N-96-01
II-A-228

EPA
United States
Environmental Protection
Agency

EPA 550/9-82-413

TRAINING MANUAL FOR MECHANICAL EQUIPMENT NOISE CONTROL PERMIT SCHEME FOR MODEL BUILDING CODE

DECEMBER 1982

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON D.C. 20460

N-96-01
II-A-228

EPA Contract 68-01-5886

EPA 550/9-82-413

WBA Report No. 1923

TRAINING MANUAL
MECHANICAL EQUIPMENT NOISE CONTROL PERMIT SCHEME FOR MODEL BUILDING CODE

DECEMBER 1980

WARREN E. BLAZIER, JR.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA 550/9-82-413	2.	3. Recipient's Accession No.
4. Title and Subtitle TRAINING MANUAL FOR MECHANICAL EQUIPMENT NOISE CONTROL PERMIT SCHEME FOR MODEL BUILDING CODE			5. Report Date DECEMBER 1980
			6.
7. Author(s) WARREN E. BLAZIER, JR.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address WARREN BLAZIER ASSOCIATES SAN FRANCISCO CALIFORNIA			10. Project/Task/Work Unit No. WBA No. 1923
			11. Contract(C) or Grant(G) No. (C) 68-01-5886 (G)
12. Sponsoring Organization Name and Address U.S. EPA - OFFICE OF NOISE ABATEMENT & CONTROL WASHINGTON D.C. 20460			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This manual specifically deals with the acoustical impact of building mechanical equipment systems on the exterior environment surrounding a building site. It has been prepared as a training and implementation guide for building officials and engineers whose knowledge and training in acoustics may be limited.

17. Document Analysis a. Descriptors

NOISE CONTROL & ABATEMENT
BUILDING CODES IN NOISE CONTROL
TRAINING MANUAL IN NOISE CONTROL MECHANICAL EQUIPMENT

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement: UNLIMITED	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
	20. Security Class (This Page) UNCLASSIFIED	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

TABLE OF CONTENTS

Page

LIST OF FIGURES vi
LIST OF TABLES vii
1. INTRODUCTION 1
2. ADMINISTRATIVE AND ENFORCEMENT DETAILS 4
    2.1 Legal Provisions 5
        2.1.1 Noise Limit Terminology 5
        2.1.2 Reference Point For Establishing Compliance 6
    2.2 Enforcement Strategy 7
    2.3 Personnel Requirements and Qualifications 9
    2.4 Training In Preparation of Worksheets 10
3. INFORMATION AND TECHNICAL DATA REQUIRED IN THE REVIEW AND ASSESSMENT OF BUILDING MECHANICAL SYSTEMS 11
    3.1 Schedule of Building Mechanical Equipment 11
        3.1.1 Equipment Identification and Operation 11
        3.1.2 Acoustical Performance Data 12
            3.1.2.1 Sound Power Levels 12
            3.1.2.2 Spectrum Classification 12
        3.1.3 Governing Noise Ordinance 12
            3.1.3.1 Noise Limits 12
            3.1.3.2 Reference Distance From Source 13
    3.2 Schedule of Noise-Control Elements 14
4. NOISE RATINGS OF BUILDING MECHANICAL EQUIPMENT 15
    4.1 Estimation of A-Weighted Noise Ratings 15
        4.1.1 Spectral Characteristics of Noise Sources 15

TABLE OF CONTENTS (Continued)

Page

4.1.1.1 Classification of Noise Sources 16

4.2 Noise Ratings of Outdoor Equipment 16

4.2.1 Self-Contained HVAC Equipment 16

4.2.2 Air-Cooled Condensing Equipment 17

4.2.3 Cooling Towers and Evaporative Condensers 18

4.2.4 Window/Wall Air-Conditioners 19

4.2.5 Power Transformers 20

4.3 Noise Ratings of Indoor Equipment 21

4.3.1 Fan Equipment 22

4.3.1.1 Example, Fan Noise Calculation 24

4.3.2 Centrifugal Compressor Equipment 25

4.3.2.1 Internally-Geared Hermetics .. 26

4.3.2.2 Direct-Drive Hermetics 26

4.3.2.3 Open-Drive Centrifugals 27

4.3.3 Reciprocating Compressor Equipment 28

4.3.4 Pump Equipment 28

4.3.5 Electrical Power Generators 29

4.3.5.1 Diesel-Engine Driven 30

4.3.5.1.1 Intake and Casing Radiated Noise 30

4.3.5.1.2 Exhaust Noise 31

4.3.5.2 Gas Turbine Driven 32

4.3.5.2.1 Casing Radiated Noise 32

4.3.5.2.2 Intake and Exhaust Noise 33

4.4 Equipment Not Listed in This Manual 33

TABLE OF CONTENTS (Continued)

Page

5. NOISE REDUCTION ELEMENTS IN SOURCE TO RECEIVER PATH 35
    5.1 Equipment Located Outdoors 35
        5.1.1 Noise Reduction With Source Distance ... 35
        5.1.2 Noise Reduction of Barriers 37
            5.1.2.1 Estimating Barrier Shielding .. 38
    5.2 Equipment Located In Mechanical Rooms 39
        5.2.1 Noise Reduction of Ductlinings 40
        5.2.2 Noise Reduction of Packaged Mufflers 43
        5.2.3 Insertion Loss of Acoustical Louvers 43
        5.2.4 Interior to Exterior Noise Reduction 44
6. PROCEDURES FOR DETERMINING POTENTIAL COMPLIANCE WITH NOISE REGULATIONS 46
    6.1 Preliminary Screening Procedure 46
        6.1.1 Computation of Maximum Equipment Levels 47
            6.1.1.1 Computation of Conversion Factor 47
                6.1.1.1.1 Equipment Location Factor 48
                6.1.1.1.2 Distance Factor 48
                6.1.1.1.3 Screening Safety Factor 48
            6.1.1.2 Ordinance Noise Limit 49
        6.1.2 Example, Preliminary Screening Procedure 49
    6.2 Comprehensive Analysis Procedures 51

TABLE OF CONTENTS (Continued)

Page

6.2.1 Procedure For Outdoor Equipment 52
6.2.1.1 Examples Using Worksheet 6.2A 53
6.2.2 Procedure For Ducted Fan Equipment 60
6.2.2.1 Example Using Worksheet 6.2B 60
6.2.3 Procedure For Equipment In Ventilated Mechanical Rooms 64
6.2.3.1 Example Using Worksheet 6.2C 64
6.2.4 Procedure For Array of Units In An Exterior Wall 65
6.2.4.1 Example Using Worksheet 6.2D 68
6.3 Cumulative Sound Level of Individual Sources 72
6.3.1 Addition of Decibels 73
6.3.2 Example, Cumulative Result of Several Sources 74
7. POST-CONSTRUCTION COMPLIANCE TESTING 76
7.1 Practical Considerations In Compliance Testing 76
7.2 Testing Technique 77
7.2.1 Microphone Location 77
7.2.2 Instrumentation 78
7.2.3 Evaluation Procedure 78
7.2.3.1 Ambient Noise Corrections 78
7.2.3.2 Test Procedure 80

TABLE OF CONTENTS (Continued)

Page

APPENDIX 1: SAMPLE PERMIT SCHEME WORKSHEETS A-1
WS 6.1: Preliminary Screening A-1-2
WS 6.2A: Outdoor Equipment A-1-3
WS 6.2B: Ducted Fan Equipment A-1-4
WS 6.2C: Indoor Equipment A-1-6
WS 6.2D: Equipment Array, Exterior Wall .. A-1-8
APPENDIX 2: BARRIER SOUND ATTENUATION A-2-1

LIST OF FIGURES

Figure		Page
6-1	Example: Preliminary Screening Procedure ...	50
6-2	Outdoor Equipment Installation, No. 1	54
6-3	Outdoor Equipment Analysis, No. 1	56
6-4	Outdoor Equipment Installation, No. 2	58
6-5	Outdoor Equipment Analysis, No. 2	59
6-6	Ducted Fan Equipment Analysis	62
6-7	Indoor Mechanical Equipment Analysis	66
6-8	Equipment Array in Exterior Wall Analysis ...	69

LIST OF TABLES

Table		Page
4-1	L_w(A), Self-Contained HVAC Equipment	17
4-2	L_w(A), Air-Cooled Condensing Equipment	18
4-3	L_w(A), Cooling Towers and Evaporative Condensers	19
4-4	L_w(A), Window/Wall Air-Conditioners	20
4-5	L_w(A), Power Transformers	21
4-6	L_w(A), Fan Equipment (Specific Sound Power) ..	23
4-7	Fan Air Volume Correction Factor	24
4-8	Fan Static Pressure Correction Factor	24
4-9	Fan Static Efficiency Correction Factor	24
4-10	L_w(A), Internally-Geared Centrifugal Compressors	26
4-11	L_w(A), Direct-Drive Centrifugal Compressors ..	27
4-12	L_w(A), Open-Drive Centrifugal Compressors	27
4-13	L_w(A), Reciprocating Compressor Equipment	28
4-14	L_w(A), Pump Equipment	29
4-15	L_w(A), Diesel Generators (Intake/Casing)	31
4-16	L_w(A), Diesel Generator Exhaust	32
4-17	L_w(A), Gas-Turbine Generators (Casing)	33
4-18	L_w(A), Gas-Turbine Generators (Intake/Exhaust)	33
5-1	Noise Reduction with Distance	37
5-2	Noise Reduction of Ductlining	42
5-3	Noise Reduction of Packaged Sound Attenuators	43
5-4	Noise Reduction of Acoustical Louvers	44
5-5	Interior to Exterior Noise Reduction	45
6-1	Addition of Decibels	73

1. INTRODUCTION

Today's modern buildings may contain a number of mechanical systems that provide the supporting services necessary for them to function as intended. The mechanical equipment incorporated in these systems represent sources of noise that must be dealt with in the building design, if their acoustical impact on both the interior and exterior environments is to be controlled at an acceptable level.

This manual specifically deals with the acoustical impact of these equipment noise sources on the exterior environment surrounding the building site, and the control of this impact by the introduction of a review process in the procedure for issuance of a building permit.

For example, procedures are given in this manual for estimating the noise level resulting at some outdoor reference point due to the operation of individual items of building mechanical equipment that are either acoustically "coupled" or actually located outdoors. These estimated noise levels are then summed on an energy basis to arrive at a total noise level (at the chosen reference point) due to operation of the combined building mechanical systems. Assuming that noise-level limits have been established, a comparison then can be made with the predicted outdoor noise level to determine whether or not the mechanical installations are likely to comply with the applicable noise code. If not found in compliance, the mechanical permit can be denied until appropriate noise reduction measures have been incorporated in the design and resubmitted for review.

This review process will also reveal which particular items of mechanical equipment have the strongest influence on the exterior noise environment. Therefore, in a situation where a non-compliance condition is indicated by the review, the equipment installations responsible can generally be identified and the amount of remedial noise reduction necessary determined.

The technical data on equipment noise levels presented in this manual are based on the results of a comprehensive survey made of typical "state of the art" products being marketed in 1977. A detailed discussion of this study, and the preliminary work done in connection with the development of procedures for use in the mechanical equipment permit scheme, will be found in a report prepared for the EPA under Contract No. 68-01-4396.*

Section 2 of this manual discusses the administrative and enforcement details necessary to implement the EPA Model Mechanical Equipment Noise Control Permit Scheme at the local building/environmental code level. Sections 3, 4 and 5 deal with the technical aspects of the acoustical review process embodied in permit scheme.

Section 6 contains the procedures to be followed in the acoustical analysis of building mechanical drawings and specifications, and for estimating resultant noise levels at some reference point in the exterior environment. Section 7 discusses procedures to be followed in field testing of the completed installations to verify compliance with the noise code.

---

* Bolt Beranek and Newman, Report No. 3566, September 1977. "Development of a Mechanical Equipment Noise-Control Permit Scheme for Model Building Code"

This manual has been prepared for use by building officials and engineers whose knowledge and training in acoustics may be limited. The analytical procedures given for estimating acoustical impact, in general, require only simple addition or subtraction of factors provided in charts and tables. However, the reviewer must be able to read and interpret architectural and engineering drawings in order to select the appropriate factors to be entered on the worksheets used in the analysis.

Because of these technical simplifications, the data on product noise levels in this manual tend to be slightly on the high side of the industry average in a given category, to provide some margin of safety in the prediction scheme. However, the reviewer is free to use data furnished by the equipment manufacturer instead, if these are based on actual tests and certified accordingly.

2. ADMINISTRATIVE AND ENFORCEMENT DETAILS

The Model Mechanical Equipment Noise Control Permit Scheme may be thought of as containing two distinct parts: legal provisions, and an enforcement strategy. The legal provisions are those sections of an ordinance, building or zoning code that specify the objective provisions (e.g., sound level limits) and/or subjective provisions (e.g., nuisance-type provisions) by which the noise from mechanical equipment must be judged. Legal provisions also provide a given individual or office, such as the building department, with the requisite authority to enforce the objective/subjective provisions.

The enforcement strategy, on the other hand, consists of those methods that the responsible office uses to encourage compliance, and to detect non-compliance when it occurs. A typical enforcement strategy for building code provisions consists of first requiring that building plans, associated specifications, and certain engineering calculations are submitted for examination before construction activity on any proposed building may commence. The building department examines the plans, specifications, calculations, etc. to verify correctness and completeness before issuing a building permit. During construction, building inspectors visit the construction site to assure that the structure is being built in accordance with the plans. Finally, the completed building is inspected for conformance, and if all is in order, an occupancy permit is issued.

The extension of this enforcement strategy to include an analysis of mechanical equipment noise levels, prior to the issuance of construction or occupancy permits, is a significant departure from current practice in most jurisdictions. Therefore, the impacts this new requirement may have on both the private and public sectors of the building industry are speculative. Clearly, there will be some cost impact introduced by the requirement for a technical analysis of the acoustical design; however, how these costs are distributed between the sectors will depend on where a particular jurisdiction places the responsibility for performing the task. On the other hand, field testing to establish compliance with noise codes is not a new requirement in many jurisdictions; the principal differences are whether this is done on a routine basis or only in response to complaints.

2.1 Legal Provisions

Statutory authority must be given the appropriate office to require submission of pertinent data, calculations, reports, etc. that it deems necessary for demonstrating compliance of proposed buildings with all laws of the jurisdiction. This authority already exists in most jurisdictions with respect to energy conservation, safety, minimum ventilation, etc. in building mechanical systems; the authority must be extended to include a noise-control analysis.

2.1.1 Noise Limit Terminology

There also may be a conflict between the method of specifying noise limits in an existing code and that upon which the model permit scheme is based. For example, the noise level estimates that result from using the procedures given in this manual are expressed in terms of the A-weighted sound pressure level (dBA).

However, some jurisdictions express noise limits on an octave-band basis (level as a function of frequency) and do not specify a corresponding limit in terms of a single-number level in dBA. Still other jurisdictions use the metrics, L_{eq} and L_{dn} which are based on A-weighted sound levels, but incorporate energy-averaging and time-weighting functions.

Where an existing ordinance is expressed in terms of octave-band frequencies, it is recommended that this be modified to provide alternative limits expressed in dB(A). Ordinances using L_{eq} and L_{dn} should not require any numerical changes in the stated limits, although some revision may be necessary in the interpretive language, to clarify how this is to be used in evaluating the noise level estimates generated by the review procedures of the permit scheme.

For example, the noise produced by building mechanical equipment may be considered "steady-state" rather than transient, as in the case of traffic-noise. Consequently, the dB(A) level predicted by the permit scheme would be equivalent to L_{eq}.

However, the metric L_{dn} is a time-weighted rating that contains a penality of 10 dB for night time as opposed to day time levels of the same amplitude. This is equivalent to reducing the noise limits by 10 dB for night time operation of building mechanical equipment relative to that permitted during the day time hours.

2.1.2 Reference Point For Establishing Compliance

One of the important variables found in the noise codes of different jurisdictions is the reference point at which prescribed noise limits must be met. Some codes use the property line of the emitter, while others specify the property-line of the receiver. There are also a few codes that reference the "point of complaint". Furthermore, most ordinances of the property-line type fail to state whether or not the reference point is near the ground or at any elevation above. This is a particularly important consideration if one is dealing with a pair of adjacent high-rise buildings or roof-top equipment installed on low-rise structures in the vicinity of multi-level dwellings.

Examples are presented in Section 6 that illustrate how important the choice of reference point is in the noise level estimation process. It will be seen that unless the ordinance is very specific in this respect, a number of legal disputes could arise concerning whether or not certain installations were in compliance.

2.2 Enforcement Strategy

The enforcement strategy must be implemented in such a way that all relevant plans are reviewed for compliance with the objective restrictions on outdoor noise. Such a thorough review probably means that either the building department is given the responsibility, or that a responsible office closely coordinates its efforts with the building department.

Second, an acoustical analysis must accompany the building permit application for all mechanical equipment or systems that radiate part or all of their noise to the exterior environment. These acoustical analyses should follow the procedures described in Section 6 and be presented in a format similar to the sample worksheets appearing in Appendix 1.

It is important to recognize that requiring these analyses to be prepared and submitted as a part of the application for permit has the following advantages:

1. This will encourage the building design team to evaluate potential problems with code compliance early during the design development phase, when corrective action can be taken with the least impact on costs and construction scheduling. For example, if the designer does not make the acoustical analysis until just prior to application for permit, he may not have the flexibility for making changes that existed during design development. Invariably, this results in higher costs for noise-control and schedule delays.

