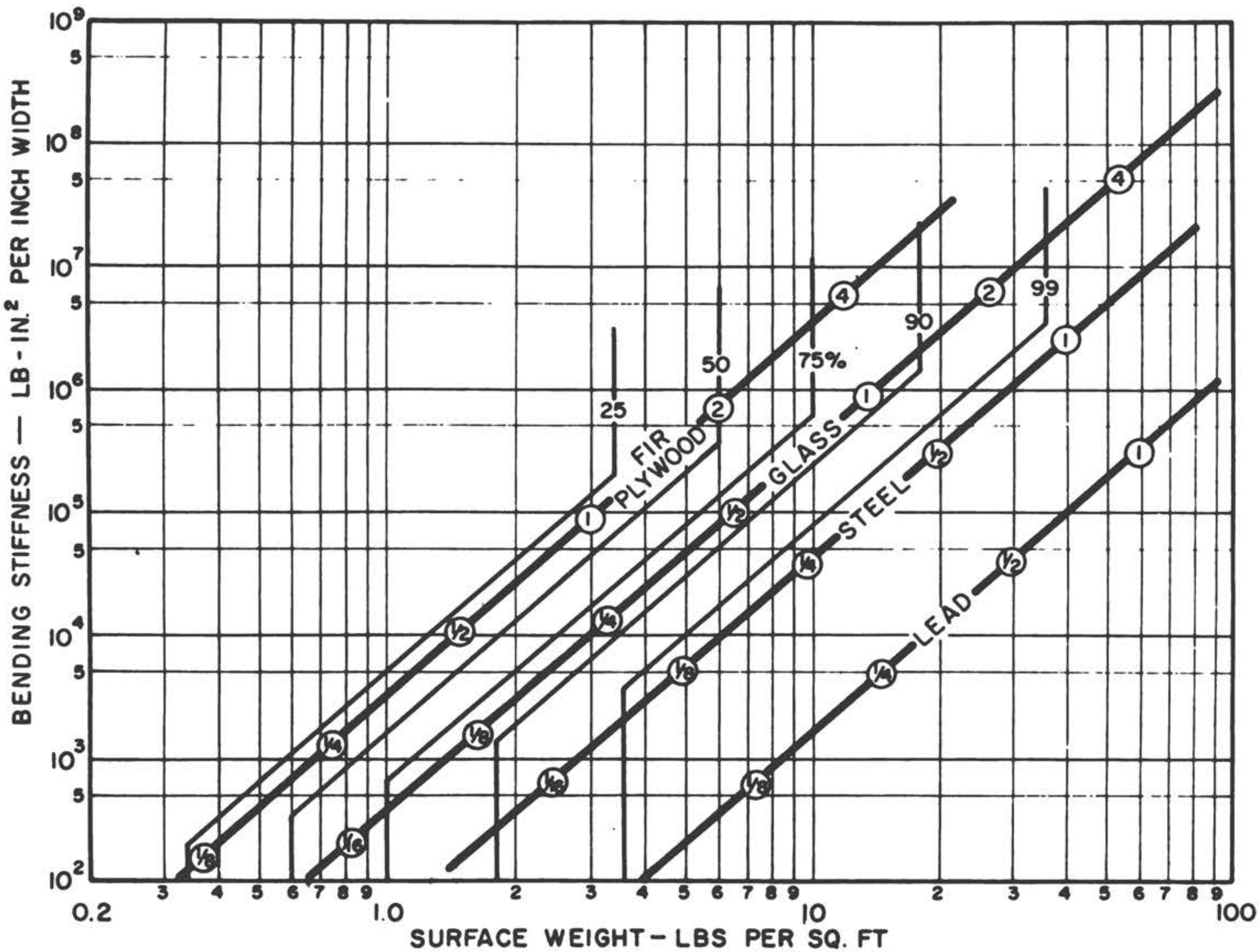

Fig. 2 - Approximate values of stiffness and weight for various thicknesses of solid panels. The circled numbers give the thickness in inches.

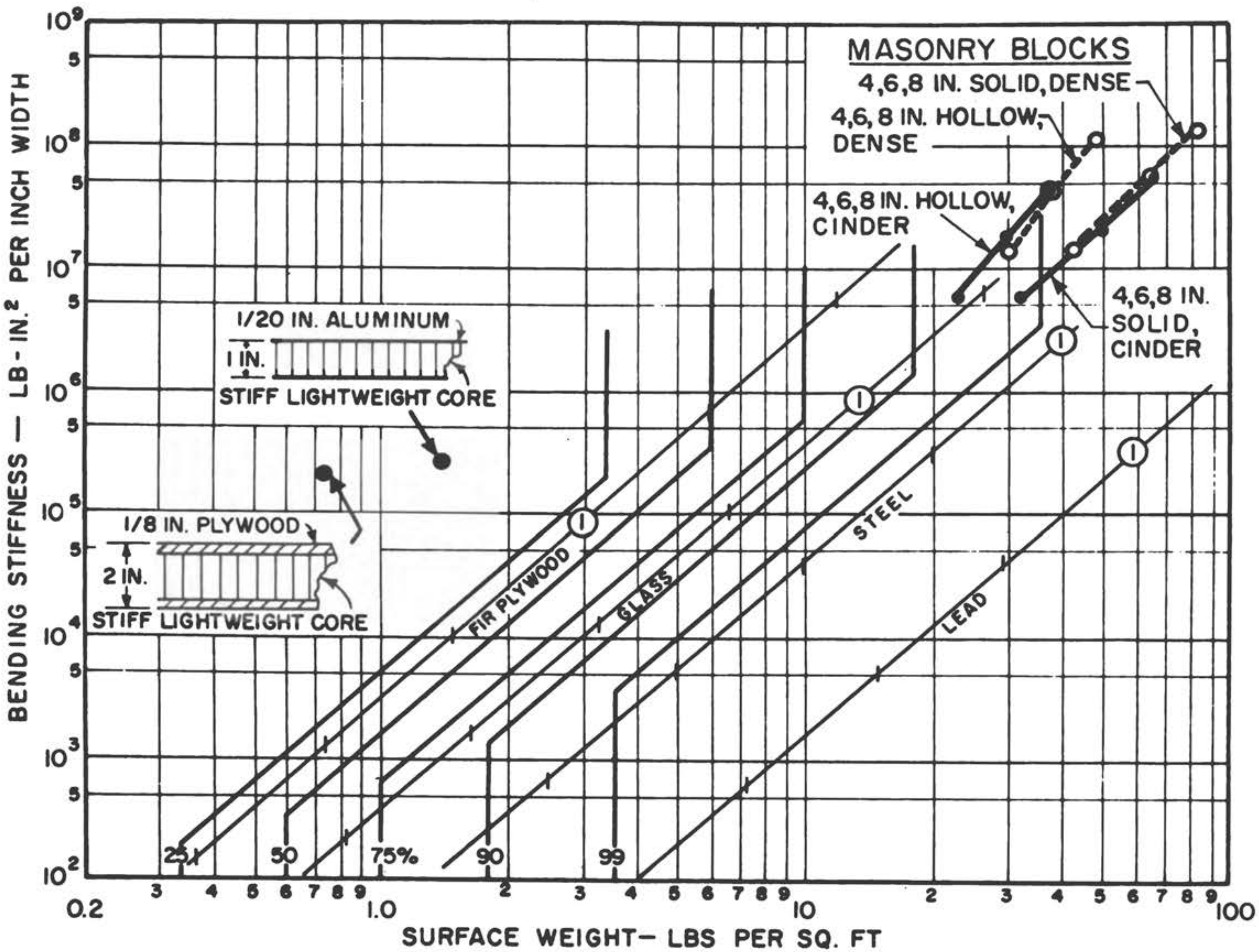

Fig. 3 - Approximate values of stiffness and weight for two lightweight-core panels and some masonry blocks.

efficient of all of these materials because of its high density and low modulus.

The curve for glass is especially significant since many materials have about this same modulus and density. Aluminum is almost identical in these respects; sand plaster is fairly similar. The curve for the dense aggregate concrete lies between glass and steel, and the curve for cinder and other light weight aggregates lies just a little above glass.

Fig. 3 shows what happens when we purposely increase the stiffness by using a honeycomb or similar light-weight core. The point to the left is for a wood-faced honeycomb panel, similar to a hollow-core door. The second point is for an aluminum faced panel 1 inch thick. Up in the extrene right hand corner of the chart are points for some of the hollow masonry blocks. Now, the two sandwich panels are obviously poor sound barriers. They have neither the weight nor the limpness required to impede sound. The hollow masonry walls, on the other hand, are more suitable. Their effectiveness, however, is in spite of their very great stiffness and comes at the expense of high weight.

I should mention that the speech isolation problem which we have been considering and which sets the position of the privacy contours on the chart is of "moderate" difficulty. There are, of course, some easier-to-solve situations when even the hollow-core panels will suffice. There are also many tougher problems which will require something better than even the heavy masonry walls.

One of the most interesting implications of these charts is the way the constant speech privacy contours tend to run parallel to the weight-stiffness curves. This amounts to saying that the privacy provided by a thin wall having critical stiffness is just as good as for the same material, ten times as thick. This is hard to believe. In order to convince ourselves that this is really so, we made another tape recording where we simulated four different glass walls, each having twice the thickness of the preceding one. The lightest is about 1/8 inch thick; the others are 1/4. 1/2 and 1 inch thick. All of these should provide between 75 and 90% satisfaction for our particular situation.

Bear in mind that these walls were simulated and that we assumed that all of them were reasonably large. Small pieces of the thicker walls, for example, observation ports in a test cell wall, will no doubt have a different performance. We have calculated the average TL's for these four walls. They increase continuously from the lightest to the thickest with a total increase of 9 decibels.

As to the problem of leaks in walls, even the best wall, say a solid inch of lead, won't do much of a job if it is bypassed by the usual shrinkage cracks, openings behind connector covers, back-to-back electrical outlets, etc. If past experience is any guide, the odds are about two to one that the next wall you build will be seriously compromised by one or more of these air leakages.

I see this problem as a very serious one, but one which has a very simple solution if only you will accept it. Before a new steam line is put into service, it is first pumped full of air and checked for leaks. The solution to the sound leak problem is very similar. Before a new room is put into service, pump it full of noise and check it for leaks. Placy a noisy vacuum cleaner in one room and go next door and listen. You will find your leaks in 1/10 the time it would take you to locate them with your eyes. If you want to look professional while hunting, get a doctor's stethoscope and probe along the edges of the wall and at other likely spots.

A wall should be carefully detailed to limit the number of serious air leaks, but even the most careful detailing will not get them all. And you should certainly look for these paths, because you can see some of them. However, a workman hunting for sound leaks without a noise source, such as a vacuum cleaner, is like a blind painter.

Sound Transmission through Suspended Ceilings and over Part-High Partitions

By Richard N. Hamme*, President
Geiger & Hamme Laboratories

The generalproblem of acoustical isolation between adjacent rooms and its relation to the sound transmission loss of partition constructions has been a familiar one for many years. Also, the acoustical treatment of ceilings for noise and reverberation control and its relation to the sound absorption coefficients of ceiling materials has long been a well-developed technology. However, with the relatively recent advent of curtain-wall partitions used in conjunction with suspended acoustical ceilings, these technologies began to intertwine so that acoustical materials manufacturers became faced with the need for sound-transmission information about suspended-ceiling configurations in addition to the sound absorption coefficients already being furnished.

Recognizing the need to establish a more extensive acoustical-ceiling technology based on a rational analysis of the general suspended-ceiling problem, the Acoustical Materials Association began two years ago to devote a substantial fraction of its research funds to the exploratory laboratory study of the specific problem of sound transmission through suspended acoustical ceilings over part-height partitions. Their research subcommittee laid out a careful and exhaustive program for a deliberate step-by-step wise development of facilities and the evolution of a method of test.

It has now become common architectural practice to erect suspended acoustical ceilings over large expanses of new construction and then subdivide the floor area by partitions that extend upward only to the suspended-ceiling height rather than to the full height of the structural ceiling or roofdeck.

This type of construction has numerous advantages for illumination, ventilation, piping, future mobility, etc., but it poses a problem of acoustical privacy that is becoming of increasing importance as well as a source of considerable confusion in evolving specifications for materials.

Cross-talk and noise interference between adjacent rooms is often attributed to sound propagation through the suspended-ceiling plenum, a diagnosis which occurs quite naturally to anyone who is familiar with the basic properties of sound-absorbing materials.

Almost all acoustical materials have been designed to function as sound absorbers by virtue of an open structure which permits the easy penetration of incident sound. Hence, without additional precaution, one cannot expect a layer of sound-absorbing material to function as a sound barrier over the entire range of frequencies encountered in architectural practice.

On the other hand, noise interference between adjacent rooms can ordinarily arise only by the successive penetration of two separate layers of sound-absorbing material, the ceilings of the source and receiving rooms, respectively; whereas noise need only penetrate a single layer of partition material. Hence, considerably more is involved in the comparison of the ceiling- and wall-transmission

*RICHARD N. HAMME earned his degree in physics at the University of Michigan, where he was formerly Supervisor of the Acoustics Laboratory of the Engineering Research Institute. He is a member of Acoustical Society of America, the ASTM Committee on Acoustical Materials, and the Committee on Sound Control of the American Society of Heating, Refrigerating and Air Conditioning Engineers.

paths than a simple comparison of the sound transmission loss of the materials of the partition and the ceiling.

Indeed, the situation is sufficiently complicated to require a step-by-step formulation of the problem, as well as a direct method of measurement of sound transmission through ceiling configurations as they are erected in practice.

It is the purpose of this discussion to offer preliminary insight into the quantitative variation of ceiling-transmission characteristics as they depend on some of the more obvious parameters of practical construction, such as the general class of ceiling material, the depth of ceiling plenum, the laterial extent of the ceiling, etc.

This information is drawn from the exploratory experimental program being conducted at the Geiger & Hamme Laboratories under the auspices of the Acoustical Materials Association, with the objective of developing a test method for evaluation of the transmission characteristics of suspended acoustical ceiling configurations.

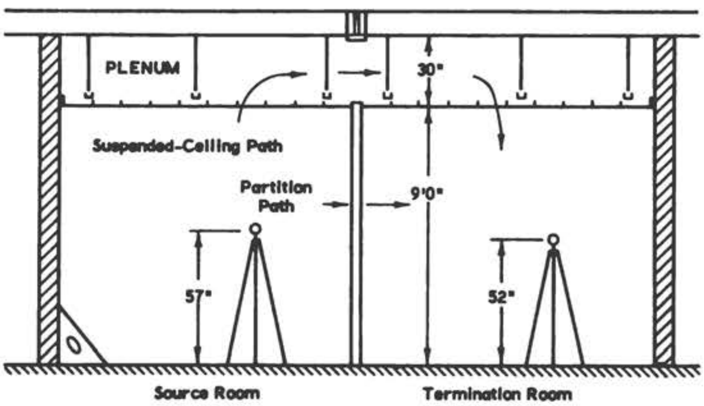

Figure 1

Schematic Section Through Two-Room Suspended-Ceiling Facility

Formulation of the Problem

A schematic sketch in Fig. 1 will serve both for formulation of the measurement problem and for description of the laboratory measurement facility. This sketch represents a vertical section through two adjacent rooms which may be assumed to communicate acoustically along only two of many possible paths; viz., by sound transmission from the source room through the part-high partition into the termination room (partition path) andby sound transmission through the suspended ceiling of the source room into the plenum, along the plenum over the part-high partition and through the suspended ceiling of the termination room (suspended-ceiling path).

A quantitative prediction of the diffuse sound pressure level produced in the termination room by a given diffuse level in the source room is easy if transmission is confined to the path through the partition. The sound-pressure attenuation (i.e., the decibel difference between diffuse source-room and termination-room levels) is given by the sound transmission loss of the partition adjusted by the logarithm of the ratio between the partition area and the termination-room absorption.

In other words, the mechanisms of attenuation, no matter how complex they may be in themselves, can be lumped along this path in terms of laboratory test data on specific materials: the random-incidence sound-absorption coefficients of the termination-room surfaces, including the ceiling, and the random-incidence sound transmission loss of the partition. However, the attenuation mechanisms along the ceiling path flanking the partition cannot be lumped so easily; quite separate mechanisms are easy to distinguish.

Focusing attention first on the source room, let us dispense summarily with one noise-reduction mechanism, simply by dint of interpretation. The diffuse sound pressure level that will develop in the source room due to the presence of a sound source of fixed power output will depend on the total absorption of the source room. Hence, the ultimate noise level in the termination room will in turn depend not only on the attenuation encountered during transmission from the source room to the termination room but also on the source-room absorption.

One must decide interpretively from the outset whether this initial degradation of noise energy should appropriately be included in the specification of the noise-reduction performance of the structure under investigation. In the comparison of partitions this factor is ordinarily neglected, but, of course, it is not ordinarily the function of a partition to provide appreciable absorption in the presence of an acoustical ceiling.

In the case of comparison of suspended ceilings which are designed to contribute absorption, the question of source-room absorption is not so easy to decide without appeal to related criteria: for example, how the source, if it be a human being, will respond in speech power output in the presence of increased absorption. However, for purposes of this discussion any noise-reduction, dependent on source-room absorption will be arbitrarily disregarded by making further reference only to the production of arbitrary source-room sound levels and subsequent attenuations. This will lead to the most conservative interpretation of the noise-reduction performance of suspended ceiling configurations.

Even after the assignment of an arbitrary source-room sound pressure level, there are several steps yet remaining in cataloging the performance along the suspended-ceiling sound transmission path represented in Fig. 1. First, there is sound transmission through the suspended ceiling of the source room which must depend on the sound transmission loss of the ceiling configuration, including transmission through both the material of the ceiling and the leaks in the configuration, and which also must depend to some extent on the absorption present in the plenum if one thinks in terms of the development of diffuse sound pressure levels in the plenum.

Second, there is the attenuation associated with the propagation of sound through the plenum opening above the partition which acts as a lined duct. This must depend on the absorption of the concealed surface of the suspended ceiling and the plenum dimensions, as well as the distance of lateral propagation over the ceiling surface.

For example, the details of ceiling construction might in one case lead to serious leaks at the joint along the partition so that leaks are immediately adjacent, whereas in another case ceiling transmission might be distributed uniformly or even localized at points remote from the partition and thereby require a long plenum propagation path before impinging on the termination-room ceiling.

Finally, there is transmission through the termination-room ceiling for which the attenuation must depend again on the ceiling transmission loss but also now on the total termination-room absorption. We have reason to suspect, then, that attenuation along the suspended-ceiling transmission path must depend in a complicated manner on the transmission loss of the ceiling configuration, the plenum dimensions and back-absorption of the ceiling material, and the room-absorption of the suspended-ceiling configuration in the termination room. In turn, the sound transmission loss ot the ceiling configuration will depend both on the sound transmission loss of the ceiling materials and on the distribution of leaks inherent in its practical suspension.

No attempt will be made here to analyze these separate contributions to the total attenuation any further conceptually, and, in particular, no effort will be made to remove the dependence of ceiling-transmission performance on the termination-room absorption contributed by the ceiling. In any fair evaluation of sound-absorptive ceilings, no quantity directly analogous to the sound transmission loss of a partition can be defined at this point independent of the field condition of application, but rather the sound-pressure attenuation of a specific and realistic suspended ceiling and room configuration will be referred to as the attenuation factor of the ceiling configuration. It is analogous to the noise-reduction factor for a specific partition and room configuration. Indeed, recent experience with the suspended-ceiling facility has cast considerable doubt on the usefulness of the sound-transmission-loss concept as applied currently in the comparison of partition configurations. This is due to the general overemphasis that is placed on the materials of a partition in comparison to the details of peripheral leakage that appears to be inherent in the field construction of partitions of the dry-material type.

Experimental Procedure

The laboratory room and ceiling configuration used for the measurement of suspended ceiling attenuation factors can be visualized by reference again to Fig. 1. A large soundproofed chamber was subdivided by a heavy partition of an adjustable type so as to obtain two identical rooms in which suspended ceilings could be constructed with a communicating plenum of adjustable depth. Each chamber measures 15'4" in the direction of the partition and 10'6" in depth so that peripheral framing could be used to accommodate suspended-ceiling areas measuring 10 x 14' with highly reproducible and adjustable edge details.

The structural ceiling is 11'6" high, and adjustment is provided for changing plenum depth from 12 to 30". Considerable care was devoted to blocking all flanking paths between the two rooms, and the partition was selected to provide attenuations greater than those expected of the ceiling configurations. Incidentally, however, the attainment of a respectable margin of safety against partition-transmitted sound has not been found to be an easy matter over the entire frequency range of interest, due primarily to the need for adjustability of a large partition of the dry-construction type.

Apparatus was assembled and microphone-survey procedures were adopted which permit measurement of attenuations over the frequency range from 125 to 4000 cps with sufficient reproducibility to justify comparisons within the data to plus-or-minus one decibel in determinations at any given frequency. Although a large number of ceiling materials and configurations have been investigated, this discussion will be limited to comparisons of two experimental acoustical materials in one particular suspension system, with the assurance that the performance described is in no way singular nor do either of the materials represent practical extremes of performance despite the fact that they differ widely.

The suspension system under discussion is of the exposed T&T grid type consisting of an interlocking lattice of formed steel T-sections of a 12" x 24" modulus. The sound-absorbing materials are cut undersize in order to provide clearance for the interlocks so that the ceiling material is gravity-held against the flanges of the T-sections with approximately 3/16" overlap. The two acoustical materials, designated here only as A and B, differ appreciably both in flow resistance and density, but each is within the range of common use for suspended-ceiling configurations in practice. Their performance is referred to that of 1/2" thick gypsum board, cut into similar 12" x 24" elements.

Dependence on Ceiling Characteristics

Fig. 2 shows the frequency spectra of the attenuation factors of full suspended ceilings of three types at a plenum depth of 30". The wide range of attenuations is immediately impressive, from 10 db to more than 40 db; as well as the profound frequency dependence with spectral slopes approaching 10 db per octave. It is immediately obvious that no realistic specification of ceiling performance can be made on the basis of a single number such as the average attenuation over a frequency range.

It is also clear that something beyond the air flow resistance and density of the materials must influence the attenuations because the heavy and impervious gypsum boards are dominated by the performance of material B at all frequencies above 500 cps. One factor, accounting for part of this apparent discrepancy, is the absence of high-frequency absorption in the termination room in the case of a full

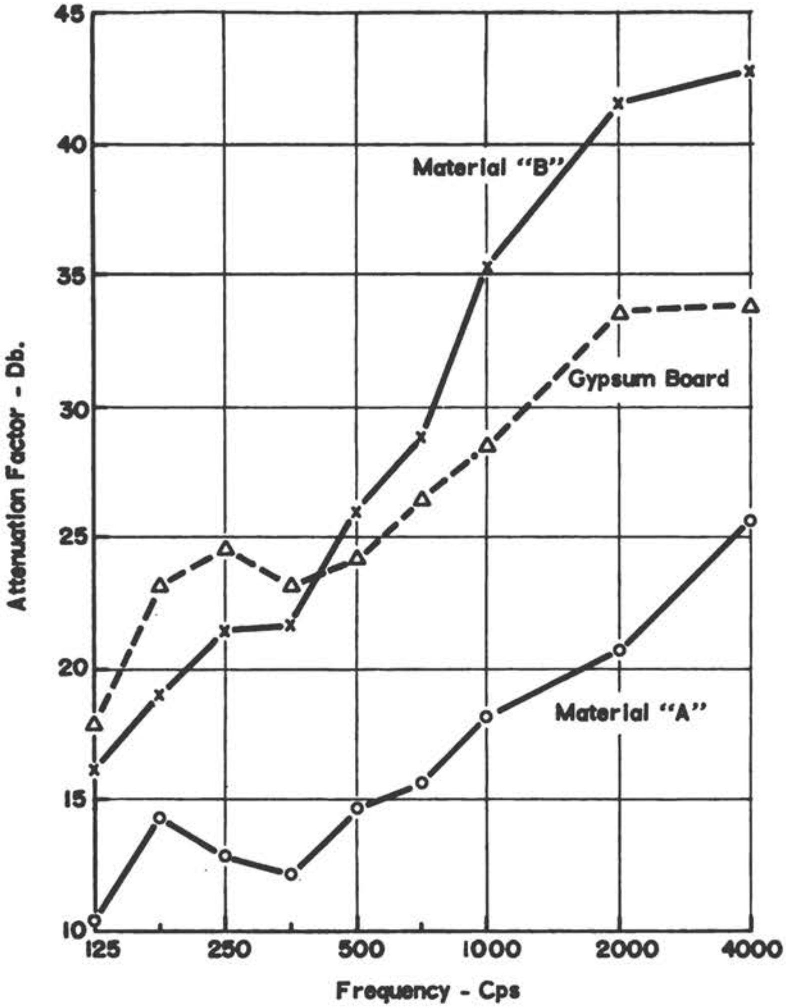

Fig. 2 - Attenuation Spectra for Entire Suspended Ceilings - 30" Plenum

gypsum-board ceiling. The random-incidence sound-absorption coefficients for the three suspended ceilings are shown in Fig. 3 for tests performed on the #7 mounting (10" airspace) by the reverberation-room method. Evidently, both materials A and B have a pronounced absorptive advantage over gypsum board in the high frequency range.

However, more important than the absorptive difference, the performance of gypsum board is being limited by leakage between the edges of the boards and the flanges of the T-sections in the suspension system.

This is demonstrated in Fig. 4 where the transmission-loss properties of simulated sections of the suspended ceilings are plotted as the random-incidence attenuation measured by a reverberation-room method. (Transmission loss is obtained from Fig. 4 by subtracting "open" attenuations from those measured for ceiling specimens.)

Notice that the transmission loss of the gypsum-board ceiling specimen is markedly increased by caulking each board in place in the grid system, thereby precluding leakage. In the uncaulked condition, material B shows higher transmission loss than gypsum board, presumably due to the high-frequency absorption that occurs at the peripheral edges of the boards where leakage would otherwise occur between hard surfaces.

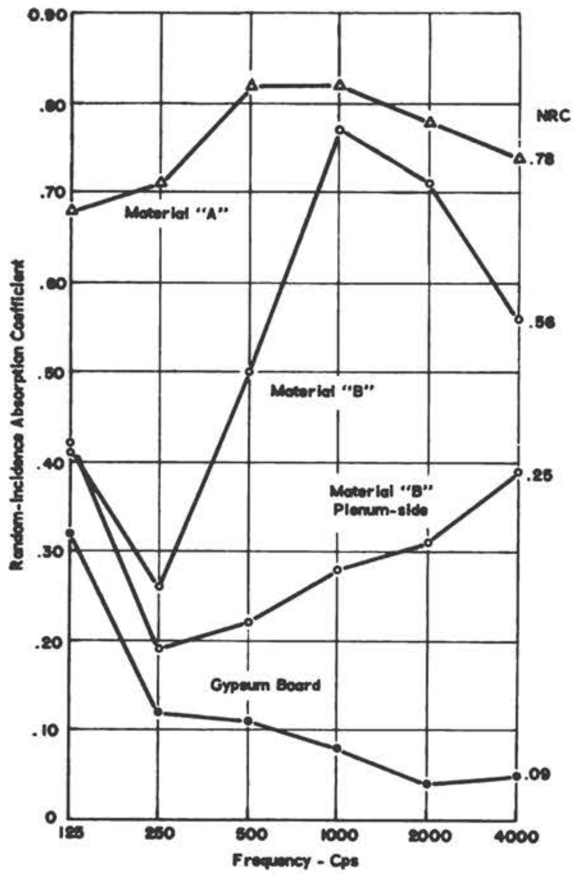

Fig. 3 - Reverberation-Room Absorption Coefficients, Simulated Suspended Ceilings, #7 Mounting - 10" Airspace

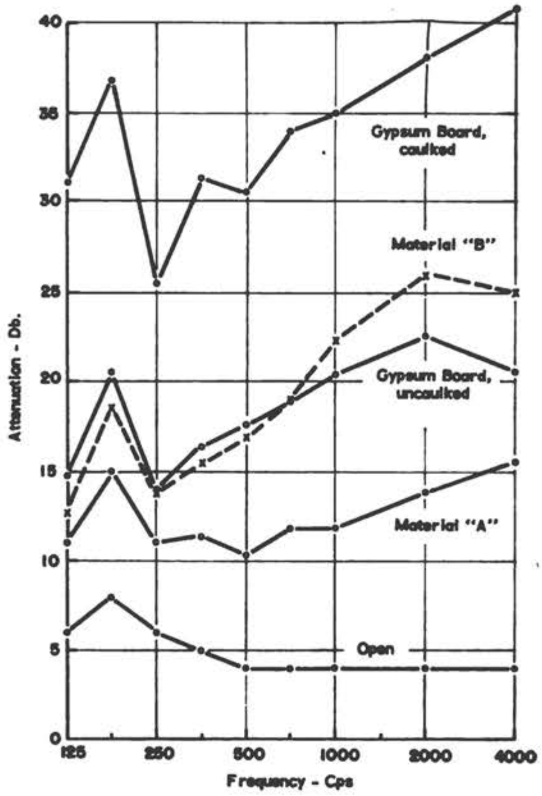

Fig. 4 - Reverberation-Room Transmission Spectra, Simulated Ceilings in Eastern System.

Dependence on Plenum Characteristics

The foregoing comparisons already demonstrate an important fact concerning suspended-ceiling sound transmission; viz., that the performance of a ceiling may depend crucially on the details of the method of suspension as well as the selection of the materials. But furthermore, since the absorption of the plenum surface of material A was measured to exceed substantially that of material B, it is also clear that increased plenum absorption is not in itself always adequate to overcome ceiling transmission due to a material's lower transmission loss. In the case of material A, this can be understood in terms of the great importance of transmission through those units of tile that lie immediately adjacent to the partition so that sound is propagated along no great distance in the plenum.

This effect is displayed in Fig. 5 where the average attenuation of progressively wider ceilings is plotted for two different plenum depths. The abscissa on this graph is the width of a strip of material A running parallel to the partition with the balance of the ceiling made up of gypsum boards. At the left hand side of the graph where the ceiling consists entirely of gypsum boards, the average attenuation is relatively high, but the attenuation drops off abruptly when a single row of material A is installed along the partitions on each side.

After the first few feet of extension, the reduction in average attenuation due to replacing gypsum board by material A gradually diminishes, but it will be noticed immediately that the continued effect becomes dependent on the depth of the plenum so that a full ceiling of material A transmits appreciably more when the plenum is deeper. It would appear that the transmission of those portions

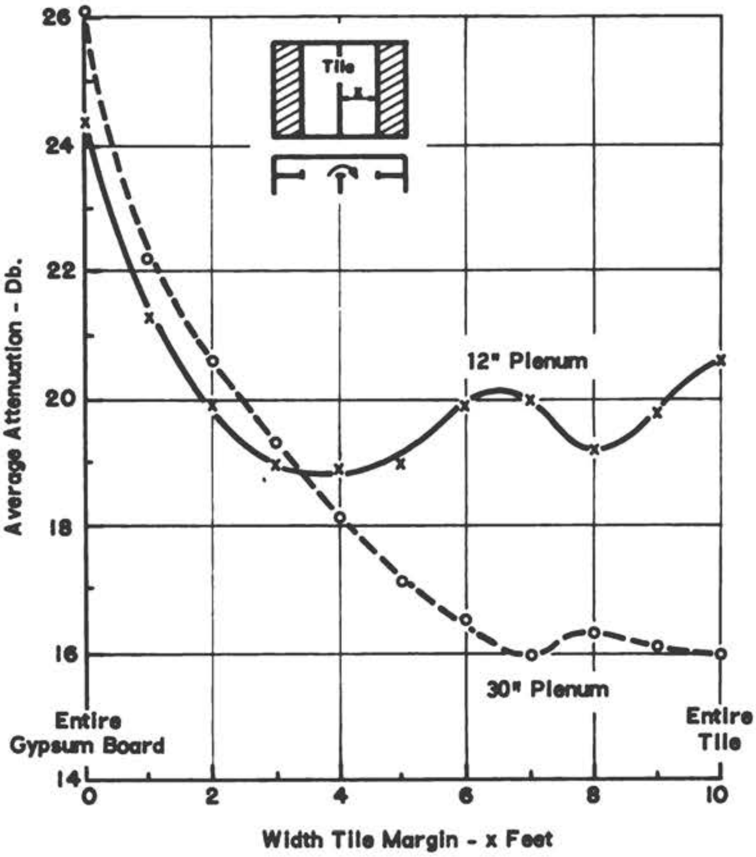

Fig. 5 - Average Attenuation vs. Margin Width, Material "A" Tile.

of the ceiling that are remote from the partition is better sealed off by progressive attenuation during sound propagation along a shallower "duct," as might be expected.

The greater relative importance of transmission through material A in the strips of material located immediately adjacent to the partition suggests rather deceptively the possibility of improving attenuation of certain ceiling configurations by replacing the margin along the partition with a relatively impervious material. However, the frequency dependence of such an effect must first be examined as shown in Fig. 6, when attenuation spectra are plotted as material A is successively replaced by a margin of gypsum boards.

In the absence of absorption on the plenum side of the sypsum board, only the low-frequency attenuations are appreciable improved by blocking the margin with gypsum board, whereas sound in the middle-frequency range appears to be propagated to remote portions of the remaining tile ceiling without appreciable loss so that attenuations are not improved greatly until nearly the entire ceiling has been replaced. These data were obtained at a 30" plenum depth.

It must be emphasized that the plenum-depth dependence demonstrated for material A is not characteristic of all suspended-ceiling configurations. This is demonstrated in Fig. 7. Here the attenuation spectra for full ceilings of materials A and B are compared for two different plenum depths with their respective transmission losses (in the same terms as Fig. 4). The pronounced difference between the two plenum depths for ceilings of material A is not reflected for material B. Sufficient data are not yet available to determine whether or not the differences in plenum absorption are sufficient to account for this difference in plenum-depth behavior, but the preliminary indications seem to make this

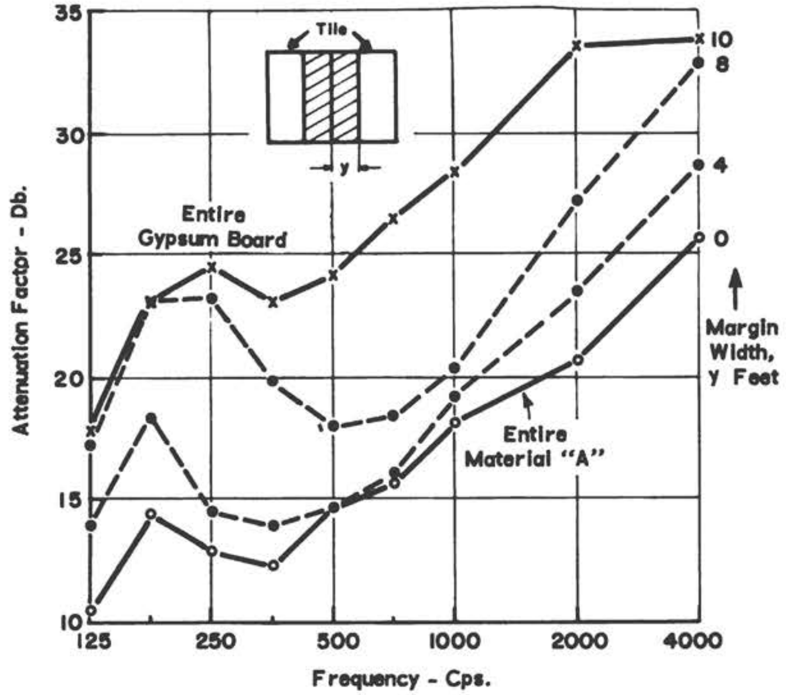

Fig. 6 - Attenuation Spectra, Material "A" vs. Gypsum Board Margin, 30" Plenum

unlikely. In any case, the data of Fig. 7 make one important point very clear: the prediction of suspended ceiling performance cannot be accomplished with any accuracy by rule-of-thumb extrapolation from sound transmission loss measurements performed on simulated ceiling specimens. At least one other significant variable appears to influence suspended-ceiling attenuation factors, and this is related to the plenum depth.

Future Study and Present Conclusions

Extension of the exploratory work reported here is currently in progress under continuing support of the Acoustical Materials Association. This involves collection of similar data on a wider variety of suspended ceiling configurations and closer investigation of plenum-depth dependence. Certain obvious limitations of the present measurement method are also under scrutiny. Among these are the effects of finite lateral extent of the plenum as currently limited by reflective walls at the soundproofing

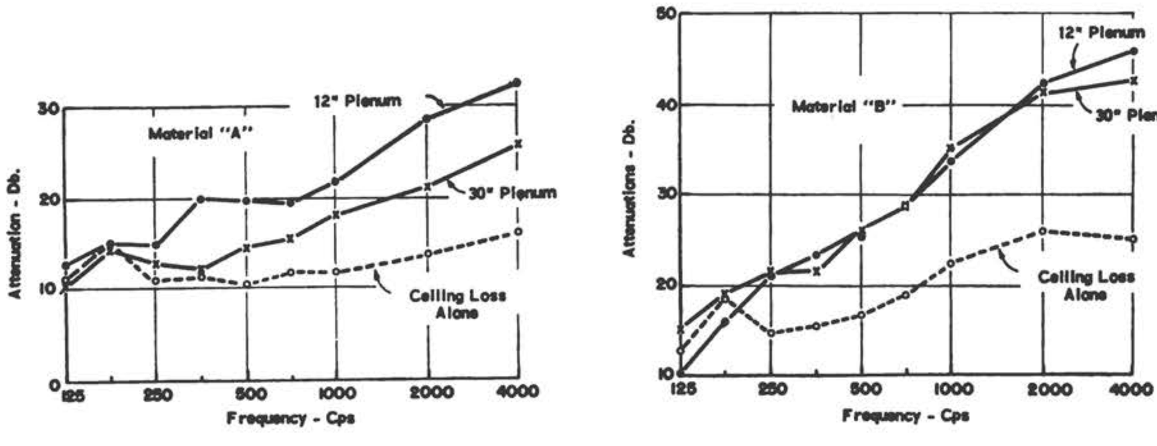

Fig. 7 - Two-Room Attenuation Spectra Compared to Transmission Loss

periphery of the facility, as well as the effects of incomplete diffusion in the chambers which is known to influence reproducibility of very low frequency measurements. In parallel with these investigations, work will be initiated with regard to practical methods for increasing the attenuation factors of suspended-ceiling configurations now commonly in use.

Clearly, present data do not yet provide an answer to the general problem of suspended-ceiling sound transmission, both because of imponderable factors remaining under investigation in the method of measurement and because of arbitrary assumptions and restrictions made in specifying the attenuation factor. However, present data do document certain definite conclusions:

(1) The attenuation of ceiling-transmitted sound depends on the interaction resultant between sound transmission, sound absorption, and plenum-duct propagation losses as each are influenced by both the ceiling material and the suspension system, and that no single one of these factors dominates all others in determining the attenuation of ceiling-transmitted sound in all conditions of practice.

(2) The attenuation of ceiling-transmitted sound cannot be deduced directly from sound-transmission-loss and sound-absorption-coefficient determinations, nor can ceiling attenuation factors be compared directly with partition sound-transmission-loss measurements, without due regard for acoustical leakage between individual elements of both the ceiling and the partition configurations.

(3) The attenuation of ceiling-transmitted sound depends as crucially on the characteristics of the ceiling plenum as it does on the characteristics of the ceiling construction itself, both dimensions and sound-absorptivity influencing the results in conjunction with the spatial distribution of acoustical leakage in the ceiling suspension system.

The Importance of Detail

By W. A. Jack*, Chief, Acoustical Section
Johns-Manville Research Center

The science of acoustics rests on a firm foundation of well-understood physical facts, bolstered by adequate mathematical theory. For many acoustical problems we have enough information on the behavior of building materials to predict the final result with accuracy, provided the actual construction is made in strict accordance with the test constructions which yielded the original data. Actual constructions often depart from the ideal because of compromises necessary on an actual job or because of insufficient attention to the importance of detail. To deal with the first reason, a designer experienced in noise control problems can often make suggestions at the planning stage which will give good over-all noise control and at the same time obtain all the other performances desired from the building. To deal with the second reason, adequate supervision is needed in all details of the construction which influence noise control.

With reference to details, we have inadequate experimental documentation at this time, but we do have considerable practical experience. It is known, for example, that part-height partitions, such as occur when a movable partition is built up to an acoustical ceiling common to two rooms, provide less noise control than when the partition is run up to the slab. It is known that a partition having sufficient mass to provide good noise control can be inadequate due to openings left by necessity, or inadvertently. Testing techniques are being established which will eventually give us documentation on these important points.

The question is often asked, just what is the result of leaving a narrow gap between the top of the wall and the ceiling? Suppose that the measured difference between two offices separated by this wall, joined to the ceiling in a leak-free manner, is 40 db, a result is obtained by averaging the readings at three microphone positions at head level in the source room and in the receiving room. Now consider the construction when there is a gap. That portion of the sound energy passing from one office to the other by way of the gap is reduced very little. If the gap is small, the amount of energy is small. However, if one stood on a ladder and listened closely at the gap, conversation in the other office could be easily understood. For gaps of the order of 1/32" the amount of energy transferred and distributed throughout the receiving room might easily be as much as the energy going through the wall itself. These two amounts combined would give a difference of 37 db, or a performance of 3 db worse than the leak-free wall.

A 40 db difference, or even a 37 difference, may be satisfactory for many kinds of occupancy, but if the problem is privacy of conversation the higher figure is better. If the problem is security, where eavesdropping must be guarded against, the 40 db and 37 db numbers do not describe the applicable situation at all and a specification so drawn would be misleading and even disastrous.

One might draw a comparison between acoustical leakage and a short circuit in residence wiring. All weak spots must be corrected in order to get satisfactory results. With two approximately equal acoustical sources it is necessary to reduce both by 40 db, say, if a 40 db reduction is to be obtained.

*WILLIAM A JACK is Chief of the Acoustical Engineering Section of Johns-Manville Research Center. He received his B. S. in Chemical Engineering from the University of Pennsylvania, is a Fellow and past vice president of the Acoustical Society of America, and a member of the Building Research Institute.

Controlling one source entirely would give only a 3 db reduction, if the other source were not reduced. In a residence, to carry our example further, design considerations dictate the selection of a 60 ampere entrance, or a 100 ampere entrance. If all goes well, adequate service is furnished. However, if there is a short circuit, the design distinction becomes purely academic. A somewhat analogous situation exists with walls which have a potentially good reduction factor but are misused with an acoustical short circuit. In order to obtain the potentially high performance available, all short circuits must be eliminated.

With his "black box" Mr. Newman demonstrated many of the factors which must be considered in sound control by partitions and walls, even though it was designed primarily to show the effects of vibration isolation, sound absorption and enclosure. The low frequency rumble was audible when the enclosure with its interior sound absorption was employed properly, there being no airborne leakage, but the source rested directly on the table top. Under these conditions an important path existed from the source via the table top, demonstrating in a particularly convincing way how all paths must be controlled. Similarly in buildings there may be walls of sufficient mass and properly leak-proof in detail, giving a construction to bar adequately even loud airborne sounds. However, if an appreciable portion of the acoustical energy gets into the structure, it may pass around by flanking paths and appear as airborne sound in otherwise quiet parts of the building. Mechanical transmission can be a problem and it must not be allowed to short circuit the effective barriers which the consultants and manufacturers have put into the building.

We advised on a vexing problem in an expensive apartment building. A well-known singer in the apartment above the complainant kept time in his singing practice by tapping his foot. The construction was heavy enough to bar the singing, which was the artistic part of the situation, but was not of a nature to bar the sound of the foot taps, which understandably annoyed the complainant. This kind of problem may call for an expensive solution, e.g., a separate hung ceiling in the complainant's apartment. The straightforward way of controlling the disturbance at the source (having the singer take off his shoe) while having a certain appeal to the acoustical engineer, was judged not to be the proper solution under the circumstances.

It is perhaps advisable to give a further example, pointing out the adverse effect of sound leakage. Suppose that a motor on vibration isolators is enclosed in a 1' x 1' x 1' box, the box being joined tightly to the floor, with no opening at all. Suppose that this procedure reduces the noise level in the room 20 decibels, a worthwhile reduction. If such an enclosure were raised only 3/4" off the floor, which is a 5% opening in terms of the surface area of the box, the noise reduction in the room would be only 12 decibels. This is a serious price, acoustically, to pay for the opening. Furthermore, even if the enclosure had a 100 decibel reduction potential, with this 5% opening the overall effect would be a mere 13 decibels. In general, openings must be provided for services and for cooling air. The remedy lies in constructing suitable sound attenuation paths for the inescapable openings. Good results can be obtained by the cooperation of all parties, with a sympatheric understanding of the physical nature of the problem.

Several papers in the Conference mention the prevalent architectural procedure of designing "open spaces." Sound is just going to travel across an open space, once it reaches it. We must reduce the level of the incident sound, or live with it. Years ago I was asked if we had a device that could be placed in a tree outside of a home, that would draw the sound energy into the device, rather than have the street traffic noise enter the house at all the windows. We smile at this, it being our only response, because nothing constructive along these lines has been developed. The problem is real, however.

Many times important acoustical details of construction are forgotten or overlooked because they are out of sight. A part-high partition, such as a bank screen, looked to all what it is - part height to sight, affording visual privacy or at least serving as a modified enclosure. It is also part height to sound but is not very effective, a result expected by its appearance. However, there are disguised part-high partitions that surprise the occupants. One may find for example a perforated metal ceiling common to two offices with a partition erected to the ceiling. In running down the noise complaint it may turn out that half the sound absorbing pads (in checkerboard fashion) have been left out of the metal pans in an economy move. It is true the cost is less and the sound absorption is usually passable. It is also true that the sound reduction between offices is exceedingly poor. What looks to the eye to be a full height partition is far from that to a sound wave.

Another point in the "out of sight--out of mind" situation is our forgetting how close things are in a building. It may seem some distance when one walks from an office to the adjacent office, through two doors and a corridor, but it is a very short trip to the sound wave that may be traveling through a radiator enclosure common to both offices. It is certainly a long distance down a corridor to the other end of a connecting suite 100 ft. away, but acoustically, to the sound that has a direct path through a common untreated ventilating duct, it is as close as across the room. It is a major trip from the basement machinery area, past fire doors and by elevator to the executive offices at the building corner having the best view, but acoustically, for vibration in the piping from an incompletely isolated compressor, it is an easy path by which to cause annoyance.

I like Mr. Watters' suggestion that we test rooms for sound leakage, similarly to the way piping is tested, before it is too late to take corrective measures inexpensively. If the use of the stethoscope permits the seeking out of sources, this is a step in the right direction. If it is understood just where the mistake is that causes the leakage, the solution is usually obvious within the limitations of design and cost.

A particularly obnoxious problem is caused by toilet noise in residences. At a time when silence is desirable we have a plumbing source that generates substantial noise, various paths that permit the sound energy to escape from the room, and a background of low noise level in which the noise intrudes. This problem will have to be met by most of the methods of the acoustical engineer, starting with location-planning by the architect. Meticulous attention to all the details, is called for, including controlling the path into the structure via the piping. A typical leakage path often exists between the apartment of one family and another via bathroom cabinets mounted back-to-back. Switch receptacles inserted into otherwise good walls can be important leakage paths. These examples demonstrate that sounds get around rather nimbly and seek out suitable paths with ease.

In connection with details of sound measurement mentioned by previous speakers, it is common acoustical practice to measure the difference between two offices by setting up a noise source in one and measuring the levels in each office. I wish to emphasize that the level at a point in the source office is both frequency-dependent and location-dependent. A similar situation exists in the receiving office. When one encounters a figure stating that the reduction between two offices is 40 decibels, the investigator should have included location averaging and an averaging of the reduction over the frequency range. There are reasons for the use of a single figure, but it should be kept in mind that frequency dependence for a given construction can cover a range of 20 db at 125 cycles per second to 55 db at 4,000 cycles per second. Location dependence for a pure tone source can be as much as 15 db from point to point and as much as 8 db even with a warble tone. Acoustical measurements have their place and, properly used, are valuable. Improperly used, they lead to arguments and confusion.

Reference has also been made to the mass law. This refers to the general fact that the average transmission loss over the frequency range is about 23 db for a panel weighing 1 lb. per sq. ft. and increases about 4.5 db for each doubling of the weight. Practical walls do not obey the mass law exactly, but near enough for the detail I wish to bring out. When a non-leaking masonry block wall of substantial weight having, say, a transmission loss of 45 db is plastered on one side, the transmission loss will increase to about 49 db. The plaster itself is heavy enough so that if it is used as a separate wall, as is done in broadcasting studio construction in which the channels of the plaster wall are carried by felt or other isolators, a substantial improvement, possibly to 60 db, is obtained. These constructions are not suitable for residences and office buildings. It would be advantageous to the industry, however, to have available details on using materials within weight and cost limitations that would take full advantage of present knowledge about isolated constructions.

Panel Discussion

Moderator - Preston Smith, Editor
Noise Control Magazine

Panel Members - Ralph Huntley, Supervisor
Riverbank Acoustical Laboratories
Armour Research Foundation

Lewis S. Goodfriend
Richard N. Hamme
William A. Jack
Robert B. Newman
B. G. Watters

H. T. Noyes, Turner Construction Co.: How effective in stopping transmission of sound through a ceiling space is the placing of a layer of gypsum board on top of the suspension system of an acoustical ceiling?

Mr. Hamme: There are at least three separate considerations to take into account here, namely, the absorption source and the termination rooms, the transmission loss in the ceiling configuration and the plenum absorption. When one puts gypsum board on the back of an acoustical material, it influences the absorption in both the source and the termination rooms by reducing the low frequency absorption in each of these spaces. So this is a step in the wrong direction. When you put gypsum board on the back of the acoustical material, you eliminate the absorption of the back side of the acoustical material and therefore reduce the attenuation in the lined duct. That's another step in the wrong direction. In increasing the sound transmission loss in the configuration, it is presumed that the gypsum board would be cut into pieces the same size as the acoustical material. If you fail to seal the leaks with the gypsum board, this is a step in no direction at all. The only thing that seems to have been accomplished is that you have increased the effect of the weight of the acoustical material and therefore have increased the sound transmission loss of the acoustical material. Thus the answer is that it depends on whether the leak initially was due to transmission loss being too low in the acoustical material, which is highly unlikely.

Mr. Jack: We had experience in using a testing room similar to that described by Mr. Hamme, that had a substantial barrier such as sheet metal or gypsum board laid on top of perforated metal ceiling. A substantial barrier over these inherently leaking ceilings is to be looked on as a definite possibility in curing this problem. We are just getting into the quantitative phase of this, and it is high time.

Mr. Hamme: I agree. I did not mean to imply that backing would be fruitless. The question dealt with a case where the sound was leaking through the configuration by sound transmission through the material. In a case like this it would be of great help to beef up the material. One could construct a rather tight, massive layer behind the system and thereby seal the leaks also, and this should be quite fruitful.

Robert Lippin, Rogers & Butler, Architects: Will the introduction of sound absorbing material in a room penetrated by sound transmission be economically feasible to reduce noise level, assuming the expense involved in adding mass to enclosure walls not desirable?

Mr. Newman: I gather that the question means can you do much toward reducing sound transmission by adding sound absorbing materials to rooms. The answer is yes, you can do something, but not very much. If you take an extreme case of a room that is highly reverberant, say a room that is all finished in concrete, and then treat it very heavily with sound absorbing materials, using a constant energy noise source, you'll find that the maximum realistic reduction in average sound level in the space is somewhere around 15 decibels. If we have a problem requiring 50 decibels isolation, and we only have 20 to start with, obviously we can't solve the problem by using sound absorbing treatment. Sound controlling treatments must be regarded largely as controllers of the environment in the room and not as primary noise control factors.

Unsigned question: If a room is sound tested and transmission leaks are found, what is the recommended method of plugging the leaks and how critical is the method used in plugging these leaks?

Mr. Hamme: The recommended procedure depends a great deal on what you'll tolerate. If the partition is still supposed to be movable afterward, I don't suppose I'd better say caulking, although it is very effective. Generally, a leak that is already in place could have been better avoided by having used in the first place a very compliant gasket of a rubber-like material, but with non-communicating pores.

Mr. Goodfriend: The typical leaks in structures between offices or apartments very often come from plumbing fixtures, radiators, lighting conduits or back-to-back outlets. These can be found readily with a noise-testing source and just your ear. You can use some kind of caulking compound for the cracks in a semi-permanent type of masonry construction or plaster wall. In the escutcheon around a pipe as it passes through the wall or floor to the ceiling you can put a material that will hold a poured sealer in place, such as felt or fiber glass, but they don't do the work. You need to put something in there that will really seal. Many master compounds can be forced in and will make a real seal between the pipe and the masonry. Or, if it is a high temperature problem, you can use asbestos cement to make a seal. Electric conduits can be sealed with a variety of compounds, and the switch boxes can be sealed in the same way.

H. F. Kleinhans, Pawling Rubber Corp.: What benefit is derived from suspending the components of a partition in resilient materials?

Mr. Huntley: It depends on a great many factors. A partition, like a door, suspended in a rubber mounting will at certain frequencies transmit much more sound than if it is fastened into the door frame solidly, because it is free to vibrate by itself and so re-radiate the sound on the other side. When it is solidly connected to its frame, it has to shake the whole frame and the surrounding wall structure in order to vibrate appreciably. Therefore, it depends on frequency to a very large extent.

Unsigned question: What is wrong with very stiff low mass panels for transmission loss? There are data available which shows transmission loss values of up to 40 db at low frequencies (50-500 cycles per second) for .035 gauge steel with compound curves.

Mr. Watters: Is this corrugated metal or bent pans? Is it the floor deck kind of thing you have in mind?

From the floor: Bent pans.

Mr. Watters: Where did the data come from? We've had so much experience with things that were stiff and light and have had data supplied to us that didn't seem believable. And, sure enough, when you get out in the field you find something altogether different. Are you sure that in a real life installation you get this sort of isolation? I doubt it.

From the floor: That particular pan was essentially of section hemispheres, little domes.

Mr. Watters: It would be hard to estimate what that would do. That's about 1-1/2 lb. per square foot construction and, if it were flat at 400 cycles, it should only give you about 25 db. When you build a full size wall as you would normally build one, an ordinary block wall, you get the sort of isolation that I talked about. I didn't give the numbers, but they don't mean too much until you reduce them to subjective reactions. However, you get numbers that are reasonably low, and sometimes test data for the same construction are unreasonably high.

T. C. Walshe, Hofstra College: Given a construction of 2 x 4" studs with 1/4" sheet rock on both sides and on one side 1/2" perforated acoustical tile, is there any difference in transmission through the wall in either direction?

Mr. Jack: There is an apparent transmission loss in two directions, because of the complexities of the technique, and physics has not been circumvented, we have merely failed to master this aspect.

Mr. Smith: You might observe some difference in the noise reduction in two directions because of the presence of absorption in the room, on one side. The transmission loss figure might not be any different, but because of the absorption on one side, the sound that got through would not build up as much in that room.

Mr. Huntley: At Riverbank, we've measured panels, especially to get an experimental answer to this question. They had an absorptive material on one side and hard steel on the other. We get the same answer within the limits of our accuracy, and that is, one or two db difference in both directions.

Mr. Newman: We've got to be extremely careful when talking about transmission loss and about noise reduction between the spaces. The noise reduction is a function of the absorptive properties of the sending and receiving rooms. The transmission loss is a function only of the construction of the partition and how it is installed. It is a kind of unique property of the partition in a particular installation situation. What we are interested in is noise reduction, not transmission loss.

William Lukacs, YMCA Nat'l. Office: In plenums above partitions can effective decibel reduction be obtained by use of materials with high "friction drag" or absorbency, set in staggered labyrinths above the ceiling?

Mr. Hamme: I should think so. When sound is going along a speaking tube and encounters some absorption, whether it is in blanket form on any of the two surfaces available, or whether it is hanging up, doesn't make too much difference. There is a bit of advantage to be gained however from the material, if it be absorbtive, lying on the back of the ceiling, as against being pasted on the structural roof or hanging, in that the sound is being forced to go through it too. Then there arises the possibility of using materials which would have a light diaphragm imbedded in them, which might also tend to seal off leaks. However, any form of absorption introduced into the plenum, would certainly make for improved attenuation factors. I might qualify that only to the extent that if there is already a great deal of absorption in the plenum you run into a point of diminishing returns.

Unsigned question: Is it practical to obtain a quiet spot by picking up a particularly objectional noise at its origin and delivering it out of phase, by means of a loud speaker, to the point where quiet is needed?

Mr. Goodfriend: This for some years was considered a Rube Goldberg trick, until Dr. Harry Olson of RCA laboratories at Princeton proved that it could be done for certain classes of noise. You can't do it with an entire room, but you can take an individual and build a little hood for him, provided you don't have to generate extremely high noise levels. It works at medium, and fairly high noise levels, but these are generally more than you would consider, architecturally. The technique applies to an individual spot, it also applies to noise-cancelling earphones. You slip the earphones on and a little microphone outside picks the sound up, reverses the phase in the amplifier and plays it back under the earphones, thereby cancelling the undesired sound. However, I don't think architects want to supply earphones to all their clients.

Douglas Halstead, Republic Aviation Corp.: What can be done to prevent transmission of noise through second floor of wood floor and wood girders and masonry walls to first floor of an old office building? The source of sound is footsteps, scraping furniture, typewriters, etc.

Mr. Newman: This is the problem of the transmission of impact sound. Any construction, whether it be old or new wood, old or new concrete, which is exposed to direct impact sounds from people walking or from typewriters resting on tables resting directly on the floor, is going to transmit a great deal of that sound to the space below. The solution lies in the introduction of some kind of resilience, whether it be the bare foot or the installation of carpet or pads under the typewriters, or the installation of a floating floor on top of the existing floor. This can be done with glass fiber blankets and floated wood floors or floated concrete floors, but in some fashion a resilient layer has to be introduced to reduce the sharpness of the impact sound.

Mr. Jack: Flanking transmission is also very important. In an old building, it is very likely that when you thump the floor you set the structure into vibration. The impact will also travel out and set the walls into vibration. If you do as Mr. Newman suggested, you will find that you have controlled the floor-ceiling noise, but your clients feels that you haven't solved the problem, he can still hear it because it is now coming down the side walls. Multiple pads at multiple sources plague us at many points. In acoustics if you have two equal sources and you wish to reduce the total noise resulting by 20 decibels, you have to knock off 20 decibels from each source. If you take all 20 db off from one source, you will only have taken the total down 3.

E. X. Tuttle, Jr., Giffels & Rossetti: Please re-define "bending stiffness." This quality is apparently independent of panel area, true?

Mr. Watters: Bending stiffness is a quality of material. It's the thing you solve for in a bean which is a product of its Young's modulus times its moment of inertia. It is one basis property of the material and its cross-sectional geometry, and it is consequently independent of the size of the panel.

From the floor (E. X. Tuttle, Jr.): The moment of inertia of a rectangle is $\frac{BDQ}{12}$ equals the area times the square of the depth.

Mr. Watters: Well, I said per unit area of the width of the wall, and this is the thing that has us confused. Yes, you'd use an inch width.

Unsigned question: Exactly how were your curves of percent occupant satisfaction obtained? Are they theoretical or practical? Are there any valid data to back up your statements?

Mr. Watters: The answer is yes and no. We rig an experiment and go out and ask people of this degree of privacy is satisfactory. Or conversely, we tell them we are going to change the degree of privacy and ask them to tell us when they are no longer satisfied. So, you find out what people consider speech privacy to be. Then you interpret your results in terms of what you have found out about intelligibility of speech. Tying these together, we are able to cast our results in the same form as a vast body of experimental data by psychologists, hearing people, and a lot of war time data on the intelligibility of speech. This gives us a powerful tool for analysing what should happen in any particular situation. In relating this back to our experiment, we can find out whether 10%, 50% or 90% of the poeple consider this to be private or not private. These are two of the steps. The third step is to add to this the theoretical performance of walls. A lot of this is foreign work and is being belatedly published in this country, but for single solid walls, we have pretty good theories of how walls of different properties should behave. The fourth thing, the background noise, diffuser noise, traffic noise or whatever else you may have, that forms a cushion of background, can be predicted quite closely for a particular situation. These steps I mention are called a scheme. Part of them are theoretical, part are practical and, when we get a complaint, we compare it with our scheme and see how it fits.

Mr. Smith: Dr. Ted Schultz of Douglas Aircraft, Santa Monica, California, wants to describe for us some of the results of tests currently being conducted which show that somewhat better performance can be obtained with lightweight honeycomb construction, so that it need not be discarded completely on an acoustical basis.

Dr. Schultz: Representatives of Douglas Aircraft are attending this meeting, not because we manufacture building materials, but because we do make a core material, a form of honeycomb structure. We hope other manufacturers will use this material to make acoustical panels which incorporate some of the suggestions I want to make.

I agree with Mr. Watters on what he said about an unmodified honeycomb type of panel. What we need in a simple partition is mass, if we want a lot of transmission loss. Lightweight panels won't do.

In our designs, we would perhaps like to deal with a simple, uncomplicated predictable mass, which has low transmission loss at low frequencies and as the frequency increases, so does the transmission loss. Mr. Watters made it clear, however, that an actual panel has stiffness, and because of this stiffness the partition departs from the ideal mass law behavior in two distressing ways. At low frequencies there is a resonance between the mass of the panel and its own stiffness, and the transmission loss falls considerably below what you would expect if you considered only its mass. At high frequencies, the flexural wave length versus the spacing on which the partition is mounted produces an effect that again lowers the transmission loss below what you would expect from purely mass law behavior.

Figure 1 shows measurements, made at the Western Electro-Acoustics Laboratory, of three panels of equal mass density. One of them, a typical office type partition, shows the resonance at low frequencies. At higher frequencies, it tends more or less to follow the mass law curve. A quarter-inch plate of glass, on the other hand, shows the coincidence effect where it departs unfavorably from its mass law behavior at higher frequencies.

And now, the sad story about ordinary, unmodified honeycomb. Empty honeycomb, as we are beginning to learn from the work of Cramer and Kurtze and others in Germany, behaves as all very stiff materials do when mounted in such a way that the flexural wave length is large as compared to the distance between supports. There is almost a constant transmission loss as a function of frequency. If the panel is built to favor our present trends in architecture, as a lightweight panel, not only is the TL constant with frequency but it is also low. However, if we fill the cells of honeycomb to varying degrees with different granular substances (Fig. 2), we can improve the behavior of the material in comparison with what you would predict from its mass alone

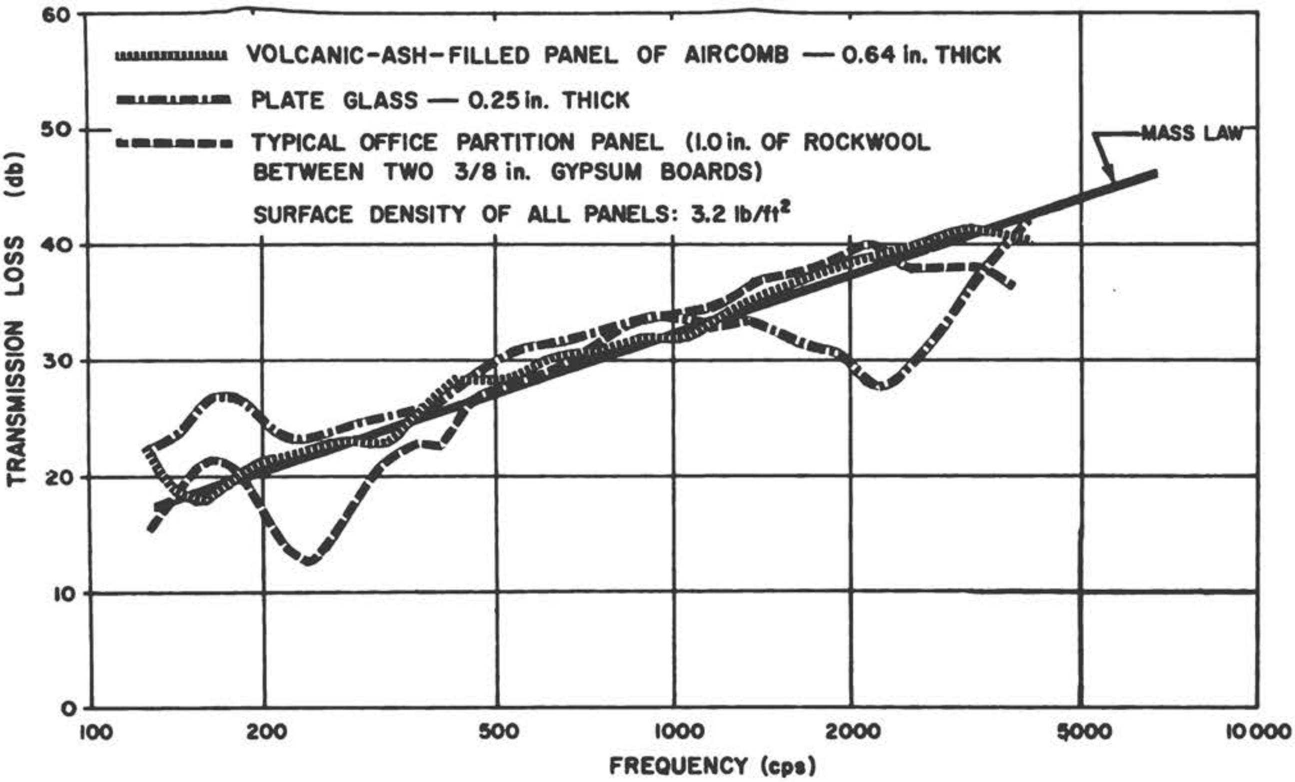

Fig. 1 - Sound Transmission Loss vs Frequency - Comparison of acoustical panels made with honeycomb core with two conventional panels of equal weight.

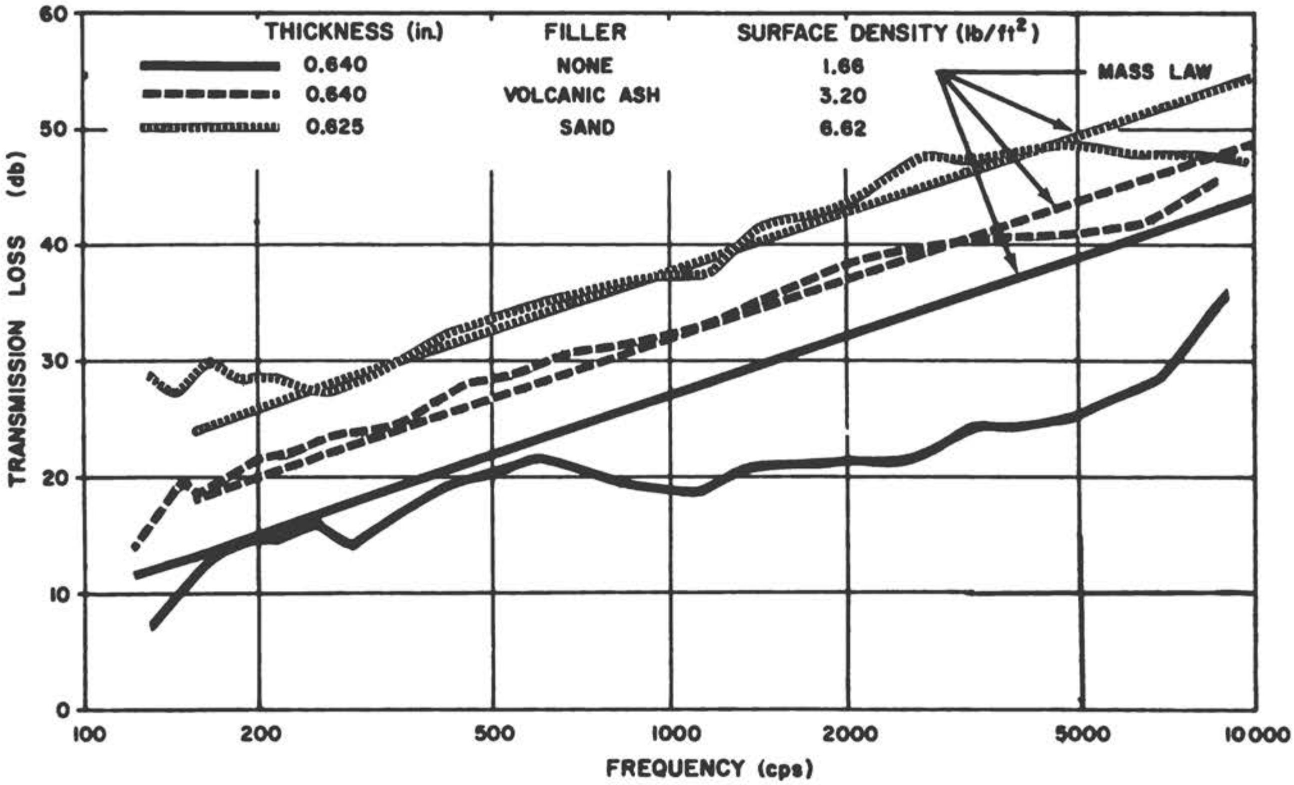

Fig. 2 - Sound Transmission Loss vs Frequency - Filled panels of honeycomb material: same thickness, different fillers.

to a very favorable situation.

Note that we no longer have a lightweight panel. However, we have a panel whose other advantages, and there are many, are in no way impaired. Indeed, it is not always desirable, perhaps never from an acoustical standpoint in terms of isolation to have a lightweight panel. It has been common today to say that if you need to get a lot of transmission loss, don't hope to get by with low mass in a simple panel. The filled honeycomb material will not solve all of your problems; it will give you a reliable behavior which does not fall below what you would predict from mass law.

Mr. Watters: I would like to thank Dr. Schultz for this extension of what we were talking about. It helps to point up the fact that in order to regain what is inherently in a panel in terms of its weight, in order to get your "weight's worth" out of the panel, you must use considerable care and skill. I would like to caution that in the past some people have been fooled by non-physical ideas which were more hopes than reasonable expectations. For example, the idea that where there is air entrained inside a partition, maybe in a foamed material of some sort, this good thermal insulator will also provide good sound insulation. Actually there is no connection. There may be some more sophisticated ways of beating the stiffness game, but I'm afraid they will be sophisticated. Don't expect by some extremely simple and, at the present time, common way to solve all the acoustical problems by using stiff, lightweight materials. This is a real problem, and there are no easy solutions.

Types of Mechanical Noise within Buildings

By C. J. Hemond, Jr.*
University of Hartford

My responsibility is to set the stage, so to speak, for discussions concerning the control of mechanical noise within buildings. In reviewing these possible noise sources I find three logical categories which may be used to group them: (a) Noises from air distribution systems, (b) Noises from mechanical equipment, and (c) Environmental noises. (See Fig. 1)

Figure 1
NOISE WITHIN BUILDINGS

(a) Air Distribution System	(b) Mechanical	(c) Environmental
Fan Motors	Service Motors (Elevators (Door openers	Built-in Radios, TV
Fan - i.e. Prime Air Mover	Gear Assemblies	Intercom Systems
Compressors (Reciprocating & (Centrifugal	Belt & Chain Drives	Telephones
	Diesel Generators	Business Machines
Water Coolers	Plumbing -- Valves, Toilets, etc.	Typewriters
Pumps	Automatic Dish Washers	Human (Walking (Talking
Pressure Reducing Dampers	Electrical (Ballasts -- Fluorescent Ltg. (Thermostats (Transformers	Surgical Carts) Food & Magazine) Hospitals Carts)
Duct Take Offs	Pneumatic Devices (Mailing Tubes)	
Grilles, Registers & Ceiling Diffusers	Autoclaves & Sterilizers	

Noises from air distribution systems will be discussed in detail by Dr. Hardy, and I shall therefore confine myself to merely itemizing possible sources.

*CONRAD J. HEMOND, Jr., who served as chairman of the subcommittee organizing the program for this conference, is Chairman of the Dept. of Engineering Sciences of the University of Hartford, and has been professor of Physics at both Amherst and Rennselaer Polytechnic Institute. He received his B.S. and M.S. degrees from the University of Massachusetts, and studied Acoustics at M.I.T. and Law at Northeastern University. He is a member of the Acoustical Society of American, the Institute of Aeronautical Sciences, and the Building Research Institute.

Our present architecture gives rise to many other types of noises. The "ring of space" referred to yesterday by Mr. Geddes can be activated in many ways. I have listed under my second category several mechanical or electrical sources which must be considered. The owner is unhappy with these noises if they give an improper "ring to the space."

Mr. Wells will suggest some general methods which are applicable toward the quieting of these sources.

Aside from these two categories we have other noises within the space which do not lend themselves to any other category than that of environmental.

Some of these latter sources can be quieted by the methods to be suggested by Dr. Hardy or Mr. Wells, and yet the final control may rest with an agreement regarding the specifications. In this field Mr. Jaros will have significant suggestions which will aid architects, builders and owners in their attempts at noise control through the writing of reasonable and adequate specifications.

It is appropriate to point out that along with the three categories of sources, there have developed several general methods of rating both the source noise and any devices proposed to quiet it. Confusion regarding these systems exists, I believe, because of a lack of understanding regarding either the basic meaning of the system or by the misuse of one system where another is more appropriate.

The ratings to which I refer are the loudness scale, the power concept, the sound pressure level, and the single number "A" scale reading. It is my personal belief that each method has its proper place and furthermore that none of them is adequate for all purposes. The final, ultimate method of rating noises has yet to be propounded.