2. The effort expended by the building department (or other responsible office) during the review process is reduced significantly because the task will be mostly one of checking the analysis by verifying that correct procedures and input data have been used.

3. The potential for costly delays in construction while awaiting approval should be reduced. The contractor will know in advance what the problems with compliance are likely to be and can take appropriate action to resolve them by negotiation.

Third, the office that is responsible for reviewing the acoustical analysis should also be given the responsibility for conducting post-construction noise tests, prior to the issuance of an occupancy permit. This office should also respond to any complaints about mechanical equipment noise. This would ensure not only that the officials who respond to the complaints are familiar with mechanical equipment noise, but that a single office is responsible for dealing with mechanical equipment noise from design through construction to occupancy and thereafter. The office would thus be kept aware of the effectiveness of its permit scheme to control mechanical noise.

2.3 Personnel Requirements and Qualifications

The number of persons required to check and evaluate acoustical analyses submitted with applications for permit, perform post-construction noise measurements and respond to complaints about mechanical noise, will obviously depend on the size of the jurisdiction and the volume of construction in the area.

A team of two people is probably a minimum requirement. One person must have the training and background necessary to read and interpret mechanical/architectural drawings and specifications. This person should have the responsibility for reviewing the acoustical analysis worksheets and recommending approval on rejection of the application. He might also serve as the interface between the building department and the mechanical/architectural/contractor representatives on matters pertaining to meeting code requirements on noise.

The second person must have training in the use of acoustical instrumentation. This individual should have the responsibility for performing post-construction noise measurements and responding to complaints about mechanical noise. Depending on the work load, this person might actually double as the member of a second team that responds to noise complaints of all types in jurisdictions that have an active noise control program.

2.4 Training in Preparation and Review of Acoustical Analysis Worksheets

Sections 3, 4, 5 and 6 of this manual have been structured to serve the dual-purpose of being both a training-aid and a procedural model for noise-analysis. However, there are certain to be questions arise when the worksheet procedures are applied to real-life situations rather than the simplified examples used for illustration in Section 6.

One solution would be to obtain the services of a person with mechanical system noise-control experience to monitor the acoustical review process initially and to provide on-the-job training of in-house personnel. It is anticipated that most of the questions which are likely to arise will occur on the first five or six projects submitted for acoustical review. By this time, the reviewer may have developed sufficient experience of his own that only occasional expert advice need be sought.

3. INFORMATION AND TECHNICAL DATA REQUIRED IN THE REVIEW AND ASSESSMENT OF BUILDING MECHANICAL SYSTEMS

In general, the principal sources of information and data required in the review process are the drawings and specifications for the building which have been prepared by the architect in conjunction with his mechanical engineer.

However, the level of detail required for an adequate noise control review is frequently not available at the time most of the other types of construction permits are usually sought. For example, the review for permit of a mechanical system design for function, safety, energy conservation and other code requirements typically takes place at a time prior to the completion of detailed design, when many of the elements affecting noise-control performance have not been incorporated. Therefore, the new requirement for a mechanical noise-control permit will mean that more detailed information must be made available earlier in the design development than it normally would occur, because the approval process may identify areas in which design changes are necessary to meet the noise ordinance.

3.1 Schedule of Mechanical Equipment

A detailed schedule of all mechanical equipment likely to affect outdoor noise levels must be provided. This will include not only that equipment which is to be installed outdoors, but also fan equipment coupled to the exterior and other machinery located in ventilated mechanical rooms.

3.1.1 Equipment Identification and Operation

The following information must appear on the Schedule for each item of equipment:

1. Type of equipment
2. Size or capacity
3. Identification symbol or tag number
4. Location and Configuration
   a. Outdoors
   b. Ducted to outdoors
   c. Ventilated mechanical room
5. Period of operation (24 hours, 7 a.m. - 7 p.m., intermittent, etc.)

3.1.2 Acoustical Performance Data

3.1.2.1 Sound Power Levels

The anticipated noise generating capacity of each piece of equipment must appear on the Schedule. These should be expressed as A-weighted sound power levels (re: 10^{-12} watt). If the manufacturer's data are used, the method of test and rating tolerance should be noted. In the absence of manufacturer's data, the noise ratings should be determined in accordance with the instructions provided in Section 4.

3.1.2.2 Spectrum Classification

Each source noise must be classified on the basis of its spectrum shape. There are four classifications of spectrum shape which are defined in Section 4.1.1.1 for use with data provided by the manufacturer. In the absence of manufacturer's data, use the classifications listed in Section 4 for the particular equipment of concern.

3.1.3 Governing Ordinance Noise Limits and Reference Distance

3.1.3.1 Noise Limits

The review procedure assumes that the governing noise ordinance is specified in terms of A-weighted sound pressure level (dBA) or its approximate equivalent. Many municipalities have ordinances which specify dBA levels as a function of time of day and zoning location. Others use either L_{eq} or L_{dn} which can be converted to an equivalent dBA level, if the noise source is continuous (rather than intermittent or transient) and its period of operation is known.

The equipment schedule should identify the appropriate noise limit for each piece of equipment. These noise limits may differ because of the time of equipment operation or differences in zoning of areas adjacent to the side of the building where the equipment is located.

3.1.3.2 Reference Distance for Establishing Compliance

In order to use the procedures in this manual to determine the potential compliance of the building mechanical systems with prescribed noise limits, a distance must be established between the equipment location and the reference point at which the regulation is to be met. This reference point may vary with different jurisdictions. Some use the property line of the noise emitter, while others specify the property line of the receiver or the closest point of potential complaint. In some ordinances of the property-line type, it is not stated whether or not the reference is at ground level or at all elevations, which is of considerable importance to the assessment of roof-top installations.

The equipment schedule should state the reference distance applicable to each item. This distance is to be measured from the centerline of equipment installed outdoors, or from the corresponding opening in the building facade for indoor installations.

3.2 Schedule of Noise-Control Elements

A schedule should be provided of noise-control elements which have been incorporated in the mechanical design for reducing outdoor noise levels. For example, these would include the use of packaged sound-attenuators on the outdoor side of fan equipment, acoustically lined ductwork, acoustical louvers in the mechanical room openings, and shielding barriers located in the source to receiver path. This schedule should identify which pieces of equipment are so treated and the estimated noise reduction expressed in terms of A-weighted sound power level. Guidelines for estimating the noise reduction performance of typical elements will be found in Section 5.

4. NOISE RATINGS OF BUILDING MECHANICAL EQUIPMENT

In this manual equipment noise ratings are expressed in terms of either the A-weighted sound power or sound pressure level. In general, most of the equipment of concern will be rated in terms of A-weighted sound power level, re 10^{-12} watt; however, a few large pieces of machinery may be rated in terms of the A-weighted sound pressure level at 3 feet (1 meter) because of measurement difficulties encountered in determining the sound power level when tests must be made under field rather than laboratory conditions.

The use of an A-weighted metric for equipment noise is consistent with the present trend in setting noise limits in municipal ordinances and codes in terms of either dBA or L_{eq}.

4.1 Estimation of A-Weighted Noise Ratings

With a few exceptions, the A-weighted sound power levels of equipment used in buildings are predictable in terms of a constant (which varies with the specific type of equipment) plus corrections for size and other operational parameters.

In the case of fans, the correction factors are based on air volume, total static pressure, and percent of peak static efficiency at the point of operation. Several types of components, such as condensing units and packaged HVAC units, correlate best with a correction factor based on the cooling capacity. Still others correlate better by a simple relationship to the total horsepower of the drive-motors.

4.1.1 Spectral Characteristics of Noise Sources

The frequency spectrum associated with a particular type of mechanical equipment may differ significantly from that of another, even though the A-weighted noise ratings are similar. Since most noise control elements are frequency-sensitive, the amount of noise reduction (expressed on an A-weighted basis) that will occur in the application to a given device depends on the spectral characteristics of the noise source.

For most building mechanical equipment, the characteristic differences in frequency content can be classified on the basis of the shape of the A-weighted octave band spectrum. Typically, a plateau region will be found that is about three-octaves wide. The center frequency of this plateau can be used to classify the characteristics of the noise source sufficiently to determine how much attenuation should result from the use of a particular noise-control device.

4.1.1.1 Classification of Noise Sources

In this manual four spectrum classifications are used for mechanical equipment subject to noise control treatment. The four classifications are as follows: (The A-weighted octave-band levels are approximately constant over a three-octave range)

Class	Plateau Center
I	250 Hz
II	500 Hz
III	1000 Hz
IV	2000 Hz

4.2 Noise Ratings of Equipment Usually Located Outdoors

4.2.1 Self-Contained HVAC Equipment

Outdoor, self-contained HVAC units provide both the functions of heating and cooling in a single integrated package. Thus, there are several component noise sources that affect the outdoor environment. The noise is typically radiated from the supply air intake and exhaust openings, the condenser fan, and from the unit casing; the highest noise levels are generally encountered during the cooling cycle.

Because of the multiplicity of noise sources, experience shows that the best correlation of total noise with unit size is on the basis of the rated cooling capacity expressed in Tons. One-Ton is equal to 12,000 Btu/hr. Typical sound power level values for such equipment are given in Table 4-1.

TABLE 4-1
A-Weighted Sound Power Levels of Self-Contained HVAC Equipment
Frequency Spectrum: Class III

Rated Capacity Tons	Sound Power Level dBA re 10^{-12} Watt
10 - 12	92
12 - 13	93
14 - 16	94
17 - 20	95
21 - 24	96
25 - 29	97
30 - 35	98
36 - 42	99
43 - 51	100
52 - 62	101
63 - 75	102
76 - 91	103
92 - 110	104
111 - 133	105
134 - 162	106
163 - 200	107

4.2.2 Air-Cooled Condensing Equipment

This equipment is installed outdoors as a remote component of the HVAC system. They generally contain one or more compressors and condensing fans. These units may also be used in conjunction with refrigeration equipment found in supermarkets and other buildings requiring freezers or coolers.

The sound power levels of this equipment are generally a function of the cooling capacity of the unit. Typical values are given in Table 4-2.

TABLE 4-2
A-Weighted Sound Power Levels of Air-Cooled Condensers
Frequency Spectrum: Class III

Rated Capacity Tons	Sound Power Level dBA re 10^{-12} Watt
10 - 11	90
12 - 13	91
14 - 16	92
17 - 20	93
21 - 24	94
25 - 29	95
30 - 35	96
36 - 42	97
43 - 51	98
52 - 62	99
63 - 75	100
76 - 91	101
92 - 110	102
111 - 133	103
134 - 162	104
163 - 200	105

4.2.3 Cooling Towers and Evaporative Condensers

This equipment is installed outdoors as a remote component of HVAC and refrigeration systems. The units generally contain fans and water-spray nozzles. Therefore, the noise produced is a mixture of fan and water noise.

The fans most commonly used are of either the centrifugal or propellor type, which have different characteristic noise spectra. The A-weighted sound power levels of typical units, as a function of total motor horsepower and fan type, are given in Table 4-3.

TABLE 4-3

A-Weighted Sound Power Levels Of Cooling Towers and Evaporative Condensers

Equipment Type	Total Fan-Motor hp hp	Sound Power Level dBA re 10^{-12} Watt
A Centrifugal Range 10-350 Hp Frequency Spectrum Class III	10 - 13	90
	14 - 16	91
	17 - 21	92
	22 - 26	93
	27 - 34	94
	35 - 43	95
	44 - 55	96
	56 - 70	97
	71 - 89	98
	90 - 113	99
	114 - 144	100
	145 - 183	101
	184 - 234	102
	235 - 298	103
	299 - 350	104
B Propeller Range 5-100 Hp Frequency Spectrum Class II	5 - 7	97
	8 - 10	98
	11 - 14	99
	15 - 19	100
	20 - 25	101
	26 - 34	102
	35 - 46	103
	47 - 63	104
	64 - 85	105
	86 - 100	106

4.2.4 Window or Through-The-Wall Air-Conditioners

This type of unit has two principal applications. The first is as a window installation in older buildings that were not planned for central air conditioning; the second is in newer construction where air conditioning is provided on a room-by-room basis with a "through-the-wall", non-ducted unit. The noise emitted to the outdoors by these units is principally that of the compressor and the condenser fan. The A-Weighted sound power levels of typical units, as a function of the Btu/hr. capacity, are given in Table 4-4.

TABLE 4-4

A-Weighted Sound Power Levels of Window and Through-The-Wall Air Conditioners

(Condenser Side)

Frequency Spectrum: Class III

Capacity Btu/h	A-Weighted Sound Power Level dBA re 10^{-12} Watt
3,500 - 4,500	73
4,600 - 5,600	74
5,700 - 7,100	75
7,200 - 8,900	76
9,000 - 11,200	77
11,300 - 14,100	78
14,200 - 17,800	79
17,900 - 22,400	80
22,500 - 28,200	81
28,300 - 36,000	82
36,100 - 45,100	83
45,200 - 56,500	84
56,600 - 70,700	85

4.2.5 Power Transformers

Sub-station transformers associated with buildings typically have electrical power ratings in the range between 250 and 10,000 KVA, and may be either radiant-cooled or fan-cooled units. These units may be located outdoors or in vaults below street level, and are often owned by the utility. The smaller transformers less than about 1000 KVA, purchased by the building owners, are typically located in mechanical rooms in several areas of the building which are ventilated to the outdoors.

The sound power levels of transformers depend on the physical size, power rating and the type of cooling used (radiant-cooled vs. fan-cooled). Because physical size and power rating are more or less interdependent, the amount of noise radiation for a given size tends to depend on the method of cooling. Typical values of A-weighted sound power levels for radiant and fan-cooled transformers are given in Table 4-5.

TABLE 4-5
A-Weighted Sound Power Levels of Transformers
Frequency Spectrum: Class I

Electrical Rating KVA	Radiant-Cooled dBA re 10^{-12} Watt	Fan-Cooled dBA re 10^{-12} Watt
220 - 280	69	72
281 - 360	70	73
361 - 450	71	74
451 - 560	72	75
561 - 710	73	76
711 - 890	74	77
891 - 1100	75	78
1101 - 1400	76	79
1401 - 1800	77	80
1801 - 2200	78	81
2201 - 2800	79	82
2801 - 3500	80	83
3501 - 4500	81	84
4501 - 5600	82	85
5601 - 7000	83	86
7001 - 9000	84	87
9001 - 11000	85	88

4.3 Noise Ratings of Equipment Usually Located Indoors

The building mechanical equipment located indoors, and of concern to the permit review, is that installed in mechanical rooms which are ventilated to the outdoors through openings in the walls or roof. Fan equipment which is ducted to the outside (air intake and exhaust) is also in this category.

4.3.1 Fan Equipment

The equation for estimating the A-weighted sound power level of fan equipment is as follows:

$$L_W(A) = K_A + A + B + C \text{ dBA re } 10^{-12} \text{ Watt}$$

where

$L_W(A)$ = A-weighted Sound Power Level re 10^{-12} Watt
K_A = A-weighted Specific Sound Power Level re 10^{-12} Watt
A = Correction for Air Volume, dB
B = Correction for Total Static Pressure, dB
C = Correction for Operating Point as a Function of Percent of Peak Static Efficiency, dB

The values of K_A and the spectrum classifications for fans of various types are provided in Table 4-6 below. The values of the correction factors, A, B, and C, are tabulated in Tables 4-7, 4-8 and 4-9, respectively, for the range of typical operating conditions encountered in practice.

TABLE 4-6
Specific Sound Power Level Fan Equipment

	Fan Type	K_A (dBA)	Spectrum Class
A.	**Centrifugal Design**		
	1. Airfoil Backward Curved Backward Inclined		
	a. Wheel Diameter, 36" & over	35	II
	b. Wheel Diameter, less than 36"	40	II
	2. Forward Curved	39	II
	3. Modified Radial		
	a. Wheel Diameter, 40" & over	45	II
	b. Wheel Diameter, less than 40"	50	II
B.	**Vane-Axial Design**		
	50% Hub/Diameter Ratio		
	a. Wheel Diameter, 40" & over	46	III
	b. Wheel Diameter, less than 40"	52	III
C.	**Propeller (Exhaust or Ventilation Applications)**	52	II

TABLE 4-7

Air Volume Correction Factor "A"

Air Volume x1000 CFM	"A" dB
1.0	30
1.3	31
1.6	32
2.0	33
2.5	34
3.2	35
4.0	36
5.0	37
6.0	38
8.0	39
10.0	40
13.0	41
16.0	42
20.0	43
25.0	44
32.0	45
40.0	46
50.0	47
60.0	48
80.0	49
100.0	50
130.0	51
160.0	52
200.0	53

TABLE 4-8

Total Static Pressure Correction Factor "B"

T.S.P. Inches, W.G.	"B" dB
1.0	0
1.25	2
1.5	4
1.75	5
2.0	6
2.25	7
2.5	8
2.75	9
3.0	10
3.5	11
4.0	12
4.5	13
5.0	14
5.5	15
6.0	16
7.0	17
8.0	18
9.0	19
10.0	20
11.0	21
12.0	22
14.0	23
16.0	24

TABLE 4-9

Static Efficiency Correction Factor "C"

% of Peak S.E.	"C" dB
93-100	0
90-92	1
87-89	2
84-86	3
81-83	4
78-80	5
75-77	6
72-74	7
69-71	8
66-68	9
63-65	10
60-62	11
57-59	12
54-56	13
51-53	14
< 51	15

4.3.1.1 Example of Fan Noise Calculation

A building exhaust fan is to handle 60,000 CFM at 2.5" W.G. total static pressure; the mechanical engineer has selected a 40" diameter, double-width, double-inlet airfoil fan (40 AF DWDI):

From the catalog performance data it is determined that this particular fan is capable of operating at a peak static efficiency of 78 percent; however, for the selected duty, the point of operation on the fan curve corresponds to a static efficiency of only 44 percent. The percentage of peak static efficiency, therefore, is 56 percent (44 ÷ 78 x 100).