Generally speaking, the loudness scale is one in which noises are rated on a subjective basis with a noise which sounds twice as loud as another being given a rating of 2, and one three times as loud rated as 3, etc. Thus sounds are rank ordered on a scale extending from soft to loud.

The power level concept is one which attempts to rate on a decibel scale the total sound energy radiated by a source per unit of time. This is further subdivided to attempt a rating over specific defined frequency ranges such as octave or half-octave bands.

The sound pressure level, on the other hand, is the measure of energy present at a point in space. It is related to the power level but it is affected by the environment surrounding the point where the measurement is taken. Thus it will present a variable number at a fixed distance from a source depending upon whether the measured sound pressure level is determined is a reverberant space, in free field or any combination thereof.

The "A" scale readings are those sound pressure levels taken on a scale when a particular weighted network of a sound level meter is used. The scale network has been electronically limited to simulate the over-all frequency response of the average human ear in its most sensitive range. Each of these methods may be correlated one to another and each has its own peculiar and particular meaning.

The discussion of types of noises, followed by methods of rating them, is not complete without calling attention to basic types of control which exist. We have heard the remark, "To quiet a noise -- go to the source." There is much truth in this statement but often we cannot go to the designer since he himself often does not understand fully why his equipment makes noise. He unfortunately accepts the fact that it does.

Certain alternatives do exist, however, and these can be categorized in 5 key words, which, in fact, with a slight addition, make a good code to remember:

a) Specify quiet equipment.

b) Shield the equipment by what might generally be called massive or sandwich type wall structures.

c) Attenuate the noise by placing absorptive devices between the source and the listener.

d) Reduce the reverberent buildup by the use of absorptive materials within the space.

e) Utilize the distance concept -- i.e., remove the source as far as possible from the listener.

Other items might be listed but to do so would merely break down some of the above topics into specialized applications. It is truly said that the acoustical consultant must of necessity be versed in many fields. Not only must he know his laws of physics, but he must know his laws of human beings. The sciences of psychology (how the two-legged animal called man reacts mentally to the presence or lack of stimuli) and physiology (how the external stimulus communicates itself to the nerve endings and how the brain receives and interprets the traduced stimuli to cause these reactions) must be studied continually to explain or to predict the reactions of man to his noise environment.

The consultant must have many of the qualities of a diplomat. He must be strong enough to convince his clients, be they architects, builders or owners, of the right and wrong of a given situation. At the same time, his ethics must be such as to state unequivocably, before the fact if possible, the calculated risks being taken when venturing into unknown areas. The consultant finally, must be well versed in the art of communication, to express ideas clearly and concisely, in the language of the layman and not in the specialized jargon of his own field.

Ventilation System Noise

By Howard C. Hardy*,
Howard C. Hardy and Associates

It is not the purpose of this paper to give a detailed manual on control of ventilation system noise, but to present a philosophy of approach by which engineers and architects can solve the problems and write realistic specifications.

The advent of air conditioning has intensified the problem of the acoustic design of ventilation systems because the amount of equipment has greatly increased and closing outside windows has virtually eliminated the ambient noise from outside sources. Mechanical engineers are also tempted to try new combinations of systems with occasional disastrous acoustical ramifications. A few of the innumerable examples of bad planning in control of ventilation noise can be mentioned.

Examples of Bad Planning

A large concert auditorium in the Midwest was plannned with a geometrical layout which gave very good listening conditions throughout the hall, but only when the ventilation was off. Knowing that this auditorium was a monumental design, the mechanical engineers had attempted to introduce a more effective scheme of ventilation by distributing the air from the ceiling through a whol~ series of jets. The resulting noise was also evenly distributed and, at first, of mysterious origin. It was perfectly described as "it sounds like water is running somewhere."

A board-of-directors room in a large corporation was designed with a beautiful decor. Unfortunately, it was a large room and the ventilation noise was so great that conversation could not be conducted without shouting between the two ends of the large conference table. This did not tend to make such meetings very harmonious.

On the other hand, there was a large legal firm which moved into a new suite of offices which had been redecorated and air conditioned. The ventilation noise, at the request of the legal firm, had been virtually eliminated. This firm also liked to operate with individual office doors open. The offices were carpeted and acoustically treated, but the background noise was so low that conversation could be easily heard from the office of one member of the firm to the other. The resulting invasion of privacy was often annoying and embarrassing. A small amount of ventilation noise would have prevented this.

Another example is that of a large air conditioned office building recently constructed in New York, in which there had been some concern over the anticipated air conditioning noise, so much so that when the plans were finished, three times as much quieting was introduced as was necessary. Not only was this excessive noise reduction program expensive - to the tune of approximately $100,000 -

* HOWARD C. HARDY heads his own firm in Chicago and is widely known as a consultant on architectural acoustics. He received his Ph.D. in Physics from Pennsylvania State University and was formerly head of acoustical research at the Armour Research Foundation. He is a Fellow of the Acoustical Society of America and a member of American Physical Society, Institute of Radio Engineers, Western Society of Engineers, Illinois Society of Professional Engineers and the Building Research Institute.

but when the building is occupied, it will probably result in many areas in an environment which is also "too quiet."

A large manufacturing office adjoining a factory was recently built in which the mechanical engineers decided to use a high velocity exhaust system. This in itself would have been satisfactory, if there had been some concern over the noise. However, the noise environment in every space of the building is quite similar and consists of an intense low frequency rumble, not unlike that heard a few miles from Cape Canaveral on a busy morning.

Our halls of ivy are not immune to these problems; they occur in many academic institutions. A large Midwestern university had an unusual number of noise problems in its lounges and lecture rooms. Although there were some 20 kinds of engineering offered on this campus, it was evident that noise control was not covered in any of them, and not one man on the faculty could be found who professed to know how to handle such problems.

Design Goals

From the above statement it is evident that there should be more widespread knowledge of noise control techniques. But there is also a fair probability of going "overboard" with too much quieting. Complete elimination of ventilation noise would almost always result in an undesirable situation.

There is always an optimum level of background noise for working spaces. In most cases an unperceived background of ventilation noise is the only means of providing a comfortable and diffuse acoustic environment to mask the distracting influence of speech, office machines, and other intermittent sounds. It is important, however, that the steady background noise have a pleasant characteristic. This desired environment can be provided by a steady broad-band noise, which has its energy in the various frequency bands balanced in such a way as to be the most acceptable to the human ear.

As an example, three acoustic spectra are shown in Fig. 1 (A, B and C). The lower parts of these graphs are plotted in the conventional manner in which noises are measured, that is in a series of eight octave frequency bands. As has been explained in previous papers in this conference, a person does not subjectively react equally to all the bands, and the ear is more sensitive for the higher frequency bands. When these spectra are placed in the proper perspective on what is known as loudness graph paper, they look like the charts shown in the upper graphs of Fig. 1. All these sounds in Fig. 1 are approximately equally loud.

The first sound is the typical high-frequency hiss which is emitted when air passes at high velocity through a grille or small air diffuser.* The second is a low frequency noise which might be characterized as a rumble. This kind of noise was the type present in the manufacturing office mentioned above. An example of a balanced noise is that of Fig. 1-C, which is the type characteristic of a well designed air conditioning unit. Noise of the third kind gives a flat curve when plotted on loudness graph paper. This is the characteristic which is heard subjectively as a pleasant sound. It is the type of soothing sound heard from a waterfall, surf, or a steady wind.

Of course, the acceptability of the sound will also depend on its level and the presence of other noises. The level of sound given in Fig. 1-C would be acceptable in an open accounting office, but not in an executive suite. Also different degrees of loudness would be acceptable in residences and in factories than would be accepted in offices.

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* In the original presentation of this paper, the noises shown in Fig. 1 were illustrated by magnetic recordings.

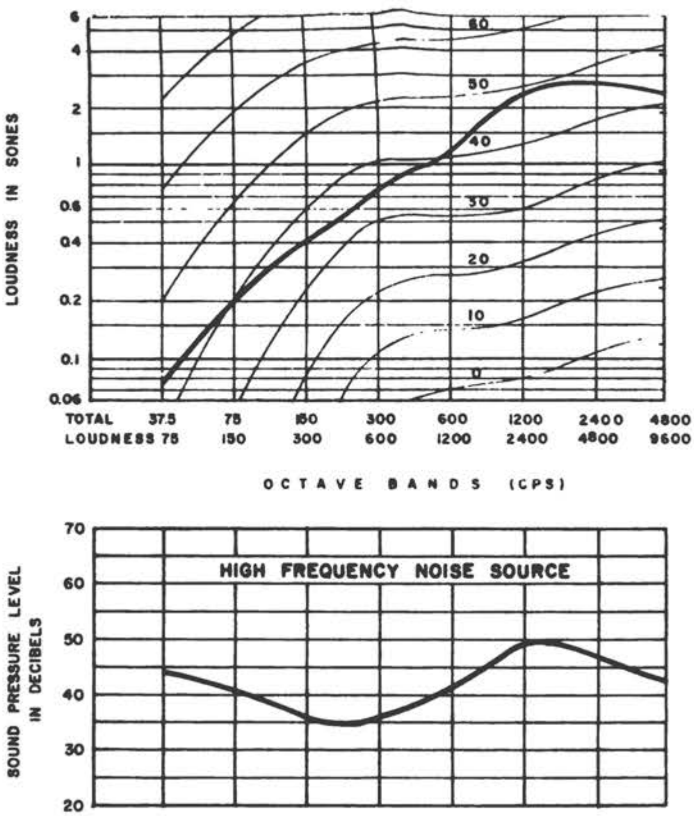


Figure 1-A

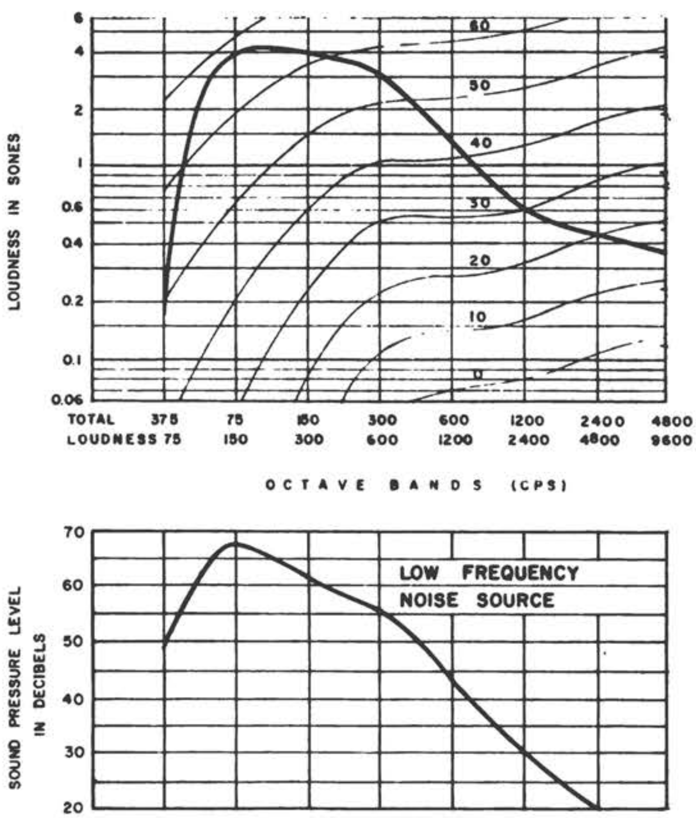


Figure 1-B

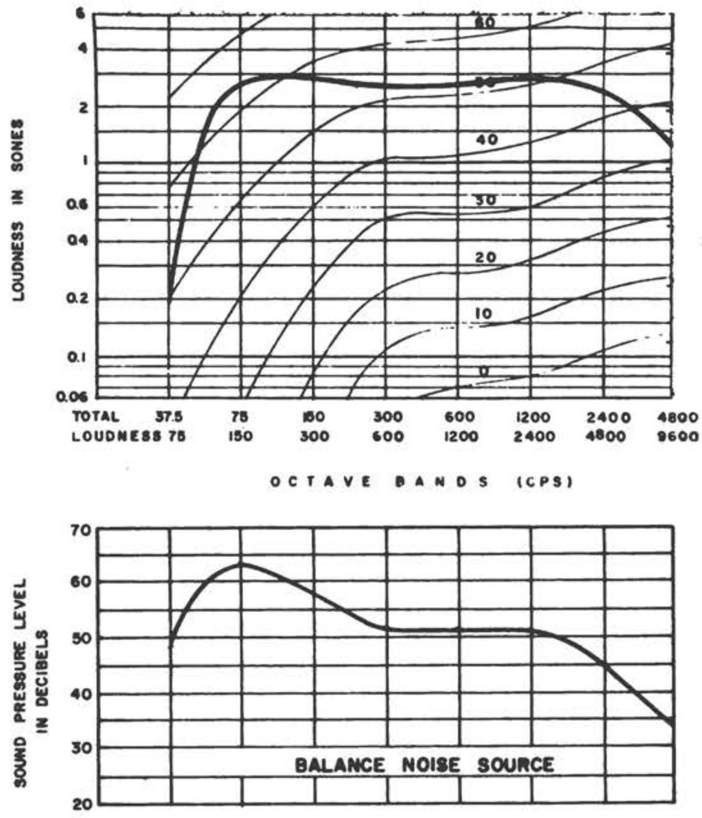


Figure 1-C

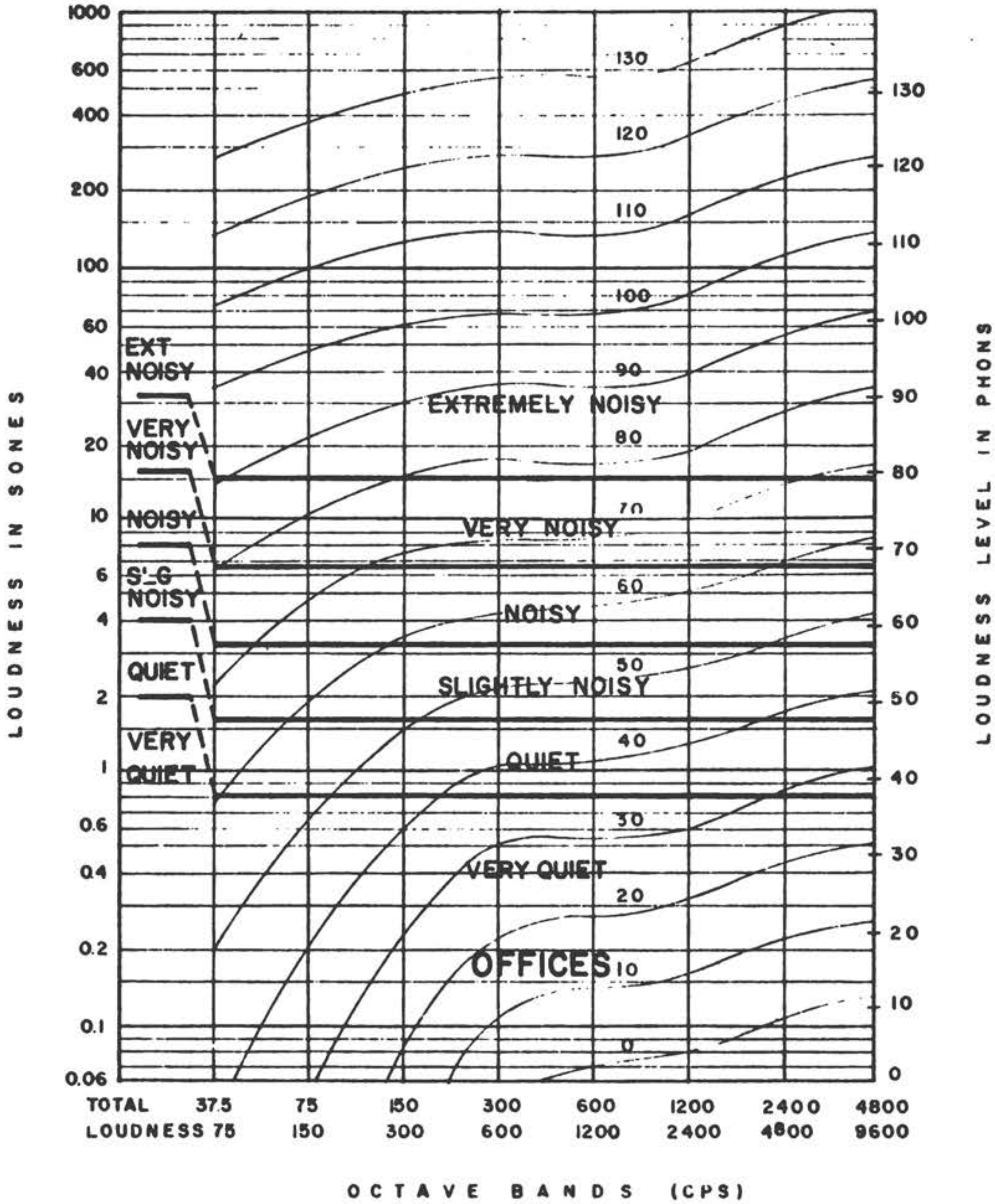
It is possible to make a set of categories for any environment by drawing horizontal lines on the loudness graph paper, as is shown in Fig. 2 for office environments, However, when one examines such a categorization closely, one finds that even in the category of offices there are wide ranges, from the desk of a foreman in a manufacturing area, to a minister's study. There is also a difference in human acceptance, which often is tempered by economical considerations.

It is possible to set loudness ratings for various acceptable environments in three categories - very quiet, quiet, and slightly noisy - and this has been done for a large number of cases. Recently, 75 such environments in 13 categories have been evaluated and the results will soon be published. Examples of some of these environments and their ratings are given in Table 1.

It can be seen, therefore, that the acoustical engineers are able to set up very realistic design goals to prescribe comfortable and pleasant acoustic working conditions. Means can be provided also so that the user can make a judicious choice, such as by playing back magnetic recordings of the desired acoustic conditions. The owner, builder, architect, or user can make his own selection with the knowledge, of course, that the quieter combination has a high price tag. It is important, however, when such tests are made, that the sound be played back against the operating noise which is expected in the particular area.

Sound Power Rating

The next step in our discussion is to describe briefly how one obtains these desired noise conditions. The techniques for computing fairly exactly what noise levels will result from a given combination of conditions have been worked out in the last few years. Unfortunately, however, much of the data needed are either not available or not widely disseminated. Also, there has been much confusion about acoustic terminology and measurement. It is desirable, for instance, that all manufacturers of



LOUDNESS IN SONES
LOUDNESS LEVEL IN PHONS
OCTAVE BANDS (CPS)
TOTAL LOUDNESS
37.5 75
75 150
150 300
300 600
600 1200
1200 2400
2400 4800
4800 9600
1000
600
400
200
100
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
0.06
130
120
110
100
90
80
70
60
50
40
30
20
10
0
EXT NOISY
VERY NOISY
NOISY
S'LG NOISY
QUIET
VERY QUIET
EXTREMELY NOISY
VERY NOISY
NOISY
SLIGHTLY NOISY
QUIET
VERY QUIET
OFFICES

Figure 2

TABLE I

RECOMMENDED LOUDNESS LIMITS FOR NOISE FROM

HEATING AND AIR CONDITIONING EQUIPMENT IN OCCUPIED AREAS

	Loudness (Sones)		
	Very Quiet	Quiet	Slightly Noisy
1. Office Areas			
Executive	1.5	2	3
Drafting room	2	4	8
3. Churches and Schools			
Classroom	1.5	2.5	4
Kitchen	4	6	8
6. Hotels			
Lobbies	2	4	8
Ball room	1.5	3	5
8 Auditoria and Music Halls			
Concert hall	0.8	1	1.5
Court room	2	3	4
12 Manufacturing			
Foundry	10	20	40
General storage	5	10	20

ventilation equipment release noise power ratings for their equipment. In some cases only very ambiguous sound levels are available, and in some cases no data at all.

To understand the reason for giving data in terms of power, one can refer to the analogies presented in Table II. In air flow measurements, the equipment supplier issues data on the cfm and static

TABLE II

ANALOGS BETWEEN MECHANICAL AND ACOUSTICAL MEASUREMENTS

	POWER	Geometrical effect	MEASUREMENT PARAMETER
AIR FLOW	Power output (cfm) x (SP)		Velocity (fpm)
HEAT	Heat flow (Btuh)		Temperature (°F)
NOISE	Acoustic power (microwatts - μw)		Sound pressure level (Decibels - db)

pressure, from which one can compute, for example, the velocity in the duct system. Similarly, in a heating system, given the amount of btu per hour and knowing the geometry of the system, one can predict the temperature at any prescribed position.

In case of acoustical engineering calculations, if one knows the acoustic power (which will usually be in units of microwatts), one can compute the sound pressure level at a prescribed point, provided one has enough information about the geometrical parameters of the space in which the noise is emitted. In a primitive way, one could rate heating systems by placing a thermometer at a certain point, or an air flow system by using a flow gage. However, this would be rather silly and very poor engineering. Trying to rate air motion noise devices by simply making sound level measurements at a certain distance is in the same category.

The modern technique requires data on the sound power of a device under defined mechanical conditions. These data should be in a series of eight octave bands. As an example the data of a particular type of air diffuser are presented in Fig. 3. Here with sound power output in microwatt is plotted for different cfm. For evaluating such sound sources, it is very convenient to compare the unknown to a standard noise source, such as shown in Fig. 4. This noise generator is very stable and emits steady noise with energy distributed in all eight octave bands. It is used at present by approximately 12 manufacturing companies. Other companies are using other standard noise generators. One only needs to compare the sound output of the unknown with the standard by measurement with a simple sound level meter and octave band analyzer.

Several companies are now issuing data, and many more are planning to release such data in the near future. The air motion industry is also preparing a measurement standard for noise measurement based on this scheme of obtaining data. It is hoped that in the future manufacturers will be supplying noise data as conscientiously as they are now giving air flow and pressure drop data.

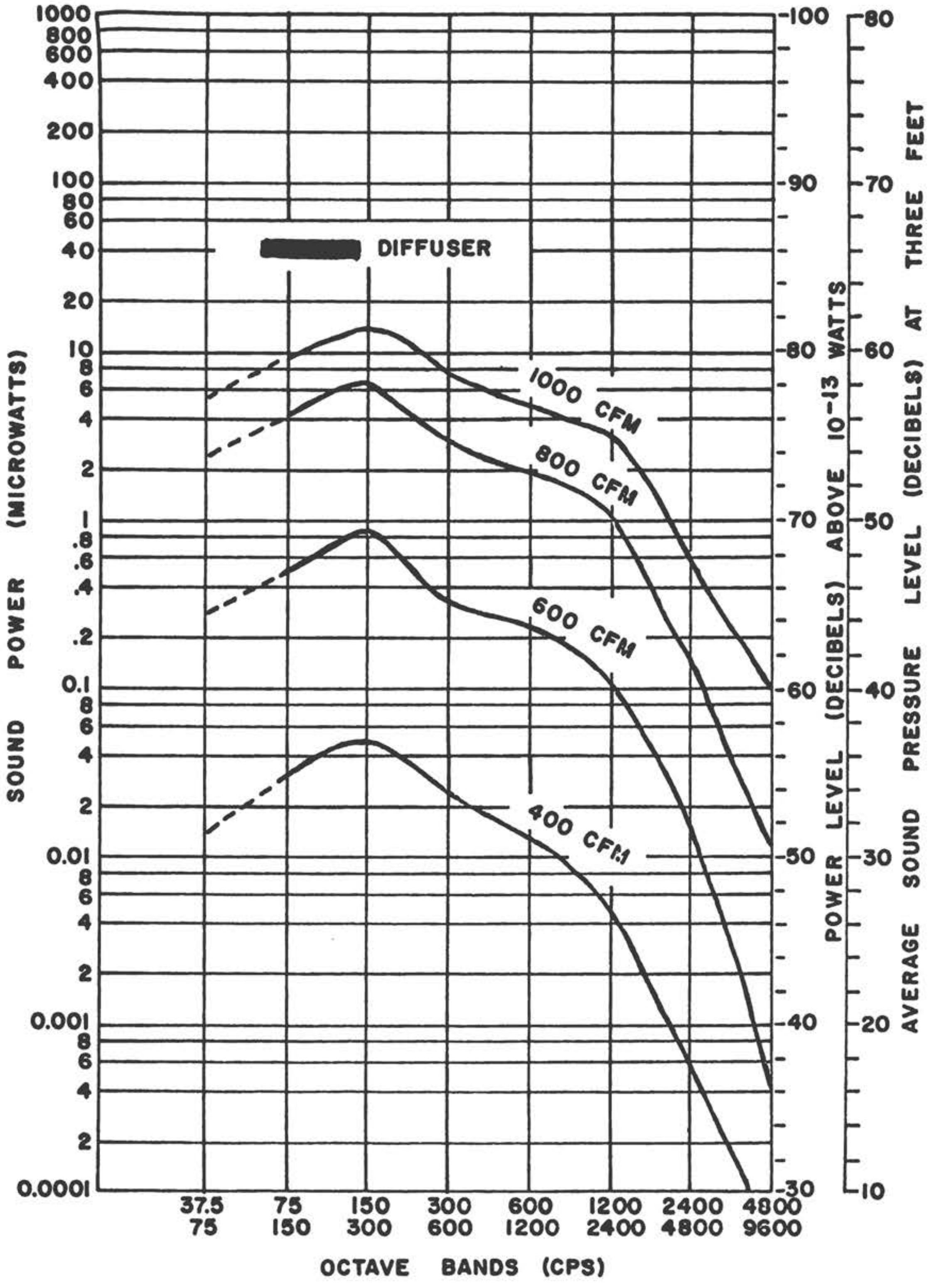
Predicting Noise Performance

A sample calculation will now be made showing how the noise levels in an office building can be predicted. In this hypothetical system, as shown in Fig. 5, there is an air conditioning unit of 60,000 cfm, which supplies each of the five floors of the building with 12,000 cfm. Each floor has a mixing unit. The air at controlled temperature is then supplied to 12 outlets, each of 1000 cfm. The calculations are straightforward, but fairly tedious. Data showing the sound power distribution and attenuation through the system are shown in Table III. Space does not permit giving each

TABLE III

NOISE CALCULATION FOR A VENTILATION SYSTEM

	Octave Band Data					
Frequencies (cps)	37.5 75	75 150	150 300	300 600	600 1,200	1,200 2,400
1. Sound power of fan (microwatts)	5,000	12,000	8,000	3,000	1,000	300
2. Divided into five branches (microwatts)	1,000	2,400	1,600	600	200	60
3. Duct attenuation (percent transmitted)	40	25	15	10	6	4
4. Sound power entering first branch (microwatts)	400	600	240	60	12	2.4
5. Sound power of mixing unit (microwatts)	10	15	30	25	25	10
6. Total sound power (microwatts)	410	615	270	85	37	12
7. Divided among 12 outlets (microwatts)	34	51	23	7	3	1
8. Duct attenuation (percent transmitted)	15	25	33	25	10	6
9. Power entering first diffuser (microwatts)	5	13	7.6	2.8	0.3	0.06
10. Sound power of diffuser (microwatts)	0.2	0.4	0.6	0.3	0.2	0.08
11. Total power entering room (microwatts)	5.2	13.4	8.2	3.1	0.5	0.14



TYPICAL SOUND POWER GRAPH

Figure 3

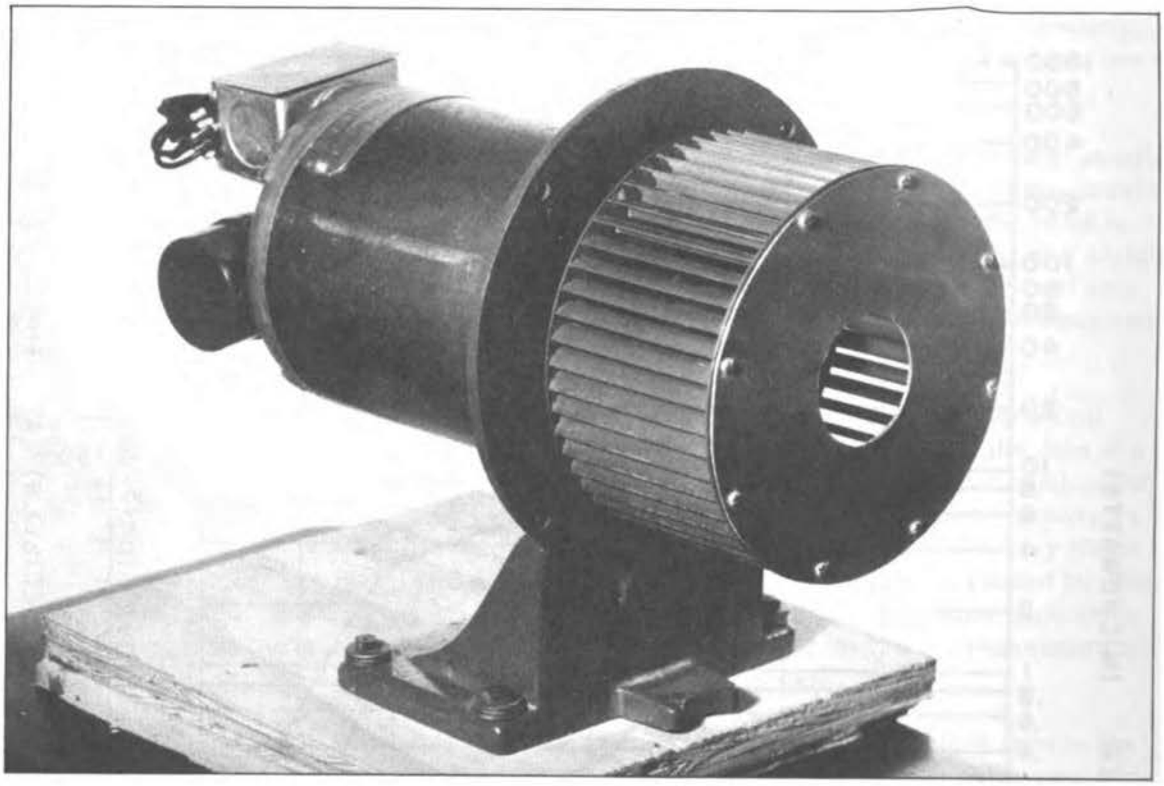


Figure 4

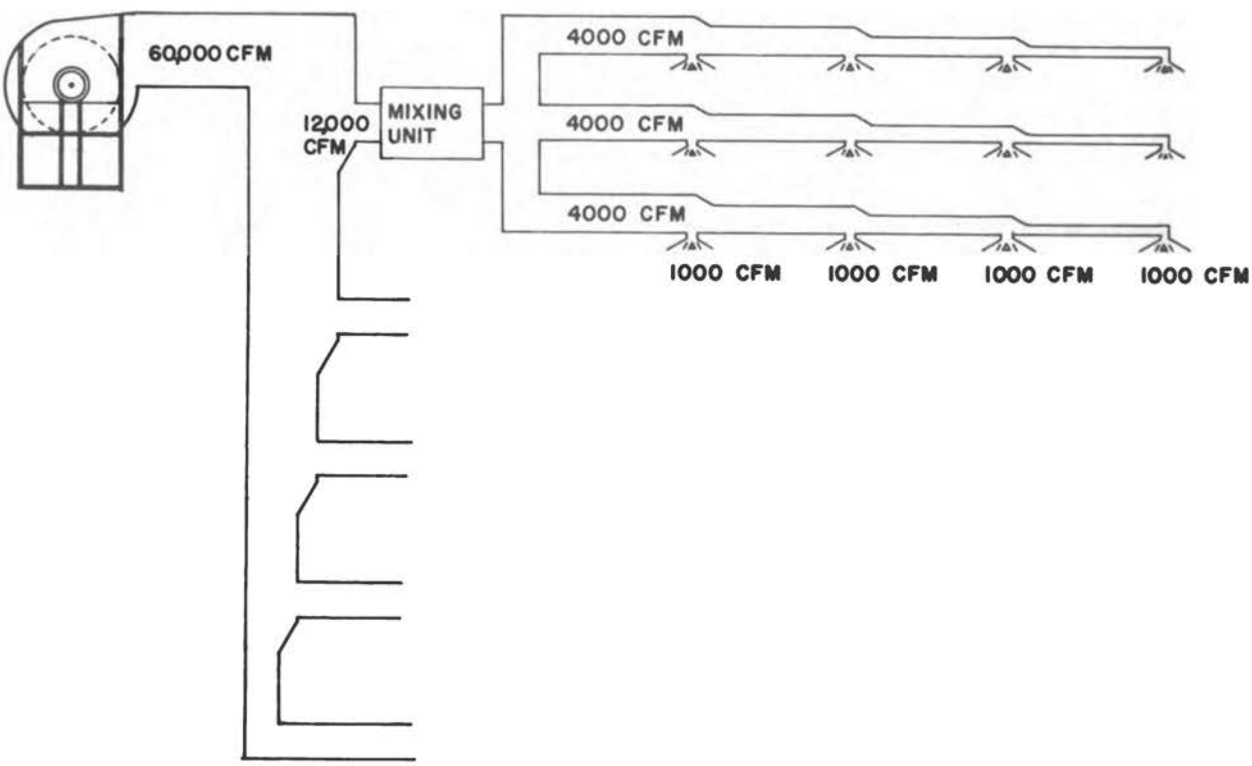


Figure 5

detailed calculation, but the table will serve to show the general procedure.

The first line of Table III gives the sound power of the fan in microwatts. These data should be available from the manufacturer. If not, they can be estimated from the horse power and pressure drop of the fan. This sound power eventually will be divided among five branches, the amount available to the first branch being that shown in line 2. We will calculate only the closest outlet to the fan which will be the noisiest. The duct attenuation to the first branch point is given in line 3, expressed as a percentage of the power available which has been transmitted.

For instance, in the 300-600 cps band, the ducts and turns have attenuated the sound energy so that only 10 percent of it is transmitted to the first branch point. The sound power reading at the first branch point is therefore that given in line 4. At this point there is a new sound source, that of the air flow through the mixing unit. Again such data should be obtained from the manufacturer, and for a particular mixing unit the sound power might be like that in line 5. When this is added to the sound power from the fan, one obtains the total sound power entering the main branch point, as shown in line 6.

There are 12 outlets in this branch point and the amount available for each outlet is that given in line 7. The duct attenuation to the first outlet is again estimated in line 8. The sound power being transmitted to the first diffuser is that shown in line 9. Here we find another sound source, the diffuser itself, whose sound power is given in line 10. The total sound power, therefore, entering the room from this diffuser is that in line 11. The amount of sound entering the room from this diffuser is that in line 11. The amount of sound entering the room is of the order of 0.001 of that which was emmitted originally by the fan.

The next step is to predict the noise level in the room. For this one would need to use a chart such as Fig. 6. One will also need to know the approximate absorption of the room. For a typical office space, large enough to use 1000 cfm, the absorption might be that given in line 2 of Table IV. (Line 1 has been taken from line 11 of Table III). The right hand coordinate of Fig. 6 is the absorption

TABLE IV

NOISE LEVEL PREDICTION WITH AND WITHOUT TREATMENT

	Octave Band Data					
Frequencies (cps)	37.5 75	75 150	150 300	300 600	600 1200	1200 2400
Before treatment						
1. Total power entering room (microwatts) (line 11 of Table III)	5.2	13.4	8.2	3.1	0.5	0.14
2. Absorption of room (sabins)	150	200	250	300	500	700
3. Predicted sound pressure level in room (decibels)	62	65	62	56	47	40
4. Design goal (decibels)	66	58	50	45	43	42
5. Attenuation required (decibels)	0	7	12	11	4	0
6. Attenuation required (percent)	0	80	94	92	40	0
After treatment						
7. Attenuation of proposed package unit (db)	5	10	16	25	30	35
Package unit before mixing unit						
8. Power entering room (microwatts)	2	2	1.6	0.8	0.32	0.13
9. Sound pressure level in room (microwatts)	58	57	55	50	44	40
Package unit after mixing unit						
10. Power entering room (microwatts)	1.7	1.7	0.8	0.31	0.2	0.08
11. Sound pressure level in room (microwatts)	57	56	52	46	42	38

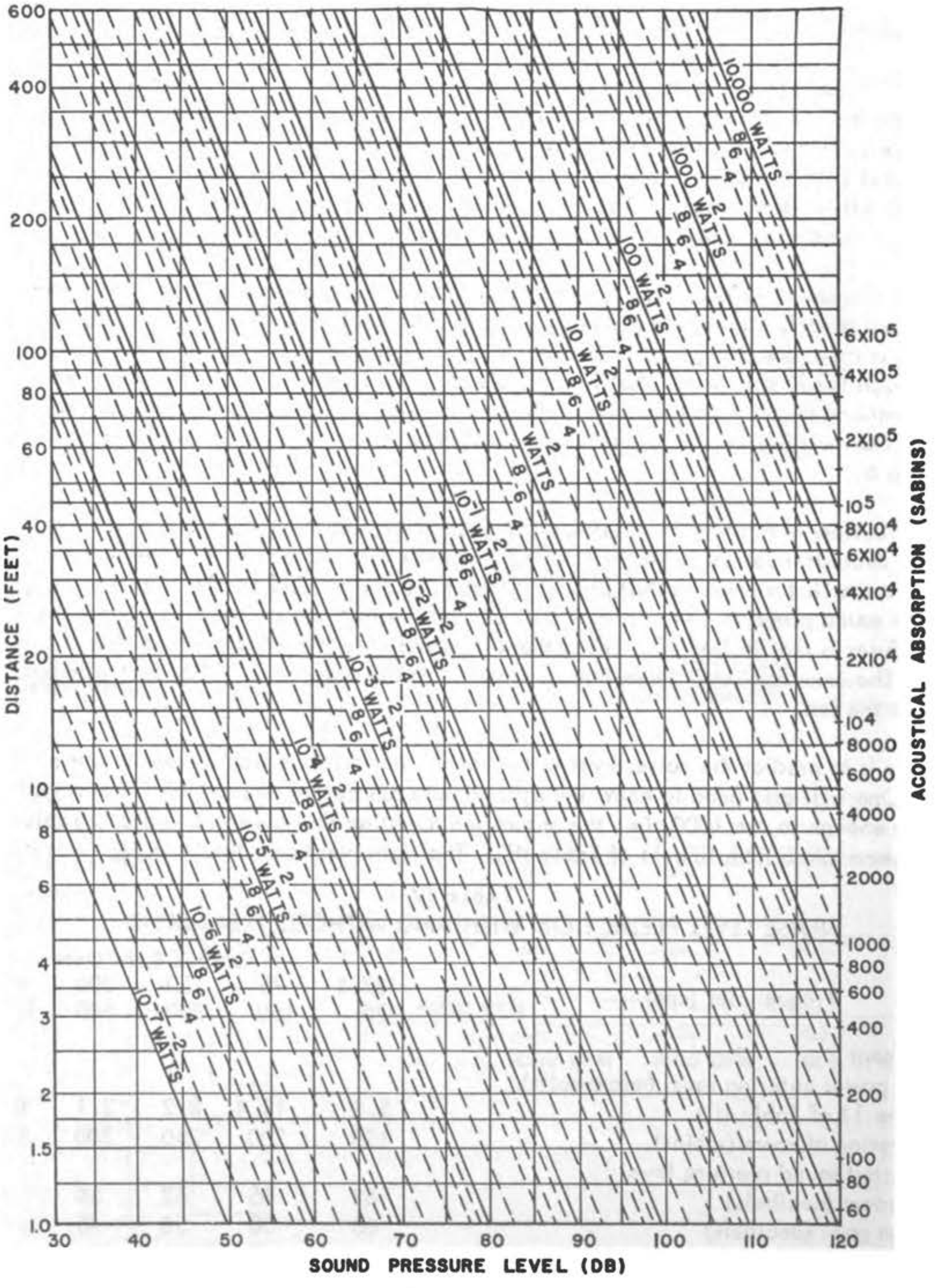


Figure 6

parameter. For instance, to calculate the first octave band, one enters the chart at 150 sabins and moves horizontally to the left to the position of the diagonal graph point for a power of 5.2 microwatts. The lower horizontal coordinate then shows that the predicted sound level would be 62 db. In similar fashion, the sound levels for the other octave bands can be predicted, and these data are given in line 3.

The design goal can be chosen by methods outlined above and might be that of line 4. The required attenuation is therefore as given in line 5. It can been seen that the largest attenuation is required in the 150–300 cps band, and this is nearly always the case for any ventilation problem in which the fan is the principal noise source. The amount of attenuation in decibels is given in line 5, but may be also shown in percentage, as in line 6.

One way of reducing this noise would be to use one of the package noise suppression units which are now on the market. The data for such a package unit may be that given in line 7. On the face of these data, it would appear that if this system is introduced in the proper place, it would solve the problem.

There is a choice of where the unit could be installed. Inserted before the mixing unit, the amount of sound power entering the room computed by the same method as in Table III, results in the data given in line 8. This would give octave band sound levels as shown in line 9. It can be seen that one does not yet reach the design goal because of the sound power contributed by the mixing unit. If one inserts the package unit after the mixing unit, the resulting sound power will be that given in line 10, and the sound pressure level that in line 11.

One can see that the design goal has been met, except for the 150–300 and the 300–600 cps bands. To obtain the design goal here, it would be necessary to reduce the velocity of the air in the diffuser either by reducing its total flow or by increasing the size. However, it appears from this calculation that the numbers will be sufficiently close to be adequate when one takes into account that this is the first and noisiest unit.

One then proceeds to the calculation for the other elements in the system. This brief discussion only outlines the general procedure. In the near future, a manual introducing this technique with full details will be issued.

Another simpler example can be described. This is shown in Fig. 7. Here are plotted the sound transmission data for the 150–300 cps band. A small fan of 2000 cfm gives out a sound power in this band of 50 microwatts. This is attenuated to 32 microwatts near the first branch point. One fourth of the sound passes into this duct at the branch point. This is attenuated to 5.5 microwatts entering room A. Successive attenuations at the other branch points result in 4.8 microwatts in room B, 4.1 in room C, and 2.4 in room D. The resulting sound pressure levels vary between 64 and 60 db. The absorption of this calculation room was 110 sabins.

Another example for a typical noise control problem is that of the manufacturing office which was mentioned above. Here a graph can illustrate another method of calculation where one follows the decibel attenuation through the duct system. This particular duct system has a large vane-axial exhaust fan, the static pressure of the branches of the system being controlled by a pressure reducer which is similar to an air distribution mixing unit. This particular pressure reducer is fitted with a silencing plenum for attenuating the high frequency noise generated by air flow through it. The noise level near the fan is that given in the upper line of the graph of Fig. 8.

These data were calculated by measurements made just outside the outlet of the fan and they are consistent with the predictions one would make from the horse power and static pressure of this fan. One can estimate the levels at various points in the system. The sound level is reduced to that given by the second line just behind one of the pressure reducers. This reduction of level is mostly due to the change in area from the main duct to that of the branch ducts.

There is a small attenuation due to duct absorption. In passing through the pressure reducer, the sound is decreased to that given by the third line, and this is the noise which is predicted just behind the intake exhaust grille. When this sound is radiated into the office, it is diffused so that it results in the level given by the 4th line, which is actually the data measured in the work space.

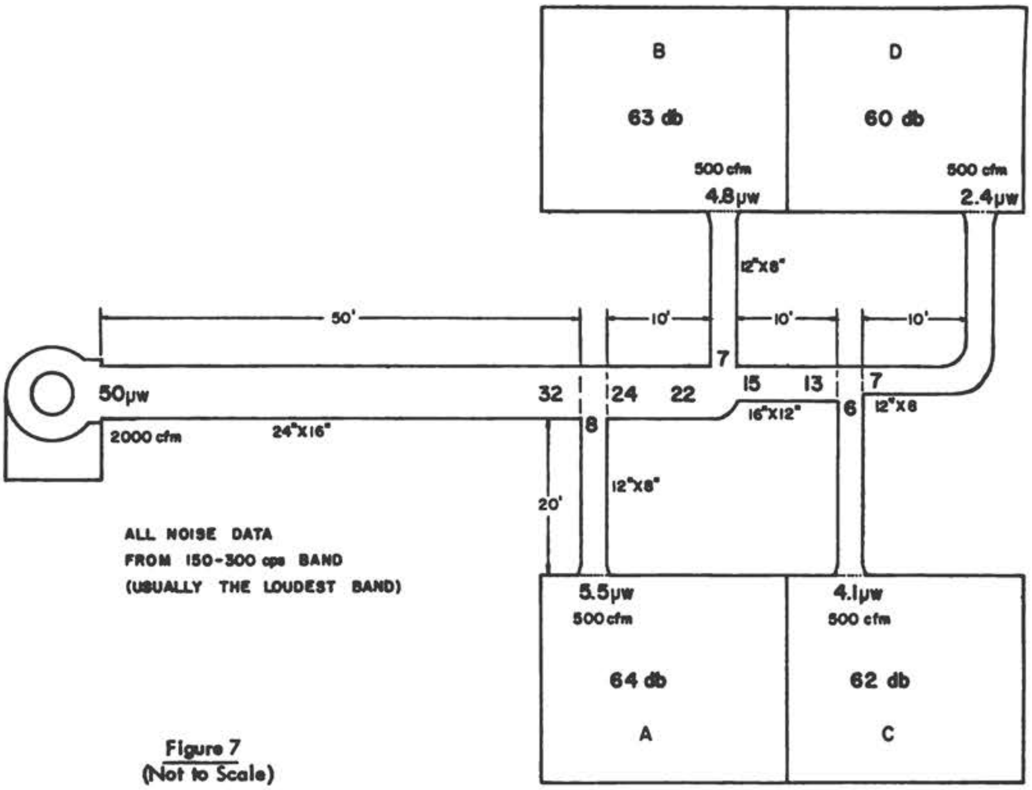


Figure 7
(Not to Scale)

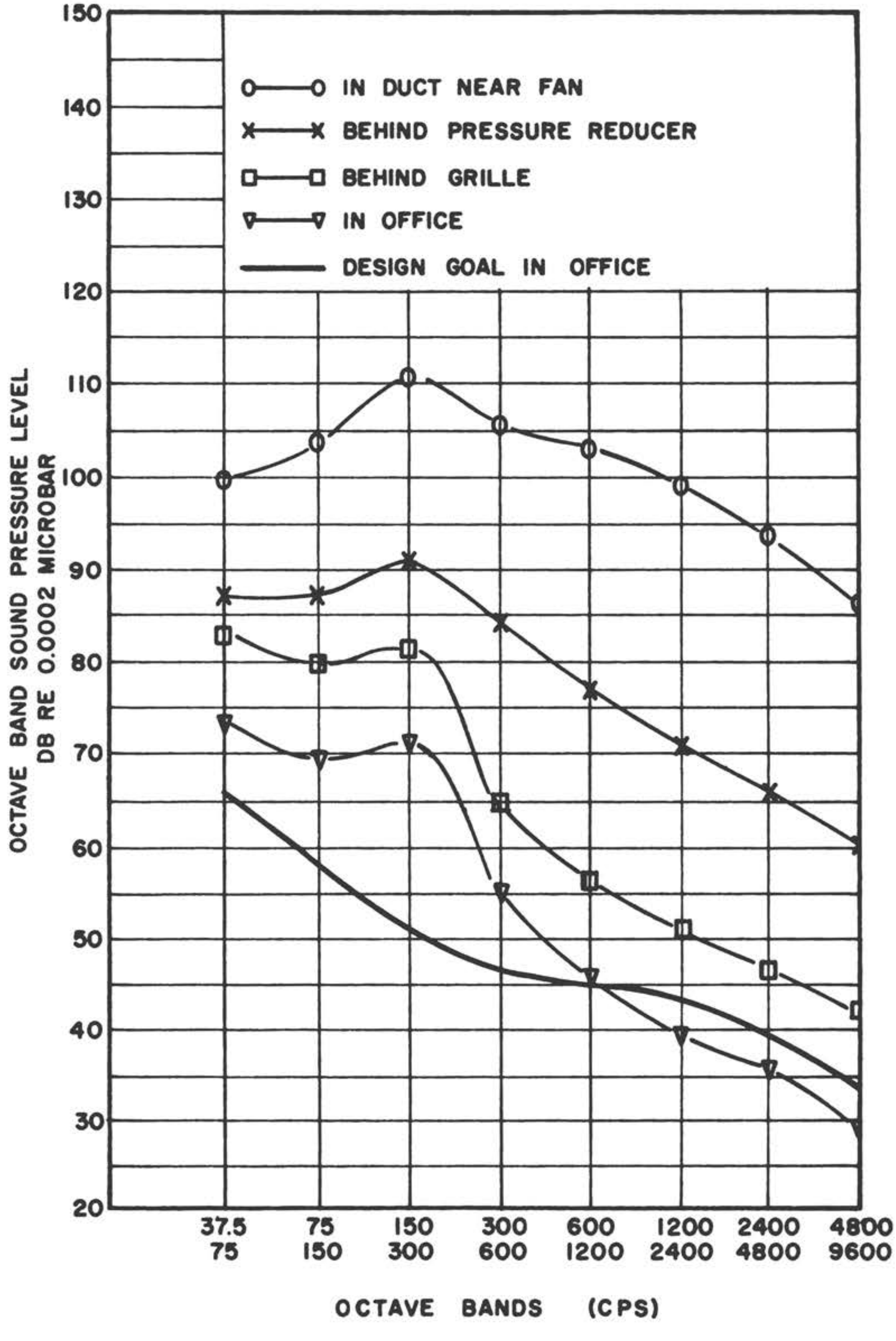
From measurements on both ends of the system one can therefore predict very well the attenuation of the sound energy. The design goal for such an office would be "slightly noisy" and is that given by the heavy line. It can be seen that there is excessive low frequency sound in the room, as was mentioned earlier for this system. A special resonant absorber to absorb the low frequency sound energy was designed to be inserted in the main exhaust duct.

Summary

In this paper are given the basic principles which an acoustical engineer uses to arrive at the desired noise conditions in a particular work environment. It can be seen that part of the design is in the human engineering field, that of setting up a proper design goal in air conditioning and ventilation systems. This design goal will hardly ever be to eliminate all of the noise, but to leave the system with a reasonably comfortable background noise which will depend on the particular environment involved.

After the design goal has been set, the general technique used in engineering the system is to take the sound power contributed by the various noise sources and to compute the sound power which arrives at a particular working space. Knowing the acoustical characteristics of this space, one then computes the sound level and compares it with the design goal. One can then decide what noise control measures will be necessary and prescribe either the point in the system where they should be installed, or what flow changes will be necessary to obtain the required noise environment.

The accuracy of any acoustical system calculation need only be to the order of 2 db, which is in energy or power a difference of approximately 40 percent. In most cases one can estimate the results within these tolerances. However, there is still much room for research in the following categories:



IN DUCT NEAR FAN
BEHIND PRESSURE REDUCER
BEHIND GRILLE
IN OFFICE
DESIGN GOAL IN OFFICE
OCTAVE BAND SOUND PRESSURE LEVEL
DB RE 0.0002 MICROBAR
150
140
130
120
110
100
90
80
70
60
50
40
30
20
37.5 75
75 150
150 300
300 600
600 1200
1200 2400
2400 4800
4800 9600
OCTAVE BANDS (CPS)

Figure 8

(1) More reliable sound data on noise sources.

(2) Better data on the noise propagation in duct systems, including the attenuation effect of duct branch points.

(3) Design of acoustic noise suppression devices which are better tailor-made to the needs of ventilating systems.

(4) Better techniques for controlling noise of high velocity systems.

Mechanical Equipment Noise

By R. J. Wells*, Acoustical Engineer
Mechanical Engineering Laboratory
General Electric Co.

Introduction

A thorough study of a noise control problem usually involves a systematic approach. Consider the all-too-common situation illustrated in Fig. 1 where a noisy machine is installed in a room adjacent to another room where quiet is desired. As indicated by the various arrows, there are quite a number of parallel paths by which the noise may reach the listener. Some of these paths may involve a single element, or principle; others involve two or more elements in series.

These relationships are perhaps better illustrated by means of the block diagram of Fig. 2. Here the solid lines represent direct mechanical coupling, and the dotted lines indicate airborne sound. Thus, inadequate vibration mounts under the machine may allow the floor to be excited excessively. This in turn vibrates the walls. Hence, both walls and floor of the adjacent room become radiators of sound.

For sound initially airborne, we must, in general, consider both radiation from the machine housing and from air intake and exhaust posts. Airborne sound will also cause the walls and floors of the rooms to vibrate and thus transmit a somewhat attenuated sound wave. Another path - this one strictly airborne - may involve sound transmission through a common ventilation duct which serves both rooms. Still another path to consider is created by the modern trend toward light-weight false ceilings. Here airborne sound goes up through the false ceiling, along the air chamber above the ceiling, and finally down through the ceiling of the receiving room.

It will be noted that all paths go through the box at the right labelled "room acoustics". This emphasizes the fact that the size, shape, and amount of sound absorption present in the receiving room will influence the sound level there. However, from a practical standpoint, such influence is definitely limited; more often than not a noise problem cannot be solved merely by increasing the absorption of the receiving room. In other words, a noise control problem usually requires a modification of one - or perhaps several - of the various transmission paths. The most important paths are, of course, those which transmit the most acoustic power. However, the determination of the relative powers transmitted by the various paths usually requires a detailed study by an acoustical engineer.

Considerations such as these lead to a well-known maxim in acoustical engineering, viz. - "The best place to control a noise is at its source." Actually, the machine itself, shown by a simple block in Fig. 2, may also be expanded into a multiplicity of sources and transmission paths. However, detailed considerations of this nature are more the responsibility of the manufacturer and so will not be expounded in this paper. Instead, I will attempt to emphasize user control which may be

*RICHARD J. WELLS took his Master's Degree in Physics at Ohio State University and is now working towards his Ph.D. in Applied Math. He has spent 4 years with General Motors' Sound Laboratory and the past 13 in GE's General Engineering Laboratory. He serves on committees for the American Standards Association, ASHRAE and the Acoustical Society of America. GE is a member of the Building Research Institute.

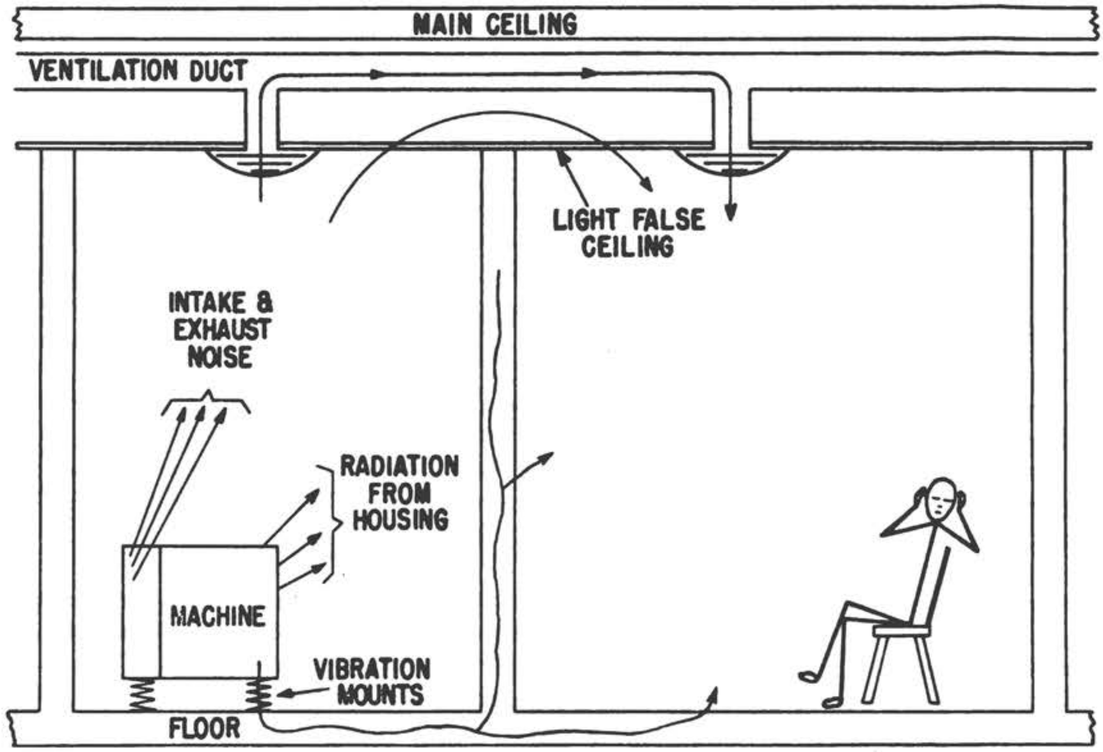


Figure 1 - Two adjacent rooms with noisy machine in one. Typical acoustic and vibration paths are indicated.

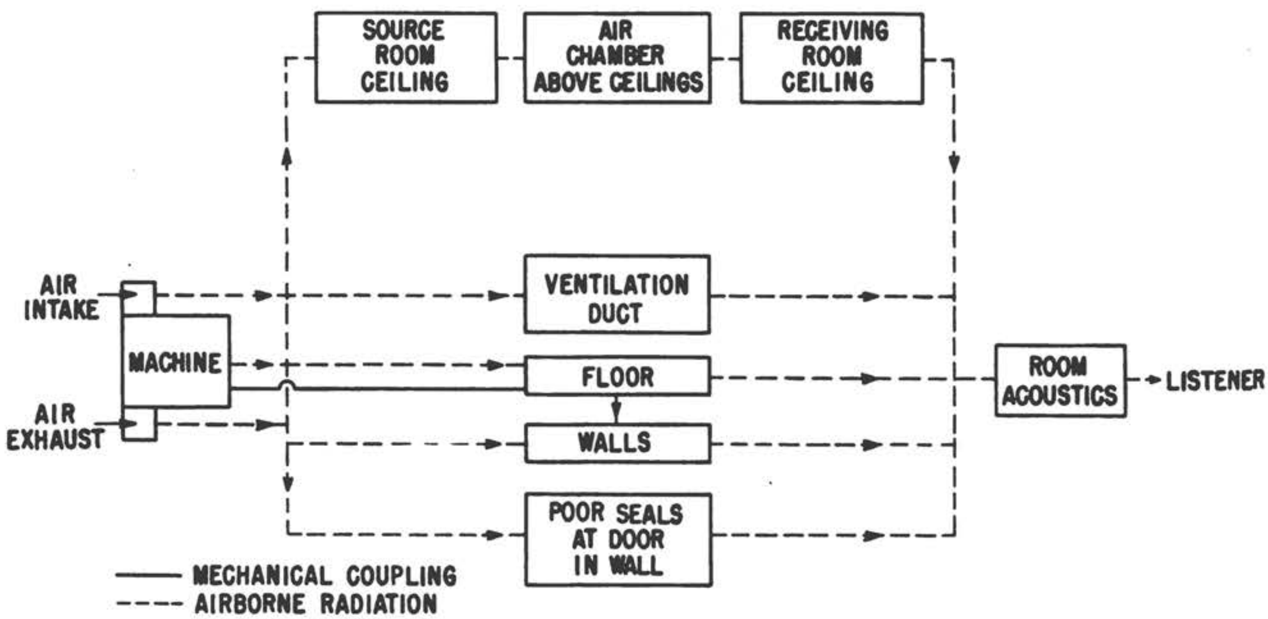


Figure 2 - Block diagram of noise transmission paths of Figure 1.

accomplished either by selecting quiet equipment, or if this is not practical, by modifying some of the transmission paths already outlined.

Noise Control at Source

There are a few ways by which builders and architects may consider noise control at the source. These include:

1. Elimination of necessity for a given machine.

2. Combination of functions to fewer machines or assemblies.

3. Substitution of inherently quieter equipment performing the same function.

The first two possibilities should always be considered, but obviously depend primarily upon the particular problem at hand. Let us, therefore, confine our attention to the third possibility. As an approach to such an endeavor we might examine Table 1 which illustrates some of the principal causes of noise in mechanical equipment. [1] These are items which should be carefully considered throughout the entire life of a machine. They are first of interest to the designer, then to the quality control engineer, then to the customer or architect who should consider such points with regard to construction and performance specifications. (Actually noise is merely a specific type of performance.) Finally, of course, the maintenance man must be concerned with many of these items.

TABLE 1

CAUSES OF NOISE

1. Static and dynamic unbalance	10. Improper assembly
2. Bearings	11. End play
3. Air cooling systems	12. Hydrodynamic forces in cooling water or oil.
4. Commutator and slip ring brushes	13. Rubbing and scraping
5. Poor alignment	14. Alternating reaction of driven load
6. Loose parts	15. Variations in magnetic forces
7. Gearing and linkages	16. Loose laminations
8. Bent or bending shafts	17. Magnetostriction
9. Loose fit of mechanical parts	

Unbalance is one of the major causes of vibration, and hence noise, especially in high-speed rotating electrical equipment. Quiet operation may well require tighter balance specifications than those customarily employed. Bearings are another common source of noise. Sliding contact bearings are usually quieter than rolling contact bearings and hence are to be preferred for large equipment. However, lubrication problems sometimes make them impractical, especially for small equipment. Where used, sliding contact bearings should be held to the closest possible tolerances, and end play restricted by thrust bearing faces.

Ventilation fans also often create noise problems. This can be minimized somewhat by improved design of the blades and air flow passages. However, in many cases the only practical solution involves the installation of some form of acoustic duct. Some manufacturers are now able to supply such acoustic treatments, upon request, as an integral part of the machine.

I will not attempt to elaborate upon all the remaining causes of noise indicated in *Table I*. Actually, this list is intended only to point out that noise may originate from many causes, and that noise control requires one to pay careful attention to many details.

I would like, however, to mention briefly one other general type of noise. This is noise due to gears. It is commonly believed that gear noise consists largely of a series of discrete tones at the tooth meshing frequency and harmonics thereof, plus a few rubbing and scraping sounds. This is not always true.

During a recent noise study of a gear-motor combination at our laboratory, an intense pure tone was observed at a frequency of only about 90% that of the tooth-meshing frequency. This tone was present for several different production-line units, and its intensity often exceeded that of the tooth-meshing tone by 5 decibels, or more.

Investigation disclosed it to be due to a cyclic error produced by the gear cutting machine. The worm wheel of this machine turns once per revolution of the gear being cut, and for this particular machine it had 120 teeth while the gear being cut had 131 teeth. In use, then, the new gear produced a pure tone at a frequency of 120/131 times the tooth meshing frequency. Errors of this sort have actually been traced through several generations of gears. The solution, of course, involves applying closer tolerances to gear cutting operations.

With regard to the selection of quiet equipment, many manufacturers are now (or soon will be) in a position to supply noise data in terms of the total radiated acoustic power as a function of frequency. From such information, plus a knowledge of building acoustics, etc., the sound pressure level at the location of interest may be estimated with reasonable accuracy. A comparison with the applicable noise criterion then serves to determine the degree of sound reduction required, if any. Briefly, the relationships involved are as follows: [2,3]

Definition Sound Power Level (re 10^{-13} watts) is given by

$$L_W = 10 \log \frac{W}{10^{-13}} = 10 \log W + 130$$

where W is the sound power in watts for the frequency range of interest.

Reverberant Field Computation (Applies to most rooms at 5 to 10 feet or more from the source)

L_p = average sound pressure level re 0.0002 microbar

$$\approx L_W - 10 \log \frac{a}{4}$$

where

$$a = \sum_{i=1}^{n} \alpha_i S_i = \alpha_1 S_1 + \alpha_2 S_2 + \ldots + \alpha_n S_n$$

represents the total sound absorption in the room. References 4 and 5 will provide considerable useful information for such calculations.

Free Field Computation (Applies to very large or highly sound treated rooms, or outdoors)

L_p = average sound pressure level re 0.0002 microbar

$$\approx L_W - 10 \log 4\pi r^2$$

if spherical radiation is assumed, or

$$\approx L_W - 10 \log 2\pi r^2$$

if hemispherical radiation is assumed, where r is the distance from the source in feet.

General Case (Transition region between free and reverberant fields - reduces to these special cases at either extreme)

L_p = average sound pressure level re 0.0002 microbar

$$\approx L_W + 10 \log \left\{ \frac{Q}{4\pi r^2} + \frac{4}{a} \right\}$$

where Q = 1 for spherical radiation and Q = 2 for hemispherical radiation.

The above relations hold only where the listener is in the same room with the noise source. Where more than one room is involved, it is necessary to take into account the various possible sound transmission paths as indicated previously. However, the total sound power radiated by the noisy machine is still a quantity of fundamental importance.

As an example of the type of acoustical information which is rapidly becoming available for various types of machines, Table 2 lists sound power levels (re 10^{-13} watts) by octave bands for three different sizes of motors. These data were obtained from the G.E. Noise Test Data Book for Medium and Small A.C. Motors.

TABLE 2

TYPICAL SOUND POWER LEVELS FOR MOTORS

		Frequency Bands, cps							
Horsepower	overall	20 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
10	83	77	71	74	80	72	70	62	51
100	99	93	91	92	92	90	86	85	81
1000	106	102	101	97	97	92	92	82	79

In case the numbers of Table 2 appear large, it should be remembered that they are not conventional sound pressure levels. Actually, the sound levels in a medium sized room would fall about 20-30 db below the tabulated values.

Not all objectionable sounds are due to large noisy machinery. Most people consider a fluorescent light to be a relatively quiet device. However, especially where a large number of lights are employed, ballast noise may become quite objectionable. For this reason, the General Electric Company has produced, for several years, sound rated ballasts. A Ballast Sound Rating Calculator - a form of a circular slide rule is also available.[6] This calculator takes into account the room acoustics, the number of ballasts, and the ambient sound level. It then determines the type of ballast required (sound rating) for a satisfactory installation from the noise standpoint. The ballast ratings are in the form of letters - A through F.

Incidentally, it should be mentioned that ballast noise is usually radiated, not from the ballast case itself, but rather from the lighting fixture which acts as a sounding board and amplifies the noise. The G.E. ballast ratings are determined by using a standard well-designed, substantial fixture. If flimsy fixtures with loose louvers, etc. are employed, the noise may be increased considerably. An obvious solution would seen to be mechanical isolation of the ballast from the fixture. However, the fixture is usually also the heat radiator for the ballast and vibration isolation would ruin the heat transfer. For new installations with false ceilings, it is possible, though, to mount the ballasts on isolated heat radiators in the dead air space above the false ceiling. The slight sound attenuation offered by the false ceiling would then be sufficient to eliminate the noise problem.

Robbins and Myers, Inc. have devised a somewhat similar calculator for use in predicting room noise due to fans.[7] This calculator also takes into account room acoustics and ambient noise. Perhaps the major difference is the fact that their scheme is based upon a fan loudness rating in sones.

Vibration Isolation

Returning to the system concept, once we have progressed beyond the basic noise source - the machine itself - we must consider means of isolation. Such isolation may be either for airborne acoustic waves or for structure-borne vibration. Consider first vibration isolation. If we follow the conventional approach, we assume the machine to be a rigid mass, the isolator to be a massless spring in parallel with a viscous damper, and the foundation to be extremely rigid. Transmissibility curves such as given in Fig. 3 may then be calculated. Here

$$\beta = \frac{\omega}{\omega_n} = \frac{f}{f_n}$$

$$\omega_n^2 = \frac{k}{m}$$

while

$$Q = \frac{k}{\omega_n c}$$

is a measure of damping. (The ratio of damping present to critical damping is 1/2Q.) Thus, about a 10 to 1 reduction in vibration - or an attenuation of 20 db - would be expected for a frequency about 3 times the resonant frequency, and for higher frequencies the vibration isolation should increase markedly. This is actually the basis upon which most vibration isolators are chosen and installed.

In many cases, however, measurements do not verify this elementary approach, especially at frequencies above about 100-200 cps. The reason is that the assumptions behind this theory are often invalidated. The machine itself is not a concentrated mass, since it has many resonant frequencies. At high frequencies, the isolator does not act as an ideal spring with a parallel dashpot - in general, it has standing wave resonances which affect its transmissibility, and the damping is not always of the viscous type. These effects are indicated in Fig. 4, and it is of interest to note that increased loading improves the situation.[8]

Perhaps most important of all, the stiffness of the foundation is usually far less than infinity.

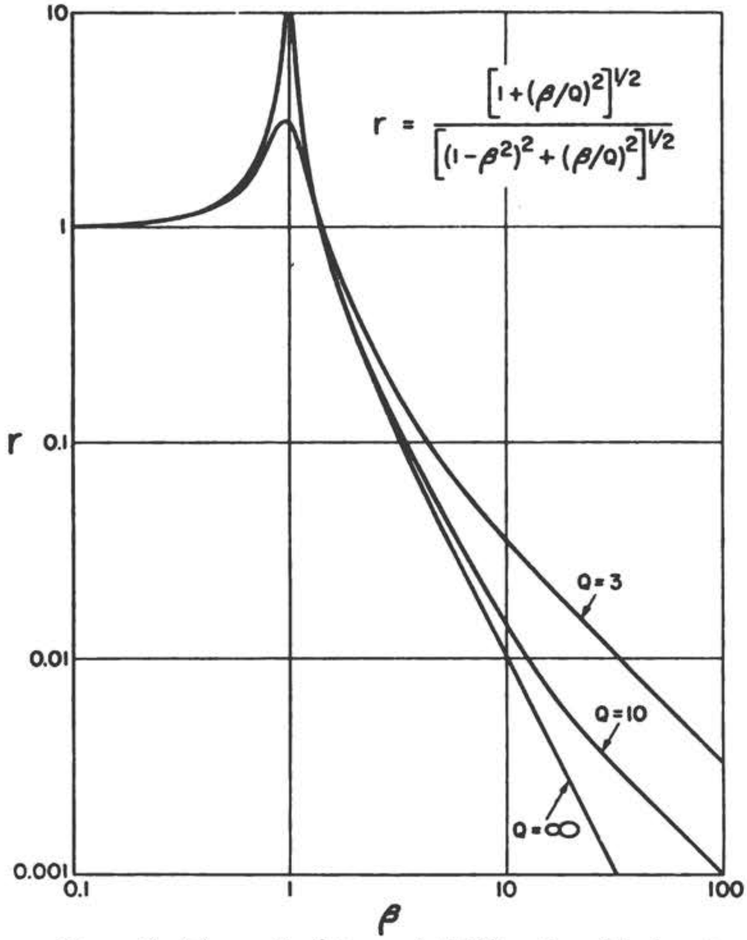


Figure 3 – Theoretical transmissibility of an ideal system consisting of a rigid mass, a massless spring in parallel with a viscous damper, and an infinitely rigid foundation. (After Plunkett)

However, if one knows the actual mechanical mobility of these three elements – the ratio of vibration velocity to the applied force driving the element – it is still possible to calculate the transmissibility. The result is most simply expressed in the form:[9]

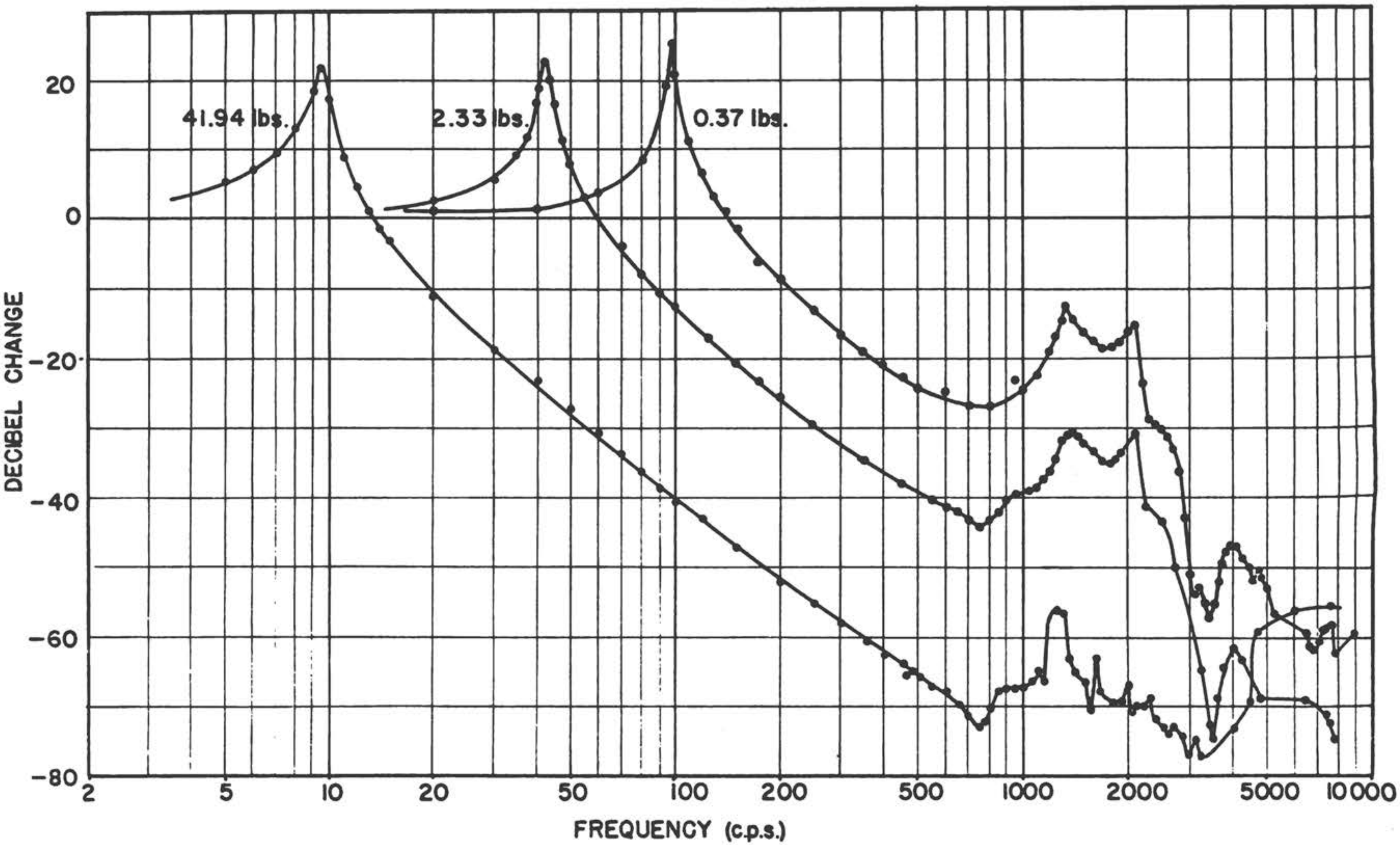
$$\tau = \frac{M_{machine} + M_{foundation}}{M_{machine} + M_{isolator} + M_{foundation}}$$

where M is mobility as defined above. From this relationship, it is obvious that the isolator is ineffective unless its mobility is high in comparison with that of both the machine and the foundation. The calculation is complicated, of course, by the fact that any of the mobilities may be positive or negative, and pure,imaginary or complex. Thus, more than one resonance may exist – and usually does.