K_A = 35 dBA (Table 4-6, Airfoil fan $< 36"$)
A = 48 dB (Table 4-7, correction for 60,000 cfm)
B = 8 dB (Table 4-8, correction for 2.5" static pressure)
C = 13 dB (Table 4-9, correction for 56% of peak static efficiency

$$L_W(A) = K_A + A + B + C$$
$$= 35 + 48 + 8 + 13 = 104 \text{ dBA re } 10^{-12} \text{ Watt}$$

4.3.2 Centrifugal Compressor Equipment

Centrifugal compressors are very common in chiller equipment used for HVAC applications in most medium and large sized buildings. Unless the cooling capacity of individual machines is required to be much in excess of 1,000 tons, the compressors are generally hermetics (motor-drive and compressor integrated in a sealed housing). In the size range above 1,000 tons, the motor-drive system is frequently separate from the compressor.

There are two basic types of centrifugal machines: the direct-drive design, where the compressor speed is the same as the motor, and the gear-drive, where the compressor speed may be several times greater than that of the motor. The radiated noise spectra of these two machine designs are distinctly different. The direct-driven equipment noise spectrum typically peaks in the region of 1000 Hz, whereas the geared-machine spectrum peaks one to two octaves higher in the frequency range.

Because of the large physical size of the equipment, most available data are obtained from measurements of sound pressure level at a distance of 3 feet (1 meter) from the machine in a normal mechanical room installation. Estimates of sound power level can be made from these data with an uncertainty in the range of ±3dB and have been incorporated in the tables of noise ratings.

4.3.2.1 Internally-Geared, Hermetic Compressors

The noise level of these machines varies as a function of the refrigeration capacity (tons) and the operating point, expressed as a percent of full load. In general, the machines are the noisiest when operating at less than 50% full load. The noise ratings listed in Table 4-10 are representative of light to medium load operation.

TABLE 4-10
Noise Ratings for Internally-Geared, Hermetic Compressors
Frequency Spectrum: Class IV

Rated Capacity Tons	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
100 - 114	88	100
115 - 147	89	101
148 - 190	90	102
191 - 245	91	103
246 - 316	92	104
317 - 408	93	105
409 - 528	94	106
529 - 681	95	107
682 - 880	96	108
881 - 1000	97	109

4.3.2.2 Direct-Drive, Hermetic Compressors

These compressors are similar to the internally-geared machines in refrigeration performance, but have a different characteristic noise spectrum, and hence, different noise ratings for the same capacity. The noise ratings listed in Table 4-11 are representative of operation in the light to medium load range.

TABLE 4-11

Noise Ratings for Direct-Drive, Hermetic Compressors

Frequency Spectrum: Class III

Rated Capacity Tons	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
100 - 116	81	93
117 - 132	82	94
133 - 151	83	95
152 - 173	84	96
174 - 198	85	97
199 - 226	86	98
227 - 259	87	99
260 - 296	88	100
297 - 338	89	101
339 - 387	90	102
388 - 442	91	103
443 - 505	92	104
506 - 578	93	105
579 - 660	94	106
661 - 755	95	107
756 - 864	96	108
865 - 1000	97	109

4.3.2.3 Large, Open-Drive, Centrifugal Compressors

Compressors in a size range above about 1000 tons are usually driven by a separate motor/gear assembly. The noise ratings listed in Table 4-12 are typical of equipment in this category.

TABLE 4-12

Noise Ratings for Large, Open-Drive, Centrifugal Compressors

Frequency Spectrum: Class IV

Rated Capacity Tons	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
1050 - 1550	99	111
1551 - 2300	100	112
2301 - 3400	101	113
3401 - 5100	102	114
5101 - 7600	103	115
7601 - 10000	104	116

4.3.3 Reciprocating Compressor Equipment

Reciprocating compressor equipment is found in a variety of sizes and applications in building mechanical systems. The most commonly encountered applications are in refrigeration and small to medium sized air-conditioning chillers. There are also applications as air compressors.

The noise levels of these machines can be correlated with the horsepower of the drive-motor. Table 4-13 lists typical noise ratings over the size range usually found in building mechanical systems.

TABLE 4-13
Noise Ratings for Reciprocating Compressor Equipment
Frequency Spectrum: Class III

Drive-Motor Hp	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
20 - 26	88	96
27 - 34	89	97
35 - 44	90	98
45 - 58	91	99
59 - 75	92	100
76 - 97	93	101
98 - 125	94	102
126 - 164	95	103
165 - 200	96	104

4.3.4 Pump Equipment

The noise levels of pump equipment used in normal building service have been found to correlate with the horsepower of the drive-motor. Table 4-14 lists typical noise ratings over the range usually encountered.

TABLE 4-14
Noise Ratings for Pump Equipment
Frequency Spectrum: Class III

Drive-Motor Size Hp	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Pressure Level dBA re 10^{-12} Watt
3.0 - 3.5	82	90
3.6 - 4.5	83	91
4.6 - 5.5	84	92
5.6 - 7.0	85	93
7.1 - 9.0	86	94
9.1 - 11.0	87	95
11.1 - 14.0	88	96
14.1 - 18.0	89	97
18.1 - 23.0	90	98
23.1 - 28.0	91	99
29.0 - 35.0	92	100
36.0 - 45.0	93	101
46.0 - 56.0	94	102
57.0 - 71.0	95	103
72.0 - 89.0	96	104
90.0 - 112.0	97	105
113.0 - 141.0	98	106
142.0 - 178.0	99	107
179.0 - 225.0	100	108

4.3.5 Emergency/Auxiliary Electrical Power Generators

Emergency electrical power systems are found in many new buildings. These systems are generally driven by either a diesel engine or gas turbine and widely vary in physical size, depending on the power requirements.

Auxiliary electrical power systems are beginning to be used in many buildings to reduce the demand on local utilities during peak periods, or to permit more than emergency operation in the event of a major power failure.

The noise impact of these systems depends on the frequency and duration of their operation. Emergency systems are typically operated for test once a week for a 30-minute period and the noise-control precautions taken are generally minimal for this reason. However, auxiliary power systems used, for example, to balance out peak-demand loads, are a different matter; the periods of operation may be several hours in duration, on a daily basis.

There is also growing evidence that systems which were initially installed for emergency power service are now being used periodically for auxiliary power. For this reason, it is recommended that both emergency and auxiliary power systems be considered in the review process as potentially operative for extended periods on a daily basis.

4.3.5.1 Diesel-Engine Driven

The noise of diesel-driven equipment is a composite of three principal sources:

Combustion air-intake
Machine casing
Combustion exhaust

When these systems are installed in buildings, there are typically two paths through which the noise is coupled to the outdoors: the first path is through openings to the exterior in the walls of the mechanical room housing the machine, required for combustion air and for ventilation. It is through these openings that the noise associated with the air-intake and casing radiated components is of concern. The second path is the combustion exhaust system which is piped to the outdoors and discharged at or near the roof.

4.3.5.1.1 Air-Intake and Casing Radiated Noise Ratings

Typical noise ratings for the combination of air-intake and casing radiated sound are listed in Table 4-15 as a function of power generating capacity, expressed in kilowatts (Kw).

TABLE 4-15

Air-Intake/Casing Radiated Noise Ratings of Diesel Equipment

Frequency Spectrum: Class III

Electrical Rating Kw	Sound Pressure Level @ 3' dBA re $2x10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
40 - 56	104	112
57 - 71	105	113
72 - 89	106	114
90 - 112	107	115
113 - 141	108	118
142 - 178	109	119
179 - 224	110	120
225 - 282	111	121
283 - 355	112	122
356 - 447	113	123
448 - 562	114	126
563 - 708	115	127
709 - 891	116	128
892 - 1122	117	129

4.3.5.1.2 Exhaust Noise Ratings

Typical ratings of exhaust noise (unmuffled) are listed in Table 4-16 as a function of power generating capacity, expressed in kilowatts (Kw).

TABLE 4-16

Unmuffled Exhaust Noise Ratings of Diesel Equipment

Frequency Spectrum: Class II

Electrical Rating Kw	Exhaust Sound Power Level dBA re 10^{-12} Watt
40 - 56	123
57 - 71	124
72 - 89	125
90 - 112	126
113 - 141	127
142 - 178	128
179 - 224	129
225 - 282	130
283 - 355	131
356 - 447	132
448 - 562	133
563 - 708	134
709 - 891	135
892 - 1122	136

4.3.5.2 Gas Turbine Driven

The noise control problems with turbine-driven equipment are similar to those of the diesels discussed above. However, there are generally three separate paths for the noise to reach the outdoors:

Casing radiated noise; path is generally through ventilation openings in the mechanical room;

Combustion air-intake noise; path is typically ducted to the exterior at or near the level of the mechanical room;

Exhaust noise; path is ducted to the exterior through a roof-stack.

4.3.5.2.1 Casing Radiated Noise

Typical noise ratings for the casing radiated component of turbine-driven equipment are listed in Table 4-17 as a function of power generating capacity, expressed in kilowatts (Kw).

TABLE 4-17
Casing Radiated Noise Ratings for Gas Turbine Generators
Frequency Spectrum: Class IV

Electrical Rating Kw	Sound Pressure Level @ 3' dBA re $2\times10^{-5}N/m^2$	Sound Power Level dBA re 10^{-12} Watt
200 - 329	113	125
330 - 529	114	126
530 - 849	115	127
850 - 1299	116	128
1300 - 1999	117	129
2000 - 3299	118	130
3300 - 5000	119	131

4.3.5.2.2 Intake Noise and Exhaust Noise

Typical noise ratings for both the intake and exhaust components of turbine-driven equipment are listed in Table 4-18 as a function of power generating capacity, expressed in kilowatts (Kw).

TABLE 4-18
Intake and Exhaust Noise Ratings for Gas Turbine Generators
Frequency Spectrum: Intake, Class IV; Exhaust, Class III

Electrical Rating Kw	Intake Noise	Exhaust Noise
	Sound Power Level, dBA re 10^{-12} Watt	
200 - 329	122	124
330 - 529	125	126
530 - 849	128	128
850 - 1299	131	130
1300 - 1999	134	132
2000 - 3299	137	134
3300 - 5000	140	136

4.4 Noise Ratings for Equipment Not Listed in Manual

In the event mechanical equipment not covered by this manual is subject to noise control review, a set of appropriate noise

noise data should be furnished by the manufacturer. These data should be expressed as an A-Weighted sound power level in dBA re 10^{-12} Watt. Should the raw data be submitted in terms of A-Weighted sound pressure level, re $2\times10^{-5}N/m^2$, the corresponding sound power level shall be estimated by adding 8dB, for equipment whose characteristic dimension is 5 feet or less, and 12dB for equipment of a larger size.

5. NOISE REDUCTION ELEMENTS IN THE SOURCE TO RECEIVER PATH

There are several noise reduction elements in the typical path between source and receiver which must be considered when determining if a particular item of mechanical equipment should meet a given noise limit. For example, the noise level at the receiving location depends upon the distance from the source and whether there are any intervening shielding barriers. In addition, there may be other noise reduction elements in the installation, such as sound-traps, mufflers, ductlining, etc., which introduce still further losses in the path between source and receiver. This section provides guidelines for estimating the amount of noise reduction to be anticipated due to these factors.

5.1 Equipment Located Outdoors

When mechanical equipment is installed outdoors, on either the ground or a rooftop, the chief noise reduction factors to be considered are the source to receiver distance and whether the line of sight between source and receiver is broken by an intervening barrier. The directivity of the noise source is also an important factor to be taken into account in certain installation geometries, particularly if the radiated sound energy is principally in one direction only.

5.1.1 Noise Reduction With Distance From the Source

The natural attenuation (noise reduction) of sound with distance from the source results from spatial spreading of the sound energy. For a point source of sound elevated in space, such as that emanating from an exhaust stack the energy spreading is spherical and the directivity factor, Q, is unity. However, when the source is located on a reflecting plane such as the ground or rooftop, the energy spreading takes place over a hemisphere and thus $Q = 2$. In this case the sound level at a given source to receiver distance is 3dB greater than it would be for the same source power radiated with a directivity, Q = 1.

Sources which are located on a reflecting plane adjacent to a wall or in an enclosing corner have directivity factors of 4 and 8, respectively, and the levels that exist at a given distance are either 6 or 9 dB greater than that due to a point source of the same total energy, but with a directivity of 1. Thus, it is essential to know the directivity pattern of the noise source when determining the attenuation due to distance.

Table 5-1 shows the number of decibels to be subtracted from the sound power level of the noise source, $L_w(A)$, to determine the resulting sound pressure level, $L_p(A)$ as a function of distance and directivity factor.

TABLE 5-1
Attenuation As A Function of Distance and Directivity

Source to Receiver Distance		$L_w(A) - L_p(A)$, dB			
Feet	Meters	Q=1	Q=2*	Q=4	Q=8
10	3.0	21	18	15	12
11	3.4	22	19	16	13
12	3.7	23	20	17	14
13-14	4.1	24	21	18	15
15-16	4.7	25	22	19	16
17-18	5.3	26	23	20	17
19-21	6.1	27	24	21	18
22-24	7.0	28	25	22	19
25-27	7.9	29	26	23	20
28-30	8.8	30	27	24	21
31-34	9.9	31	28	25	22
35-38	11.1	32	29	26	23
39-40	12.3	33	30	27	24
43-47	13.7	34	31	28	25
48-53	15.4	35	32	29	26
54-60	17.4	36	33	30	27
61-67	19.5	37	34	31	28
68-75	21.8	38	35	32	29
76-84	24.4	39	36	33	30
85-94	27.3	40	37	34	31
95-106	30.9	41	38	35	32
107-119	34.4	42	39	36	33
120-133	38.6	43	40	37	34
134-150	43.3	44	41	38	35
151-168	48.6	45	42	39	36
169-189	54.6	46	43	40	37
190-212	61.3	47	44	41	38
213-238	68.7	48	45	42	39
239-267	77.1	49	46	43	40
268-300	86.6	50	47	44	41

* This column is to be used in the Preliminary Screening Procedure of Section 6.

5.1.2 Noise Reduction Due to Barrier Shielding

A barrier which is introduced in the path between a noise source and the receiver location is potentially capable of providing a noise reduction on the order of 5-20 dBA. The actual amount of attentuation achieved in a given situation depends on several factors:

1. Barrier Construction. To be effective, the barrier must be a continuous solid wall or obstruction of some type which weighs at least 4 lbs./ft.^{2}. Constructions weighing less than this are likely to be acoustically transparent.

2. Barrier Height and Width. The height and width of the barrier above a noise source are critical factors. A barrier that just breaks the line-of-sight between source and receiver will provide a noise reduction of about 5 dBA; if the height is less than this, there will be no attenuation. To achieve noise reductions greater than 5 dBA, the barrier must be larger in size than that necessary to just break the visual path between source and receiver.

3. Source to Barrier and Receiver to Barrier Distance. The position of the barrier with respect to the source and receiver determines the extent of the "shadow zone" within which the barrier is effective and thus the amount of noise reduction obtained. In general, the closer either the source or receiver is to the barrier, the greater the attenuation.

5.1.2.1 Estimating the Magnitude of Barrier Shielding

The interrelation between barrier height and width, source to receiver distance and barrier position in affecting the noise reduction provided is complex. Although a barrier that just breaks the line-of-sight will provide about a 5 dBA noise reduction, irrespective of source/receiver geometry, the method for determining the improvement resulting from an increase in barrier height or position involves a more rigorous analysis.

A method for making such an analysis is provided in Appendix 2 and this should be used whenever a problem solution depends on barrier design. However, allowing a 5 dBA credit for any barrier which breaks the line-of-sight is recommended in the initial analysis for permit approval; if the answer obtained is too high, relative to the noise limit, then a detailed analysis of the barrier should be made.

5.2 Equipment Located Within Mechanical Rooms

The exterior noise level resulting from equipment located within a building mechanical room depends on several additional factors beyond those of significance with outdoor equipment installations. For example, if the mechanical room is ventilated the equipment noise reaching the outdoors has generally experienced some losses due to "room-effects" and the path through which the energy is coupled from inside to outside. An example is with fan equipment where either the air inlet or exhaust is ducted or passed through plenums that have acoustical treatment.

The most common noise reduction elements in the coupling path are absorptive ductlinings, sound-traps or mufflers, and acoustical louvers inserted in the building openings. These noise reduction devices are frequency-sensitive and, therefore, the amount of attenuation provided in a given situation depends on the spectrum of the input noise energy. In Section 4, the noise ratings for equipment of various types which have been listed also identify the "spectrum class", or frequency characteristic, associated with each item. The noise reduction ratings for the several elements discussed in this section are presented in terms of the spectrum classes of the input energy usually encountered by the devices in typical applications.

5.2.1 Noise Reduction Performance of Ductlinings

The most commonly encountered use of acoustically lined ductwork is with fan equipment. With respect to fan noise radiated outdoors, there are two principal sources:

1. Supply Fan Inlet. In a typical air-distribution system fresh, outside air is drawn in through the inlet to the supply fan through openings in the building exterior that are ducted to the equipment. Therefore, the noise generated at the supply fan inlet can be radiated to the outdoors.
2. Return/Exhaust Fan Outlet. In a typical air distribution system some of the air is recirculated and some is exhausted to the outside. Return/exhaust fans are used for this purpose and the noise radiated to the outdoors is that generated at the fan discharge.

The fan noise radiated outdoors can be reduced in magnitude by lining the connected ductwork with acoustical materials of various thicknesses and densities. Thicknesses of either 1 inch or 2 inches are frequently used; the material is generally either flexible glass fiber blanket in a density of 1½ lbs./cu. ft. or rigid glass fiber board with a density in the range of 3-5 lbs./cu. ft.

The amount of sound attenuation that can be obtained with ductlinings depends upon several factors. The principal factors are size and shape of the duct, the lining thickness, and the duct length. The attenuation obtained is also frequency sensitive and thus depends on the spectrum of the input source.

Table 5-2 may be used for estimating the noise reduction of lined ductwork whose least cross-dimension is in the range of

30 - 48 inches. Ducts in this size range are typical of those used on the supply fan inlet or return/exhaust fan outlet in many buildings. For ducts smaller than this, the length required to obtain a given attenuation is about 30% less; with larger ducts, the equivalent length is about 30% greater.

TABLE 5-2
Attenuation of Ductlining*

Input Spectrum	Class II				Class III			
Duct Shape	Rectangle		Round		Rectangle		Round	
Lining Thickness	1"	2"	1"	2"	1"	2"	1"	2"
Required Length ⟶ For This Attenuation ↓	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
1	1	1	1	1	1	1	1	1
2	3	2	3	2	2	2	2	1
3	5	3	5	3	3	3	3	2
4	7	4	7	4	4	4	4	2
5	9	6	9	6	6	5	5	3
6	11	8	12	8	8	6	7	4
7	13	10	15	10	10	7	9	5
8	16	12	18	13	12	8	11	6
9	19	14	21	16	14	9	13	7
10	22	16	24	19	16*	10	15	9
11	25	18	27	22	18	11	17	11
12	28	20	30	25	21	12	19	13
13	31	22	34	28	24	14	21	15
14	34	24	38	31	27	16	23	17
15	37	27	42	34	30	18	25	19
16	40	30	46	38	33	20	27	21
17	43	33	50	42	36	22	29	23
18	46	36	54	46	39	24	31	25
19	50	39	58	50	42	26	33	27
20	54	42	62	54	45	28	35	29
21	58	45	66	58	48	30	37	31
22	62	48	70	62	52	32	40	33
23	66	51	74	66	56	34	43	36
24	70	54	79	71	60	36	46	39
25	74	57	84	76	64	38	49	42
26	78	60	89	81	68	40	52	45
27	82	63	94	86	72	42	55	48
28	86	66	99	91	76	44	58	51
29	90	69	104	96	80	46	61	54
30	94	72	109	101	84	48	64	57

---

*For example: To obtain 10 dB attenuation of a Class III input spectrum using rectangular ductwork with 1"-thick lining requires a length of 16 feet.

5.2.2 Noise Reduction Performance of Packaged Sound Attenuators

Packaged sound attenuators are frequently used in place of duct-lining in HVAC systems. Although these devices are available in a variety of sizes and shapes, the typical noise reduction performance is primarily dependent on their length and the pressure drop experienced by the airflow through them.

The noise attenuation (insertion loss) of typical devices used in HVAC systems is provided in Table 5-3; the variables are shape, length and pressure drop.

TABLE 5-3
Insertion Loss of Packaged Sound Attenuators

Shape	Length	Pressure Drop	Average Insertion Loss, dB Class II	Average Insertion Loss, dB Class III
Rectangular	3'	Low (Below 0.1 in. w.g.)	11	16
	5'		16	21
	7'		18	25
Rectangular	3'	Medium (0.1-0.3 in. w.g.)	14	20
	5'		18	25
	7'		22	29
Rectangular	3'	High (Above 0.3 in. w.g.)	18	26
	5'		22	33
	7'		24	35
Cylindrical	2-3 Diameters	Low (below 0.3)	15	20
		High (above 0.3)	19	26

5.2.3 Insertion Loss of Acoustical Louvers

The openings in a building facade adjacent to mechanical equipment spaces are generally fitted with a set of louvers.

In many cases the louvers are simply sheetmetal or wood and have no acoustical value in terms of noise reduction. However, in some cases acoustical louvers are installed for noise control purposes; the insertion loss provided by typical assemblies is given in Table 5-4.

TABLE 5-4
Insertion Loss of Acoustical Louvers

Pressure Drop		Average Insertion Loss, dB		
		Class II	Class III	Class IV
Low:	(Less than 1.0" w.g. @ 1000 fpm)	8	10	10
High:	(Greater than 1.0" w.g. @ 1000 fpm)	10	13	12

5.2.4 Interior To Exterior Noise Reduction Across Opening

The sound power radiated by equipment enclosed in a mechanical space is dissipated by absorption within the room and by transmission out of exterior openings in the sidewall. The fraction of the total noise power which is transmitted outdoors depends on the relationship between the area of exterior opening and the effective area of absorption attributable to the interior surfaces of the mechanical room.

Typical losses for the relationships which will be encountered in most situations are listed in Table 5-5. For a given percent of opening area to floor area of the mechanical room, there are two choices. The first is for a fairly live mechanical room having a minimal amount of surface acoustical treatment; the second is for a room with distributed ceiling and sidewall treatment.

TABLE 5-5

Interior to Exterior Noise Reduction Across Opening

Percent Opening Area to Floor Area	Room Acoustical Treatment	
	Minimal	Distributed Ceiling/Sidewall
33	0 dB	3 dB
25	1	4
20	2	5
16	3	6
13	4	7
10	5	8
8	6	9
6	7	10
5	8	11
4	9	12
3	10	13
2.5	11	14
2	12	15
1.5	13	16
1	14	17

6. PROCEDURES FOR DETERMINING THE POTENTIAL COMPLIANCE WITH NOISE REGULATIONS

Two procedures have been provided for use in the mechanical equipment permit review. The first is a coarse screening procedure which may be used to identify potential problem areas in which a more detailed analysis should be made during the review process. The use of this procedure, as an initial step, should significantly reduce the number of items in a typical mechanical equipment schedule that require analysis in depth.

The second procedure is more detailed in that the entire path between source and receiver is analyzed in predicting the noise level reaching the reference point established for compliance. To some degree this procedure is interactive with the noise-control design since the requirements for additional noise control measures are established if a problem is identified. In this respect, it is envisioned that the mechanical design engineer may make use of the procedure well in advance of the permit review in order to ensure meeting the noise regulations in the most cost-effective way and to avoid the need to redesign in a last-minute effort to obtain approval.

6.1 Preliminary Screening Procedure

In principle, the Preliminary Screening Procedure is a reverse-analysis, working backwards from the reference point, at which the regulation must be met, to the building equipment installation. For a given noise limit, equipment location and separation distance, the procedure calculates the maximum sound power level of the noise emitter which would be permissible under the regulation. The noise level ratings of the equipment are then compared with the corresponding maximum levels established for the appropriate installation geometries to determine whether the ordinance is likely to be met or exceeded.

Because the screening procedure does not take into account any noise reduction in the source to receiver path which might exist due to barrier shielding, mufflers and other noise control devices, the result is conservative in identifying those items of mechanical equipment whose noise levels may be excessive. However, a sizable group of mechanical noise sources more than likely will be eliminated as potential problems by the screening procedure, thus reducing the number of items that require a more detailed analysis.

6.1.1 Computation of Maximum Permissible Equipment Noise Levels

The maximum permissible noise power level of the emitter, $L_{ws}(A)$, is computed by adding the losses in the source to receiver path to the specified sound pressure level, $L_{pr}(A)$, of the ordinance limit. Mathematically, this can be expressed as:

$$L_{ws}(A) = L_{pr}(A) + [L_{ws}(A) - L_{pr}(A)]$$

where the quantity $[L_{ws}(A) - L_{pr}(A)]$ represents the losses in the source to receiver path expressed as a conversion factor, C/F, dB, from sound pressure level to sound power level.

6.1.1.1 Computation of Conversion Factor

The power level/pressure level conversion factor, C/F, is a function of three elements:

1. Equipment Location, E/L, dB (outdoors, ducted to outdoors or in a ventilated equipment room)
2. Source to Receiver Distance, S/R, dB
3. Screening Safety Factor, S/F, dB (at the discretion of the reviewer, but should not exceed 5 dB)

thus, $C/F = E/L + S/R - S/F$, dB.

6.1.1.1.1 Equipment Location Factor

Three categories are used in identifying equipment locations:

1. Category A: Equipment installed outdoors on either the ground or a roof-top.
2. Category B: Fan equipment within a mechanical room that is ducted to the exterior.
3. Category C: Equipment in a ventilated mechanical room.

The values of the equipment location factor, E/L, for each category are as follows:

1.	Category A:	0 dB
2.	Category B:	+2 dB
3.	Category C:	+10 dB

6.1.1.1.2 Source to Receiver Distance Factor

The source to receiver distance factor, S/R, is normalized to a directivity factor, Q=2. For Category A, the distance is that measured from the equipment centerline to the ordinance reference point. For Categories B & C, S/R is determined by the distance between the center point of the opening in the building facade to the ordinance reference point. Values of S/R as a function of distance are given in Table 5-1 of Section 5.1.1 under the column, Q=2.

6.1.1.1.3 Screening Safety Factor

The use of a screening safety factor, S/F, is recommended to account for effects of nearby reflections from adjacent buildings and the fact that the distance factor, D/F, is normalized to a directivity of Q=2. (For example, equipment located on the ground/roof near a reflecting wall or inside corner will have directivity factors 2-6 dB higher).

In general, the magnitude of the safety factor should range between 0 and 5 dB, depending on the site conditions and the judgment of the reviewer.

6.1.1.2 Selection of Ordinance Noise Limit

Ordinance noise limits are usually established with reference to zoning district and time of day. For example, the most stringent requirement usually is in a single-family residential zone between the hours of 10:00 p.m. to 7:00 a.m.; the least stringent requirement is an industrial/commercial zone in the daytime.

It is quite possible for a building to be sited such that two zoning districts abut the property. Consequently, the governing noise limit, L_{pr}, may vary as a function of equipment location and its period of operation. For example, a piece of building equipment that is scheduled to operate 24 hours per day would have to meet the nighttime rather than the daytime noise limit; if the potential impact would be experienced in two different zoning categories, the screening should be based on meeting the more stringent noise limit.

6.1.2 Example Using the Preliminary Screening Procedure

Worksheet 6.1 illustrates the tabular information necessary for preliminary screening and the procedure to be followed in sorting out equipment that will obviously comply from that which potentially may exceed the ordinance.

A sample worksheet solution is shown in Figure 6-1 for a small commercial building to be located in an area where the ordinance noise limits are 65 dBA (daytime) and 55 dBA (nighttime).

Worksheet 6.1 - Preliminary Screening

1 Equipment Symbol	2 Equipment Description	3 Size, Capacity, or Operating Conditions	4 Hours of Operation	5 Location Category (below)	6 Reference Distance (Sec.6)	7 Location Factor (below)	8 Distance Factor (Sec.6)	9 Safety Factor (Sec. 6)	10 Conversion Factor (7+8-9)	11 Code Noise Limit (dBA)	12 Sound Power Limit (10+11)	13 Sound Power Rating (Sec.4)	14 Difference (13-12)	15 Analysis Required
C-1	*Centrifugal Compressor*	*450 Tons*	*7am 7pm*	*C*	*25'*	*10*	*26*	*5*	*31*	*65*	*96*	*106*	*10*	*Yes*
C-2	*Reciprocating Compressor*	*40 Tons*	*24 Hrs.*	*C*	*50'*	*10*	*32*	*5*	*37*	*55*	*92*	*98*	*6*	*Yes*
CT-1	*Cooling Tower*	*150 Hp, Centrifugal*	*7am 7pm*	*A*	*50'*	*0*	*32*	*5*	*27*	*65*	*92*	*101*	*9*	*Yes*
CD-1	*Air-Cooled Condenser*	*40 Tons, Propellor*	*24 Hrs.*	*A*	*140'*	*0*	*41*	*5*	*36*	*55*	*91*	*97*	*6*	*Yes*
HW-1	*Hot Water Pump*	*20 Hp*	*7am 7pm*	*C*	*50'*	*10*	*32*	*5*	*37*	*65*	*102*	*98*	*-4*	*No*
CHW-1	*Chilled Water Pump*	*40 Hp*	*7am 7pm*	*C*	*25'*	*10*	*26*	*5*	*31*	*65*	*96*	*101*	*5*	*Yes*
CW-1	*Condenser Water Pump*	*75 Hp*	*7am 7pm*	*C*	*25'*	*10*	*26*	*5*	*31*	*65*	*96*	*104*	*8*	*Yes*
S-1	*Supply Fan (Airfoil)*	*50,000 CFM @ 4" TSP*	*7am 7pm*	*B*	*50'*	*2*	*32*	*5*	*29*	*65*	*94*	*93*	*-1*	*No*
RE-1	*Return/Exhaust (Airfoil)*	*45,000 CFM @ 1.5" TSP*	*7am 7pm*	*B*	*50'*	*2*	*32*	*5*	*29*	*65*	*94*	*86*	*-8*	*No*
S-2	*Supply Fan (Airfoil)*	*10,000 CFM @ 2.5" TSP*	*24 Hrs.*	*B*	*25'*	*2*	*26*	*5*	*23*	*55*	*78*	*87*	*9*	*Yes*
RE-2	*Return/Exhaust (Airfoil)*	*8,000 CFM @ 1" TSP*	*24 Hrs.*	*B*	*25'*	*2*	*26*	*5*	*23*	*55*	*78*	*81*	*3*	*Yes*
T-1	*Transformer (Radiant Cooler)*	*800 KVA*	*24 Hrs.*	*C*	*12'*	*10*	*20*	*5*	*25*	*55*	*80*	*74*	*-6*	*No*

Location Category	Location Factor
A: (Outdoors)	0 dB
B: (Ducted Outdoors)	2 dB
C: (Ventilated Mech. Room)	10 dB

FIGURE 6-1

There are openings in the building exterior at distances of 12, 25 and 50 feet from the reference property lines.

It will be seen that the Preliminary Screening Procedure reveals that 4 of the 12 items of equipment do not require further detailed analysis because their noise emission levels are lower than the maximum permitted. On the other hand, the magnitudes of excess noise produced by the remaining equipment range from 3-10 dBA and some additional noise control measures will be necessary to ensure meeting the ordinance. Therefore, the next step in the review process is to use the more comprehensive analysis procedure of Section 6.2 to determine if adequate controls actually have been incorporated in the design of these particular equipment installations.

6.2 Comprehensive Analysis Procedures

A detailed analysis should be made of all mechanical equipment which the Preliminary Screening Procedure (Section 6.1) indicates may potentially exceed the regulations. The analysis procedure that should be followed will depend on the location and configuration of the equipment installation.

In general, one of four analysis procedures will be applicable to the review of a specific potential problem. These procedures cover the following situations:

1. Equipment in outdoor locations;
2. Fan equipment in mechanical rooms with one side ducted to the outdoors;
3. Machinery in ventilated mechanical rooms;
4. Equipment installed in an exterior wall, e.g., an array of "through-the-wall" air-conditioners.

6.2.1 Procedure For Use With Outdoor Equipment

For building mechanical equipment installed outdoors, there are usually only two noise reduction elements in the source to receiver path that are significant to the analysis. The first is the natural attenuation, due to spreading, over the distance between source and receiver. The second is the attenuation due to shielding by barriers of some type that break the line-of-sight between source and receiver. The directivity of the noise source due to local reflections must, of course, be considered in the calculations, but this factor affects the initial level of the source and not the attenuation over the path to the receiver.

The general equation for determining the sound level at a reference point, $L_p(A)$, at a distance, D, and a directivity factor, Q, is:

$$L_p(A) = L_w(A) - [L_w(A) - L_p(A)] - \text{Barrier Shielding, dB}$$

where:

$L_w(A)$	is the equipment sound power level obtained from either the tables provided in Section 4, or the manufacturer's certified rating. These must be expressed as A-Weighted sound power levels.
$[L_w(A) - L_p(A)]$	is the attenuation as a function of distance and directivity factor as discussed in Section 5.1.1 and given in Table 5-1.
and,	the loss due to barrier shielding is determined from the guidelines given in Section 5.1.2.

Sample Worksheet 6.2A illustrates the steps in the procedure for determining the compliance of outdoor equipment. The worksheet requires the use of the tables provided in Sections 4 and 5 for data entries with regard to source noise levels and sound attenuating elements in the path between source and receiver. The other information required for the worksheet must be obtained from the drawings and specifications prepared by the Architect/Mechanical Designer, as discussed in Section 3.

Part 1 of the worksheet lists the data required concerning the item of equipment to be analyzed and the necessary details about the installation configuration. Part 2 contains the procedure for calculating the sound level at the reference point based on the information developed in Part 1.