The simplest case to consider in detail is where both the isolator and foundation behave as pure springs, while the machine acts as a pure mass. In this event, the transmissibility becomes

$$\tau = \frac{-j/\omega m + j\omega/k_1}{-j/\omega m + j\omega/k_2 + j\omega/k_1}$$

where ω is the driving angular frequency, m is the machine mass, and k_1 and k_2 are the stiffnesses of



— Decibel change vs. frequency

Figure 4 - Measured attenuation of a simple vibration isolated system consisting of a mass, shear type rubber mount, and rigid foundation. (After Muster)

of the foundation and isolator respectively. This expression is plotted in Fig. 5 for several ratios of k_2/k_1. In general, the resonant frequency is reduced, and above resonance there is an antiresonance

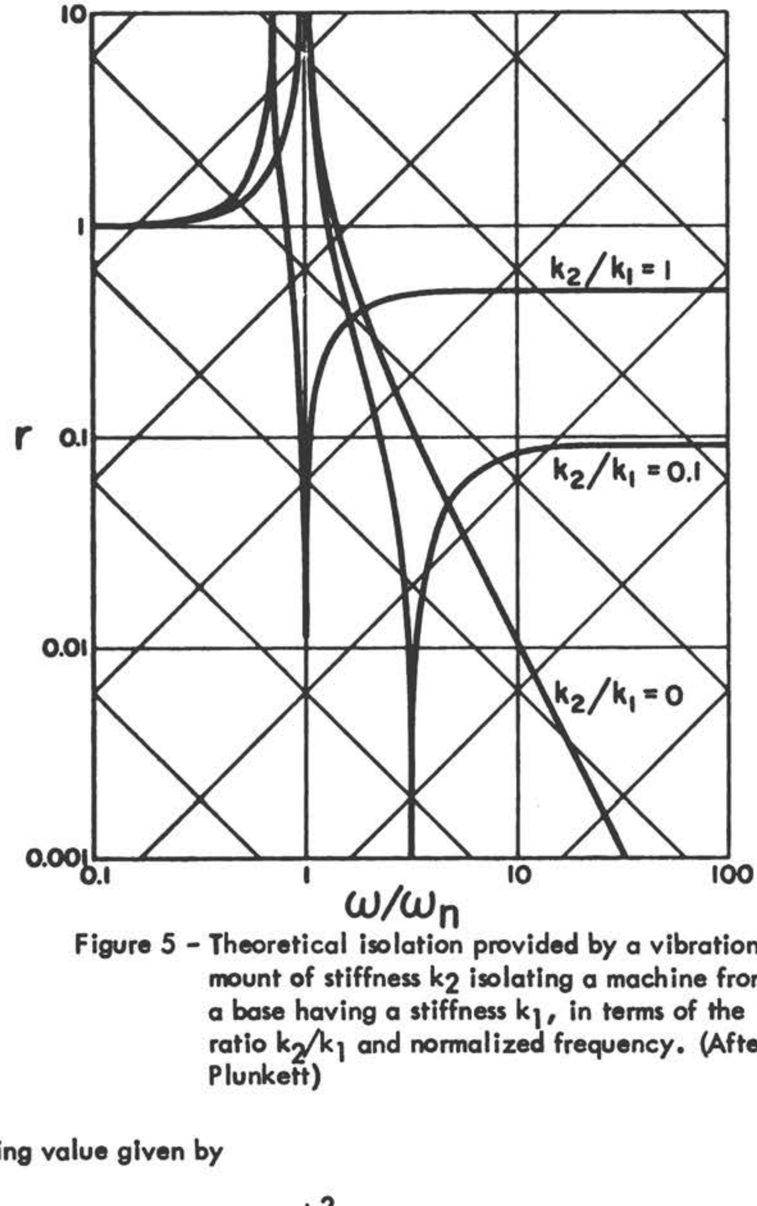


Figure 5 - Theoretical isolation provided by a vibration mount of stiffness k_2 isolating a machine from a base having a stiffness k_1, in terms of the ratio k_2/k_1 and normalized frequency. (After Plunkett)

followed by a limiting value given by

$$\tau = \frac{k^2}{k_1 + k_2}$$

Expressing this another way, if we assume a foundation stiffness of 2×10^5 lb/in., the isolation to be expected at high frequencies can be related to the machine weight and the natural frequency of the system (on a rigid foundation) as indicated in Fig. 6.[10] From these curves, it is apparent that the heavier the machine the lower the natural frequency must be to maintain the same isolation.

It should be remembered, of course, that we are still considering a rather simple system. In general, the foundation and the isolator are not simple springs, and the machine will probably not behave as a pure mass. However, the original equation still holds. Fig. 7 shows how calculations based upon actual measured mobilities have agreed with measured isolation.

Perhaps the most important conclusion to draw here is thot one should be extremely careful about

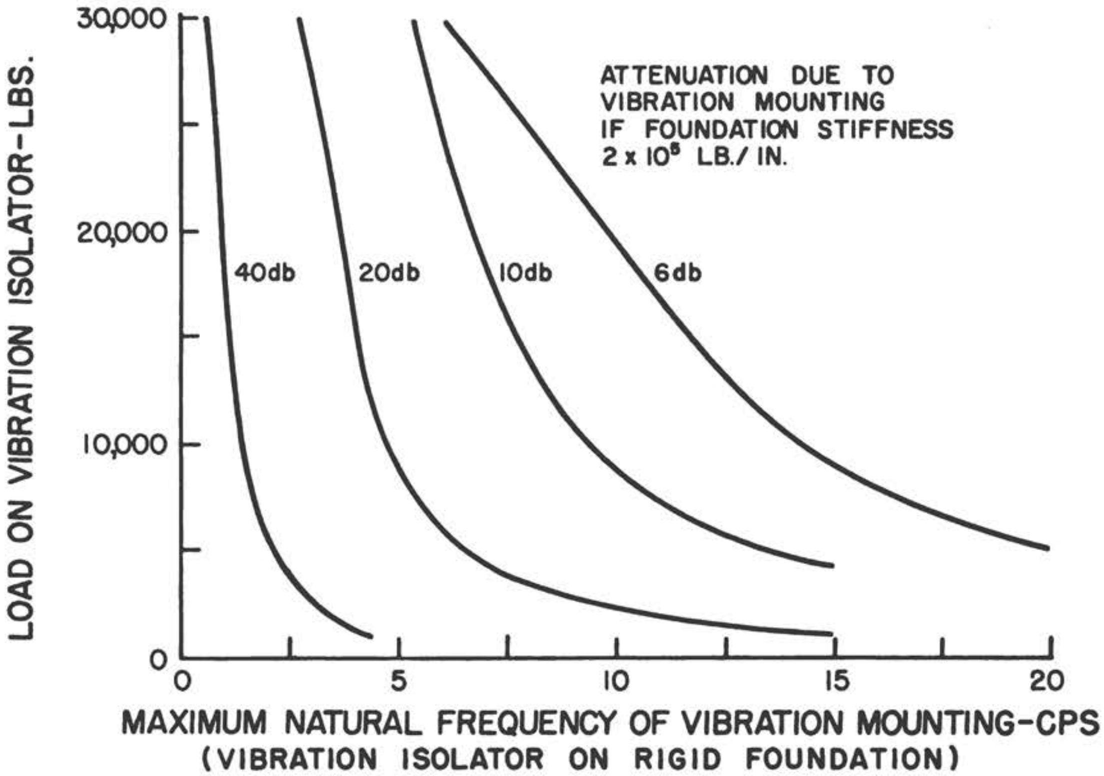


Figure 6 - Effect of load and natural frequency on the attenuation of a vibration mount, assuming foundation stiffness to be 2×10^5 lb/in.

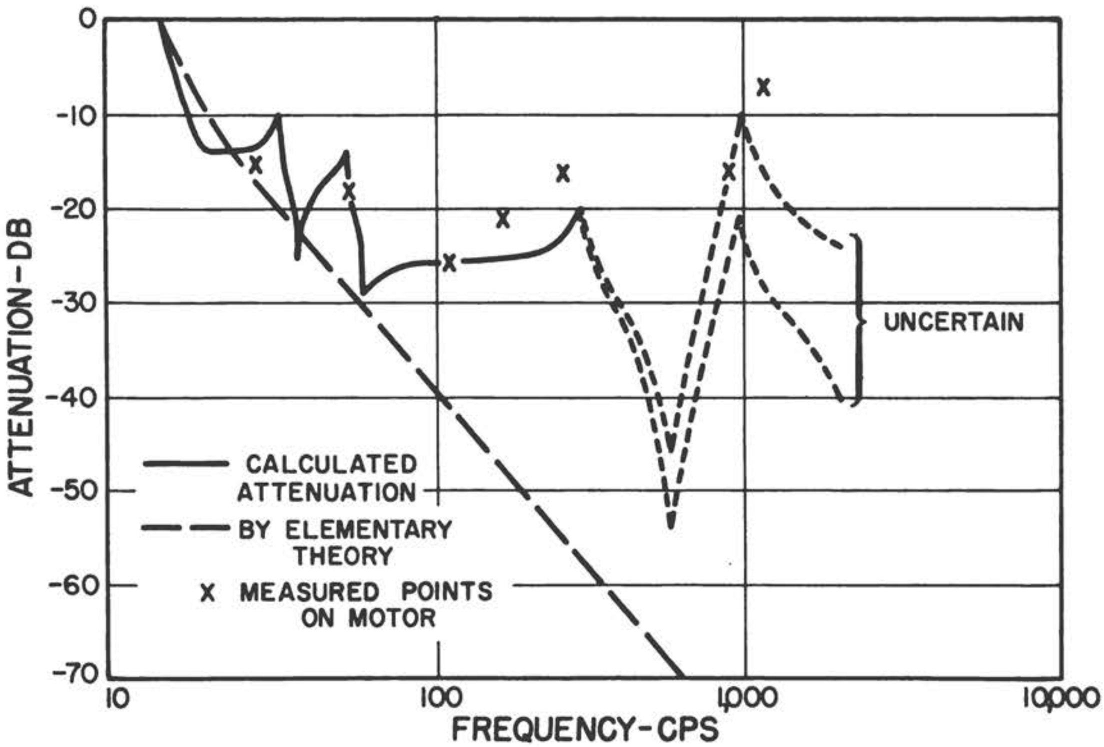


Figure 7 - Predicted values, in decibels, of vibration reduction using both elementary theory and actual mobility calculations. Measured values of attenuation are also indicated. (After Plunkett)

choosing the foundation upon which machines are to be mounted. In one case with which I am familiar, an air conditioning system rated at about 40 tons, or a half-million BTU per hour, was mounted on the roof of a small assembly room. Although vibration isolators were used, the roof was so flexible that their effectiveness was nullified. The result was a severe noise complaint. In order to solve the problem, it was necessary to mount the equipment on extremely soft springs in tension (a natural frequency of about 1 cps) so that the mobility of the isolator became appreciably greater than that of the roof.

From experiences such as these, it can be concluded that the best place to mount noisy vibrating machines is on a rigid ground or basement floor. In fact, in extreme cases it is advisable to make a break in the floor around the machine and support this floor section upon separate footings.

One other point might be mentioned on isolation mounts. In order to minimize coupling between several possible modes of vibration, it is desirable that the mounts be symmetrically located about the center of gravity of the machine, and that the mounting feet be placed in such a manner that the isolation mounts lie in one plane which also passes through the center of gravity.[11]

Enclosures

Let us turn now to the problem of airborne noise radiating from a machine. Above 100-200 cps, airborne sound usually exceeds structure-borne sound in importance. If this is a problem, and the actual noise-generation mechanism cannot be controlled, an enclosure about the machine may well be the only practical solution. However, there are several points to watch here.

If a rigid walled box constructed of a material with a sound transmission loss of 30 db - at the frequency of interest - is placed over the machine, perhaps bolted to it, the noise reduction will in all probability be far less than 30 db. In fact, it is entirely possible that the noise may be increased. During a recent turbine noise investigation we found just such a case. Exterior panels were rigidly bolted to supports protruding through an insulation lagging. The coupling was sufficient to cause the panels to become sounding boards for the high-frequency turbine-bucket whistle. As a result, the sound level in the building increased by about 5 db when the exterior panels were attached. The solution obviously involves vibration isolation of the enclosure from the machine.

Another point to consider is the fact that the sound level near a machine - within the enclosure - will be higher than it was at the same location before the enclosure was placed over the machine. This is due to the existence of standing waves which cause the sound pressure to build up. Hence, the full benefit of an enclosure is not realized unless sound absorbing material is placed on the inner walls to minimize this effect.

The importance of making an enclosure as tight as possible has already been discussed in a previous paper. However, in many cases, an airtight enclosure is impractical. Some provision must be made for air cooling, or perhaps for exhaust gases. In such cases, sound treated ducts offer one solution.

In general, the sound attenuation of a duct, in decibels at a given frequency, varies almost directly with the duct length, and roughly directly with the ratio P/A, where P is the perimeter of the duct cross-section, and A is the area of the cross-section. Hence, to increase the sound attenuation, ducts are often subdivided or even honey-combed with absorbent splitters. It is also possible to purchase package sound attenuators from several manufacturers for such purposes. Specifications on such attenuators usually give pressure drop characteristics as well as sound attenuation.

Plenums

An alternative approach to the air passage sound treatment problem involves the use of acoustical

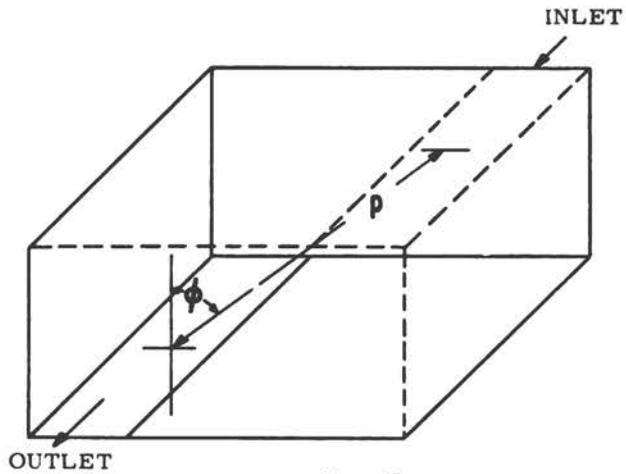


Figure 8

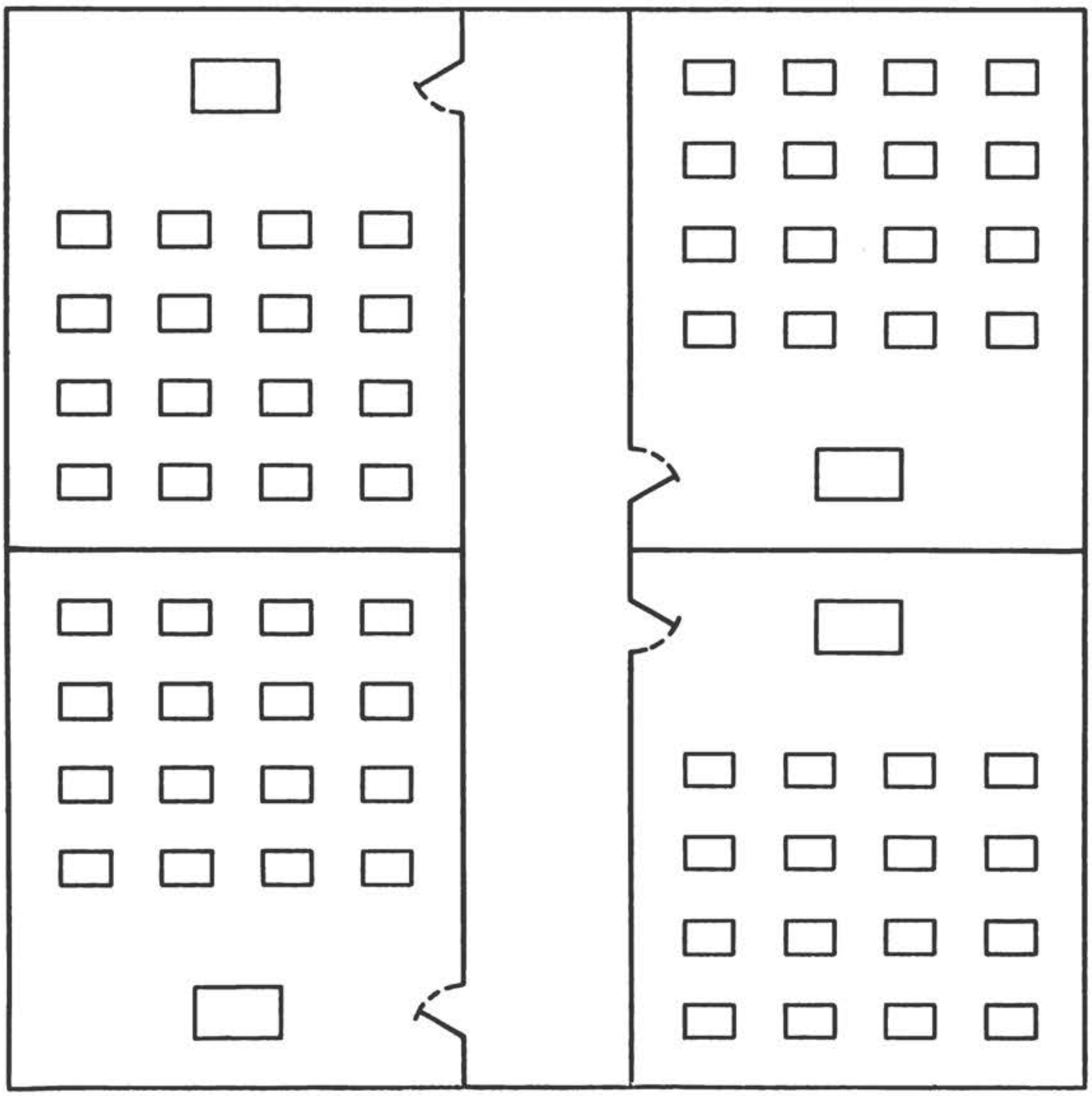


Figure 9

plenum chambers.[12,13] Fig. 8 illustrates the general principle. The intake and exhaust openings are usually placed at opposite ends of a diagonal - as far apart as possible. All interior walls are lined with a good sound absorbing material. The sound attenuation to be expected from such a plenum may be estimated from the relation:

$$\text{Attenuation in db} = 10 \log_{10} \frac{1}{S\left[\frac{\cos\varphi}{2\pi d^2} + \frac{1-\alpha}{a}\right]}$$

where

a = total absorption within chamber, sabines

S = plenum exit areas, square feet

d = diagonal distance from entrance to exit, feet.

α = absorption coefficient of lining material

φ = angle between the diagonal, d, and the normal to the plenum openings.

Tests have indicated that this equation is generally pessimistic by 5 db or more at low frequencies, but checks fairly well for frequencies where the plenum dimensions all exceed one wavelength.

As a closing remark, I would like to suggest that this same approach may be employed to minimize cross-talk between rooms opening upon a common corridor. Fig. 9 shows a plan view of such a situation. If the walls and ceiling of the corridor are sound treated, it will act as an acoustical plenum and noise reductions of 20 db or more may be achieved.

References:

1. "Designing for Quiet Operation", BuShips Note 9110. August 1, 1958.

2. R. J. Wells, "Apparatus Noise Measurement", Power Apparatus and Systems, pp. 1170-1173, December 1955.

3. L. L. Beranek, "Acoustics", p. 361, McGraw Hill, 1954.

4. "Sound Absorption Coefficient of Architectural Acoustical Materials", Bulletin of Acoustical Materials Association.

5. H. Burris-Meyer and L. Goodfriend, "Acoustics for the Architect", Reinhold, 1957.

6. General Electric Company, Section GEN-147, Schenectady 5, N.Y.

7. Fan Noise Calculator, Propellair Division, Robbins and Myers, Inc., Springfield, Ohio. Also, R. A. Gerlitz, "New Method Simplifies Predicting Noise Levels", pp. 122-126, Heating Piping and Air Conditioning, April 1958.

8. "Resilient Mountings for Reciprocating and Rotating Machinery", Engr. Report No. 3 (Confidential), O.N.R. Contract No. N7-onr-32904

9. R. Plunkett, "Interaction Between a Vibratory Machine and Its Foundation", pp. 18-22, Noise Control, January 1958.

10. R. O. Fehr and R. J. Wells, "Noise Reduction of Machinery and Vehicles", pp. 30-40, Noise Control, January 1955.

11. C. E. Crede, "Vibration and Shock Isolation", Wiley, 1951.

12. R. J. Wells, "Acoustical Plenum Chambers", pp. 9-15, Noise Control, July 1958.

13. R. J. Wells, "Noise Control Problems in Air Conditioning Equipment", pp. 138-143, Heating Piping and Air Conditioning, August 1957.

14. C. M. Harris, "Handbook of Noise Control", McGraw Hill, 1957.

Specifications for the Control of Noise from Mechanical Equipment

By Alfred L. Jaros, Jr.*
Jaros, Baum & Bolles, Engineers

Editor's Note: Departing from its usual procedure, the Building Research Institute has not deleted references in this paper to trade names, since this paper is written as a model for specification. The author has mentioned these names with the understanding that they should be considered only as what the specification writer happened to specify here, and not as the author's recommendations or as standard practice.

* * * * * * *

1. Since the time available to any one speaker is far too short for adequate presentation of this subject, the writer's remarks have been supplemented by appended material. Essentially, this consists of actual "extracts" quoted from specifications prepared in recent years for projects, in which keeping mechanical noise from annoying tenants was important. To each extract, there are attached Notes (commenting on the reasons for, or the application of, that particular portion of the specifications); such notes are only for this paper, and of course would not appear in an actual specification.

2. In relation to the appended material, there are a number of considerations which the reader should bear in mind:-

(a) The material quoted should in no case be regarded as "the latest," or as a complete specification for those items listed. Only those parts having some bearing on the issue of sound control have been quoted. To avoid needless length, other parts of the same paragraphs have generally been ommitted.

(b) Much of the "detail" quoted was worked out specifically to fit the individual needs of a particular project at that time. In other types of buildings, or other kinds of air-conditioning systems, such details might change; they will also change with time.

(c) The material quoted should not be considered as including all possible measures. Others will no doubt occur to the user, as the needs of his projects develop. Likewise, trade-names where quoted should be considered only as what the writer happened to specify here, and not as a recommendation or standard practice.

(d) The criteria set up (in Paragraph 42-5) as to acoustic results were specifically for a high-class office building in a busy part of a modern city; higher or lower acoustic levels might be considered appropriate for other kinds of buildings, or for other locations. As stated in Note J, they might better constitute a separate specification "Article." Also, these criteria were based upon

* ALFRED L. JAROS, JR. is a partner in the firm of Jaros, Baum & Bolles, consulting engineers, New York. He graduated from Columbia with a degree in Mechanical Engineering, is past president of the New York Association of Consulting Engineers, and belongs to the American Society of Mechanical Engineers, the National Society of Licensed Professional Engineers, and the Building Research Institute.

the writer's personal experience and opinion as to what could be secured at that time with commercially practicable, good equipment.

(e) The writer realizes that present-day thinking in the acoustic field is veering from the (over-all noise) decibel to other methods of definition (more representative of the response of the human ear). However, the criteria set up in the appended material are on such a basis as can be readily and directly checked with portable equipment available to the engineer and contractor.

3. A most important requirement for protection of "occupied" spaces against noise originating in machine rooms (and which cannot be defined in the mechanical specification) is that where refrigerating compressors are mounted elsewhere than on a solid foundation on ground -- for example, in a penthouse above the main roof level -- the architectural and structural designers should provide a sufficiently heavy stone-concrete slab, amply reinforced, and well-supported structurally, under the entire machine room. Nothing will more effectively prevent transmission of vibration or noise resulting from mechanical equipment in such a room into other parts of the building than an ample mass of rigid masonry between the machine room and other areas.

For the same reason, walls of machine rooms should be of solid masonry, doors should fit tight and probably may need gaskets. Even quite small openings will permit the transmission of an astonishing amount of noise.

4. For similar reasons, masonry shafts which either enclose high-velocity supply ducts, or which act as return ducts from the various floors of a tall building, should be built of solid masonry (not of poorly-jointed hollow blocks), made as tight as possible around all necessary openings, and where building space-conditions permit air-pressure reducing valves and "following" attenuators should be inside of the shaft rather than in the hung-ceilingoutside. Necessary access doors, again, should fit tight and be gasketed.

5. By the same reasoning (as in Para. 4), sound attenuators on high velocity ducts should be in the machine room or elsewhere above the heavy masonry slab in the case of penthouse fan-rooms. Attenuators located above an ordinary hung ceiling (in the top floor) will not prevent a certain amount of the noise, from the fans or other machine room equipment from being "radiated" from the sheet metal ducts ahead of the attenuators into the ceiling space and thence into occupied spaces. Where attenuators have to be located in such hung ceilings of top floors, provisions should be made for encasing the and the ducts leading to them, in solid masonry of some type.

6. In especially critical areas, the engineer should specify that manufacturers or contractors must construct full-scale mock-up installations of the particular device or scheme under conditions defined to closely parallel those expected at the building; and must perform such tests in his presence as will enable him to verify that the performance falls within acceptable limits. Such tests should precede final acceptance of the device concerned.

7. It should be noted that specifications usually will not give any data as to the method of computing the attenuating effect of the sound-attenuators designed or selected for each duct systems; this is a fairly complex computation calling for some skill and knowledge and the design or selection of attenuators should also take account of the degree of attenuation resulting from the duct system itself (from turns in ductwork, length of ducts, from passage of the air, from the fans, through subsequent coils or other devices which would have any attenuating effect, etc.). Naturally, the designer must also know the sound-level and sound-"spectrum" produced by the fans. This is one reason for requiring the contractor to submit such data for the actual make of fans he wishes to use. Suffice it to say that all of this computation, etc., is a "design" problem affecting layout and drawings and not quite germane to the subject of specifications.

"9. GENERAL AS TO HEATING, VENTILATING AND AIR CONDITIONING

901. The work throughout shall be executed in the best and most thorough manner, under the director of, and to the satisfaction of, the Architects and Consulting Engineers who will jointly interpret the meaning of the drawings and specifications, and shall have the power to reject any work and materials which, in their judgment, are not in full accordance therewith. Wherever the phrase 'NO NOISE' is used in this specification, it shall mean no noise (in excess of the requirements of Para. 4205) sufficient in the judgment of the Architects and Engineers to be objectionable to occupants."

Note A. It is important to define who will pass on the acceptibility of the results. The last sentence (or a similar one) results from complaints or questions heretofore raised by contractors who objected to such phrases as "no noise audible outside of the machine rooms" in earlier specifications on the ground that it is commercially impracticable to eliminate, literally, all noise. This later phrasing has been acceptable to bidders in recent cases.

"10. APPROVALS, SUBSTITUTIONS, ETC.

1001. Wherever hereinafter the words 'for approval', or 'approved', are used in regard to manufactured specialties, or wherever it is desired to substitute a different make or type of apparatus for that specified, all information pertinent to the adequacy and adaptability of the proposed apparatus shall be submitted to the Architects and Consulting Engineers, and their approval secured before the apparatus is ordered.

1002. Wherever operating results (such as quantity delivered, pressure obtained, sound-level limitations, or the like) are specified, or a definite make and size of apparatus is specified for which such quantities are readily determinable, the make and size of apparatus it is proposed to use must conform substantially (in regard to such operating results) to the quantities specified or implied.

1003. Approvals for equipment starred (*) in Paragraph 1301 will be given only after the receipt of complete and acceptable performance data showing performance of all equipment over the complete load-range, in tabular or graphical form as directed, as well as weight, dimensions, materials, and other usual data."

"11. SUB-CONTRACTS, ETC.

1101. Wherever hereinafter guarantees of durability, operating capacity, proper functioning, sound-level limitations, or the like are called for -- or wherever it is specified that the manufacturer shall furnish test certificates or performance curves, shall supervise the installation of his apparatus, test or adjust it after installation, keep it in repair for a stated period, or render other similar services, This Contractor will be held responsible for the performance of the specified service under the actual conditions of installation. The same shall apply to cases where special adjustment or other services are necessary to insure the proper and efficient functioning of apparatus, even though not specifically hereinafter called for. It is intended that the entire plant, when finally delivered, shall be ready in every respect for satisfactory and efficient operation, and This Contractor is hereby made responsible for this result.

1102. In any case where This Contractor's own employees cannot adequately perform the above described service, he shall stipulate such performance in his contracts with sub-contractors, manufacturers, etc., or else shall subsequently pay them any additional fees required therefor."

"13. DRAWINGS AND INFORMATION REQUIRED

1301. Shop drawings of complicated portions of piping, ductwork, etc., (or of portions involving major changes from what has been approved), shall be submitted to the Architects and Engineers and approval secured before the work is fabricated and installed. Manufacturers' and shop drawings of the following apparatus -- also tabulations or graphs where necessary -- giving full information as to dimensions, performance, materials, fitness, sound-levels, and other pertinent facts, shall be submitted to the Architects and Engineers and their approval secured before the apparatus in question is ordered, built or installed.

*Water Circulating Pumps
*Refrigeration Unit
*Under-Window Units
*Fans, all types
*Air Reducing-Valves
*Sound Traps
*Grilles, Registers and Diffusers
*Air Mixing Units and Air Valves
Motors
*Foundation Details
*Cooling Tower"

Note B. Materials quoted from Articles 10, 11, and 13 extends the control of the Architects and Consulting Engineers, so that the intended results should not be voided as a result of accepting other makes of equipment, or of claims that the responsibility for unsatisfactory results is not This Contractor's, but that of some manufacturer or supplier.

* - See Paragraph 1003

"15. TESTING AND ADJUSTING

1501. After the entire installation has been completed, This Contractor shall operate the equipment under normal conditions during both winter and summer seasons, making all required adjustments to balancing valves, air vents, automatic controls, circulators, air dampers, grilles, pressure-reducing valves, fans, refrigerating equipment, dehumidifiers, etc., until all performance requirements are met.

1502. All fan systems shall be operated for as long a time as will be necessary to test air flow from all openings, acoust results, etc., make all necessary damper and other adjustments until even distribution and quiet operation shall be obtained throughout the various systems, with air quantities required at each outlet or inlet as directed on the drawings. Test reports showing pertinent operating data, such as cfm at each outlet, fan rpm, room sound contour levels, etc., shall be submitted to the Architects and Engineers for record.

1505. The entire testing and adjusting program of the air distribution system shall be performed by qualified personnel in the employ of This Contractor, but not actively engaged in the task of installing this system. This Contractor shall submit a list of personnel or the names of sub-contractors, with qualifications, to the Engineers for approval before commencing with the testing and adjusting work. He shall also submit a detailed procedure for approval before starting the testing and adjusting. Upon completion of the work, This Contractor shall certify that the systems are delivering the air quantities, pressure, maximum sound-levels (or less), etc., shown on the Engineers' design drawings or specified. Said certification letter, along with an extra set of test reports, shall be submitted to the Architect."

Note C. (Paragraphs 1501, 1502, and 1505). Particularly in the case of air-handling units and systems, proper testing and adjusting upon the completion of the installation is an essential factor in securing the intended results. It should therefore be required and defined.

"19. TEMPORARY HEAT FOR CONSTRUCTION PURPOSES

1901. Temporary heat will be provided by the General Contractor.

1902. If the installation of the heating and air-conditioning system if far enough advanced, some portions of it may be used for temporary heat, subject to the approval of the Architects and Engineers. Window units may be used as gravity hot water convectors only. All elements of direct radiation may be used, if not exposed to the weather.

1903. Under no circumstances shall any air-handling system be used as a source of temporary heat, until the building has progressed to a point where no dust, dirt or rubbish are on the premises served by such air-handling systems."

Note D. (Temporary Heat) The important factor here is not to allow any air-handling equipment to be used for temporary heating at times when dirt or rubbish might get into the ducts or other parts of the system as a result. Much annoying noise can result from sand or other small articles being propelled around in ductwork.

"26. INSTALLATION OF PIPING

2603. Pipework shall conform fully to the following requirements.

(a) Piping shall be properly graded to secure easy circulation, and prevent noise and water hammer. Steam piping shall pitch at least 1 inch in 20 feet; return piping shall pitch 1 inch in 20 feet; water piping shall pitch 1 inch in 60 feet. Steam and return piping shall pitch downward in the direction of flow. Water piping shall pitch upward in direction of flow. Dirt pockets shall be provided at all riser heels, low points, and other places where dirt and scale may accumulate. Proper provision shall be made for expansion and contraction in all portions of pipework, to prevent undue strains on piping or on fixtures, or apparatus connected therewith."

Note E. Proper pitching of pipes is important to avoid water hammer or other sources of noise.

"34. CENTRAL CHILLED WATER PLANT

3404. Compressors

(a) Compressor rotors shall be statically and dynamically balanced.

(h) The complete compressor-motor-cooler-condenser unit shall be installed on a fabricated steel base with suitable spring vibration-isolators. Mounting details shall be as submitted by the manufacturer of the machine, and as approved by the Architects and Consulting Engineers.

(i) The steel base with isolators for the refrigeration unit shall be set upon a concrete pad at least 4" high over the complete floor area of the equipment. This pad will be built by the General Contractor, but necessary anchor bolts, etc., and steel inserts shall be furnished and set under this section."

Note F. (Refrigerating Compressors) Proper balancing of rotors, and proper mounting of compressors on vibration-absorbing bases, is a most important factor. Compressors will generate much noise in the machine room, and the effort here should be to avoid "carrying" this noise into other parts of the building. Sub-paragraphs (h) and (i) might well be moved to what is called herein Paragraph 6404.

"35. COOLING TOWER

3506. Fans shall be manufacturer's standard induced-draft fans, shall be of stainless steel or Monel metal or cast aluminum alloy. Allowable tip speed shall not exceed 10,500 feet per minute. Fan wheels shall be dynamically balanced. Each fan shall be driven through a right angle, single-reduction, spiral-bevel gear reducer with AGMA Class II rating, 50% in excess of the nominal motor rating.

3507. For each cell, the motors, gears, and fans shall be mounted on a common structural frame -- mounted on the tower structure by approved neoprene-in-shear isolation equal to "Type RG-galvanized iron construction" made by Vibration Mountings, Inc.

3508. Motor shall have a nameplate rating in excess of the required input to the gears."

Note G. Cooling-tower fans, and their drives, should be well made and as quiet as feasible. This is both to minimize vibration which might be carried through the supports of the cooling-tower into the building structure, and also to reduce to a reasonable degree the sound emitted outdoors, which could sometimes annoy nearby buildings.

On very high-class projects, the following might be added to cooling tower specifications: Between the cooling tower framework and the dunnage beams below, there shall be four layers of 3/8" ribbed neoprene pads (of Vibration Mountings, Shearflex, or equally approved make), set with ribs of adjacent layers at right angles, steel skin stock between layers and steel mounting plate above and below. Loading shall not exceed 50 psi; static deflection shall approximate 1/4" total. Through-bolts shall have neoprene snubbers.

"36. CONDENSING AND CHILLED WATER PUMPS

3601. Furnish and install where shown on the drawings, the main centrifugal pumps of sizes, types and performance ratings as approved, and of approved make.

3602. Each horizontally-split pump shall be of single-stage volute type with cast-iron body, fully bronze-fitted, double suction inlet, bronze impeller, flanged suction and discharge outlets, properly lubricated outboard bearings, and mounted with its motor on integral cast-iron baseplate provided with drain outlets.

3605. Each pump shall be provided with mechanical shaft seals as manufactured by John Crane, or as approved, suitable for the operating conditions and pressures of the pump.

3607. Each pump shall be guaranteed to circulate not less than the specified quantity of water against the specified circulating head when operating continuously without overheating the motor or bearings, etc., and without producing noise audible anywhere in the building outside of the space in which the pumps are installed. Quiet operation is mandatory."