6.2.1.1 Examples 1 and 2 Using Sample Worksheet 6.2A

Two examples are given that demonstrate the analysis of outdoor equipment installations. The first deals with the installation of a cooling tower for a small commercial building where an option exists for its location on the roof or on the ground.

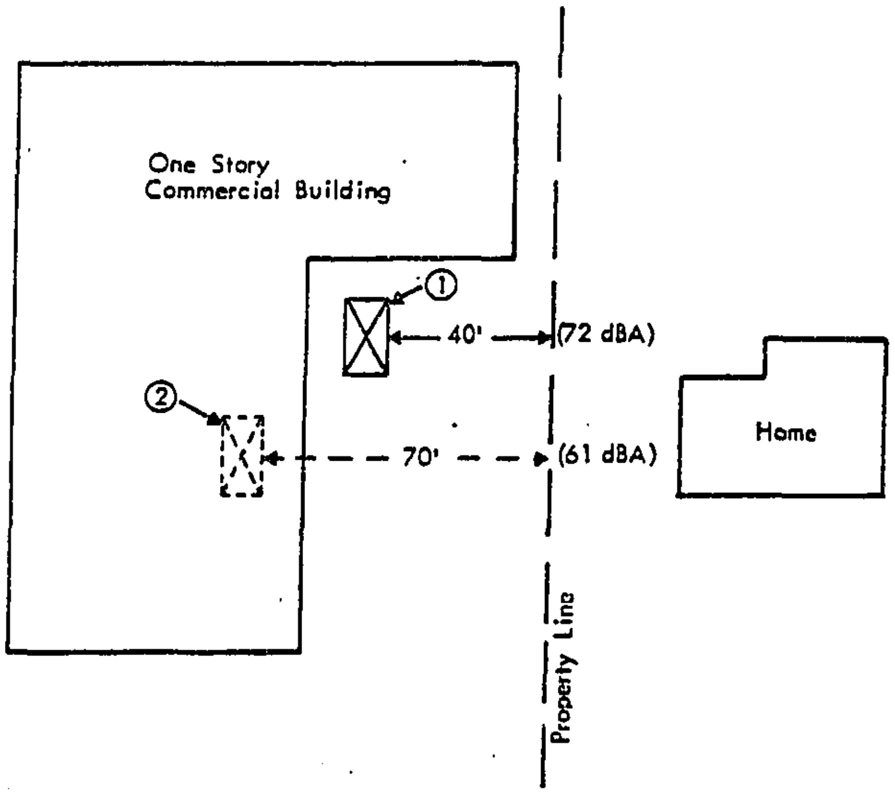
The second example deals with the installation of a cooling tower on the roof of a high-rise structure that is adjacent to an apartment building. This example demonstrates how the ordinance language, with respect to the reference point of measurement, can influence the result of the analysis.

Example 1: Small Commercial Building Adjacent to Residence

A 50-hp centrifugal-type cooling tower is to serve a one-story commercial building that is located adjacent to a residential neighborhood. The reference point for evaluation is the nearest point on the intervening property line as illustrated in Figure 6-2.

Two installation options exist:
1. Location of the cooling tower on-grade, near an inside corner.

50 Horsepower Centrifugal Cooling Tower



Option 1: Location on Grade
Option 2: Location on Roof

FIGURE 6-2. OUTDOOR EQUIPMENT INSTALLATION - EXAMPLE 1

2. Location on the roof, with a set-back sufficient to prevent its being seen from the close-in approach to the building. However, it will be visible from the residence.

The sample worksheet relating to this example is shown in Figure 6-3. The solution is first obtained for option 1; the solution for option 2 is shown in parentheses.

Part 1

Steps 1-4: Identify the equipment type and size.

Step 5: List the sound power level of the equipment based on Table 4-3 (96 dBA re 10^{-12} Watt).

Step 6: Identify the installation locations for the two options.

Step 7: Indicate that two sidewall reflecting surfaces exist for option 1 and that none exist for option 2. (The tables used in conjunction with the worksheet assume all sources have a reflecting plane at the base.)

Step 8: Indicate that the line of sight to the reference point (property line) is unobstructed in both cases.

Setp 9: Indicate the equipment distances to the reference points.

Part 2

Step 10: Enter the sound power level determined in step 5.

Step 11: Determine the directivity factor, $Q=8$, for option 1, 2 for option 2.

Step 12: Correction for shielding; none.

Step 13: Correct radiated sound power level for shielding; no change.

Step 14: Correct for distance using Table 5-1; 24 dB for option 1, 35 dB for option 2.

SAMPLE WORKSHEET 6.2A FIGURE 6-3

Outdoor Equipment

Part 1: Reference Data

1. Equipment Description *Centrifugal Fan Cooling Tower*
2. Identification Symbol on Drawings *CT-2*
3. Manufacturer and Model Number *XYZ 1040A*
4. Operating Conditions *50 Hp*
5. A-Weighted Sound Power Level *96* dBA re 10^{-12} Watt *(Table 4-3)*
   Spectrum Class *II*
   - *x* Calculated from tables
   - ______ Certified test data (attach substantiation)
6. Installation Location:
   - *x* On-grade
   - *(X)* Roof-top
7. Presence of Nearby Reflecting Surfaces:
   (X) a. None ______ b. One *x* c. Two
8. Line of Sight between Equipment and Reference Point:
   - *x (X)* a. Unobstructed
   - ______ b. Broken by solid barrier, roof setback, etc.
9. Distance, Equipment to Reference Point *40 (70)* feet
   x (X) Perpendicular distance ______ Slant distance

Part 2: Sound Level Estimation

10. Sound Power Level (from line 5) *96* dBA re 10^{-12} Watt
11. Directivity Factor, Q: *8 (2)*
    - a. If 7a checked, Q = 2
    - b. If 7b checked, Q = 4
    - c. If 7c checked, Q = 8
12. Correction for Shielding:
    - a. If 8a checked, enter 0 *0 (0)* dB
    - b. If 8b checked, enter:
      - (1) 5 (allowance w/o calc.) or ______ dB
      - (2) Result of computation using Appendix 2 (attach calc's.) ______ dB
13. Subtract line 12 from line 10 *96 (96)* dBA re 10^{-12} Watt
14. Distance Correction (from Table 5-1) using distance shown on line 9 for Q shown on line 11) *24 (35)* dB
15. Subtract line 14 from line 13 to get Sound Level at Reference Point *72 (61)* dBA re 2 x 10-5 N/m2

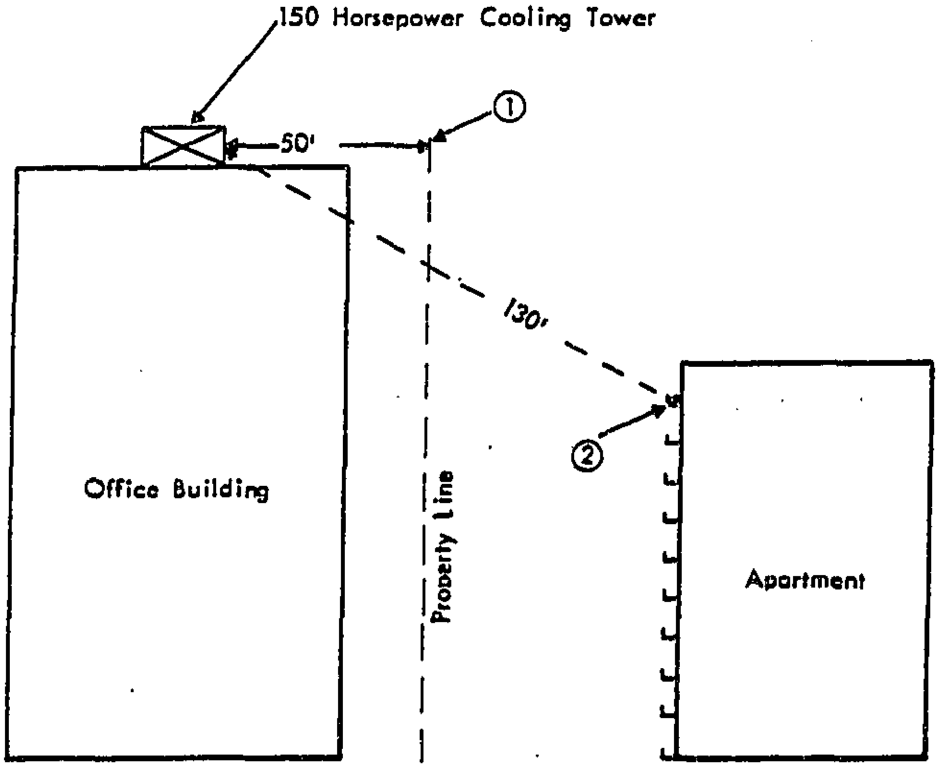
Step 15: Subtract the distance correction from the adjusted sound power level to find the sound level at the reference point: 72 dBA for option 1, 61 dBA for option 2.

This example demonstrates the influence of directivity and distance on the sound level at the boundary of the receiver. For example, the 11 dB difference between option 1 and option 2 would represent the difference between compliance and non-compliance with a daytime ordinance of 65 dBA. On the other hand, if the equipment were to operate at night and the ordinance under these conditions was 55 dBA, then a greater set-back, or the installation of a shielding barrier, would be required to achieve compliance.

Example 2: Office Building Adjacent to Apartment Building.

A 150 hp centrifugal-type cooling tower is to be installed on the roof of a high-rise office building. The closest property line boundary perpendicular to the tower is 50 feet away. There is a lower apartment structure with exterior balconies across the street. The slant distance from the tower to the closest balcony is 130 feet, but the line of sight is broken. (See illustration in Figure 6-4). Determine the sound level due to the tower at two points: 1) the property line, and 2) the closest balcony face.

The worksheet for Example 2 is illustrated in Figure 6-5, first with the calculations for case 1 (the property line) and then with the calculations for case 2 (the balcony face) shown in parentheses. It will be noted that the solution relative to the property line predicts a sound level of 69 dBA, whereas the level at the balcony face is 13 dBA lower (56 dBA). This demonstrates the difference between choosing a reference point



Case 1: Evaluation in Plane of Property Line

Case 2: Evaluation at Closest Receiver

FIGURE 6-4. OUTDOOR EQUIPMENT INSTALLATION - EXAMPLE 2

SAMPLE WORKSHEET 6.2A FIGURE 6-5

Outdoor Equipment

Part 1: Reference Data

1. Equipment Description *Centrifugal Fan Cooling Tower*

2. Identification Symbol on Drawings *CT-1*

3. Manufacturer and Model Number *XYZ 2050 B*

4. Operating Conditions *150 Hp*

5. A-Weighted Sound Power Level *101* dBA re 10^{-12} Watt *(Table 4-3)*

Spectrum Class *II*

x Calculated from tables

____ Certified test data (attach substantiation)

6. Installation Location:

____ On-grade

x (X) Roof-top

7. Presence of Nearby Reflecting Surfaces:

x (X) a. None ____ b. One ____ c. Two

8. Line of Sight between Equipment and Reference Point:

x a. Unobstructed

(x) b. Broken by solid barrier, roof setback, etc.

9. Distance, Equipment to Reference Point *50 (130)* feet

x Perpendicular distance *(X)* Slant distance

Part 2: Sound Level Estimation

10. Sound Power Level (from line 5) *101* dBA re 10^{-12} Watt

11. Directivity Factor, Q: *2*

a. If 7a checked, Q = 2

b. If 7b checked, Q = 4

c. If 7c checked, Q = 8

12. Correction for Shielding:

a. If 8a checked, enter 0 *0* dB

b. If 8b checked, enter:

(1) 5 (allowance w/o calc.) or *(5)* dB

(2) Result of computation using Appendix 2 (attach calc's.) ____ dB

13. Subtract line 12 from line 10 *101 (96)* dBA re 10^{-12} Watt

14. Distance Correction (from Table 5-1) using distance shown on line 9 for Q shown on line 11) *32 (40)* dB

15. Subtract line 14 from line 13 to get Sound Level at Reference Point *69 (56)* dBA re 2 x 10^{-5} N/m^2

at the property line as opposed to a location at the closest receiver in an existing land-use..

The shielding correction accounts for 5 dB of this difference; the remaining 8 dB is the effect of the greater distance. In this regard, the shielding correction of 5 dB which was used in the example is allowable for any barrier that breaks the line of sight. A larger deduction probably would result by using the detailed calculation procedure of Appendix 2; this procedure is recommended if shielding losses greater than 5 dB are required to achieve compliance.

6.2.2 Procedure for Use With Ducted Fan Equipment

The analysis procedure for use with ducted fan equipment has three main steps. First, the A-Weighted sound power level of the fan is calculated based on the fan type, size and operating point as tabulated on the equipment schedule. Second, all of the losses due to absorption and spreading are determined and added together to obtain the total losses over the path from source to receiver. The third step is to subtract the path losses from the fan sound power level to determine the A-Weighted sound level at the receiver reference point. Sample Worksheet 6.2B details the steps in this procedure.

6.2.2.1 Example 3 Using Sample Worksheet 6.2B

A building exhaust fan, of the vane-axial type, is ducted to an opening in the side of a high-rise office building. There is a lower apartment building across the street with balconies. The geometry is similar to that illustrated in Figure 6-4, which was used in conjunction with Example 2, above.

The vane-axial fan is 60" in diameter and handles 37,800 cfm against a total static pressue of 1.5 inches, w.g. The static efficiency at the chosen operating point is 64 percent; the peak static efficiency of the fan design is 80 percent.

A rectangular 54" x 64" discharge duct is connected to the fan and is acoustically treated for a length of 16 feet with one-inch-thick ductliner. The duct opening at the building face is connected to a louvered plenum. The louvers are of the non-acoustical type.

An analysis is required for two reference conditions:

Case 1. Evaluation at the property line perpendicular to the building opening at a distance of 20 feet.
Case 2. Evaluation at the balcony face of the closest apartment unit across the street. The slant distance is 95 feet at an angle of 40° below the normal to the opening.

The step by step analysis using Sample Worksheet 6.2B is illustrated in Figure 6-6. Part 1 of the worksheet details all of the reference data required for the calculation procedure. This information should be obtainable from the equipment schedule in the construction documents submitted for permit review. Part 2 of the worksheet is the step by step calculation procedure to determine the resulting sound level at the receiver reference point. In the example shown, the numbers in parentheses refer to the Case 2 reference conditions.

It will be seen that a difference of 17 dBA exists in the results between the analyses at the two different receiver locations (65 dBA, Case 1; 48 dBA, Case 2). 14 dBA of this difference results from the greater distance to the receiver reference point and 3 dBA is due to the lower noise radiation at the off-axis angle of 40° with respect to the normal to the building

SAMPLE WORKSHEET 6.2B
FIGURE 6-6
(Page 1)

Ducted Fan Equipment

Part 1: Reference Data

1. Equipment Description *Vane-Axial Exhaust Fan*
2. Designation on Drawings or Schedule *E-1*
3. Manufacturer and Model Number *XYZ 60-26½-860*
4. Service Application:

   _____ Supply Air   _____ Return Air   *X* Exhaust Air

5. Fan Type:
   - _____ a. Airfoil
   - _____ b. Backward Curved/Inclined
   - _____ c. Forward Curved
   - _____ d. Radial
   - *X* e. Vane-Axial
   - _____ f. Propeller
6. Fan Diameter: *60* inches
7. Fan Operating Point:
   - a. Volume *37,800* cfm
   - b. Total Static Pressure *1.5* inches, w.g.
   - c. Brake Horsepower *14* hp
   - d. Static Efficiency at Operating Point *64* %
   - e. Peak Static Efficiency on Fan Curve *80* %
   - f. Percent of Peak Static Efficiency at Operating Point *80* %
8. Configuration:
   - *X* a. Ducted
     - (1) Duct Width *64* inches
     - (2) Duct Height *54* inches
     - (3) Duct Length *16* feet
     - *X* (4) Ductlining:
       - (a) Lining thickness *1* inches
       - (b) Length of straight lined duct *16* feet
       - (c) Lined elbow with minimum 10 ft. of lining beyond elbow in direction of sound propagation:
         - _____ Yes
         - *X* No
     - _____ (5) Packaged Sound Attenuator:
       - (a) Manufacturer & Model Number _____
       - (b) Static Pressure Drop at 1000 fpm ___ inches, w.g.
     - _____ (6) Acoustical Louvers
       - (a) Low Pressure Drop _____
       - (b) High Pressure Drop _____
   - _____ b. Non-Ducted (Plenum Intake or Discharge)
9. Distance, Building Opening to Reference Point *20 (95)* feet
   - *X* Perpendicular Distance
   - *(X)* Slant Distance; Off-Axis Angle *40* degrees
10. Line of Sight between Equipment and Reference Point
    - *X (X)* a. Unobstructed
    - _____ b. Broken by solid barrier, roof setback, etc.

FIGURE 6-6
(Page 2)

SAMPLE WORKSHEET 6.2B (Continued)

Part 2: Sound Level Estimation at Reference Point

11. Calculation of Fan Sound Power Level (Based on Lines 5, 6, 7):

    a. Specific Sound Power Level, K_A (Table 4-6) *46* dBA
    b. Volume Correction, A (Table 4-7) *46* dB
    c. Static Pressure Correction, B (Table 4-8) *4* dB
    d. Static Efficiency Correction, C (Table 4-9) *5* dB
    e. Sound Power Level (11a + 11b + 11c 11d) *101* dBA re 10^{-12} Watt

12. Corrections for Absorption and Spreading Losses:

    a. Lined Straight Duct (Table 5-2): *10* dBA *(Class II Spectrum)*
    b. Elbow Attenuation (Line 8a(4)(c)): *0* dBA
        (1) If "yes" checked, enter 5
        (2) If "no" checked, enter 0
    c. Packaged Sound Attenuator (Table 5-3): *-* dBA
    d. Radiation Directivity: *2 (5)* dB

        If axis of line between opening and reference point is:

        0° - 30°, enter 2
        30° - 60°, enter 5
        60° - 90°, enter 8
    e. Barrier Shielding (Section 5.1.2): *-* dBA
    f. Distance Factor (use Table 5-1, Q = 2): *24 (38)* dB

13. Total Losses (add Lines 12a through 12f): *36 (53)* dBA

14. Sound Level at Reference Point: (Line 11e minus Line 13) *65 (48)* dBA re $2x10^{-5} N/m^2$

opening. This example emphasizes the importance of clearly defining in the noise control regulations where the reference is to be taken in establishing compliance.

6.2.3 Procedure for Use With Equipment Located in Ventilated Mechanical Rooms

Equipment such as compressors, pumps and transformers is usually located in mechanical rooms that are ventilated to control thermal build-up. The procedure given in this section is to be used for mechanical rooms which are ventilated by natural rather than forced-draft air circulation. Naturally ventilated mechanical rooms will have openings to the outside that are either fitted with louvers or a metal grating. The louvered openings may or may not introduce an acoustical loss depending on their design. Sample Worksheet 6.2C details the step by step analysis for equipment installations of this type.

6.2.3.1 Example 4 Using Sample Worksheet 6.2C

A 950-ton, internally-geared, hermetic centrifugal chiller is to be installed in a mechanical room on the top floor of the office building described in the previous examples. The mechanical room has a floor area of 1500 ft^2 and there is an opening in the sidewall for ventilation which has an area of 150 ft^2 and is fitted with low pressure drop acoustical louvers. There is no surface acoustical treatment in the room.

An assessment is desired at two reference points outdoors. The first is at a distance of 20 ft. directly opposite the opening; the second is for a slant distance of 95 ft. to an apartment building across the street at an angle of 40° relative to the opening. There is no intervening barrier that breaks the line-of-sight.

The step by step analysis using Sample Worksheet 6.2C is illustrated in Figure 6-7. The pertinent information about the installation is tabulated in steps 1-12. The calculation of the sound levels at the reference points is carried out in steps 13-21; the numbers in parentheses refer to the solution for a 95 ft. slant distance.

Note that the same difference of 17 dBA occurs between the levels at the two reference points as was found in Example 3, although the absolute values are different. This is because the chosen reference distances and radiation angles are the same.

However, suppose that the ordinance limit at the 20 ft. distance was 65 dBA. This analysis shows that a level of 68 dBA is predicted, an excess of 3 dBA. To bring this installation into compliance, the designer would have at least four options for a solution:

1. Add distributed acoustical treatment to the ceiling and sidewalls of the mechanical room (good for 3 dBA per Table 5-5).
2. Use high pressure drop louvers instead of the low pressure drop type in the ventilation opening (see Table 5-4).
3. Reduce the size of the ventilation opening if feasible (see Table 5-5).
4. Determine if the equipment manufacturer can provide a machine whose certified sound power rating is lower than that given in Table 4-11 for typical equipment in this category.

6.2.4 Procedure for Use With an Array of Air-Conditioning Units Installed in an Exterior Wall

Many buildings such as apartments, hotels, motels and small offices are air-conditioned by using an array of "through-the-wall" units that serve occupied spaces around the perimeter.

FIGURE 6-7
(Page 1)

SAMPLE WORKSHEET 6.2C

Building Mechanical Equipment Indoors

Part 1: Reference Data

1. Equipment Description *Hermetic, Internally-Geared Centrifugal Chiller*
2. Identification Symbol on Drawings *CH-1*
3. Manufacturer and Model Number *XYZ IG-95*
4. Operating Conditions *950 tons*
5. Area of Equipment Room Floor: *1500* ft.^{2}
6. Area of Total Exterior Openings: *150* ft.^{2}
7. Percent Opening Area to Floor Area: *10* %
   - *x* a. Opening unshielded from equipment
   - ____ b. Opening shielded from equipment
8. Room Acoustical Treatment:
   - *x* a. None to minimal
   - ____ b. Distributed ceiling/sidewall treatment
9. Acoustical Treatment of Opening:
   - ____ a. None
   - ____ b. Packaged sound attenuator
   - *x* c. Acoustical louvers
10. Distance, Building Opening to Reference Point: *20 (95)* ft.
    - *x* a. Perpendicular distance
    - *(x)* b. Slant distance
11. Angle Between Building Opening and Reference Point: *0 (40)* degrees.
12. Line of Sight, Building Opening to Reference Point:
    - *x (x)* a. Unobstructed
    - ____ b. Shielded

FIGURE 6-7
(Page 2)

SAMPLE WORKSHEET 6.2C (Continued)

Part 2: Calculated Sound Level at Reference Point

13. Equipment Sound Power Level (From Tables, Section 4): *109* dBA re 10^{-12} Watt *(Table 4-11)*
    - a. Spectrum Class: *III*

14. Correction, Interior Shielding (Line 7a or b): *0* dB

    Unshielded, enter 0
    Shielded, enter 3

15. Correction, % Opening Area to Floor Area: *5* dB

    (Use Table 5-5 and the data from lines 7 and 8a or b)

16. Correction, Sound Attenuation in Opening (line 9): *10* dBA *(Table 5-4, low p/d)*

    None, enter 0
    Packaged Attenuator (see Table 5-3)
    Acoustical Louvers (see Table 5-4)

17. Correction, Distance from Opening to Reference Point: *24 (38)*dB

    (From Table 5-1, Q = 2, using distance on line 10)

18. Correction, Radiation Directivity (from line 11): *2 (5)*dB

    0° - 30°, enter 2
    30° - 60°, enter 5
    60° - 90°, enter 8

19. Correction, Exterior Shielding (line 12 and Section 5.1.2): *0 (0)*dB

    Unshielded, enter 0
    Shielded, enter 5 or Appendix II calculation

20. Total corrections (sum of lines 14 - 19): *41 (58)*dB

21. Sound Level at Reference Point (line 13 minus line 20): *68 (51)*dBA re $2 \times 10^{-5} N/m^2$

This type of equipment installation must be modeled acoustically as a large "extended-area" source whose noise radiation pattern depends on both the geometry of the array and its distance from the receiver reference point. For example, when the distance to the receiver reference point is less than about one-third of the long dimension of the array, the reduction in noise level due to spreading is substantially less than that experienced by a "point-source" of sound energy; at greater distances the noise reduction begins to approach that of a point-source. Sample Worksheeet 6.2D should be used for analyzing equipment installations of this type.

6.2.4.1 Example 5 Using Sample Worksheet 6.2D

A two-story motel is to be air-conditioned using "through-the -wall" room units whose average capacity is 12,000 btu/hour. On the side of the building adjacent to the property line there will be a total of fourteen units installed. The width of the array, measured from the centerline of the first unit to that of the last, is 90 feet; the height of the array from the first to second story is 10 feet.

A noise level analysis is required at two reference points: the property line at a distance of 20 ft., and at the closest boundary of an adjacent building which is 50 ft. away.

The analysis of this installation is illustrated in Figure 6-8, using Sample Worksheet 6.2D. Part 1 lists all of the reference information required and Part 2 shows the step-by-step solution for the two source-to-receiver distances specified. The solution based on the lesser of the two distances (20 ft.) is shown in parentheses.

Steps 9-12 are used in the determination of the total sound power

FIGURE 6-8
(Page 1)

SAMPLE WORKSHEET 6.2D
Array of Equipment In Exterior Wall
Part 1: Reference Data

1. Equipment Description: *Window Air-Conditioner*
2. Identification Symbol on Drawings: *RAC 1-14*
3. Equipment Size or Capacity: *12,000 BTU/h*
4. A-Weighted Sound Power Level (single unit average): *78* dBA re 10^{-12} Watt
5. Number of Units in Exterior Wall: *14*
6. Dimensions of Multiple Array:
    a. Vertical distance between centerlines of first and last units: *10* ft.
    b. Horizontal distance between centerlines of first and last units: *90* ft.
7. Largest Dimension of Equipment Array (line 6a or 6b): *90* ft.
8. Distance from Building to Receiver Reference Point: *50 (20)* ft.

FIGURE 6-8
(Page 2)

SAMPLE WORKSHEET 6.2D (Continued)
Array of Equipment In Exterior Wall
Part 2: Sound Level Estimation at Reference Point

9. Equipment Sound Power Level (single unit average): 78 dBA re 10^{-12} Watt
10. Total Number of Units: 14
11. Correction Factor for Number of Units (use Table A below) 11 dB
12. Total Sound Power Level (line 9 + line 11) 89 dBA re 10^{-12} Watt
13. One-Third of Largest Array Dimension: (line 7 ÷ 3) 30 ft.
14. Distance to Reference Point: (line 8) 50 (20) ft.
15. Noise Radiation Pattern (check one):
    - x a. Line 14 is equal to or greater than line 13, proceed to step 16
    - (x) b. Line 14 is less than line 13, proceed to step 18
16. Distance Correction if Line 15a is checked: 32 dB
    (Use Table 5-1, Column Q = 2 at distance shown on Line 14)
17. Sound Level at Reference Point: (Line 12 minus line 16) 57 dBA re $2\times10^{-5}N/m^2$
18. Distance Correction if Line 15b is checked:
    - a. Largest array dimension x reference distance: (Line 7 times line 8) (180) ft.^{2}
    - b. Distance correction factor: (Use Table B below) (17) dB
19. Sound Level at Reference Point: (Line 12 minus line 18b) (72) dBA re $2\times10^{-5}N/m^2$

FIGURE 6-8
(Page 3)

SAMPLE WORKSHEET 6.2D (Continued)

Array of Equipment In Exterior Wall

TABLE A

Correction Factor For Number of Units (Line 11)

Number of Units (Line 10)	Correction Factor (Line 11)	Number of Units (Line 10)	Correction Factor (Line 11)
2	3 dB	16-18	12 dB
3	5	19-23	13
4	6	24-29	14
5	7	30-36	15
6-7	8	37-45	16
8-9	9	46-56	17
10-12	10	57-72	18
→ 13-15	[✓ 11]	73-90	19
		91-110	20

TABLE B

Correction Factor for Building to Receiver Distance (Line 18b)

Array Factor (Line 18a)	Distance Factor (Line 18b)	Array Factor (Line 18a)	Distance Factor (Line 18b)
45-57 ft.^{2}	12 dB	451-570 ft.^{2}	22 dB
58-72	13	571-720	23
73-90	14	721-900	24
91-110	15	901-1100	25
111-140	16	1101-1400	26
→ 141-180	[✓ 17]	1401-1800	27
181-225	18	1801-2300	28
226-280	19	2301-3000	29
281-360	20	3001-3900	30
361-450	21	3901-5000	31

level represented by the array of fourteen units. Steps 13-15 are used to determine which of two procedures is to be followed in calculating the noise reduction over the source-to-receive path. The procedure chosen depends on the relationship between the width of the array and the distance to the receiver reference point.

The solution for the 50 ft. reference distance is 57 dBA and is shown on line 17. The solution for the 20 ft. reference distance is 72 dBA, as shown on line 19. The relative difference between the levels at the two points is 15 dB, as compared with a difference of about 8 dB that would have resulted if the noise had radiated from a point-source rather than an extended area-source. In other words, the noise level at 20 ft. is actually much higher than that which would occur with a point-source of the same total sound power. This is because the drop-off in noise level with distance is much less for an area-source out to about a distance equivalent to one-third the width of the array (30 ft. in this example). Beyond this distance, the noise reduction proceeds at a faster rate and eventually approaches that of a point source.

6.3 Cumulative Sound Level of Individual Noise Sources

The noise analysis procedures discussed in Sections 6.1 and 6.2 deal with installations of individual items of equipment. Consequently, the resulting noise level estimates at the receiver reference point are valid for only the equipment under consideration and do not take into account the contributions of other equipment noise sources that might be present simultaneously. In other words, each item of equipment may be found to satisfactorily meet the noise level regulation, as individual sources, but, in combination, might result in a situation wherein the regulation was actually exceeded. Therefore, the final step in the review process should be to consider the cumulative effect of all sources.

6.3.1 Addition of Decibels

Decibel quantities are logarithmic numbers which cannot be combined by simple algebraic addition to obtain the cumulative level resulting from the combination of several sources. For example, 63 dB + 63 dB does not equal 126 dB, but only 66 dB. A very simple, but adequate schedule for adding decibels is given in Table 6-1 below:

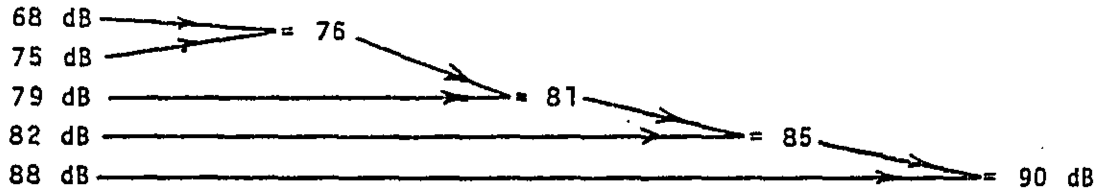
TABLE 6-1

Addition of Decibels

When two decibel values differ by:	Add the following amount to the higher value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

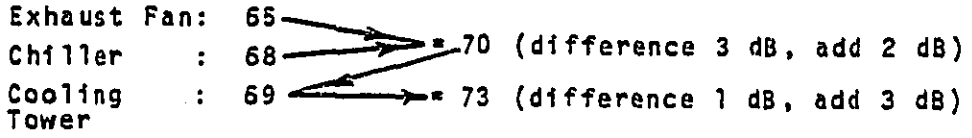
The simplified addition rules above involve rounding off of some sums to the nearest whole number, resulting in the possibility of a small error. In general, the above procedure will yield sums accurate to the nearest 1 dB.

When there are several decibel levels to be added, they should be added two at a time, starting with the lower valued levels and continuing the addition procedure of two at a time until only one value remains. To illustrate, suppose it is desired to add the following five sound levels, using the above summation procedure:



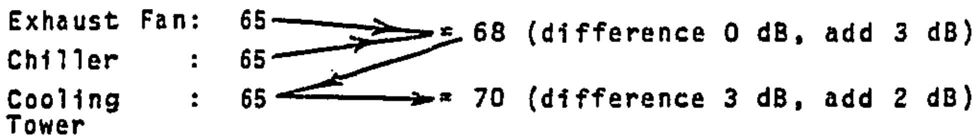
6.3.2 Example 6 Illustrating the Cumulative Result of Several Equipment Sources

In Section 6.2, three different equipment installations in a high-rise building were analyzed to determine the noise level of each with respect to a property line distance of 20 ft. from the building face. In Example 2, a cooling tower installed on the roof was calculated to have a level at the property line of 69 dBA. In Example 3, the discharge of a vane-axial exhaust fan produced 65 dBA and the chiller noise emanating from a ventilation opening in the mechanical room (Example 4) was 68 dBA at the same point of reference. Suppose now that the noise regulation specified a maximum limit of 70 dBA at the property line for this particular zoning district. From the above analysis, it is clear that each of the three noise sources, taken individually, will meet the regulation. However, what is the actual noise impact of the three sources if the cumulative effect is considered? The solution is shown below:



It will be seen that the cumulative effect of the three sources is a property line noise level of 73 dBA. Therefore, the regulation would be exceeded by 3 dBA if interpreted in terms of the cumulative level of all sources. In this case it would be necessary to incorporate the additional noise-control measures in the installations to meet the regulation.

One solution would be to reduce the received levels of both chiller and cooling tower noise to 65 dBA. As illustrated below, this would result in a cumulative noise level at the property line of 70 dBA.



It should be recognized that quieting the exhaust fan instead of the other two sources will not solve the problem because the combination of chiller and cooling tower noise still adds up to 72 dBA. In general, one must concentrate on quieting the noisiest sources first.

7. POST-CONSTRUCTION COMPLIANCE TESTING

The acoustical analyses of building mechanical systems submitted for review with applications for permit are based on drawings and specifications that must be implemented in construction. The noise level estimates that are made at this time are, in effect, part of a screening process that assesses the capability of the proposed construction to meet the restrictions imposed by the noise code.

However, the approval of an acoustical design and the issuance of a permit on this basis does not absolve the applicant from the responsibility to comply with the code in the completed construction. Therefore, post-construction testing for compliance is an important element in the enforcement strategy for an effective noise control program.

7.1 Practical Considerations in Compliance Testing

One of the anticipated difficulties in conducting post-construction compliance tests is that the prevailing ambient noise levels in the region of the building site may be higher than those specified in the code. Under these conditions it cannot be demonstrated that the building mechanical systems meet code requirements, even if they actually do. However, it can be established that the building does not meet the code if the measured noise level is higher with the systems on than when turned off.

In most urban areas the ambient noise levels are almost entirely determined by motor-vehicle noise. The magnitude of this ambient noise varies over a wide range as a function of traffic density in the area. Typical daytime levels range from about 60 dBA along residential streets to 75 dBA adjacent to major arteries carrying heavy traffic; nighttime ambient levels tend to be about 10 dBA lower.