Note H. Some of the worst noise problems which the writer has encountered, in the early days of air-conditioning large buildings, came from pumps operating under high water "heads." Pump seals, tightened to meet these heads, caused vibration which was carried through connecting pipes, pipe-hangers, etc., into the building construction, and "sympathetic vibration" of partitions and furring in major ground-floor spaces such as restaurants and showrooms proved to be a potent source of annoyance. Proper selection of pumps, adequate quality of motors, pump-impellers, seals, etc., and proper mounting of pumps and connecting piping to eliminate transmission of vibration are necessary to guard against such difficulties.

"41. FAN-COIL TYPE UNITS

4107. Unit motors shall be of the split-capacitor type with three speeds of operation. Motors shall be equipped with oil cups for lubrication with the oil cups located for easy accessibility. Motors shall be extra-quiet operating.

4110. All electric wiring between fan motor and fan switch shall be done by the fan-coil manufacturer. Provide the necessary quick disconnects for easy removal of fan section and provide suitable terminals for field connection of power wiring.

4111. All units shall be guaranteed to operate quietly within the limits of Para. 4205. Any units which do not fulfill the requirements for quiet operation, in the opinion of the Engineers, shall be replaced without additional cost to the Owner."

"42. GENERAL AS TO UNITS (BOTH INDUCTOR AND FAN-COIL)

4201. Cabinets for window units, including steel and removable front panels and return grilles, will be furnished and installed under other sections of the specification. Discharge grille and collar shall be furnished by the unit manufacturer and turned over to General Contractor for installation. Grille frames and bars shall be of ample strength to support the weight of a window cleaner. Discharge grilles shall be furnished with approved access panels.

4202. Units shall be suitably supported and fastened to prevent all vibration.

4203. The manufacturer of the window units shall jointly with This Contractor meet the performance requirements of the peripheral air-conditioning system as described in this specification and as shown on the drawings. If the performance characteristics of his particular window units make necessary some modification to the systems as originally designed, he shall submit such modifications to the Architect and the Engineers for approval. The manufacturer shall assist This Contractor in all problems of installing, testing and adjusting the peripheral air-conditioning system.

4205. Acoustic Performance and Guarantees

(a) The induction unit manufacturer shall submit to the Engineer, guaranteed sound power level ratings by octave bands. These ratings shall list both unit sound power generation and unit sound power attenuation data for the unit types and sizes operating as in an installed condition as per plans and specifications. The sound power generation data shall be listed for the specified operating unit nozzle pressures, for operating conditions of wide open damper, and for operating conditions of damper pressure drop equal to 1-1/2" water gauge. Neither the manufacturer nor the specific unit selections will be approved until such data have been submitted.

(b) The manufacturer of the under-window air-conditioning units, and This Contractor, shall jointly guarantee that when the complete equipment, as installed, is operated in the occupied spaces served thereby, that the room acoustic characteristics shall comply with the noise criterion of curve No. NC-30 as per Figure 3 of the Article "Revised Criteria for Noise in Buildings" by Leo L. Beranek, published in the January 1957 issue of the periodical "Noise Control." The noise levels shall be measured at a position having line-of-sight view of the unit or units and located between 5 feet and 8 feet from the nearest unit. The noise measurements shall be carried out at a time and under such conditions that the background noise levels in the measurement area, when the air supply is turned off, are lower than the NC-30 noise levels in the octave frequency bands. The NC-30 noise levels are listed in the following table.

Octave Frequency Band (cps)	NC-30 Noise Level (db re 0.0002 microbar)
20- 75	60
75- 150	51
150- 300	43
300- 600	37
600- 1,200	32
1,200- 2,400	30
2,400- 4,800	28
4,800-10,000	27

(c) Noise levels shall be measured, for guarantee purposes, by General Radio Corporation Sound Level Meter and a General Radio Corporation Octave Band Analyzer. The unit manufacturer shall be responsible for furnishing these instruments and all others required for such tests. A suitable acoustic calibration of the noise measurement system shall be included in the tests.

(d) The unit manufacturer shall be required to complete a mock-up of the installation in his plant prior to the approval of his equipment in order to furnish suitable evidence as to the acoustic characteristics of his units."

Note I (Articles 41 and 42 - Conditioning Units) Since these units are directly in the occupied spaces, specifying both their performance and the details which will make this performance possible becomes especially important. In this particular specification, the writer chose to include the detailed definition of acoustic performance and how it was to be measured in paragraph 4205, because the units in private offices would be so large a factor in securing low noise levels. It would have been equally easy to put what is here contained in paragraph 4205 in a separate section, entitled for example, "Acoustic Standards, Air Conditioning," which perhaps would be a better location for such a generalized set of criteria. Sub-paragraph (b) calls for the use of the NC-30 scale, because the intent is to achieve sound levels within the comfortable auditory range. For many projects NC-30 might be adequate, and it has been the writer's experience that outside noises from the street make it impracticable to maintain sound levels much below this in city office buildings -- also that unless "slow response" is used, momentary noises, from passing trucks, or from those talking outside of a private office for example, will make it impossible to establish what the equipment itself is doing.

"43. INTERIOR ZONE AIR-CONDITIONING SYSTEM

4301. A low-pressure air-conditioning system shall be provided for the interior zone space of the 3rd to top floors. This system shall be based upon not less than __ cfm per square foot of usable space in the interior zones, including elevator lobbies and corridors. This system shall be separate from, and in addition to, the under-window units and primary air systems serving the outside zones. A separate return air fan shall be provided, extracting return air from the interior zone spaces, and discharging the same in controlled proportions to this conditioned air supply unit, and to 'spill' outside of the building.

4303. Conditioned air shall be delivered to the various floors through vertical high or 'medium' velocity ducts running in shafts, and connecting at each floor through suitable branches, each with approved 'reducing valve' automatic-damper of approved make, followed by approved acoustic attenuator chamber to eliminate noise resulting from flow in the vertical duct and dampers. These attenuators shall connect to horizontal ductwork of low-pressure type on each floor. Maximum high-pressure duct velocities under this alternate shall be limited to __ fpm, and pressure-drop of high pressure duct system shall be limited to a maximum of 0.6" w.g. per hundred foot run. Approved attenuators shall also be provided between the fans in penthouse and the main vertical ducts, if needed to eliminate the excess sound resulting from operation of high or medium pressure fans, and to secure sound levels in tenant spaces not exceeding those called for in Para. 4205."

Note J. (Section 43) The various items listed in this Section are those features of an interior zone air-conditioning system, which in the writer's experience have a substantial bearing on the sound-level maintained in the occupied spaces (apart from what has been said previously as to the construction of masonry shafts) and which it is therefore important to define.

"45. CENTRIFUGAL FANS

4501. Furnish, erect and connect complete, all supply, return and exhaust fans. All major fans shall be of the backward-curved, nonoverloading, silent-running, high speed centrifugal type.

4502. The capacities of the fans shall be in accordance with approved fan schedules. Fans shall have direction of rotation, discharge direction, arrangement, to suit space conditions.

4505. All fans shall be guaranteed to fulfill the specified requirements. When used in conjunction with air valves (Art. 53), sound attentuation (Art.55), and vibration-isolation mounts (Art. 64), fans shall not produce noise in excess of the criteria set forth in Para. 4205 in any occupied portions of the building (outside of the fan rooms and other machine spaces). This Contractor and the manufacturer will be held responsible to replace any fans found unsatisfactory in this regard, without added cost to the Owners. Wheels shall have ample strength. They shall be statically and dynamically balanced to avoid vibration, and shall have blades to secure quiet, efficient operation. Fans shall be of the non-overloading type.

4506. Generally, the fans are to be driven with V-belt drive, of ample capacity, of Texrope or equally approved make. Sheaves shall be adjustable ratio type, of steel and of approved make; they shall be sized to give the required fan speed with the motor sheave at about the middle of its range of adjustment. There shall be at least two belts, capable of carrying the entire load with one belt off.

4508. Each fan and its motor drive shall be supported on an approved vibration-absorbing base of wood or steel, with shear rubber or spring mounting, on top of 4" concrete pad and as elsewhere specified herein. All fans and motors must be set on their bases and properly aligned.

4509. Each fan motor shall be sized to drive its respective fan when fan is operating at a speed (due to pulley adjustment) of 5% in excess of that required to meet the fan performance. No motor shall operate within the 'service factor' range."

Note K. (Centrifugal Fans) as with the conditioning units, it is desirable to specify definitely those features of the fans or of their performance which have a definite bearing on the acoustic level that will be obtained.

"49. SHEET METAL DUCTWORK

4903. Ductwork for the high-velocity peripheral systems, and for the high-velocity vertical risers of the interior system between the fan outlet and the air valves on each floor shall be as follows:

(a) Circular conduit in sizes up to and including 8" nominal inside diameter shall be made of 26-gauge zinc-grip steel of spiral lockseam construction and circular conduit; 9" to 20" nominal inside diameter shall be made of 24-gauge zinc-grip steel of spiral lockseam construction. It shall be assembled with prefabricated fittings made up of 20-gauge zinc-grip steel. Conduit and fittings shall be as made by Carrier, York or as approved. Joints at conduit ends and at fittings shall be made tight with Minnesota Mining and Mfg. Co. synthetic rubber sealing compound; joints shall be fastened with drive or twist screws. Hangers for horizontal conduits of all sizes shall be spaced not more than 48" apart.

(b) As an alternate, circular ducts 9" to 20" diameter may be made of 22-gauge galvanized steel with longitudinal grooved seam. Seam shall be sealed with EC-800 mastic.

(c) Circular ducts in sizes 22" and over shall be made of 20-gauge zinc-coated steel of grooved seam or welded construction. All joints on ducts not of spiral lockseal construction shall be welded. Joints at conduit ends and at fittings shall be made as described under (a) above.

4904. (a) Rectangular high-pressure ductwork shall be constructed of best bloom galvanized steel of the following U. S. Standard gauges:

Up to 19" width	-	No. 22 U. S. Gauge
20" to 60" width	-	No. 20 U. S. Gauge
61" to 90" width	-	No. 18 U. S. Gauge
91" and over width	-	No. 16 U. S. Gauge

(b) Such ducts shall be braced as follows:

Up to 11" larger dimension	-	None
12" to 24" larger dimension	-	1-1/4" x 1-1/4" x 1/8"
25" and over larger dimension	-	1-1/2" x 1-1/2"

Bracing angles shall be spaced 18" on centers on rectangular high-pressure ducts 12" wide and over in fan rooms. Outside of fan rooms, bracing shall be on 48" centers for ducts up to 60" wide, and on 32" centers for ducts over 60" wide.

(c) Ducts over 19" wide shall have all joints welded. This ductwork shall be cross-broken on 48" (or 32") dimensions and installed with matched angle-iron corner frames of the same sizes as shown above for bracing.

(d) The angle frames themselves shall be welded at corners for stiffness and shall be leg-welded, riveted, bolted, or screwed to the duct, with all bolt heads round on the inside of the ductwork. All connecting seams shall be gasketed with a 1/8" thick EC-1202 gasket and covered with Minnesota Mining and Mfg. Co. synthetic rubber sealing compound. Hangers shall be as described for conventional ducts, except that cradle type hangers shall be used, and piercing of ducts by hangers, pipes, etc., will not be permitted.

4905. All low-pressure ductwork except where otherwise specified, shall be made of best bloom galvanized steel of the following U. S. Standard gauges:

Up to 30" width	-	No. 24 U. S. Gauge
31" to 60" width	-	No. 22 U. S. Gauge
61" to 90" width	-	No. 20 U. S. Gauge
91" width and over	-	No. 18 U. S. Gauge

(b) Such ducts shall be made with S-slit joints on sizes up to 12" wide and bar slips on sizes in excess of 12" wide.

(c) Such ducts shall be braced as follows:

20" - 40" larger dimension - 1" x 1" x 1/8" angles.
41" - 90" larger dimension - 1-1/2" x 1-1/2" x 1/8" angles

All bracing angles shall be a minimum of 4 feet apart, except on ducts 61" and larger, in which case the bracing angle shall be 32" apart. Angle bracing shall be carried around all four sides of ducts. Angles shall be installed flat to flat and rigidly fastened by welding or bolting with lock washers at duct corners.

4908. Tuttle & Bailey 'ducturns', or other approved turning vanes, shall be provided in all cases where 90° square elbows are used. All other changes in direction, both horizontal and vertical, shall be shaped to permit the easiest possible air flow, using full-sized bends wherever possible, or fixed deflectors where full-radius curves cannot be obtained.

4910. Should it prove necessary to make provisions for vertical hangers of the ceiling construction -- or others -- to pass through ducts, provide streamline-shaped sleeves around such construction hangers so as to fully protect the duct from being punched with holes for the passage of such hangers. Any such streamlined sleeves shall be made airtight at top and bottom of ducts, and shall be shaped to facilitate air-flow.

4911. All register boxes and other openings of the ductwork must be kept tightly closed during construction to keep out rubbish.

4912. Access doors shall be provided in the ducts wherever required for access to fusible link dampers or other controls. They shall close tight over gaskets, with approved clamping devices."

Note L. (Sheet Metal Ductwork) The construction of the ductwork (especially in high-pressure and high-velocity systems), the types of joints, methods of bracing and supporting, etc., all have substantial effects on sound level in the occupied spaces. Ducts that are too frail or inadequately braced may rattle. Duct joints that leak may whistle. Ducts that are not correctly shaped at turns, splitters, and branches, or that have dampers badly designed and located, may produce turbulence that will add noise to the air coming through the ducts. These are largely problems for the layout designer, but the specification should, as far as possible, guard against such difficulties. Note Paragraph 4910; such stream-lined sleeves around hangers passing through ducts are a detail which has been used by the writer for over 40 years, but, where the plans and specifications have not defined this, we still find plenty of work installed with hangers just "punched through" the duct. If the hanger happens to be anything else than a round rod, it can set up considerable turbulence, cause extra noise in the ducts, and leakage where the holes for the rod pierce the top of the duct. It can not only upset the desired air quantities, but cause added noise, all of which can be carried on into the occupied spaces.

"52. FLEXIBLE CONNECTIONS

5201. Fan connections, both at inlet and discharge, shall be made with flexible materials so as to prevent the transfer of vibration from fans to ductwork connecting thereto. Connections shall be made of heavy woven asbestos cloth except as otherwise noted below.

5202. The flexible connections shall be approximately 6" long and held in place with heavy metal bands securely attached to prevent any leakage at the connection points.

5203. The flexible connections at the discharge ends of fans for high-pressure air conditioning systems shall be of vinyl-covered woven Fiberglas, of lengths noted above and fastened as above. It is the intent that these flexible connections shall withstand the operating air-pressure, shall not permit air leakage, and shall not transmit vibration."

Note M. (Flexible Connections) These are important to minimize conduction of vibration or noise from the fan itself into the metal of the ductwork, which might act as a sounding board and materially increase the sound-level carried by the air in the duct.

"53. AIR CONTROL VALVES

5301. There shall be furnished and installed, manually-adjustable pressure-reducing air valves of approved sizes in each branch take-off from high pressure interior zone riser. Valves shall be constructed of rigid air-foil shapes, acoustically treated to minimize noise regeneration. External flock coating may be applied on all vanes.

5302. Air Valve Performance Requirements

(a) The air valve manufacturer shall submit to the Engineer guaranteed sound power level ratings by octave bands. These ratings shall list both unit sound power generation and unit sound power attenuation data for the air valve types and sizes operating as in an installed condition as per plans and specifications. The sound power generation shall be listed for an upstream pressure of 1-5/8" water gauge and a downstream pressure of 3/8" water gauge. Note that all air valves shall be selected for an operating pressure difference of 1-1/4" water gauge. Neither the manufacturer nor the specific unit selection will be approved until such data have been submitted.

(b) The manufacturer of the air valves and This Contractor shall jointly agree that when the complete equipment, as installed, is operated in the intended spaces served thereby, that the room noise levels shall comply with the noise criterion described in Paragraph 4205 above.

The noise levels shall be measured at a position between 5 ft. and 8 ft. from the nearest unit. The noise measurements shall be carried out at a time and under such conditions that the background noise levels in the measurement area, when the air supply is turned off, are lower than the NC-30 levels in the octave frequency bands.

(c) Noise levels shall be measured, for guarantee purposes, by General Radio Corporation Sound Level Meter and a General Radio Corporation Octave Band Analyzer. The unit manufacturer shall be responsible for furnishing these instruments and all others required for such tests. A suitable acoustic calibration of the noise measurement system shall be included in the tests.

(d) The unit manufacturer shall be required to complete a "mock-up" of the installation in his plant prior to the approval of his equipment in order to furnish suitable evidence as to the acoustic characteristics of his units.

(e) If the air valve performance will not permit meeting the criterion hereinabove outlined, then the ductwork immediately downstream of each such air valve shall be lined with acoustic lining for a sufficient length to permit the referenced criterion to be met. The Engineer shall be the final judge as to the extent of acoustic lining, if any, required, and such acoustic lining, if any, as he may direct shall be so installed. Acoustic lining shall be at least 1" thick neoprene-coated Fiberglas Aerocore, at least 1-1/2 lb. density or equally approved. Note that all duct sizes on the drawings denote clear free dimensions, and therefore, indicate (where acoustic lining is installed) not the sheet-metal dimensions, but the inside clear dimensions of the acoustic lining. Acoustic lining shall be attached with adhesives, bolts and washers, or otherwise, according to manufacturers' recommendations, and/or as approved. Where acoustic lining is installed, a corresponding thickness of exterior duct installation may be omitted (where such insulation is specified).

5303. This Contractor shall furnish and install all branch transition ductwork immediately upstream and downstream of each air valve and furnish and install acoustically lined ductwork immediately downstream of each air valve. The drawings show specific duct sizes for these transition and lined branches, but, depending upon the actual air valve and manufacturer thereof, these sizes may change. This Contractor shall be responsible for the furnishing and installation of these transitions and lined branches whatever their exact final sizes may be."

> Note N (Article 53) Pressure-reducing valves for high and medium pressure duct systems must not only regulate the air quantity and pressure properly, but must do this with a minimum of turbulence and noise. Air-foil shapes are important, as are even such small details as "flock coating." It is most important to specify in some detail the attenuators on the leaving side of such reducing valves; these can be simpler than those at the outlets of main high-pressure fans, but they are still a necessary detail to eliminate needless sound in rooms.

"54. GRILLES, REGISTERS AND DIFFUSERS

5408. Each air supply outlet shall have the capacity as noted on the approved drawings and shall be guaranteed to give the required throw with draftless diffusion. Where manufacturer's recommendations require duct sizes differing from those shown on the approved drawings, This Contractor shall provide same at no additional cost to the Owners. All registers and diffusers shall be provided with directional and volume controls specified, and shall be of such dimensions (including the accessory equipment) as to conform to the building space conditions. All grilles, registers and diffusers shall be so selected as to comply with Para. 4205, above, and shall be jointly guaranteed by their manufacturers and by This Contractor to perform in accordance therewith."

"55. SOUND ATTENUATORS

5501. There shall be furnished and installled in the discharge ductwork of each high pressure conditioning supply fan, sound-absorbing attenuators consisting of a cylindrical metal sleeve of the same material and thickness as the duct. The attentuator shall be lined with 2" thick Fiberglas TWF wool covered with glass cloth, with all edges similarly bound with glass cloth. For systems with backward-curved blade fans, density as compressed and installed shall be 4 lbs./ cu. ft. -- for forward-curved blade fans, 6 lbs./ cu. ft. Materials, as applied, shall have at least as high sound-absorbing coefficients as:

Material	125 Cycles	250 Cy.	500 Cy.	7000 Cy.	N. R. C.
2" - 4 lb.	0.54	0.68	0.99	0.88	0.90
2" - 6 lb.	0.35	0.79	0.99	0.91	0.90

There shall be applied on the inside of the insulation a No. 2 mesh galvanized wire cloth or 1-1/2" x 3" diameter expanded metal, 16 gauge (.063), to hold the Fiberglas in place. The ductwork connecting to the attenuator shall fit within the interior diameter of the absorber so that the outside sheet metal diameter of the attenuator shall be approximately 4" greater than that of the duct. Where shown on the drawings, the absorber shall be of the concentric type, consisting of one absorber concentrically located within another of dimensions as shown on the drawings. In such absorbers, each of the three surfaces exposed to the flowing air shall be constructed as noted herein. The length of each sound absorber shall be as shown on the drawings or longer as required by the manufacturer, to assure that there shall be sufficient noise attenuation (in each of the octave bands) of the fan and ductwork so that in combination with the acoustic characteristics of the under-window units and the air valves, the complete installation will meet the acoustic characteristics defined by Curve No. NC-30 as per Figure 3 of the article, "Revised Criteria for Noise in Building" by Leo L. Beranek, published in the January 1957 issue of the periodical, "Noise Control." Where the drawings so show, or job conditions make it advisable, the total length shown for any sound-trap may be subdivided into separate sections, separated by elbows or other duct sections, and aggregating at least the total length called for.

5502. Where rectangular attenuators are shown or approved, they may be shortened by use of internal "egg-crate" acoustic baffles of equal construction, arranged to maintain proper net cross-section area for air-flow.

5503. All supply air casings (from the air inlet to the fan inlet inclusive) shall be lined with 3" thick Fiberglas of density between 6 and 10 lbs. per cu. ft. All return air plenums shall be similarly lined. All exhaust ducts connecting to outside air louvers shall be similarly lined for a distance of 30 ft. behind the louver. The inside clear dimensions of such ducts shall be the dimensions shown on the drawings.

5504. Length, details, and functioning of sound-attenuators in conjunction with the actual fans and air distribution system shall be adequate to secure, in the occupied spaces, acoustic results equal to those defined in Par. 4205. Sound attenuation boxes where necessary for this result shall be installed also on leaving side of floor reheat coils or reducing valves."

5505. All pipe sleeves and duct openings penetrating floor slabs, partitions, walls, etc., shall be packed with Fiberglas and sealed with nonhardening mastic."

Note O (Sound attenuators) With present-day high velocity systems, these are an essential part of an installation which must give quiet results. The particular types of construction described in this specification have worked well in practice, but it will be recognized that there are many other types available today, including various "manufactured" attenuators designed to be installed in a chamber or duct at the job. Given several types which can produce equivalent results in quieting the system, the choice is primarily an economic one: which method of achieving the desired acoustic results will cost least, or take least space under practical job conditions.

"57. ELECTRIC MOTORS

5701. All electric motors of sizes and types as specified for driving heating, ventilating and air conditioning equipment shall be furnished and erected under this Section. All motors shall be of proper power and speed to suit the specified makes of equipment; if other makes of equipment are accepted in any case, the proper adjustment of motor speed and power must be included without additional cost to the Owners. Drawings shall be submitted for approval before the equipment is purchased.

5704. All motors shall be of quiet-operating type, guaranteed to fulfill the specified requirements without producing objectionable sound audible outside of machine rooms. All belt-connected motors shall have adjustable bases and set-screws to maintain proper belt tension. All fan-motors shall have adjustable sheaves for speed adjustment, and one belt more than computed."

"64. FOUNDATIONS

6401. All equipment, piping, etc., shall be mounted on or suspended from approved foundations and supports, all as specified herein, as shown on the drawings, or as required.

6402. All concrete foundations and supports will be furnished and installed by the Concrete Contractor. This Contractor, however, shall furnish to the Concrete Contractor, shop drawings and templates for all concrete foundations and supports, and in addition, shall furnished to the Concrete Contractor all required anchor bolts and Fiberglas pads, and shall cooperate with the Concrete Contractor to insure the proper installation of all these elements. The Concrete Contractor will install all concrete inertia blocks, all concrete blocks suspended by vibration isolating devices, and all concrete blocks resting on Fiberglas pads, in metal pan forms. The Concrete Contractor will furnish and install both the concrete and the metal pan forms, but This Contractor shall show the metal pan forms, as well as the concrete work, on his shop drawings. This Contractor shall submit to the Engineer shop drawings showing the complete details of all foundations including the necessary concrete work, steel work, vibration attenuating devices, etc.

6403. All floor-mounted equipment shall be erected on 4" high concrete pads over the complete floor area of the equipment, unless specified to the contrary herein. Wherever hereinafter vibration-eliminating devices and/or concrete intertia blocks are specified, these items shall, in all cases, be in turn mounted upon 4" high concrete pads unless specified to the contrary herein.

6404. Mounting of Centrifugal Refrigeration Compressors

(a) Each machine (compressor-turbine-cooler-condenser unit) shall be installed on a suitably reinforced concrete foundation which shall, in turn, be supported by a suitable number of properly located hook type vibration isolation mounts, each having a total static deflection of no less than 1". Each such mount shall be Type SFHM. Vibration Mountings, Inc., or as approved. Each such mount shall, in addition, be mounted on a pad of two layers of 3/8" thick ribbed Neoprene pads, Shear-Flex, Vibration Mountings, Inc., or as approved. The two layers shall be mounted with ribs perpendicular and with a metal plate no less than 1/16" thick inserted between the two layers. The static deflection of each layer shall be 1/16", making the total deflection of the two pads equal to 1/8". The hook mounts with their Shear-Flex sub-bases shall be mounted on a 4" high concrete pad as specified in Para. 6403. The details of the mounting of the hook mounts upon the pad shall be such as to result in a ribbed rubber pad loading of 30 to 50 lbs. per sq. in. Foundation details shall be as submitted by the manufacturer of the machine, and as approved by the Engineer.

6405. Mounting of Centrifugal Fans

(a) All floor-mounted fans, except those located in the sub-basement mechanical equipment rooms:

(1) Each such fan and driving motor shall be mounted on an integral structural channel or heavy angle iron frame with spring and rubber vibration isolation units. These vibration-isolating mountings shall have no upward restraints and no supplementary vertical snubbers to resist belt tension. Motor slide rails shall be included as part of the base.

(2) The structural base for the fan and the motor shall be continuous and integral.

(3) Each vibration isolating mount shall consist of two (2) mounts in series, one mounted upon the other. Each such top mount shall be a rubber-in-shear mount, Type R, Vibration Mountings, Inc., or as approved. Each such bottom mount shall be a spring mount, Type SFNC, Vibration Mountings, Inc., or as approved. The rubber-in-shear mounts shall have a static deflection of 1/4" and the spring mounts shall have a static deflection of 1".

(4) The vibration-isolating mounts described in the sub-paragraph hereinabove, shall be mounted upon a concrete inertia pad which shall, in turn, be mounted upon a 4" high Fiberglas pad. The Fiberglas pad shall extend completely under the concrete inertia pad shall turn up and wrap around the sides of the concrete inertia pad. Fiberglas shall be PF-614 for a loading of 75 to 150 lbs. per sq. ft.; PF-615 for a loading of 100 to 200 lbs. per sq. ft.; PF-616 for a loading of 150 to 300 lbs. per sq. ft. and PF-617-618 for a loading of 200 to 400 lbs. per sq. ft. The concrete inertia pad shall be complete enveloped by a concrete curb 4" wide extending to the top of the concrete inertia pad. The weight of the concrete inertia pad shall be equal to twice the sum of the weights of the fan rotor, the fan pulley, the motor rotor and the motor pulley.

(b) All floor-mounted fans located in the sub-basement mechanical equipment rooms:

(1) Mounting shall be as described in Para. 6405 (a) above, except that the vibration-isolating mounts may be mounted directly upon the 4" high concrete pad called for in Para. 6403, and the inertia pad and Fiberglas pad with surrounding concrete curb need not be installed.

6406. Mounting of Centrifugal Pumps

(a) All floor-mounted pumps, except those located in the sub-basement mechanical equipment room:

(1) Each pump shall be mounted on a reinforced concrete base having a weight equal to the weight of the pump and motor and contained water, but no less than 10" high.

(2) Each base for horizintally-split pumps shall include supports and base

elbows for the discharge and suction connections.

(3) Each base shall be supported by vibration-isolating mounts of type identical with those required for fan under Para. 6405 (a)(3).

(4) Where concrete bases are "T" shaped or other than rectangular shape, vibration isolation mountings shall be installed around the "T" or other shaped projections. It is the intent that no concrete mass be improperly supported.

(5) Vibration-isolating mounts shall be supported from structural brackets extending outward and upward from and around the periphery of the concrete base, and shall rest upon a concrete inertia pad. The brackets shall be installed to that height which will locate the vibration-isolating mounts at the elevations of the vertical center of gravity of the pump-motor-concrete base unit. The weight of the concrete inertia pad shall be equal to twice the weight of the concrete base under the pump. The inertia pad shall be mounted upon a Fiberglas pad with an enveloping curb as described hereinabove for fan equipment. The Fiberglas pad loading schedule shall be as described above for fan equipment.

(b) All floor-mounted pumps located in the sub-basement mechanical equipment room:

(1) Mounting shall be as described in Para. 6406 (a) above, except that the vibration-isolating mounts may be mounted directly upon the 4" high concrete pad called for in Para. 6403, and the inertia pad and Fiberglas pad with surrounding concrete curb need not be installed.

(c) The piping connections on all pumps shall be installed with spool pieces for the possible future installation of wire reinforced rubber and fabric flexible hose with integral rubber flanges and split steel take-up rings, Spring-Flex Type RFP, Vibration Mountings, Inc., or as approved. The bursting pressure of all such elements will be at least five times the operating pressure. All lengths shall be as shown on the drawings. Flexible connections for condensing water pumps shall be furnished as shown on the drawings.

6407. Mounting of Control Air Compressors

(a) Control air compressors shall be located in the sub-basement mechanical equipment room. They shall, however, be mounted as per the requirements of Para. 6406 (a).

6408. Support of Piping in Equipment Rooms and Where Exposed on the Roof

(a) Water Piping

(1) All such piping shall be hung on resilient hangers. These hangers shall be combination rubber-in-shear and spring hangers, Type RSH, Vibration Mountings, Inc., or as approved. The spring in each such hanger shall have an initial deflection, under the installed load, of 1.0", and shall be so sized as to permit an additional deflection of 1.0".

(2) Where such piping is supported from the floor below, brackets shall be welded to the piping and the piping supported from these brackets by means of vibration-isolating mounts, each consisting of one Type R, Vibration Mountings, Inc., or as approved, and one Type SFNC, Vibration Mountings, Inc., or as approved, in series, as for the support of fans and pumps. These mounts shall rest on a 4" high concrete pad as per the requirements of Para. 6403. The spring in each hanger shall have an initial deflection, under the installed load, of 1.0", and shall be so sized as to permit an additional deflection of 1.0".

(3) Wherever piping is exposed to the outdoors, hangers called for hereinbefore shall use Neoprene rather than rubber.

(b) Steam and Condensate Piping

(1) All such piping shall be hung from resilient hangers. These hangers shall be rubber-in-shear hangers, Type RHB, Vibration Mountings, Inc., or as approved.

(2) High pressure steam piping connecting to steam turbine shall be hung from hangers as required under Para. 6409 (a).

6409. Mounting of Secondary Water Coolers and Heat Exchangers and Steam Condensers for Refrigeration Machine Turbine Drives.

(a) Each such item of heat exchange equipment shall be mounted upon suitable concrete piers, except that, if practicable, the secondary water heat exchangers may be hung from the building construction above.

(b) Each such item of equipment shall be mounted by means of suitable brackets on spring and rubber vibration isolation units. Each such unit shall consist of two (2) mounts in series, one mounted upon the other. Each such top mount shall be a rubber-in-shear mount, Type R, Vibration Mountings, Inc., or as approved. Each such bottom mount shall be a spring mount, Type SFNC, Vibration Mountings, Inc., or as approved. Each such rubber-in-shear mount shall have a static deflection of 1/4" and each such spring mount shall have an initial deflection, under the installed load, of 1.0", and shall be so sized as to permit an additional deflection of 1.0". These mounts shall, in turn, be installed upon the concrete piers called for in Para. 6410 (a) above. If the secondary water heat exchangers are hung from the building construction above, the hangers shall comply with the requirements of Para. 6408(a)(1).

6410. Furnish and install, as shown or approved, all necessary supports for equipment furnished under this specification. To meet the varying conditions in each case, these supports shall consist of pipe-stands, steel angle or strap hangers, saddles, brackets, etc., as shown or approved. All such supports shall have substantial flanges, bolted to floor construction; hangers shall be supported from the framing as described hereinabove. Supports shall be properly located with reference to any supporting pads, legs, etc., of the equipment carried, and must be of such number and so distributed as not to throw any undue strains upon the shells. All details shall be as approved.

6411. Provide suitable brackets, pipe-stands, piers or other supports, for the various float traps, receivers, etc. Also provide suitable supports for all tempering stacks, air filters, mixing and control dampers, etc., securely clamped to steel beams, colums, or bearing walls. All details of this work shall be as shown on the drawings or as approved.

6412. This Contractor shall guarantee that the work as installed by him will not result in the transmission of objectionable noise or vibration to any occupied parts of the building; and he shall take full responsibility for any necessary modifications necessary to secure this result."

Panel Discussion

Moderator - Dr. Richard G. Clark, Director,
Division of Research, Hillyer College,
University of Hartford

Panel Members - Leonard R. Phillips, Vice President
Anemostat Corporation of America

Howard C. Hardy
Conrad J. Hemond, Jr.
Alfred L. Jaros, Jr.
Richard Wells

Mr. Phillips: Do you think that with the data presently available in the design of multi-story buildings, it is feasible to start with the fan, plenum, ducting, etc., and calculate the proper component to result in the room noise level that meets the design conditions?

Mr. Hemond: No, because you put the word feasible in there, and because of the lack of specific data regarding what I consider the prime source, and that is the fans. There are some data available, including equations for computing based on horsepower, based on quantity of air flow, actual measurements, but I don't believe it is possible to make an accurate and precise computation. We do make computations and we have excellent methods for making valid assumptions, but your question was can we specifically, with any system, tie down the exact level which will be present in the final receiving room.

Mr. Hardy: I do it every now and then, and we come out within a couple of db. Now, you have to realize that a couple of db is pretty close, but it is still 40% off. When you talk in terms of power, most engineers wouldn't accept 40%, say on structural engineering jobs, but they will accept 40% on an acoustical job. Our kind of engineering wouldn't do in the case of electrical or mechanical devices. Sometimes I think we're asking too much. If I played a record and made a 1 decibel change, you couldn't tell it in the audience; about a 2 is where you'd start. At about 4 you wouldn't find it so difficult. The second point is that there is no general data in the field on the sound power of various fans. We occasionally get hold of such data by subterfuges of various kinds. Also, there isn't a great deal of difference in the various companies products in the same range. They are quite close competitively, so if you know the difference between the two products, you pretty well know what the other fellow has. I'm not nearly so worried about fans. We can rate the sound power of a fan very closely, if we know its mechanical properties, how many blades it has, what its horsepower is, and what its steady pressure is. But I do worry about the mixing units. I work with a company that makes makes mixing units and I have inside dope on what those mixing units do. I worked with a roofing company that makes ventilators and I have inside dope on what they do, and the same with diffusers. I showed you some od the curves on diffusers today. Now, I plead that these datn get out into public hands. I don't feel they should be the private data of any individual. To make it more confusing, the data in the field of duct attenuation is very sloppy, and our engineers have had to work out their own set to get the correct answers.

Mr. Jaros: I would like to make two comments from a practical rather than a theoretical point of view. No matter how carefully you design a large, elaborate duct system in a big building, it is never put in exactly as you designed it. There are all sorts of job conditions that lead to slight changes in runs, perhaps changes in size, perhaps bumps sticking out into the ducts, or bad joints, or even riveted heads or attached bracing angles. There is always an uncertain supply of noise making elements, on a moderate scale perhaps that cannot be predicted by theory. Secondly, assuming that it were possible to go through this compilation with sufficient accuracy for every place in a large building, and we may be talking about thousands of outlets in various floors and rooms. No owner of a new building is ever going to allow an engineer the time necessary to go through this process, room by room, outlet by outlet, to establish close and exact figures for each space. Most modern buildings are built against time, to meet a budget and to meet a renting date, and to meet the requirements of loaning institutions whose loans are conditioned upon its being ready by a certain date. We never have time to do the job as thoroughly as we'd like to. In addition to all the other computations involved in air quantities, cooling effects, heating effects, controlled by what happens when people come in and out of a room, when sun comes in a window or doesn't, to add this volume of detail to computation room by room and outlet by outlet would mean postponing the construction for many months. We do take short cuts.

Mr. Hardy: The biggest problem I have is the numbers they have on the blueprints where they say there is 500 CFM going down this duct and 750 going down the next one, etc. These are gross observations in many cases, and there are quite sloppy adjustments in the flows of the duct system. If the duct system is balanced properly, and you can come out pretty reasonably in noise, unbalance will lead to many problems that shouldn't be there, that weren't on the blueprint, but are in the final construction. You have to have diligence in the building end of it, in the regulation end of it, and the owner end of it, to have these things balance.

Mr. Jaros: From my point of view, you do have to make this sort of a computation, but you make it by the quickest and most direct method. Then you add a sufficient factor of safety from experience so that the results will not be objectionable. This may mean that you are doing a little more than is necessary in many cases, but this is better than doing too little, or having what would have been enough noise control upset by adjustment of air flow and other such factors so that the final result is unsatisfactory.