The noise codes pertaining to "stationary" sources that have been established in many local jurisdictions tend to be in the range of 55-60 dBA for residential areas during the day and 50-55 dBA at night. Thus, it will be seen that post-construction compliance testing in an urban environment may not always be practical.

However, responding to complaint situations is another matter. The fact that a complaint has been made suggests that the normal ambient in the area has been elevated by the introduction of a new noise source. In these cases measurements with and without this source operating may be interpretable in terms of the noise code limits.

7.2 Testing Technique

7.2.1 Microphone Location

Most noise codes define where measurements are to be made when testing for compliance. However, as pointed out in Section 2.1.2, many of the existing codes are vague with respect to the microphone location in the vertical reference plane. This can be a very important factor, particularly when testing in response to a complaint.

One way to resolve this problem would be to locate the microphone above the source property line at an elevation which intersects a line drawn between centerline of the source and the closest receiver location or point of complaint. Such a convention for microphone placement would ensure that any noise reduction that occurred due to barrier shielding would be properly assessed in terms of its geometry with respect to the source and receiver.

For example, with roof-top mounted equipment, noise measurements made at the property line near ground level are likely to show significantly lower values, due to shielding by the building side-wall, than those across the street at the same slant distance, because of different shielding losses in the source to receiver path.

7.2.2 Instrumentation

The basic instrument recommended for measurement of A-weighted sound levels (dBA) should satisfy at least the applicable requirements for Type 1 sound-level-meters as defined in American National Standard, S1.4-1971, or the most recent revisions thereof. Prior to measurements the instrument should be standardized to within ±0.3 decibel by means of an approved acoustic calibrator.

7.2.3 Evaluation Procedure

7.2.3.1 Ambient Noise Corrections

The particular measurement procedure used for testing the noise level compliance of completed construction will vary with the circumstances encountered. In general, the ambient noise level due to sources not related to the building should be about 10 dBA below the code limit to obtain correct direct readings of equipment noise levels that are actually at the code limit. If this condition does not exist then corrections to the measured data are required to account for the ambient contribution to the total noise.

For building equipment noise that just meets the code limit, the table below illustrates how the actual measured level is affected by the ambient noise level:

Ambient Noise Level	Measured Total Noise Level	Difference: Total - Ambient
Code Level - 10 dBA	Code Level	10 dB
Code Level - 6 dBA	Code Level + 1 dBA	7
Code Level - 2 dBA	Code Level + 2 dBA	4
Code Level	Code Level + 3 dBA	3
Code Level + 2 dBA	Code Level + 4 dBA	2
Code Level + 3 dBA	Code Level + 5 dBA	2
Code Level + 5 dBA	Code Level + 6 dBA	1

In actual practice it will be found that both the typical ambient levels and those due to mechanical equipment will be fluctuating with time rather than steady, constant, values. Therefore, some form of averaging is required if these levels are to be expressed as single numbers. The preferred type of visual averaging is to use the "slow" meter damping function of the sound level meter and read a value corresponding to the "central tendency" of the fluctuation, together with the range over which it occurs. The range will provide an index to the uncertainty of the reading.

The reliability of corrections made to measured data for the contribution of ambient noise depends not only on the relative level of the two but also on their statistical fluctuations with time. In general, the uncertainty of the correction increases rapidly for differences between the total noise and the ambient alone of less than 6 dB. In case of a legal dispute about code compliance, it could be very difficult to defend if the ambient level was within a few dB of the measured data.

Therefore, it is recommended that compliance tests for the purpose of legal enforcement be conducted with caution whenever the ambient noise environment is less than 6 dBA below the specified code limit. Expert advice may be required in these cases.

7.2.3.2 Test Procedure

At some time in advance of construction completion, it is recommended that a survey be made of the prevailing ambient noise environment in the area of the site. If the ambient noise levels are found to be less than 6 dBA below the code limit during the period of the survey, it is recommended that a time-history be obtained over an extended period to determine if lower ambients occur. In situations where the ambient is traffic-noise dominated, levels during the nighttime hours may be 10 dBA lower than during the day.

After completion of construction when all building mechanical systems are operating properly, compliance testing should begin with a repeat of the original survey to determine what the new noise environment is. If the measured levels do not exceed the limits of the noise code, no further tests are required since all building mechanical systems are in compliance.

However, if it is found that the measured levels exceed the code, the next step would be to determine the extent to which the ambient noise (without the building systems operating) has influenced the result. This evaluation can be made in two ways:

1. Use the results of the initial survey made prior to construction, if there is reason to believe that the ambient has not changed significantly.
2. Turn off the building mechanical systems and evaluate the ambient directly.

If it is established that the ambient levels are not affecting the test results, the next step should be the determination of which elements of the building mechanical systems are responsible for the noise in excess of code. This can be done by cycling individual pieces of equipment or systems and determining their contributions to the total noise using the procedure given in Section 6.3.1.

This diagnostic testing role may not be considered a part of compliance testing by some jurisdictions. Rather, the attitude may be that compliance tests will be done on a go, no-go basis, and that such diagnoses are the contractor's responsibility. On the other hand, if the analysis done during application for permit indicates that compliance should have resulted, then the installation should be inspected for deviations from the approval drawings.

In some instances deviations from the approved design may have been granted pending a demonstration of post-construction compliance. In others, noise control elements which the permit review revealed might be borderline requirements may have been omitted. In either case, the jurisdiction probably cannot entirely divorce itself from participation in some form of diagnostic activity after the fact. Field experience in this regard would provide valuable feedback on how to obtain better control on the outcome of future construction.

APPENDIX 1

SAMPLE PERMIT SCHEME WORKSHEETS

Worksheet 6.1 - Preliminary Screening

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Equipment Symbol	Equipment Description	Size, Capacity, or Operating Conditions	Hours of Operation	Location Category (below)	Reference Distance (Sec.6)	Location Factor (below)	Distance Factor (Sec.6)	Safety Factor (Sec. 6)	Conversion Factor (7+8-9)	Code Noise Limit (dBA)	Sound Power Limit (10+11)	Sound Power Rating (Sec.4)	Difference (13-12)	Analysis Required

Location Category	Location Factor
A: (Outdoors)	0 dB
B: (Ducted Outdoors)	2 dB
C: (Ventilated Mech. Room)	10 dB

SAMPLE WORKSHEET 6.2A

Outdoor Equipment

Part 1: Reference Data

1. Equipment Description ____
____
2. Identification Symbol on Drawings ______________________________
3. Manufacturer and Model Number _________________________________
4. Operating Conditions ____
5. A-Weighted Sound Power Level _____ dBA re 10^{-12} Watt
Spectrum Class _____
_____ Calculated from tables
_____ Certified test data (attach substantiation)
6. Installation Location:
_____ On-grade
_____ Roof-top
7. Presence of Nearby Reflecting Surfaces:
_____ a. None _____ b. One _____ c. Two
8. Line of Sight between Equipment and Reference Point:
_____ a. Unobstructed
_____ b. Broken by solid barrier, roof setback, etc.
9. Distance, Equipment to Reference Point _____ feet
_____ Perpendicular distance _____ Slant distance

Part 2: Sound Level Estimation

10. Sound Power Level (from line 5) _____ dBA re 10^{-12} Watt
11. Directivity Factor, Q: _____
a. If 7a checked, Q = 2
b. If 7b checked, Q = 4
c. If 7c checked, Q = 8
12. Correction for Shielding:
a. If 8a checked, enter 0 _____ dB
b. If 8b checked, enter:
(1) 5 (allowance w/o calc.) or _____ dB
(2) Result of computation using Appendix 2 (attach calc's.) _____ dB
13. Subtract line 12 from line 10 _____ dBA re 10^{-12} Watt
14. Distance Correction (from Table 5-1) using distance shown on line 9 for Q shown on line 11) _____ dB
15. Subtract line 14 from line 13 to get Sound Level at Reference Point _____ dBA re 2×10^{-5} N/m^2

SAMPLE WORKSHEET 6.2B

Ducted Fan Equipment

Part 1: Reference Data

1. Equipment Description ______________________________

2. Designation on Drawings or Schedule ____________________

3. Manufacturer and Model Number _________________________

4. Service Application:

_____ Supply Air _____ Return Air _____ Exhaust Air

5. Fan Type:
   - _____ a. Airfoil
   - _____ b. Backward Curved/Inclined
   - _____ c. Forward Curved
   - _____ d. Radial
   - _____ e. Vane-Axial
   - _____ f. Propeller

6. Fan Diameter: _____ inches

7. Fan Operating Point:
   - a. Volume __________ cfm
   - b. Total Static Pressure ______ inches, w.g.
   - c. Brake Horsepower _____ hp
   - d. Static Efficiency at Operating Point _____ %
   - e. Peak Static Efficiency on Fan Curve _____ %
   - f. Percent of Peak Static Efficiency at Operating Point _____ %

8. Configuration:

_____ a. Ducted

(1) Duct Width _____ inches
(2) Duct Height _____ inches
(3) Duct Length _____ feet
_____ (4) Ductlining:
(a) Lining thickness _____ inches
(b) Length of straight lined duct _____ feet
(c) Lined elbow with minimum 10 ft. of lining beyond elbow in direction of sound propagation:
_____ Yes
_____ No
_____ (5) Packaged Sound Attenuator:
(a) Manufacturer & Model Number ________________
(b) Static Pressure Drop at 1000 fpm ___ inches, w.g.
_____ (6) Acoustical Louvers
(a) Low Pressure Drop _____
(b) High Pressure Drop _____

_____ b. Non-Ducted (Plenum Intake or Discharge)

9. Distance, Building Opening to Reference Point ______ feet

_____ Perpendicular Distance
_____ Slant Distance; Off-Axis Angle ______ degrees

10. Line of Sight between Equipment and Reference Point

_____ a. Unobstructed
_____ b. Broken by solid barrier, roof setback, etc.

SAMPLE WORKSHEET 6.2B (Continued)

Part 2: Sound Level Estimation at Reference Point

11. Calculation of Fan Sound Power Level (Based on Lines 5, 6, 7):

    a. Specific Sound Power Level, K_A (Table 4-6) _____dBA
    b. Volume Correction, A (Table 4-7) _____dB
    c. Static Pressure Correction, B (Table 4-8) _____dB
    d. Static Efficiency Correction, C (Table 4-9) _____dB
    e. Sound Power Level (11a + 11b + 11c 11d) _____dBA re 10^{-12} Watt

12. Corrections for Absorption and Spreading Losses:

    a. Lined Straight Duct (Table 5-2): _____dBA
    b. Elbow Attenuation (Line 8a(4)(c)): _____dBA
        (1) If "yes" checked, enter 5
        (2) If "no" checked, enter 0
    c. Packaged Sound Attenuator (Table 5-3): _____dBA
    d. Radiation Directivity: _____dB

        If axis of line between opening and reference point is:

        0° - 30°, enter 2
        30° - 60°, enter 5
        60° - 90°, enter 8
    e. Barrier Shielding (Section 5.1.2): _____dBA
    f. Distance Factor (use Table 5-1, Q = 2): _____dB

13. Total Losses (add Lines 12a through 12f): _____dBA

14. Sound Level at Reference Point: (Line 11e minus Line 13) _____dBA re $2x10^{-5} N/m^2$

SAMPLE WORKSHEET 6.2C

Building Mechanical Equipment Indoors

Part 1: Reference Data

1. Equipment Description ______________________________
2. Identification Symbol on Drawings ______________________
3. Manufacturer and Model Number _________________________
4. Operating Conditions ______________________________
5. Area of Equipment Room Floor: __________ $ft.^2$
6. Area of Total Exterior Openings: __________ $ft.^2$
7. Percent Opening Area to Floor Area: __________ %
   __________ a. Opening unshielded from equipment
   __________ b. Opening shielded from equipment
8. Room Acoustical Treatment:
   __________ a. None to minimal
   __________ b. Distributed ceiling/sidewall treatment
9. Acoustical Treatment of Opening:
   __________ a. None
   __________ b. Packaged sound attenuator
   __________ c. Acoustical louvers
10. Distance, Building Opening to Reference Point: __________ ft.
   __________ a. Perpendicular distance
   __________ b. Slant distance
11. Angle Between Building Opening and Reference Point: ______ degrees.
12. Line of Sight, Building Opening to Reference Point:
   __________ a. Unobstructed
   __________ b. Shielded

SAMPLE WORKSHEET 6.2C (Continued)

Part 2: Calculated Sound Level at Reference Point

13. Equipment Sound Power Level (From Tables, Section 4): _____dBA re 10^{-12} Watt

    a. Spectrum Class: ______

14. Correction, Interior Shielding (Line 7a or b): _____dB

    Unshielded, enter 0
    Shielded, enter 3

15. Correction, % Opening Area to Floor Area: _____dB

    (Use Table 5-5 and the data from lines 7 and 8a or b)

16. Correction, Sound Attenuation in Opening (line 9): _____dBA

    None, enter 0
    Packaged Attenuator (see Table 5-3)
    Acoustical Louvers (see Table 5-4)

17. Correction, Distance from Opening to Reference Point: _____dB

    (From Table 5-1, Q = 2, using distance on line 10)

18. Correction, Radiation Directivity (from line 11): _____dB

    0° - 30°, enter 2
    30° - 60°, enter 5
    60° - 90°, enter 8

19. Correction, Exterior Shielding (line 12 and Section 5.1.2): _____dB

    Unshielded, enter 0
    Shielded, enter 5 or Appendix II calculation

20. Total corrections (sum of lines 14 - 19): _____dB

21. Sound Level at Reference Point (line 13 minus line 20): _____dBA re $2\times10^{-5}N/m^2$

SAMPLE WORKSHEET 6.2D

Array of Equipment In Exterior Wall

Part 1: Reference Data

1. Equipment Description: ____________________
2. Identification Symbol on Drawings: ____________________
3. Equipment Size or Capacity: ____________________
4. A-Weighted Sound Power Level (single unit average): __________ dBA re 10^{-12} Watt
5. Number of Units in Exterior Wall: __________
6. Dimensions of Multiple Array:
    - a. Vertical distance between centerlines of first and last units: __________ ft.
    - b. Horizontal distance between centerlines of first and last units: __________ ft.
7. Largest Dimension of Equipment Array (line 6a or 6b): ______ ft.
8. Distance from Building to Receiver Reference Point: ______ ft.

SAMPLE WORKSHEET 6.2D (Continued)

Array of Equipment In Exterior Wall

Part 2: Sound Level Estimation at Reference Point

9. Equipment Sound Power Level (single unit average): _______ dBA re 10^{-12} Watt
10. Total Number of Units: _______
11. Correction Factor for Number of Units (use Table A below) _______ dB
12. Total Sound Power Level (line 9 + line 11) _______ dBA re 10^{-12} Watt
13. One-Third of Largest Array Dimension: (line 7 ÷ 3) _______ ft.
14. Distance to Reference Point: (line 8) _______ ft.
15. Noise Radiation Pattern (check one):
    _____ a. Line 14 is equal to or greater than line 13, proceed to step 16
    _____ b. Line 14 is less than line 13, proceed to step 18
16. Distance Correction if Line 15a is checked: _______ dB
    (Use Table 5-1, Column Q = 2 at distance shown on Line 14)
17. Sound Level at Reference Point: (Line 12 minus line 16) _______ dBA re $2\times10^{-5} N/m^2$
18. Distance Correction if Line 15b is checked:
    a. Largest array dimension x reference distance: (Line 7 times line 8) _______ ft.^{2}
    b. Distance correction factor: (Use Table B below) _______ dB
19. Sound Level at Reference Point: (Line 12 minus line 18b) _______ dBA re $2\times10^{-5} N/m^2$

SAMPLE WORKSHEET 6.2D (Continued)

Array of Equipment In Exterior Wall

TABLE A

Correction Factor For Number of Units (Line 11)

Number of Units (Line 10)	Correction Factor (Line 11)	Number of Units (Line 10)	Correction Factor (Line 11)
2	3 dB	16-18	12 dB
3	5	19-23	13
4	6	24-29	14
5	7	30-36	15
6-7	8	37-45	16
8-9	9	46-56	17
10-12	10	57-72	18
13-15	11	73-90	19
		91-110	20

TABLE B

Correction Factor for Building to Receiver Distance (Line 18b)

Array Factor (Line 18a)	Distance Factor (Line 18b)	Array Factor (Line 18a)	Distance Factor (Line 18b)
45-57 ft.^{2}	12 dB	451-570 ft.^{2}	22 dB
58-72	13	571-720	23
73-90	14	721-900	24
91-110	15	901-1100	25
111-140	16	1101-1400	26
141-180	17	1401-1800	27
181-225	18	1801-2300	28
226-280	19	2301-3000	29
281-360	20	3001-3900	30
361-450	21	3901-5000	31

APPENDIX 2

SOUND ATTENUATION BY BARRIERS

A barrier is a solid wall or obstruction which breaks the direct line of sight between a sound source and a receiver. An effective barrier has no holes or air gaps and has a surface weight of at least 4 lb/ft^2. Figure A-2.1 shows a typical geometrical configuration of source, receiver, and intervening infinite barrier. The sound attenuation provided by this simple barrier is a function of the source-to-barrier distance (R), the receiver-to-barrier distance (D), and the line-of-sight break distance (h).