Floor Question: At what state would you make these computations? In other words, what is the critical moment?

Mr. Hardy: Well, it is a similar problem to setting up specifications. It's setting up specifications for static pressure drop and CFM supply. You could do it much easier if the manufacturers would give you brochures with tables of information available on noise. First participation is necessary in the early conferences on the building, contact with the mechanical engineer in the early stages to find out what the sore spots are, where the duct is likely to be, what the floors are going to be, what's going to be the other possible use of the floor, so you get the general over-all picture. The next stage is the detailing of the sound control devices, detailing the ventilation system, and what noise controlling device is to be used in the elements of that system. Then the over-all check on the final system to see that something didn't slip up. Usually the main job is done after the main system has been reasonably detailed. The specs. have not been written, but the system has been determined. Then you put in the specs the elements you need.

Floor Question: Do you have any preference for the performance type spec and a proprietary type spec?

Mr. Jaros: You can't answer that in general terms. It depends upon the nature of the project, who the owners are, the time and other factors entering into the construction of the building, and how it's going to be used. In many types of government building, you can't really write a proprietary type of spec. You can name a lot of makes with the qualifying phrase, "or equally approved" and usually someone other than you will have the approval. This is almost equivalent to throwing the field wide open. On a privately owned project requiring something quite unusual you can probably write an exact proprietary specification calling for the exact article that you think will best do the job.

Floor Question: Equipment manufacturers are being asked to determine power level ratings. What type of room and what equipment should they have to determine the rating?

Mr. Wells: One of the most prevalent methods of obtaining total power is the use of a reverberant room. If you place the equipment off the middle of the room a little bit and put your mike half the dimension of the room away from the equipment, by a proper calibration you can measure the total power radiated by the machine from the mike reading at this one point. Of course, you;ve got to take readings at more than one point in order to average out all the standing noise in the room. And this means that you take two or three points or wave your mike around a little, but generally speaking you obtain at a quick reading the total power at the frequency band you're interested in. Then you do this for another octave band, and so you get the total sound power spectrum. All you need is a calibrated reverberant room, some microphones and some form of indicating instrument.

Mr. Hemond: These pleas we're making for these power readings will impose burdens on manufacturers. It will also bring out one point, that while there are independent test facilities available in the U. S. they are too few to take on the entire building industry. We will have to develop more of these laboratories with the assistance of industry.

Floor Question: In calculating lined duct attenuation, what formula will give you the best results?

Mr. Hardy: Well, you can find quite a few formulae, and this is a very technical question. The most used equation is the so-called Sabian equation which was developed some 20 or 30 years ago by Hale Sabine. This isn't too valid an equation. I have one which I use, which has not been published, and which actually fits the Sabian experiments better than the Sabian equation itself. You don't have to do this over a tremendous frequency range. It nearly always happens that the critical band of frequency for the duct will be a 150 to 300 cycle band. In the old days we used to say 256 cycles for everything. Silence 256 cycles, and you silence the duct properly. And this isn't such a bad rule of thumb. If your equations work only in that band, you'll be doing pretty good, but I do think the equations I have work over an extended range. What is more important is the duct branch points and the "turns" and what they do.

Floor Question: Mr. Jaros, in your specifications on page 10, you make the manufacturer of window air conditioning units and the contractor jointly responsible for the acoustical performance. How is it possible when the manufacturer has no control over the other system noise contributors such as fans, ductwork, vibrating equipment, etc., and when the manufacturer has no control over the acoustical properties of the occupied space which will effect the db level shown. Can anything be done to solve this complex problem?

Mr. Jaros: That part of the spec was written specifically to fit separate units in the room, either fan core units or inductor type units. In the case of the fan core units, no air from ducts is reaching them. The only noise they put out is of the units themselves. Therefore as long as you can compare the sound level in the room with the unit running to that when the unit is shut down, you have a pretty exact test of what that unit is doing to the room. This is a case where the manufacturer of the unit is primarily responsible for what the unit does, but since it is the subcontractor or supplier to the mechanical contractor with whom the owner's contract is, this was the reason for making them jointly responsible.

Now, turning to the inductor unit, it is true that it is receiving air from what is called a primary air system through small ducts. However, the inductor unit itself starts out by providing an attenuating chamber in which this air is expanded after it has passed through the ejector nozzles that power the unit. Again, the manufacturer is able to control the amount of attenuation which this duct air, in conjunction with other flow through the unit, produces. Now remember that in both instances these specs were written to fit the units in the paragraph we're discussing, so I think that no one else than the manufacturer and his superior contractor, who is his mechanical subcontractor on the building, can determine in advance what the particular unit supplied will do. This is one of the cases where we have never had a complaint from a contractor that he was being asked to take unfair responsibility.

Floor Question: I believe the air conditioning industry has established through exhaustive tests what is an optimum confort condition in an occupied space. I would like an explanation of what human comfort is as related to noise levels.

Mr. Hardy: A psychologist does not sit in an ivory tower and figure what people ought to have. It is done by actual surveys, in actual working spaces, of the reaction of the people who work in those spaces. Some have been done by Gallup poll type techniques, but they don't give much valuable data. A lot of people don't know how to answer these types of questions. Your best answers come from office engineers and plant engineers who have studied such things. The most exhaustive test of this kind has been made by the Eastman Kodak Co. They have 27,000 people working at Kodak Park and acoustical engineers have obtained a lot of their data from evaluation of what these people do. So it is partly empirical, partly psuedo-scientific, partly from experience.

Mr. Hemond: About these criteria curves, I think it is fair to say that these are criteria; they are goals based on the best knowledge we have from all of the possible sources and they are being continually modified.

Mr. Jaros: This also applies to what the gentlemen said about the heat and humidity comfort data that have been published. There is no such thing as a temperature and humidity level that will satisfy everybody. There is probably no such thing as a sound level that will satisfy everybody. What is published in my field is a statistical average that is found to satisfy the great majority. In fact, these change with time and with location. In Maracaibo, Venezuela, we found that people demand 73° in hot weather for comfort, where up here people would call that too cold. We have experience where a man in one office complains it's too hot, and the man in the next office says it's too cold. This applies to acoustic comfort as well. You can only take an average. I've heard comments from the speakers on the acoustics of this room, usually derogatory. A man in the air conditioning field doesn't think the acoustics are too bad, but he doesn't like the air conditioning. The air conditioning doesn't bother me, nor do the acoustics, but the illumination does.

Floor Question: Doesn't the fan manufacturers' association establish some limitations on the sound energy liberated by fans? If you established limitations, you'd cover a multitude of sins; you'd cover all the sources of noises.

Mr. Hardy: The fan manufacturers' association 20 years ago had a code on sound measurement. This is outmoded now. A sound measurement standard is now being prepared by a joint committee of ASHRAE and ACRI. This is a slow process, but it is moving along. It will be based on a sound power measurement in octave bands, and probably be based on comparing it to a standard noise source. That makes it easier to calibrate. Manufacturers of roof ventilators, fans, unit heaters, air conditioning, will take off that code and write industry codes for their particular industry. One very excellent standard is that of the Compressed Air and Gas Institute which came out 2 weeks ago and which could serve as a model for people who would like to know what a standard should be like.

Mr. Phillips: The measurement of fan noise as established by the codes already referred to was made by measuring at points around the outside of the fan. Techniques are only being disseminated now for measuring the noise that is coming through the outlet of the fan or duct. Until proper microphones are standardized it is difficult to measure the sound in the duct itself. The technique starting with the sound power measurement of the total energy of the fan is just a little different.

Noise Control in Buildings
http://www.nap.edu/catalog.php?record_id=21391

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Panel Discussion

Moderator - Frederick G. Frost, Jr., FAIA
Frederick G. Frost, Jr., and Associates

Panel Members - Dr. Thomas Mariner,
Research & Development Center,
Armstrong Cork Company

Lyle F. Yerges, Merchandise Manager,
Industrial Sound Control,
United States Gypsum Company

Lewis Goodfriend
Richard Hamme
Howard C. Hardy
Robert B. Newman

J. D. Schlumpf, IBM Corp.: How can the noise from vane axial or tube axial fans be reduced in short, over-all duct length?

Mr. Hardy: The easiest way to quiet a fan is to run it at slower speeds. If you run it at half the speed it will be down 15 db, and that's quite a drastic jump. You can design a short, sufficient sound absorber to fit on such units. I know one company which is doing this, but most such devices are custom built. You could design a unit that would reduce the noise about 15 db in the length of, say, 4 feet, if you went at it systematically, and maybe that's a place where more research ought to be done.

Unsigned question: What significance can be attached to sound transmission loss ratings from the National Bureau of Standards and the Riverbank Labs, in view of the fact that the correlation of results between and within the two labs leaves much to be desired? Results on identical constructions vary as much as 10 - 15 dbs, over a period of a few years. What is the significant difference between a 40 and 50 db. partition if results at all frequencies are in the same proportion to each other?

Mr. Goodfriend: There are two factors. One is that each of these laboratories is not identical to the other. There are small differences in instrumentation and in what might appear to be panel size, dimension and installation techniques. These differences will lead to differences in the transmission loss ratings at each frequency. I believe that the Riverbank Lab has made some changes recently in their techniques which give slightly different numbers, but all of these numbers are a method of rank ordering different panels or classes of panels. The result you get in the field will depend on the size of the panel, the configuration, exact method of installation. Using the same workmen, you can hope that the panels with a higher transmission loss in these books will give you a higher transmission loss in the field than some panel with a lower number, but don't expect to get 50 decibels at a thousand cycles in transmission loss or attenuation between two rooms. First of all, attenuation is not transmission loss and even if you could calculate the transmission loss you wouldn't get it in the field, because of field installation methods.

Mr. Hamme: I don't agree with the conclusion that was built into the question. I do not think so much is left to be desired in the correlation between Riverbank and the Natl. Bureau of Standards. I've seen data on comparisons of samples which can be built identically in the two labs, and the agreement is remarkably good. On the other hand I see quite clearly where people might think the correlation was not good. This arises from a misunderstanding of sound transmission loss. The sound transmission loss is not a property of a material; it is a property of configuration of material. It has become well known that the leaks through structures along joints can easily dominate the amount of sound that actually comes through a panel structure. It is not so much a matter of the desirability of correlation between the labs, as it is a better understanding of the limitations of the technology. When people submit materials to the lab, much better care must be taken to understand the meaning of the test method. When you do submit samples you must submit them for tests under circumstances incorporating the features which may not give you as good an answer, but which are realistic under the particular circumstances, and will bear some correlation to the field results.

If I were an architect confronted with two apparent transmission losses through the same partition, I wouldn't be one bit happier after listening to this learned answer. I still wouldn't know what to do. If I am confronted with that problem, do I assume that the higher of the two values represents a perfect panel, while the lower of the two values perhaps represents a panel which inadvertently had some leaks, and shall I assume that in practice I am more likely to get the latter case and therefore use the lesser of the two values?

Mr. Mariner: There are facilities available and others under development for the testing of partitions and ceilings under conditions that closely simulate those of actual practice. I believe we can get lab test data that bear directly on the construction problem that faces you, and in the meantime you will not be able to look at numbers or hear numbers quoted without reading the description of the sample on which the test was performed. Every lab that performs tests not only gives the test a number, but writes a detailed description of what was tested, and it's mandatory to read this.

Mr. Yerges: These seems to be some idea that if you call it science, a number defines completely and thoroughly what you're looking for. Science at best is disciplined curiosity, so you might as well find out the empirical answer, which is probably much better than any single number. Choose an architect or engineer, not because he has a license, but because of his performance. I wish we could give you the magical ten commandments to help you, but you have seen profiles on various partitions, you have learned that two identical numbers don't tell you anything about their performance.

Mr. Goodfriend: There have been a number of field tests made on sound transmission of plaster and lath walls on various studs and these don't agree completely among themselves. The Bureau of Standards in BMS 144 has several sets of tests on identical panels, or as close as could be possible, and they don't agree.

Unsigned question: What is the significance between two ratings? Would you attach significance to a 3 db or a 10 db difference, or where would you draw the line? An architect would probably select the highest one, not knowing what he was getting into.

Mr. Hardy: We do not have anywhere near the field data we need on any of these installations. The manufacturers and suppliers of these materials should get much more field data than they have. We don't have enough information on the materials used in the field, and the kind of sounds they encounter. Most can't give advice on what would be good practice in installing this material. Let's not put too much emphasis on a lab rating, not that that is not important. I assure you that the rank order you get in the lab is not the rank order you get in the field.

Mr. Hamme: I think the day of mutual debunking between lab people and consultants is gradually waning away. We should agree on a certain type of construction and how it should be tested to give information that will be usable in the field and indicate the end result. This requires better communication between the consultant and the laboratory, and understanding of the limitations of the methods in both places.

William Lukacs, YMCA Natl. Council: Has constructive work been done to reduce such elevator machine room noise as switch clacking, gear shifting, motor noises, reversing, starting, etc.?

Mr. Wells: There is no elevator man here to contradict me, but I think very little has been done at the source. It can be done within the space itself and keep the noise from being transmitted to to other spaces.

Mr. Jaros: The great trouble with elevators is that the ropes have to pass through holes. You cannot isolate the elevator machine room from the rest of the building as effectively as you can other types of machine rooms, because in many cities, the codes specify sufficient holes for the lines to pass through.

Mr. Frost: By the very nature of the conditions, yes.

A. D. Krieger, IBM Corp.: What have you found to be the most effective way of reducing fan motor noise where the air handling unit is ceiling suspended inside the occupied space?

Mr. Hardy: It's tough to try to suspend a thing from the ceiling and get vibration isolated. It is much easier to mount it on a floor suspension. A lot of the noise is structure borne noise, and not the noise from the motor. The noise from the motor of the fan in most cases will be less than the noise of the fan itself, but the vibration transmission of the sound of the motor might be pretty high.

F. R. Goldschmied, Westinghouse Electric Co.: Would there be a premium price paid for quieter fans and blowers on the basis of definite noise specifications?

Mr. Frost: There is interest in it and clients are willing to pay for it.

Unsigned question: There has been much discussion regarding the use of attenuators in duct systems. Does this reflect a trend away from the use of the acoustical duct liner which has proven itself effective and economical over the years?

Mr. Hardy: As to the relative merits of packaged units and duct liners, it's hard to give a black-and-white answer. Generally, you could get the job done cheaper with a duct liner, but then you'd have to calculate it out. You have to do a lot of calculation to see how much you need, and it's pretty convenient to pick up a package and stick it in the duct. Sometimes there isn't room to do a duct lining job, particularly when the duct is pretty wide. I don't think the packaged units on the market today are the last thing in design. They are interim designs; better ones will be designed in the future. They will fit the uses of the duct better and be cheaper. Not much research has been done on duct lining lately, and I think these people could come up with better materials for internal duct sound sealers.

Mr. Jaros: The attenuator is not necessarily a pre-packaged unit. It may be tailor-made for the job, and frequently is. The real difference between the attenuator and the continuous duct lining is in the field of space or economics. You may be able to put the attenuator into the fan room or the mechanical floor, so that the necessary attenuation is achieved before the noise gets out into the rest of the building. If you do the attenuation bit by bit through the duct system, you are going to have ducts in many parts of the building still noisy enough so that you've got to encase them better at high cost, in order to protect the rest of the building. Third, the way to practical economy is to substitute the packaged article for a lot of loose labor, spread out all over the building, because on-the-job labor is getting $4 or $5 an hour and fringe benefits, sometimes for very little work. In big building, the cost of carrying linings all through such a system will be many times the cost of equal attenuation by something concentrated near the fan. And again, that cost will be reflected in higher sheet metal costs; the ducts have to be bigger to hold the line. So the trend we see is toward the concentrated attenuator, either factory or tailor-made for the job by the contractor, in preference to extensive runs of linings through the duct.

Unsigned question: When several vibrating machines are mounted on the concrete floor slab of one room and create too much noise in the office below, how do you determine which machine or machines are causing the trouble?

Mr. Newman: Shut them off, one at a time.

Mr. Frost: Is it important to know the quality of the sound?

Mr. Newman: Yes, it is, because the measures you needed to control one machine may be very simple and that machine may be the offender. You may spend a lot of money you don't need to.

W. Bainbridge, U. S. Gypsum Co.: The talk on partitions was mostly about heavy block partitions which are little used. We would like some discussion on lightweight steel stud resilient clip types.

Mr. Yerges: Mr. Watters' talk did not preclude that type of construction. He made it clear he was talking about simple types of construction. It is possible to get around the mass law by various means. Essentially what is necessary is the type of isolation you have heard of here; mounting the various surfaces so that they do not rigidly connect. In simple terms, sound is vibration in an elastic medium. So, if you are going to prevent its transfer, you either have to eliminate the elasticity or the vibration. There are various ways of doing it; one is a vibration isolator, which can be a tiny little clip or a massive construction. Any means of breaking off the transfer of vibratory energy from one side to the other. The answer is that multiple layers and resiliently mounted surfaces can do this, but the job must be done by someone who knows what he is doing and by properly trained mechanics.

H. F. Miller, Davis, Cochran & Miller: Can noise be isolated by transparent partitions composed of multiple thicknesses of glass or plastics?

Dr. Mariner: With glass, it has been quite commonly done. Glass is really quite good for inhibiting transmission, and it can be used the same way as any other material. Several panels in series, using common concepts of peripheral absorption in the interspace where desirable and depth to reduce the coupling between panels can improve the transmission loss at the lower frequencies. In short, applied to transparent materials, all of the physical concepts that are applicable to opaque materials are still constant.

Bernon P. Chamberlin, W. Parker Dodge Assoc.: In buildings with partitions to the ceiling only, what solutions have been tried to reduce sound transmission? How successful have they been?

Mr. Hamme: There's rather a dearth of quantitative information here, but I can indicate what can be done. We can work from the paper I gave, where I broke it up into different contributions to the total attenuation. Introduction of absorption into the plenum space will be effective provided leaks into adjacent rooms are far enough separated so that the sound will have to propagate some distance in the plenum. This absorption could be applied to the structural ceiling, could be laid on the hung ceiling, or could be hung in the space, but I have no direct quantitative information on how much noise control could be accomplished. It would depend on how much absorption was originally in the plenum. There is the possibility of systematically beefing up the ceiling as one would if it were a partition that was leaking. If the ceiling materials themselves are relatively opaque, so that one has the assurance that the unwanted sound is really coming through leaks rather than material, then you will gain the most by a tighter fit of the elements of the suspension system.

On the other hand, if the configuration is such that the air is floating right through it, the thing to do is to try to seal off this air flow by an impervious backing material and try to attain a balance. By gaining higher transmission loss, you don't lose too much absorption, because the absorption of the ceiling depends upon what's behind it, not only on what's exposed. There is the very real possibility of looking at your critical spaces as particular spaces and, around them, extend your wall with a plenum closer which can be of rather simple construction and still supplement the attenuation of the transmission path adequately.

Mr. Frost: Baffles, too would help, I suppose.

Mr. Hamme: Yes, if you mean by that, those hung in space.

Mr. Yerges: I have a standing bet with any architect or consultant I have worked with that where they have a problem of sound transmission from office to office, without leaving my office, I will give them odds that there is an opening so big that it is much more important than any transmission through any of the surfaces. A job in a library at the University of Wisconsin had a suspended perforated metal pan ceiling, and two classrooms across the corridor were useless because you never knew which teacher you were answering when the question was asked. So, an acoustical consultant convinced them to spend $3,000 to baffle the spaces above the classrooms which was obviously the answer and $3,000 later they found he had done a grand job; you could hear a little better now. What he forgot to look at was the two doors to the classrooms directly across the corridor from one another. They had enormous ventilating grilles through which you could nearly walk. So, for $15 they solved the problem by putting a piece of plywood over one of them. Moral -- don't park your brains and grab a handbook. Look first for a convector pipe between offices, or a duct or grille between offices, or an enormous crack between them. Look for the openings first. When you're sure they're closed, and the ducts are closed, then possibly you have a problem with the construction.

Unsigned question: Where partitions terminate at the acoustical ceiling, would it be best to have transmission loss through ceiling and over partition balanced with transmission loss through partitions, i.e., equal in intensity, or would it be best to have an imbalance?

Dr. Mariner: There is little profit in having a wall through which the attenuation or rather the bulk sound transfer, is much less than through the ceiling or vice versa. It is better to have them compatible, mainly for reasons of economy.

Mr. Goodfriend: The noise reduction or attenuation between rooms should be equal, not the transmission losses, because even a little hole with a transmission loss of zero is still a hole. You can't balance the transmission losses; you've got to save the noise reduction from one space to the other.

Unsigned question: How can crackling noises in metal-clad buildings (curtain wall construction) be eliminated? These are due to temperature changes, effect of sun, etc.

Mr. Hardy: About the same way you attack squeaks in cars. You have to have a resilient joint between; you have to have a snug fit; you might use dampening materials on the surfaces. This is an architectural problem that should be worked out by curtain wall suppliers.

J. D. Schlumpf, IBM Corp.: What acoustical treatment would you recommend for a dishwasher room with all surfaces hard and glazed? The material must be fireproof, moistureproof, resist entrainment of airborne greases and odors.

Dr. Mariner: I assume that the partition between the diswasher room and the conference or lecture hall has been examined in terms of the instructions we have been receiving through this conference, and the only leak remaining of significance is the pass door for serving. The noise sources then would be machines somewhat remote from this opening, and dishes being dropped close to the pass door from the dishwasher room to the conference room. Dishwasher rooms present a difficult acoustical problem. You have a good starting point for the use of absorbent materials, since the reduction ultimately achieved is measured by the ratio of the final to the initial absorption. The limitations of what can be used to comply with sanitary codes have been implied, which will vary from spot to spot. A good solution is to provide a good sound absorber with a frequency characteristic suitable for the application, wrap it in lightweight plastic a few thousandths of an inch thick, and hang it on battens from the upper part of the dishwasher room where it isn't subject to spattering. This is washable, can be made fireproof by the proper selection of materials, will not entrain fumes, or odors, and it can be cheap and can be discarded. By using this method, the noise originating in the room can easily be reduced by 6 decibels. To inhibit noises originating near the opening, such as impact noises from dishes, select a surface that is resilient. Then you can, with similar treatment backed up to inhibit transmission through it, build a duct around the opening. This does not attenuate the noises that originate in the room and coming through the hall, but it absorbs at the point of origination a large portion of the noise produced there. The absorptive material at the point where the dishes are dropped, and the reflectance of the absorbent material in the surface in the surface on which the dishes are dropped, together encompass a large fraction of the sphere in which sound can be radiated. This can reduce the available open area for sound radiation and improve your situation by 6 decibels.

Unsigned question: What about transmission through the floor?

Dr. Mariner: It is impossible to give a general answer because the environment in terms of the stiffness of the floor, etc., can vary so greatly. These things have to be treated case by case.

Mr. Newman: Certainly, resilient isolation of any moving equipment is essential if we are going to cut out sound transmission to the space below, that means resilient isolation of garbage grinders, dishwashers, etc. This is hard to do, but it can be and has been done.

Floor comment: You must use material that will resist water and grease.

Mr. Newman: Yes, and there are such materials.

Floor question: What type of piping material would you use? This is usually a source of sound transmission.

Mr. Newman: You can use hose.

Floor comment: You can't very well use a flexible connector with a garbage disposal unit.

Mr. Newman: Yes you can; hoses have been used in a number of cases.

Mr. Yerges: If you must have a dishwasher room next door to the conference room, don't do noisy things at hours when conferences are going on. This is the cheapest acoustical treatment there is.

Mr. Frost: How about paint as as acoustical material?

Mr. Newman: As far as we know, there isn't going to be any acoustical paint unless it becomes quite thick and porous, with intercommunicating air pores. Foamed plastic materials may be developed which will foam in place and have intercommunicating air pores, but they certainly have to build up an appreciable thickness. It can't be done with ordinary thin paint, that is, either absorption or isolation.

Floor question: Is there any advantage in having heavy viscose coatings on lightweight aggregate concrete block?

Mr. Newman: If porosity is the problem, then certainly the paint will seal the pores, but there are other problems in lightweight masonry having to do with the stiffness to mass ratio.

Robert Lippin, Rogers & Butler, Architects: Why do acoustical engineers provide incomplete specs to architects leaving material types, methods of fastening and application for architects to decide?

Mr. Goodfriend: So many architects have said, "Leave the architectural design to the architects."

Mr. Lippin: In one auditorium job, the acoustical engineer specified a material by Johns-Manville that hadn't been produced for 10 years. Fiberglas acoustical specifications were not given, frequencies were not given, what type, etc.

Mr. Yerges: An acoustical engineer is no different than an architect, enginer, doctor, or dentist. He is a professional man; his professional competence is an individual thing. You should choose him with the care you choose any other professional man. The only answer is that a competent man will give you a competent job.

M. Dormont, Voorhees Walker Smith Smith & Haines: What has been done to reduce the erosion of duct lining?

Mr. Newman: Manufacturers of duct lining materials realize that wind erosion in the duct work is a problem. Some of the materials have very long fibers and don't erode very easily. Sometimes the materials are coated with sprayed-on layers of vinyl and other plastic materials. In very high velocity applications the liners may have to be covered with fabric and perforated metal coverings, depending on how high the velocity is and what materials you are using. There have been many instances where "general itch" has been experienced throughout the building from glass or mineral fibers being blown out of the system and down the necks of the building occupants.

Unsigned question: What material can be used in hospitals for absorption purposes that would meet requirements for sterility, washability and non-shedding characteristics under rough handling? Acoustical plaster has not proven satisfactory for absorption purposes.

Mr. Yerges: Get in touch with a big manufacturer of acoustical tile. There are at least eight who can supply you.

Wm. Batchelor, Tuttle & Bailey: Although there seems to be general agreement of the necessity of source power, considerable confusion will be created by the application of varying standards or yardsticks of room performance. Sones and phons seem to require transfer charts to obtain values from measured decibels of sound pressure. Why not limit the standards of room performance to a system capable of being directly measured?

Mr. Hardy: Engineers rebel at subjective measurements. They think you can get a meter that reads everything. When you get into subjective things like human engineering, there is no meter that measures what a man does when he sits in a chair, or his reaction to a color or lighting situation, but we can calculate from some physical data a pretty fair result of human reaction under certain circumstances. In the case of ventilation noise, because it is a good steady sound, we can get a better reaction than we could in the case of intermittent sounds, but don't expect to get a meter that will provide all the answers.

F. R. Goldschmied, Westinghouse Electric: Can you calibrate a quasi-reverberant room with a known source of some spectrum shape, to be used with noises of widely different spectrum shapes?

Mr. Hardy: Yes, you can. This topic should be discussed privately with one of the consultants, however. It would confuse most people more than it would help them out.

Bernon P. Chamberlin, W. Parker Dodge Assoc.: Please expand on some problems and solutions in connection with light weight masonry block construction. Porosity is not the main problem.

Mr. Newman: Sometimes it is the main problem. Once you get the unit filled up, you may still find it isn't very good because of coincidence effects. It won't behave as well as its mass would lead us to believe it would.

Mr. Chamberlin: Would coating one side with plaster have any effect?

Mr. Newman: No, the plaster coating would increase the weight a little bit and would stop any porosity, if that were the trouble. You would have to fir your plaster out from the wall to get any appreciable benefit from adding plaster to it.

Unsigned question: When the consultant writes noise specifications for a particular room, he has the choice between: 1) over-all noise level in db "A" scale, 2) NC curve, 3) loudness in sone, and 4) sound power produced by a particular piece of machinery in the 8 octave bands. Which seems most practical for all concerned at this time?

Dr. Mariner: The best method to apply is for the consultant to determine the criteria which apply to final assessment of the acoustical space. This involves not only his experience and experiments; and his familiarity with experience and experiments of other people which predict average response, but it implies familiarity with the personality of the persons involved. Having this, he then directs his attention to satisfying these criteria. And, whether sones, phons, decibels, attenuation factors, or transmission losses come in between, is of very little consequence.

Floor question: When should the architect call in an acoustical consultant to be sure of having the correct acoustics in the completed church or auditorium he is designing.

Mr. Goodfriend: The earlier you call in an acoustical consultant the happier you'll be in the long run. Where you have a room that is so large you must have a sound system, it must be integrated in the acoustical design. You can't just say we have an acoustical design and let's get the X-Y-Z company to come in and lay out a sound system, and expect to have anything but an unhappy situation.

Mr. Jaros: The only intelligent way to build a successful building is for the architect to be the head of a team which includes structural, acoustical, and mechanical men who can give him any advice he needs. If he calls them in later, he may find he has to scrap a lot of his work to make things work out properly.

Mr. Yerges: I wish I could have that remark emblazoned on the AIA headquarters building. It is the best remark I have heard on the subject.

A. D. Benjamin, Voorhees Walker Smith Smith & Haines: On duct linings that have an interior finish of glass cloth, can this cloth be coated with a plastic without affecting the attenuation?

Mr. Yerges: The answer is no. There will be some effect, but it isn't always serious.

Fritz Nathan, AIA: What is the recommended construction method of false ceiling between room and plenum: 1) acoustical tile on plastered hung ceiling; 2) acoustical tile on plaster board; 3) suspended acoustical tile?

Mr. Newman: The heaviest and tightest plenum surface you can put up. A tightly plastered well designed ceiling to which tile could be stuck would probably be the best. A well made suspended gypsum board or similar base would be next, and the last would be suspended acoustical tile with nothing behind, which would probably not be satisfactory. It depends on what transmission you can tolerate. If you're worried about transmission from office to office, be very careful about suspending acoustical tile with nothing behind it; you're probably going to invite problems.

Unsigned question: In your experience have you found it necessary in general to provide acoustical treatment for sound absorption in operating rooms of hospitals?

Mr. Newman: It is very desirable, but seldom done. It is like the problem of dishwashers, sanitation, etc. This is a very good removable unit that can be wrapped in plastic and be taken out and thrown away or sterilized and used again. Quite often the problem is bypassed because the room has to be hoseable, and so on.

Mr. Yerges: Many of us have awaited this opportunity to delve into the philosophy of acoustics. Don't be frightened by its esoteric terms. As a matter of fact, everything we know about this subject Newton knew. Our problem is that we use language no one can understand, but this can be solved with common sense. First of all you must ask yourself, "what am I trying to do and for whom?" My architect friends may argue, but essentially, isn't a building a controlled environment? Every building is built today for the occupancy of people. That automatically tells you what you're looking for, in a controlled environment. You can't put a single number on it -- there are almost 3 billion people and you'll have 3 billion answers. Just ask yourself what you're trying to do and when the job requires someone with more specific skills or information, call him in.

Mr. Newman: There will be no surprises, acoustically speaking, in 1959 and there is no excuse for some of the surprises a building owner gets today.

Mr. Goodfriend: When the architect thinks about illumination and air conditioning, he should also think about acoustics. This will help to effect what Mr. Newman and Mr. Yerges were talking about.

Mr. Hamme: I highly recommend using ones ears. Walk into a room, use your ears, look around and confirm what has been said at this conference. There is not enough communication between all of us. This may be the fault of the acoustic people, who talk a trade language all their own. We'll have to make it more understandable. There's a great deal of information available which isn't being used, isn't being communicated, and I hope that BRI can be the medium to provide such communication.

Dr. Mariner: I am impressed with the serious desire to receive information evidenced here, and I am sure there is much more available than is being disseminated, I would like to see everyone who has information, whether it be academic or technical, see that the information is put out where it can be used. Secondly, I agree regarding the importance of acoustics in building as part of the environment. However, a building, in addition to being for the occupants, is something for people to look at, and I hope it will always stay that way.

Mr. Frost: Architecture is a combination of art and science, and I am glad to learn that acoustics still has some art left in it, that it is not all science.

Mr. Parkinson: One of the major purposes of BRI is to provide the avenue of communication we all know is so vital to progress. If this meeting has served that purpose, it has been successful.

Appendix I

SURVEY OF BRI MEMBER INTEREST IN ACOUSTICAL DESIGN IN BUILDINGS

A questionnaire was mailed to all participating members of the Building Research Institute on January 13, 1958, to give them the opportunity to express their specific interest in the field of acoustical design. The results of the survey are tabulated on the following pages.

Response to Questionnaire

	BRI Member Organizations at Time of Mailing	Replies	Percentage
Manufacturing Companies (including Trade Associations)	215	63	29%
Acoustical Consulting Firms	4	2	50%
Architect-Engineer Firms	88	27	31%
Individual University Faculty Members	32	6	19%
General Contracting Companies	25	3	12%
Specialty Contracting Companies	20	4	20%
Home Building & Prefabricating Companies	20	4	20%
Individual Research Organization Personnel	18	5	28%
Publishing Companies	10	1	10%
Building Owner Members	22	15	68%
TOTAL	454	130	29%

TABLE I - INTERESTED IN A BRI ACTIVITY ON ACOUSTICAL DESIGN IN BUILDINGS	Manufacturers			Construction			Design			Other			
	Acoustical Products	Related Products	Products Not Related	General Contractors	Specialty Contractors	Home Bldrs. & Prefabs.	Acoustical Consultants	Architects & Engineers	University Faculties	Research Organizations	Consumer Press	Bldg Owners & Operators	TOTAL
Yes	22	30	1	3	4	4	2	27	6	4	1	15	119
No	-	-	6	-	-	-	-	-	-	-	-	-	6
Uncertain	-	-	4	-	-	-	-	-	-	-	-	-	4

TABLE II - SPECIFIC INTEREST - BUILDING TYPES	Acoustical Products	Related Products	Products Not Related	General Contractors	Specialty Contractors	Home Bldrs. & Prefabs.	Acoustical Consultants	Architects & Engineers	University Faculties	Research Organizations	Consumer Press	Bldg Owners & Operators	TOTAL
Manufacturing	7	3	1	2	1	-	-	8	-	-	-	6	28
Commercial	8	5	-	1	-	-	-	5	-	-	-	3	22
Schools	3	6	-	1	-	-	-	9	2	1	-	3	25
Housing	6	5	-	-	-	4	-	1	2	2	1	2	23
Office Buildings	8	10	-	3	2	-	-	11	-	-	-	10	44
Institutional Buildings	3	4	-	3	2	-	-	10	-	-	-	4	26
Auditoriums (incl. Churches)	2	1	-	-	-	-	-	9	1	-	-	3	16
All Types	9	10	0	0	1	0	2	6	3	2	0	0	33

TABLE III - RELATIVE IMPORTANCE OF KINDS OF ACOUSTICAL SOLUTIONS TO RESPONDENTS		Acoustical Products	Related Products	Products Not Related	General Contractors	Specialty Contractors	Home Bldrs. & Prefabs.	Acoustical Consultants	Architects & Engineers	University Faculties	Research Organizations	Consumer Press	Bldg Owners & Operators	TOTAL
Noise Reduction	1st	9	8	-	-	2	1	-	4	1	1	-	4	30
	2nd	3	3	-	-	-	-	1	2	-	-	-	3	11
	3rd	1	-	-	-	-	-	-	1	-	-	-	-	2
Sound Isolation	1st	1	8	-	-	-	-	1	4	2	1	-	3	20
	2nd	7	3	-	-	1	-	-	2	-	-	-	3	16
	3rd	2	-	-	-	-	-	-	3	-	-	-	1	6
Acoustical Correction	1st	4	1	-	-	-	-	-	1	-	-	-	1	7
	2nd	3	-	-	-	-	-	-	4	1	-	-	1	9
	3rd	3	2	-	-	1	-	1	2	-	-	-	3	12
All of Equal Importance		4	4	0	2	1	2	1	17	3	1	1	6	42

TABLE IV - SPECIFIC INTEREST PROGRAM TOPICS

	Manufacturers			Construction			Design			Other			
	Acoustical Products	Products Not Related	Related Products	General Contractors	Specialty Contractors	Home Bldrs. & Prefabs.	Acoustical Consultants	Architects & Engineers	University Faculties	Research Organizations	Consumer Press	Bldg Owners & Operators	TOTAL
1. Acoustical Studies of Building Types:													
a. Various	-	-	-	-	-	-	-	3	-	-	-	-	3
b. Housing	3	-	-	-	-	3	-	-	-	-	1	-	7
2. Educational Programs on Acoustical Mat. & Theory:	2	-	2	-	-	-	-	3	-	1	-	3	11
3. Dissemination of Data Abstracts & Bibliographies:	-	-	-	-	-	-	-	3	-	-	-	4	7
4. Problems with Acoustical Materials:													
a. Fire Resistance & Fire Proof Tile	3	-	1	-	-	-	-	-	-	-	-	1	5
b. Acoustical Plaster	2	-	1	-	-	-	-	1	-	-	-	-	4
c. Installation Methods for Acoustical Tile	2	-	2	1	-	-	-	-	-	-	-	-	5
d. Suspended Metal Acoustical Ceilings	1	-	3	-	-	-	-	-	-	-	-	1	5
e. Foamed in Place Plastic Absorptive Mat.	-	-	3	-	-	-	-	2	-	-	-	-	5
f. Decor., Cleaning & Maint. of Absorptive Mat.	1	-	1	-	1	-	-	2	-	-	-	2	7
g. Absorption Data for Interior Furnishings	1	-	-	-	-	-	-	-	-	-	-	-	1
h. Grade Acoustical Mat. for Humid Areas	-	-	-	-	-	-	-	1	-	-	-	1	2
i. Simple Field Evaluation Methods for Effectiveness of Acoustical Treatments	-	-	-	-	-	-	-	1	-	-	-	-	1
5. Noise Transmission Through Walls and Floors:													
a. General - Walls	5	-	10	1	1	2	-	3	-	1	-	3	26
b. General - light weight construction, incl. partitions & metal curtain walls	2	-	8	-	-	2	1	4	3	-	-	3	23
c. Walls - Impact Noise Transmission	2	-	3	-	-	-	-	-	-	-	-	-	5
d. Use of Gaskets for Door & Wall Joints	-	-	4	-	-	-	-	1	-	1	-	1	7
e. Curtain Wall Floor-to-Floor Barriers	-	-	2	-	-	-	-	3	-	-	-	-	5
f. General - Floors, Incl. Impact Noise	2	-	-	-	1	2	-	2	1	1	-	-	9
6. Mechanical Equipment and Acoustics:													
a. Noise Isolation & Reduction from Plumbing, Air Cond. & Mech. Equip. Sources	2	-	4	1	2	2	1	8	1	-	-	5	26
b. Correlation of Lighting, Air Cond. & Acoust. Ceiling Systems	1	-	4	-	1	-	-	3	-	-	-	3	12
7. Other Noise Problems:													
a. Evaluation of Relative Importance of Different Noises	1	-	8	-	-	-	1	1	-	-	-	1	12
b. Relate Airborne Noise & Space Planning	2	-	1	-	-	-	-	2	3	2	-	-	10
c. Noise from Thermal Expansion of Metal Curtain Walls	-	-	-	-	-	-	-	2	-	-	-	-	2
d. Noise Reduction in Manufacturing Processes	1	1	1	-	-	-	-	-	-	-	-	1	4

Attendance at the Conference

Acheson, Eugene	Simmons College, 300 Fenway, Boston, Mass.
Adams, George C.	Project Engineer, Rollform, Inc. 14001 Intervale, Detroit 27, Mich.
Albright, Gifford H.	Assoc. Prof., Dept. of Arch. Pennsylvania State University, University Park, Pennsylvania
Aldridge, W. F.	N. Y. Bell Telephone System, 140 West Street, N.Y.C.
Allison, David	Forum, 9 Rockefeller Plaza, N.Y.C.
Altieri, John	Voorhees Walker Smith Smith & Haines, Arch. 101 Park Avenue, New York 17, New York
Anderson, G. M.	McGraw Edison Co., W. Orange, N.J.
Attwood, James W.	Vice President and Assistant General Manager, Unistrut Corp. 4118 S. Wayne Road, Wayne, Mich.
Aylworth, Lois	101 Charles Street, N. Y. 14, N.Y.
Baape, Peter	Anemostat Corp., Box 2128, Hartford, Conn.
Bachhuber, Marten	Utica College of Syracuse University, 520 Plant St., Utica, N.Y.
Bainbridge, Wm. W.	P.E. U. S. Gypsum Co., 300 W. Adams St., Chicago 6, Ill.
Baker, Allen J.	Virginia Metal Products, Inc., Orange, Virginia
Barlow, Raymond S.	Anemostat Corp. of America, Hartford, Conn.
Barradale, Stewart D.	Mgr. Bldg. Research, Southwest Research Institute, 8500 Culebra Rd., San Antonio 1, Texas
Barry, Theodore	Phillips Exeter Academy, Exeter, N.H.
Barsuk, Erwin	Wigton Abbott Corporation, 1225 South Avenue, Plainfield, N.J.
Barton, R. H.	Elastomer Chemicals Dept., E. I. duPont de Nemours & Co., Inc. 1750 N. Olden Ave., Trenton, N.J.
Batchelor, Wm.	Tuttle & Bailey, Warren St., New Britain, Conn.
Beardsley, Wallace P. Jr.,	Beardsley & Beardsley, 64 So. St., Auburn, N.Y.
Benjamin, Arthur	Voorhees Walker Smith Smith & Haines, Arch. 101 Park Avenue New York 17, N.Y.
Bernhard, Harold C.	Partner, Shreve, Lamb & Harmon Associates, 11 E. 44th St., N.Y.C.
Bevans, R. S.	American-Standard Corp., Monroe Street, Union, New Jersey
Blazier, Warren, Jr.	Borg-Warner Corp., York Division, York, Pa.
Bogert, A. Z.	A. Z. Bogert Company, West Point, Pa.
Bond, S. C.	Heyl-Bond-Miller, Arch. No.1 Lehigh Parkway, N. Drive, Allentown, Pa.
Bontempo, Joseph F.	Joseph F. Botempo & Associates, 115 Shields Street, Rochester, Pa.
Bossung, Chas. F.	U. S. Gypsum Co., 300 W. Adams St.,Chicago 6, Ill.
Botka, Leslie M.	Curon Division, Curtiss-Wright Corp., Quehanna, Pa.
Braasch, A. M.	International Latex Corp., Dover, Del.
Brashear, R. H.	N. Y. Telephone Co., 158 State Street, Albany, N.Y.
Brennan, Martin J.	Vice President, Jacobson & Company, Inc. 227 East 44th Street, New York 17, New York
Briggs, John F.	Carrier Corporation, Northeastern Regional Office, 385 Madison Ave., New York 17, New York
Brown, A. E.	Assoc. Architect, Albert Kahn, Assoc. Architects & Engineers, 345 New Center Building, Detroit 2, Michigan

Brown, J. Sanger	New York Life Ins. Co., 51 Madison Ave., New York, N.Y.
Buergin, R. G.	Dir. of Tech. Service, National Gypsum Co., 1650 Military Rd., Buffalo 17, N. Y.
Burda, Robert L.	Humble Oil & Refining Co., P.O. Box 2180, Houston 1, Texas
Burgess, E. B.	Assistant Aircomb Administrator, Douglas Aircraft Co., Inc., 3000 Ocean Park Boulevard, Santa Monica, California
Burkart, Ernest D.	Acoustical Materials N. Y. Co., Inc., 20 Loudonville Rd., Albany, N.Y.
Burris-Meyer, Harold	Consultant, 734 Fifteenth St., N.W., Washington 5, D.C.
Buttolph, L. J.	Executive Secretary, The National Noise Abatement Council, 36 West 46th St., New York 36, N.Y.
Bygrave, Robert	Pittsburgh Corning Corp., 1 Gateway Center, Pittsburgh, Pa.
Cady, Sheldon H.	Sales Supervisor, Barrett Division, Allied Chemical Corp. 40 Rector Street, New York 6, New York
Caldwell, Donald B.	Minnesota Mining & Mfg. Co., 900 Bush Ave., St. Paul, Minn.
Caravaty, Raymond D.	Assoc. Prof., Rensselaer Polytechnic Institute, School of Architecture Troy, New York
Cardinell, R. L.	L. S. Goodfriend & Assoc. 1 The Crescent, Montclair, N.J.
Carlos, John James	Editor, Architectural & Eng. News. 452 Fifth Ave., N.Y.C. 18
Carr, J. Gordon	J. Gordon Carr & Assoc., 80 West 40th St., N.Y. 18, N.Y.
Carrell, Don	Acoustical Materials Corp., 363 Park Ave., E. Hartford, Conn.
Carter, William R.	Lloyd E. Mitchell, Inc. 3004 Ridgewood Ave., Baltimore, Md.
Cathcart, Robert M.	New York Artcrafts, Inc. 280 Madison Ave., New York, N.Y.
Chaffee, F. D.	Director of Physical Plant, St. Lawrence Univ. Canton, N. Y.
Chamberlin, Bernon P.	W. Parker Dodge Assoc.,Red Mill Rd., Rensselaer, N.Y.
Charles, H. H.	Dir. Architectural Research, Reynolds Metals Co., 5th & Cary Streets, Richmond, Virginia
Cherici, Pier	Voorhees Walker Smith Smith & Haines, Arch. 101 Park Ave., New York 17, N.Y.
Christian, Harry	Voorhees Walker Smith Smith & Haines, Arch.,101 Park Ave., New York 17, N.Y.
Christiano, Thomas D.	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Clarke, E. T.	NAPPA, McMaster University, Hamilton, Ontario Canada
Clarke, Richard G.	Director, Div. of Research, University of Hartford, P.O. Box 1948, Hartford, Conn.
Claus, Karl M.	The Mosaic Tile Company, Pershing Road, Zanesville, Ohio
Clavin, James V.	Physical Plant Administrator, Fordham University, New York 58, N.Y.
Clements, W. A.	New Castle Products, Inc., New Castle, Indiana
Cleneay, W. Allen	Monsanto Chemical Co., 800 N. Lindbergh, St. Louis, Mo.
Coe, B. N.	Owens Corning Fiberglas Corp., 16 E. 56th St., N.Y.,N. Y.
Coiro, Ettore	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Connolly, J. M.	McGraw-Hill Publishing Co., 330 W. 42nd St., N.Y. 36, N.Y.
Connor, Frederick A.	F. A. Connor, Inc., 140 Powell Street, Lowell, Mass.
Conway, Joseph J.	Rockefeller Center Inc., 30 Rockefeller Plaza, N.Y., N.Y.
Cook, Albert	American Zinc Inst., 60 E. 42nd St., New York 17, N.Y.
Costello, John G.	National Gypsum Co., 325 Delaware Ave., Buffalo, N.Y.
Cox, Edwin S.	Vice President, Asbestospray Corp., Newark, N.J.
Cutten, William K.	James Lees & Sons, 2815 Washington St., Allentown, Penna.
Daigle, Sidney	Unistrut Southern Service, P.O. Box 1231, New Orleans 13, La.
Darrow, Carl	National Lumber Mfg. Assoc., 420 Lexington Ave., N.Y. 17, N.Y.

Davidson, Frank A.	Harrison & Abramovitz, 630-5th Ave., New York 20, N.Y.
Deegan, Wm. J. Jr.	Chief Engineer, Modular Construction, American Bridge Div., U. S. Steel, 204 Frick Bldg., Pittsburgh, Pa.
Delavan, L. P.	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., N. Y. 17, N.Y.
de Groot, R. C.	Davis Acoustical Co., Hartford, Conn.
De Lisle, Mr.	Joseph Laplume Ltee, 1855 Villiers St., Montreal, Canada
de Moll, Louis	The Ballinger Co., 1625 Race St., Philadelphia 3, Pennsylvania
De Nunzio, Michael	Port of New York Authority, 111-8th Ave., N.Y., N. Y.
Dinion, Hyland	Port of New York Authority, 111-8th Ave., N.Y., N.Y.
Dodge, Arthur B. Sr.,	Chairman, Dodge Cork Co., Inc., Lancaster, Pennsylvania
Doherty, P. J.,	Syska & Hennessy Inc., 144 East 39th St., New York 16, N.Y.
Donovan, Daniel K.	Research Engineer, Larsen Products Corp., 4934 Elm St., Bethesda 14, Maryland
Darmont, Milton	Vorrhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Dorrance, George P.	Technical Advisor, Turner Construction Co., 150 E - 42nd St., New York 17, N.Y.
Drinkwine, Harvey N.	Middleburg College, Middleburg, Vermont
Dunbar, James Y.	Wm. J. Scully Acoustics Corp., 425 Lexington Ave., N.Y.C.
Economides, Leander	Chief, Mech. Div., Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Elliott, Walton S.	Gustin-Bacon Mfg. Co., 230 Park Ave., New York, N.Y.
Elliott, William S.	The Vermiculite Assn., Inc., 6467-83 Place, Rego Park 79, N.Y.
Erf, Herbert A.	H. A. Erf Acoustical Co., 3868 Carnegie Avenue, Cleveland 15, Ohio
Erney, Paul	Elop Hansson, Inc., 711 Third Ave., New York, N.Y.
Eyre, Jim	Owens Corning Fiberglas Corp., 16 E. 56th St., N.Y., N.Y.
Farr, Robert L.	Bureau of Yards & Docks (Navy), Washington 25, D.C.
Farrell, William R.	Bolt, Beranek & Newman Inc., 50 Moulton St., Cambridge, Mass.
Fidden, George	Davis Acoustical Corp., 45 - 4th Ave., Albany, N. Y.
Findlay, R. G.	Inland Steel Products Co., 230 Park Ave., N.Y. 17, N.Y.
Fischer, Robert E.	Associate Editor, Architectural Record, 119 W. 40th St., N.Y. 18, N.Y.
Flint, John	Southern Acoustics & Supply Co., 254 E. Paces Ferry Rd., N.E., Atlanta, Ga.
Fobes, Malcolm, R.	Goucher College, Towson 4, Maryland
Folley, M. D.,	Partner, Sargent-Webster-Crenshaw & Folley, 2112 Erie Blvd. G., Syracuse 3, N.Y.
Fowler, Mark S.	Johns-Manville Sales, 270 Madison Ave., N.Y.C., N.Y.
Friedman, Henry	Voorhees Walker Smith Smith & Haines, Arch. 101 Park Ave., New York 17, N.Y.
Frost, Frederick, Jr.	Frederick Frost, Jr. & Associates, 144 East 30th St., N.Y. 16, N.Y.
Gaston, J. E.	Gen. Mgr., Bldg. Materials Research, Armstrong Cork Co., Research & Development Center, Lancaster, Pa.
Gates, Ralph B.	Radcliffe College, 12, Appian Way, Cambridge 38, Mass.
Gates, W. L.	The Celotex Corp., 120 So. LaSalle St., Chicago, Illinois
Geddes, Robert L.	Architect, Geddes-Brecher-Qualls, 258 S. Van Pelt, Philadelphia 3, Pa.
Gill, G. Douglas,	Partner, Grayson Gill, Archt. Eng., 1913 San Jacinto, Dallas 1, Texas
Goldberg, Norman	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Goldschmied, Fabio R.	Mgr. Adv. Dev. Engineering, Westinghouse Electric Corp., Sturtevant Division, Hyde Park, Boston 36, Mass.
Goodfriend, Louis	Lewis S. Goodfriend & Associates, Montclair, N.J.
Gratton, O. J.	Universite de Montreal, 2900 Mt. Royal Blvd., Montreal, Quebec, Canada

Greenberg, I. Joseph	Charles Luckman Associates, 24 East 51st Street, N.Y. 22, N.Y.
Griffen, William	Cliff G. Haller Co., 711, W. Robinson, Orlando, Fla.
Haas, Herbert W.	Environmental Health Section, Sanitary Engineering Branch, National Institutes of Health, Bethesda 14, Maryland
Hackel, Arnold	Voorhees Walker Smith Smith & Haines, Arch. 101 Park Ave., N. Y. 17, N.Y.
Hamme, Richard	Geiger & Hamme, Acoustical Consultants, Ann Arbor, Michigan
Hanft, J. D.	Turner Construction Co., 1500 Walnut St., Philadelphia 2, Pa.
Hanzalek, Wm. V.	Curtiss Wright Corp., Research Division, Quehana, Pa.
Hardy, Howard C.	Consultant, Howard C. Hardy & Associates, 22 W. Madison Street, Chicago 2, Illinois
Harmon, W. M.	United Sheet Metal Co., Inc.,540 S. Drexel Ave., Columbus 9, Ohio
Harris, Ralph F.	E. I. duPont de Nemours & Co., Inc., P.O. Box 406, Wilmington, Del.
Halstead, Douglas M.	Republic Aviation Corp., Farmingdale, L.I., N.Y.
Healy, John J.	In Charge of Research, Harrison & Abramovitz, Architects, 630 Fifth Ave., New York, N.Y.
Hemming, Charles B.	Dir. Research & Development, United States Plywood Corporation, P. O. Box 126, Brewster, New York
Hemond, Conrad, Jr.	Assoc. Prof. and Chairman, School of Engineering, University of Hartford, Hartford, Connecticut
Henszey, William P.	343 Lexington Ave., New York, N.Y.
Hickman, J. S.	Inland Steel Products Co., 4101 W. Burnham St., Milwaukee 15, Wis.
Higgins, J. R.	Mgr. Product Dev. Dept., Gustin-Bacon Mfg. Co., 2920 Fairfax, Kansas City, Kan.
Hill, Vaughn H.	E. I. duPont de Nemours & Co., Inc., Engineering Dept., Wilmington, Delaware
Hirschorn, Martin	Industrial Acoustics Co., 341 Jackson Ave., N.Y. 54, N.Y.
Hoffman, W. O.	Buensod Stacey Inc., 45 W - 18th St., N.Y., N.Y.
Holtby, Robert	Davis-Fetch Co., 22 Wright Street, Rochester, N.Y.
Homan, Leon J.	Parsons Brinckerhoff Hall & Macdonald, 165 Broadway, N.Y.C.
Horn, Walter	L. J. Wing Mfg., Co., No. Stiles St., Linden, N.J.
Hotchkiss, John G.	American Institute of Steel Construction, 101 Park Ave., N.Y.17,N.Y.
Howard, Robert J.	Reynolds Metals Co., 6601 W. Broad St., Richmond, Va.
Howell, T. E.	Caterpillar Tractor Co., Peoria, Ill.
Huber, A. J.	Vincent G. Kling, 917 Corinthian Ave., Philadelphia, Pennsylvania
Huggins, Donald	Owens Corning Fiberglas Corp., Newark, Ohio
Humes, Harold L.	Vice President, Baldwin-Hill Co., 500 Breunig Ave., Trenton 2, N.J.
Huntley, Ralph	Riverbank Acoustical Laboratories, Armour Research Foundation, Geneva, Illinois
Ingram, H. W., Jr.	Rhode Island School of Design, College St., Providence, R.I.
Irish, Ellwood,	Chief Engineer, Unistrut Corporation, 4118 S. Wayne Road, Wayne, Michigan
Jack, William A.	Section Chief, Acoustics Bldg., Johns-Manville Research Center, Manville, New Jersey
Jaros, Alfred L.Jr.,	Partner, Jaros, Baum & Bolles, 415 Lexington Ave., New York, N.Y.
Jentoft, Arthur P.	H. H. Robertson Co., 60 Markham Drive, Pittsburgh 28, Pa.
Jones, Allen R.	Medical Research Div., Esso Research & Engineering, P.O. Box 45, Linden, N.J.
Kelly, W. E.	The Mo saic Tile Company, 607 S. Ball St., Arlington, Virginia
Kelto, R. W.	Chrysler Corp., Airtemp Div., 1600 Webster, Dayton 1, Ohio
Kempson, Norman W.	Johnson & Johnson, New Brunswick, N.J.
Kendelhandt, Roger D.	N. Y. Tel. Co., 140 West Street, N.Y.C., N.Y.
Kime, Joseph M.	B. F. Goodrich Co., Brecksville, Ohio

King, Sol	President, Albert Kahn Assoc. Architects & Engineers, 345 New Center Bldg., Detroit 2, Michigan
Kingsbury, H. F.	Prod. Dev. Eng., Pittsburgh-Corning Corp. P.O. Box 39, Port Allegany, Pa.
Kleinhans, Herbert L.	Mgr. Product Dev., Pawling Rubber Corp., Pawling, N.Y.
Kling, Vincent G.	Vincent G. Kling, 917 Corinthian Avenue, Philadelphia, Pennsylvania
Kodaras, M. J.	Acoustical Consultants, 41-14 24th St., N.Y., N.Y.
Krieger, A. D.	IBM Corporation, Dept. 745, Poughkeepsie, N.Y.
Krucek, John	Asbestospray Contractors Division, 32 South LaSalle Street, Chicago, Illinois
Lancaster, J. E.	Mgr. of Eng., A.C. & R. Div., Worthington Corp., Ampere Station, East Orange, New Jersey
Lane, Charles E., Jr.	New York Life Insurance Co., 200 E. 66th St., N.Y. 21, N.Y.
Lang, Saundra	Mechanical Contractor Magazine, 45 Rockefeller Plaza, N.Y.20,N.Y.
Leaver, Eugene H.	University of New Hampshire, Service Bldg., Durham, N.H.
Leax, James	Davis-Fetch Co., 5505 Centre Avenue, Pittsburgh 32, Penna.
Leek, William A., Jr.	Davis Acoustical Co., 45-4th Avenue, Albany, New York
Lichtgarn, James	Otis Elevator, 260 11th Avenue, N.Y.C., N.Y.
Lindahl, Robert	The Miller Company, 99 Center Street, Meriden, Connecticut
Lippin, Robert	Rogers & Butler, Architects, 219 East 44th Street, N.Y.17, N.Y.
Livingston, Maxine	Family Home Editor, Parents Magazine, 52 Vanderbilt Ave., N.Y. 17, N.Y.
Lord, H. G.	Commercial Trade Sales Div., National Gypsum Co., 325 Delaware Avenue, Buffalo 2, N.Y.
Lucier, Charles T.	Parke Davis & Co., Jos. Campau at the River, Detroit, Michigan
Lukacs, William	A.I.A., Dir. of Research, YMCA National Council, Bldg. Service, 291 Broadway, New York 7, N.Y.
MacKay, Gerald	University of Buffalo, 3835 Main Street, Buffalo, N.Y.
Macrae, John	Owens-Corning Fiberglas Corp., 16 E. 56th Street, N.Y.C., N.Y.
Maiello, John T.	International Business Machine Corp., 2 La Grange Ave., Poughkeepsie, N.Y.
Manson, William A.	Manson & Utley Inc., 200 N. 21st Street, Richmond, Virginia
Mariner, Thomas	Armstrong Cork Co., Lancaster, Pennsylvania
Martin, Terence T.	Eastern Representative, National Bureau For Lathing & Plastering Inc., 443 Cyrus Place, New York 58, New York
Mastroferte, J.	Otis Elevator Company, 260 11th Avenue, N.Y., N.Y.
Mays, Howard D.	The Mosaic Tile Company, Pershing Rd., Zanesville, Ohio
McAuley, John J.	Insul-Coustic Corp., 54-18 43rd St., Maspeth 78, Queens, N.Y.
McBride, W. B.	Humble Oil & Refining Co., P.O. Box 2180, Houston 1, Texas
McFarlane, D.	A. E. Furnival Co., Ltd., 43 McCormick St., Toronto 9, Canada
McGarr, John D.	F. P. Wiedersum Assoc., 10 Columbus Circle, N.Y., N.Y.
McKeeby, Donald H.	International Business Machines Corp., Owego, New York
McKenna, Edward D.	New York Life Insurance Co., 51 Madison Ave., N.Y., N.Y.
McKinley, John R.	A. E. D'Ambly, 117 So. 17th St., Philadelphia 3, Pa.
McLoughlin, Theresa	Acoustical Materials Assoc., 335 East 45th Street, N.Y. 17, N.Y.
Mebane, Joan	Architectural Forum Magazine, 9 Rockefeller Plaza, N.Y., N.Y.
Merrill, B. W.	Chief Eng., New Castle Products, Inc., 1711 'I' Ave., New Castle, Indiana
Merritt, Frederick S.	Senior Editor, Engineering News Record, 330 W. 42nd St., N.Y.36,N.Y.
Merritt, Malcolm, Jr.	Editor, Modern Sanitation & Building Maintenance, 855 Avenue of the Americas, New York 1, N.Y.
Michaels, S.E.	Procter & Gamble, M.A. & R. Bldg., Cincinnati 17, Ohio
Miles, E. C.	Pittsburgh Plate Glass Co., One Gateway Center, Pittsburgh, Pa.

Milkton, Alexander G.	Baltimore & Ohio Railroad, 1303 B & O Building, Baltimore, 1, Md.
Miller, Henry F.	Davis, Cochran & Miller, Architects, 29 Whitney Ave., New Haven, Connecticut
Millet, Raymond J.	Con. Edison Co. of N.Y., 4 Irving Place, Room 2015S, N.Y.3,N.Y.
Millman, Irving,	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Mirabella, J.P.	International Business Machines Corp., South Road, Poughkeepsie,N.Y.
Monk, C. B., Jr.	Mgr. Field Eng. & Dev., Structural Clay Products Research Foundation, Geneva, Ill.
Morrell, D. L.	Burgess-Manning Company, 5970 Northwest Highway, Chicago 31,Ill.
Morrison, George W.	University of Maryland, (Professional Schools) Baltimore 1, Md.
Muessig, Lew	Acoustical Materials Co., 363 Park Avenue, E. Hartford, Conn.
Mulqueen, Leo F.	Acoustics, 5148 Mass. Ave., N.W., Washington 16, D.C.
Munchhausen, H. V.	Munchhausen Soundproofing Co., Inc., 290 Riverside Dr., N.Y.C.
Nash, George G.	L. J. Wing Mfg., Co., Inc., Linden, N.J.
Nathan, Fritz	Architect, 200 Central Park So., N.Y. 19, N.Y.
Neereamer, L. H.	John Graham & Co., 444 Fifth Avenue, N.Y.C., N.Y.
Newnam, Robert B.	Vice President, Bolt,Beranek & Newman,Inc., 50 Moulton St., Cambridge, Mass.
Nocar, C. J.	E. F. Hauserman Co., 6800 Grant Ave., Cleveland, Ohio
Nowak, Motthew A.	Architectural Research, Texas Engineering Experimental Station, College Station, Texas
Noyes, H.T.	Chief Eng., Turner Construction Company, 150 East 42nd St., N.Y. 17, N.Y.
Nozko, Henry	Acoustical Materials Co., 363 Park Ave., E. Hartford, Conn.
Oden, Marjorie, Mrs.	Consulting Engineer Magazine, 141 E. 44th St., N.Y. 17, N.Y.
Ogden, F. W.	The Miller Company, 99 Center Street, Meriden, Connecticut
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Olvany, William J.	William J. Olvany, Inc., 100 Charles St., N.Y. 14, N.Y.
Osborn, Robert J.	Heating Piping & Air Conditioning Magazine, 1734 Grand Cent. Term. Building, New York 17, N.Y.
Page, George S.	Arch. Sales Div., Pawling Rubber Corp., Pawling, N.Y.
Park, A. D.	Armstrong Cork Co., Lancaster, Pennsylvania
Parker, Harold C.	Harold C. Parker, Inc., 25 N. E. 29th Street, Oklahoma City, Okla.
Parkinson, John S.	Dir. of Gen. Research and New Bus. Development, Johns-Manville Research Center, P.O. Box 159, Manville, New Jersey
Parodi, Bernard	Voorhees Walker Smith Smith & Haines, Arch.,101 Park Ave., New York 17, New York
Pass, Vincent L.	Pennsylvania State University, Dept. of Architecture, University Park, Pennsylvania
Pellicoro, Paul	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Pennell, S. Howard	Pennell & Wiltberger, Consulting Engineers, 1201 Chestnut Street, Philadelphia 7, Pennsylvania
Peruffo, Joseph D.	IBM Corp., Stream Lane, Pleasant Valley, N.Y.
Peterson, Carl, M. F.	M.I.T. (Eastern Reg. Group NAPPA) 77 Mass. Ave., Rm. 24-205, Cambridge 39, Mass.
Phelps, A. H. Jr.,	Procter & Gamble, MA & R Bldg., Cincinnati 17, Ohio
Philip, D. Ivor	Dominion Tar & Chemical Co., Ltd., Toronto, Ont., Canada
Phillips, Howard E.	Bldg. Eng. American Tel. & Tel. Co., 195 Broadway, N.Y.7, N.Y.
Phillips, Leonard R.	Anemostat Corp. of America, Hartford, Conn.
Pincus, David	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17 .

Pintof, J. H.	U. S. Gypsum Co., 300 W. Adams St., Chicago, Ill.
Poiesz, Clem	U. S. Public Health Service, Rm. 1522 Tempo R. Bldg., Washington 25,D.C.
Pollock, Gordon J.	E. F. Hauserman Co., 6800 Grant Ave., Cleveland, Ohio
Pomerantz, Herbert	Voorhees Walker Smith Smith & Haines, Arch., 101 Park Ave., New York 17, N.Y.
Potter, Allen	Torrington Manufacturing Co., 100 Franklin Dr., Torrington, Conn.
Potts, M. V.	Southern Acoustics & Supply, Birmingham, Ala.
Power, George E.	Group Leader, Moulding & Bonding, American Cynamid Co., 1937 W. Main Street, Stamford, Conn.
Quin, Murray L.	Sr. Dir. of Research, Day-Brite Lighting, Inc., 5411 Bulwer Ave., St. Louis 7, Mo.
Raab, R. H.	Eastern Products Corp., 1601 Wicomico St., Baltimore, Md.
Raupp, Gordon	New York Telephone Co., 101 Willoughby St., Brooklyn, N.Y.
Reardon, William F.	General Electric Company, 1 River Road, Bldg. 36 - Room 204, Schenectady 5, New York
Rees, Malcolm F.	Baldwin-Hill Company, 500 Breunig Ave., Trenton, N.J.
Rees, Willis	Owens-Corning Fiberglas Corp., Newark, Ohio
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Rippeteau, Darrel D.	Sargent-Webster-Crenshaw & Folley, 1402 Washington St., Watertown, New York
Ritchie, K. M.	Baldwin-Hill Company, 500 Breunig Ave., Trenton 2, N.J.
Robinson, Richard M.	Colvin, Robinson & Assoc., Architects, 206 E. Huron, Ann Arbor, Mich.
Rohdenburg, T.K.	School of Architecture, Columbia University, New York 27, N.Y.
Ross, Donald E.	Carrier Corp., 385 Madison Ave., New York, N.Y.
Roth, F. G.	Vincent G. Kling, 917 Corinthian Ave., Philadelphia, Pennsylvania
Rothenstein, Guy G.	F. P. Wiedersum, Assoc., 65 Roosevelt Ave., Valley Stream, N.Y.
Rowley, B. C.	Technical Coordinator, American Cynamid Co., 30 Rockefeller Plaza, New York 20, N.Y.
Ryan, T. Gerald	Joseph F. Bontempo & Assoc., 115 Shields St., Rochester, Pa.
Sanders, Guy J.	Industrial Acoustics Co., 341 Jackson Ave., N.Y., N.Y.
Saulson, Saul	Vice President, Albert Kahn Assoc., 345 New Center Bldg., Detroit 2, Michigan
Schlumpf, James D.	IBM Corp., Owega, New York
Schneller, Jas. W.	National Gypsum Co., 325 Delaware Ave., Buffalo, N.Y.
Scholz, W. R.	Giffels & Rossetti, 1000 Marquette Bldg., Detroit, Mich.
Schuessler, Delores J.	Johns-Manville Corp., Manville, N.J.
Schultz, T. J.	Douglas Aircraft Company, Inc., 3000 Ocean Park Blvd., Santa Monica, California
Sefton, Robert	Goldstone & Dearborn, Architects, 1270 Ave. of Americas, N.Y.C.
Shea, Yale R.	Product Development Engineer, Inland Steel Prod. Co., 4101 W. Burnham Street, Milwaukee, Wisconsin
Sherwood, Richard M.	Aluminum Co. of America, Box 1012, New Kensington, Pa.
Simprenant, F. Ron	G. F. Commercial Sales, 64 Kensington Rd., Glens Fall, N.Y.
Sirine, Donald F.	Sherwood, Mills & Smith, Arch., 65 Broad St., Stamford, Conn.
Skogsberg, Richard E.	U. S. Gypsum Co., 300 W. Adams St., Chicago 6, Ill.
Smith, C. R.	IBM Corp., South Road, Poughkeepsie, New York
Smith, Preston,	Editor, Noise Control Magazine, New York, N.Y.
Smith, Ralph B.	Drew Univ., Madison, N. Y.
Smith, Warren H.	Bechtel Assoc., 485 Lex. Ave., N.Y. 17, N.Y.
Softy, C. D.	IBM Corp., 2 LaGrange, Poughkeepsie, N.Y.
Souder, James J.	Partner, Kiff Colean Voss & Sounder, Architects, The Office of York & Sawyer, 101 Park Ave., N.Y. 17, N.Y.

Spencer, Herbert R.	Ceramic Industry, Chicago, Erie, Pennsylvania
Stark, Charles H.	Owens Illinois Plywood Co., River Road, Waterville, Ohio
Stewart, James A.	Bolt, Beranek & Newman Inc., 50 Moulton St., Cambridge, Mass.
Steinmetz, J. R.	Vincent G. Kling, 917 Corinthian Ave., Philadelphia, Pa.
Sullivan, R. R.	Asst. Mgr., Applied Science Area, Wood Conversion Co., Cloquet, Minnesota
Susmann, Kay	Architectural & Engineering News, 452 Fifth Ave., N.Y.18, N.Y.
Suriani, Adrian S.	A. E. D'Ambly, 117 So. 17th St., Philadelphia 3, Pa.
Swartz, John B.	The Mosaic Tile Co., Pershing Road, Zanesville, Ohio
Szendy, Emil J.	Burns & Roe, 160 West Broadway, N.Y.C.
Talley, T. A. Jr.	T. A. Talley & Son, 1501 Sledd St., Richmond 20, Va.
Thomson, Parkin	Bishop Products Ltd., Lakeshore Road, Toronto, Canada
Toby, James	Davis-Fetch Co., 416 Tallman Street, Syracuse, N.Y.
Thulin, Fred	Thulin, Woods & Isensee, 105 So. La Salle St., Chicago, Ill.
Tighe, J. C.	Vincent G. Kling, 917 Corinthian Ave., Philadelphia, Pa.
Tuft, R. D.	Tuttle & Bailey, Corbin Ave., New Britain, Conn.
Tuttle, Edward X., Jr.	Associate, Giffels & Rossetti, Marquette Bldg., Detroit, Mich.
Ufford, Leonard M.	Dartmouth College, 5 Barrymore Road, Hanover, N. H.
Vermilya, Howard P.	Vice President, American Houses Inc., 83 Allison Road, Princeton,N.J.
Viguers, C. L. III	Berger Acoustical Co., Inc., 355-C Lancaster Ave., Haverford,Pa.
Volse, Louis A.	American Builder, 30 Church Street, New York 7, N.Y.
Wald, Henry	P.E., Architectural & Engineering News, 452 Fifth Ave., N.Y.C.18
Walsh, Ambrose	Mechanical Contractor Magazine, Room 570, 45 Rockefeller Plaza, New York 20, N.Y.
Walsh, John H.	Owens-Corning Fiberglas Corp., 16 E. 56th St., N.Y., N.Y.
Walshe, T. G.	Hofstra College, Hempstead, L.I., N.Y.
Warrington, Herbert D.	Skidmore Owings & Merrill, 425 Park Ave., N.Y. 22, N.Y.
Washburn, Paul J.	Johns-Manville, 22 E. 40th St., N.Y., N.Y.
Waterfall, Wallace	Exec. Secretary & Treasurer, Acoustical Materials Association, 335 E. 45th St., New York 17, N.Y.
Watters, B. G.	Bolt, Beranek & Newman, Inc., 50 Moulton St., Cambridge 39, Mass.
Webber, Harold H.	Groton Associates, Inc., Hollis St., Groton, Mass.
Weber, George O.	University of Maryland, College Park, Maryland
Weeks, John T.	Architectural Record, 119 W. 40th St., N.Y. 18, N.Y.
Weinhold, Julius F.	Dir. of Physical Plant, Cornell University, Ithaca, N.Y.
Welanetz, Peter P.	Williams College, NAPPA, Williamstown, Mass.
Wells, Richard	General Electric Company, 1 River Road, Schenectady 5, N.Y.
Werkema, T. E.	Ind. Research Analyst, Dow Chemical Co., Midland, Mich.
Wetzel, Wallace P.	Temple University, Broad & Montgomery, Philadelphia 22, Pa.
Williams, F. W.	W. F. Webster Cement Co., 1101 Hanzlik Ave., Baltimore, Md.
Wilmot, R. S.	New York Telephone Co., 140 West St., Rm. 102, N.Y. 17, N.Y.
Wilson, Allen	Vice President, Architectural Products Div.,Burgess-Manning Co., 5970 N. W. Highway, Chicago 3, Ill.
Wilson, Gerald	Consultant-Acoustics, 1025 Dutch Ridge Road, Beaver, Pa.
Wilson, James D.	Dartmouth College, 34 E. Wheelock St., Hanover, N.H.
Woods, Kenneth	Thulin Woods & Isensee, 105 So. LaSalle St., Chicago, Ill.
Yeo, R. M.	University of Western Ontario, London, Ontario, Canada
Yerges, Lyla	U. S. Gypsum Co., 300 W. Adams St., Chicago 6, Ill.
Yontar, M.	Edison Research Labs., Thomas A. Edison Industries, West Orange, N.J.
Young, James M.	University of Rochester, 94 Westland Ave., Rochester 18, N.Y.
Zionts, Samuel E.	Associate, Schell & Deeter, Architects, Three Gateway Center, Pittsburgh 22, Pennsylvania

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