It should be noted that for barriers of finite width, sound may propagate around the sides of the barrier as well as over the top and, therefore, such a barrier provides less attenuation than an infinite barrier. The situation becomes even more complex for 2, 3, or 4-sided barriers, where sound reflection between non-absorptive barrier walls may also compromise the attenuation. Finally, barrier attenuation may be compromised by the use of walls with low surface weight. Due to these considerations, the practical upper limit of barrier performance lies in the range between 15 and 20 dB.

A procedure for estimating the sound attenuation provided by finite, single-wall barriers is outlined below. The method, adapted from Reference 29, calculates the reduction in A-weighted sound level provided by a barrier, based on a point source model evaluated at a frequency of 565 Hz. The procedure is considered applicable to all building mechanical equipment spectrum classes, with an expected accuracy of ±3 dB. In practice, where non-ideal noise sources are the rule rather than the exception, greater

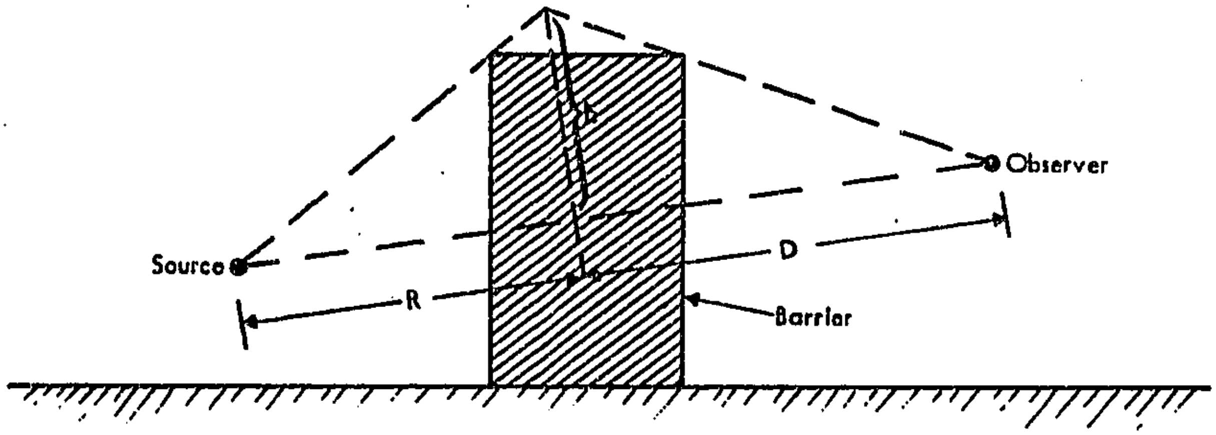


FIGURE A-2.1. SIMPLE BARRIER CONFIGURATION discrepancies are possible. Nevertheless, the calculation procedure presented below yields an estimate of barrier noise reduction which is useful for design purposes.

Barrier Evaluation Procedure

1. Determine the observer location of interest.

2. Locate the source at a point 1/3 down from the top and 1/2 in from the front and sides of the equipment noise source.

3. Locate the barrier profile and obtain accurate values for the following quantities (see Figure-A-2.1): h, the shortest distance from the barrier top to the line of sight from source to observer (feet); R and D, the slant distances, along the line of sight, from the barrier to the source and observer, respectively. (Specifically, R and D are the two segments into which h breaks the line of sight.) Note that h is *not* the height of the barrier above ground, but the distance from the barrier top to the line of sight.

4. Enter at the top of Figure A-2.2 with the value of h on the left-hand scale; move right to intersect the curve corresponding to R (or D, whichever is *smaller*).

5. Move down to intersect the curve corresponding to the value of D/R (or R/D, whichever is greater than unity).

6. Move right to intersect the vertical scale in order to find the potential barrier shielding, A_1, in decibels, corresponding to an ideal barrier of infinite length.

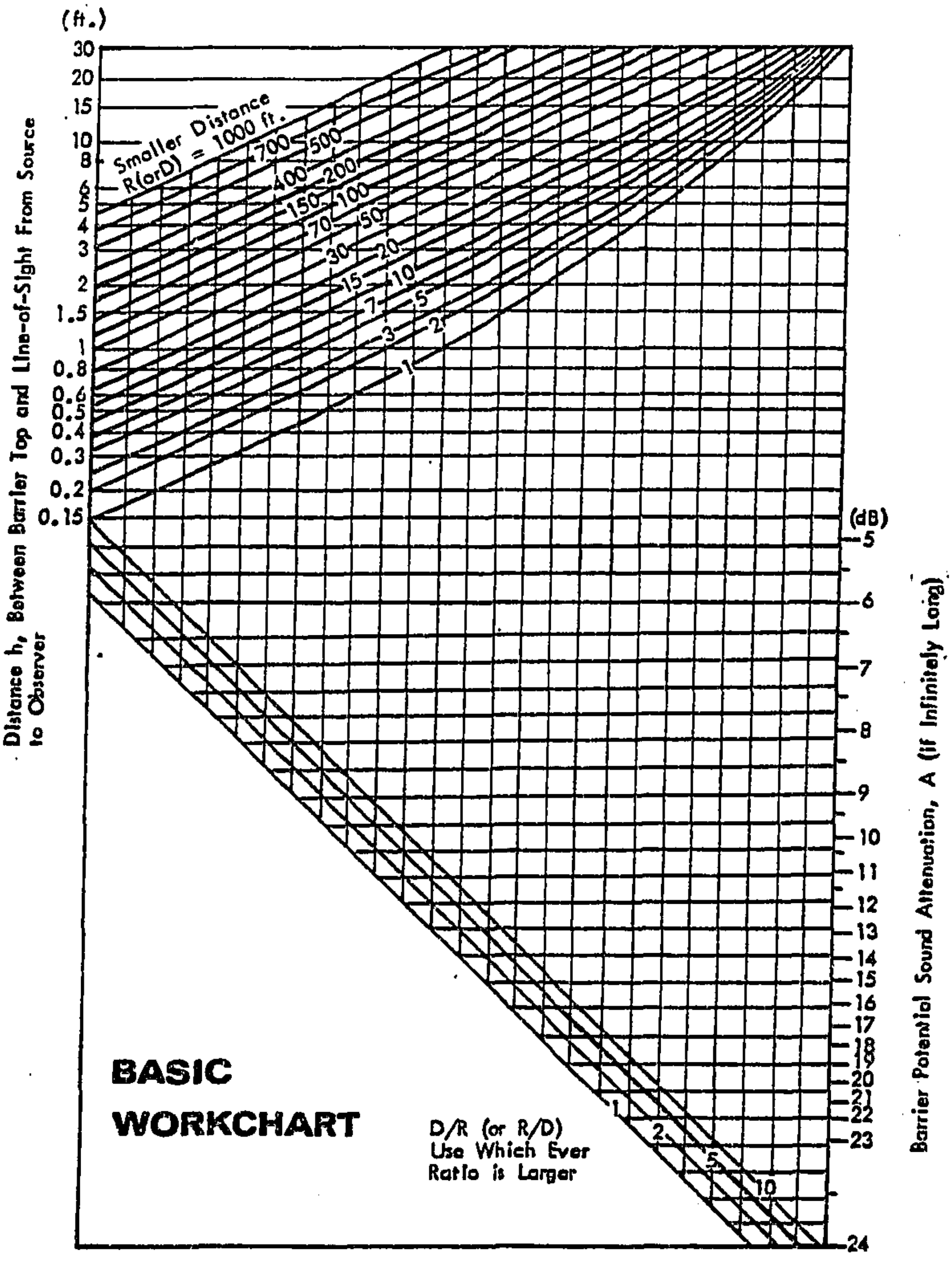


FIGURE A-2.2. BASIC WORKCHART FOR BARRIER SOUND ATTENUATION

7. If there are no sound paths around the sides of the barrier, and the barrier has a surface weight greater or equal to 4 lb/ft², then the estimated barrier attenuation may be taken to be A_1.

8. If there are no sound paths around the sides of the barrier, and the barrier has a surface weight less than 4 lb/ft², then the barrier attenuation may be estimated by combining A_1 with TL_{500} (the transmission loss of the barrier wall evaluated for the 500 Hz octave frequency band). A simplified method for combining decibel attenuations is provided in Table A-2.1.

9. If there are sound paths around one or two sides of the barrier, calculate the barrier attenuations A_2 and A_3 for these paths in the horizontal plane, as described in steps 3 through 6 above. The source locations for these calculations, however, should be at the *side* of the equipment closest to the barrier edge being evaluated.

10. Estimate the overall barrier attenuation by combining A_1, A_2, A_3, and TL_{500} (whichever apply) in a step-wise fashion, using the method in Table A-2.1

TABLE A-2.1

SIMPLIFIED COMBINATION OF DECIBEL ATTENUATIONS

When Two Decibel Attenuation Values Differ by:	Subtract the Following Amount from the Lower Value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

Example

Estimate the sound attenuation of the barrier configuration illustrated in Figure A-2.3. The barrier is constructed of 1/2 inch plywood with a surface density of 1.5 lb/ft² and a sound transmission loss of 18 dB in the 500 Hz octave band ($TL_{500} = 18$).

1. The observer location, O, is as indicated on Figure A-2.3.

2. The source location, S_1, for the "over-the-top" sound path is chosen at the center of the machine (plan view) and 1/3 down from the top as shown on Figure A-2.3.

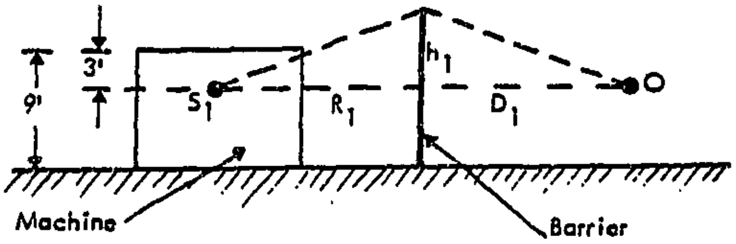
3. The quantities h_1, R_1, and D_1 are obtained from a scale drawing, as indicated in Figure A-2.3.

4. Entering the workchart with $h_1 = 6.3$ ft on the left-hand scale, a line is drawn to the right to intersect the curve corresponding to R = D = 16 ft (see Figure A-2.4).

5. Moving down, a line is drawn to intersect the curve corresponding to R/D = 1 (see Figure A-2.4).

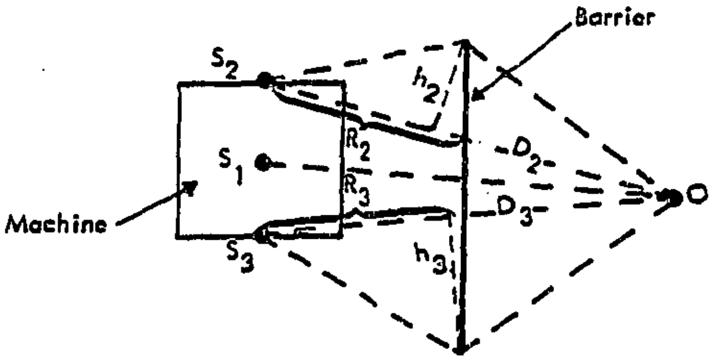
6. Moving right, a line is drawn to intersect the vertical scale in order to find $A_1 = 17$ dB (see Figure A-2.4).

Since there are sound paths around the sides of the barrier and the surface weight of the barrier is less than 4 lb/ft², the calculation proceeds to Step 9.



R_1 = 16'
D_1 = 16'
h_1 = 6.3'

ELEVATION



R_2 = 16'
D_2 = 17'
h_2 = 7.5'

R_3 = 16'
D_3 = 16'
h_3 = 11'

PLAN VIEW

FIGURE A-2.3. BARRIER EVALUATION EXAMPLE

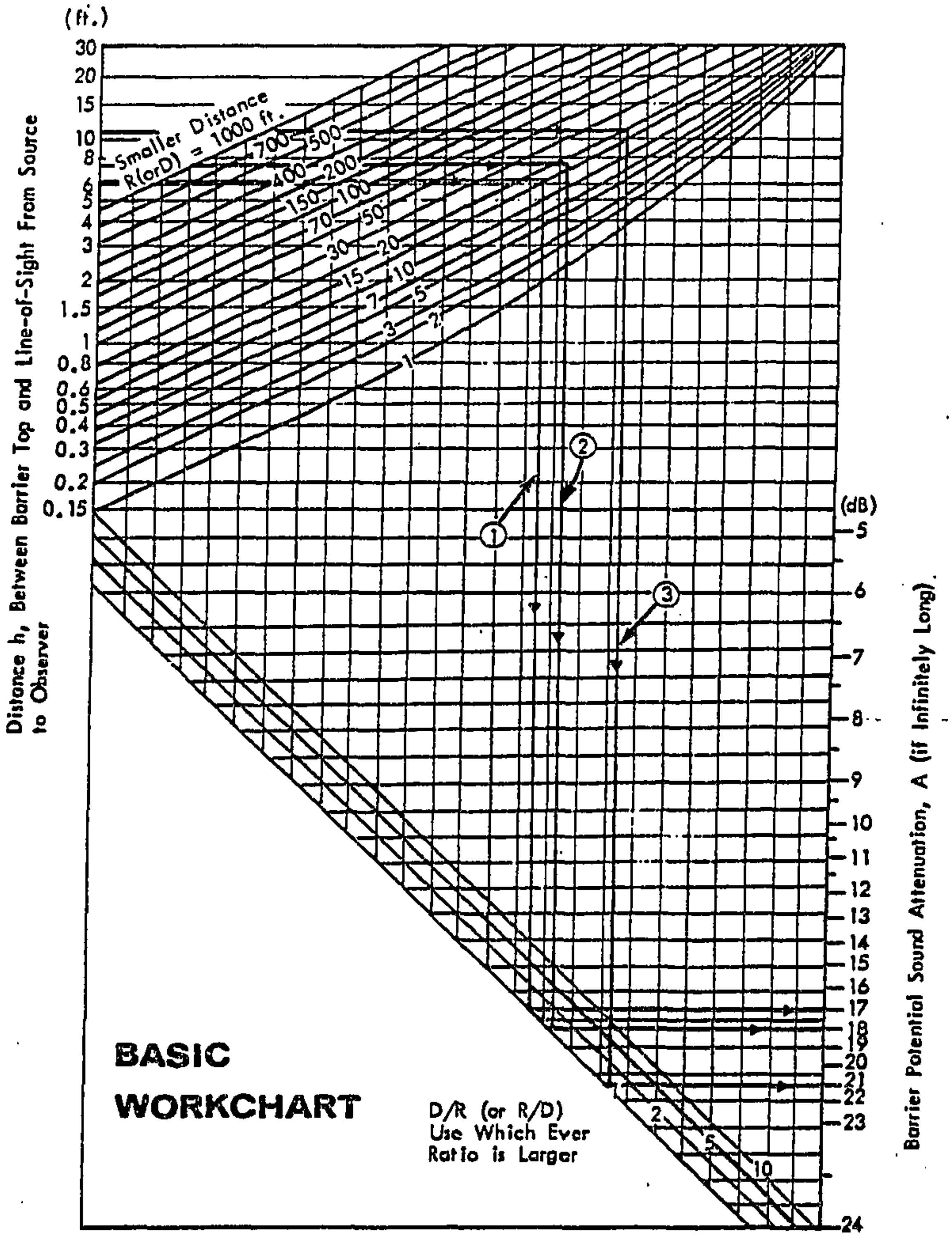
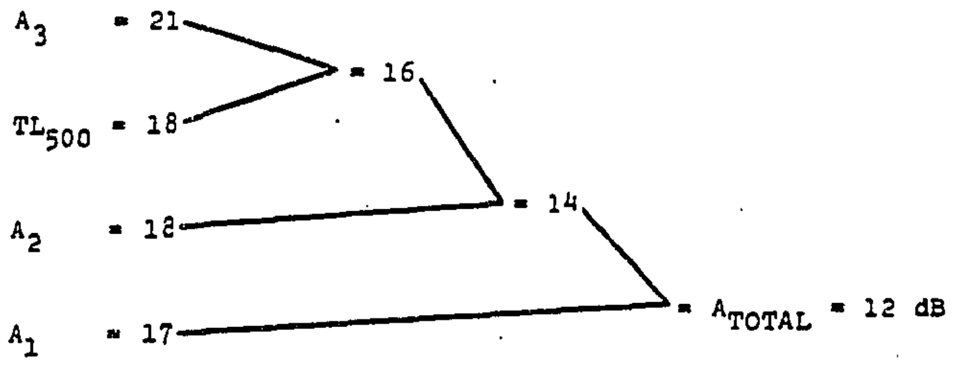


FIGURE A-2.4. WORKCHART SOLUTION TO BARRIER EVALUATION EXAMPLE

9. The source locations, S_2 and S_3, for the sound paths around the two sides of the barrier are chosen at the ends of the machine as illustrated in Figure A-2.3. The attenuation values A_2 and A_3 for these paths are calculated in the same manner as A_1. The workchart computations, shown on Figure A-2.4, result in values of $A_2 = 18$ dB and $A_3 = 21$ dB.

10. The overall barrier attenuation is estimated by combining A_1, A_2, A_3, and TL_{500} using the method of Table A-2.1. In order to do this, the component attenuations are arranged in descending order and combined as shown below.



Thus, the procedure estimates an overall barrier attenuation of 12 dB, which is well below the attenuation of any one component path.