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INSULATION OF BUILDINGS AGAINST HIGHWAY NOISE

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GLOSSARY

Absorption — The dissipation of noise energy by viscous interaction at porous surfaces such as carpets or draperies.

Acoustic Baffle — A fitting in a ventilation duct that attenuates noise traveling along the duct while presenting little flow resistance.

Attenuation — A reduction in the noise level of transmitted noise, as often provided by a berm, wall, or acoustically-absorptive ground surface. The amount of attenuation is measured in dB.

Decibel — A unit for describing the amplitude or level of acoustical quantities – see Level. Decibel is abbreviated dB.

EWNR — Abbreviation for Exterior Wall Noise Rating, a single-number rating of the maximum attenuation of a particular type of exterior wall construction.

Histogram — A graph showing the frequency of occurrence of noise at various levels.

Infiltration — The leakage of air through wall panels due to incomplete sealing of corners, window frames, and doors.

L_{eq} — Abbreviation for Equivalent Noise Level, a metric for describing the noise level of a time period of fluctuating environmental noise with a single number. L_{eq} is an average level based on the average energy content of the noise rather than average noise pressure level. It is the constant noise level which would contain the same amount of acoustical energy as a fluctuating level for the given period. L_{eq} values are not measured directly, but are computed from measurements, often taken over 1, 8, or 24-hour periods. These measurements, and the resulting L_{eq} values, are usually A-weighted.

L_{10}, L_{50}, L_{90} — Statistical metrics indicating the noise level which is exceeded for a particular percentage of the time during a given period. The percentage exceeded corresponds to the subscript for each metric.

Level — A scale for describing the amplitude of acoustical quantities - usually 10 times the logarithm (base 10) of the ratio of an acoustical quantity of the same kind.

Metric — A measure of noise. Some metrics are complex and may account for characteristics such as noise duration, noise level, frequency content, time of occurrence, or single events.

Noise Level — The instantaneous sound pressure level defined as SPL = 10 log (P^2/P^2_{ref}) where P is acoustic pressure and P_{ref} is 20 micro-Pascals (20 uN/m^2 or 2 x 10^{-4} microbar). The frequency distribution of the pressure is usually A-weighted. A-weighted noise levels can either be calculated or measured using instrumentation with an A-weighting network.

NR — Abbreviation for Noise Reduction, the difference between the noise levels immediately outside and inside a structure. Noise reduction can be measured directly or calculated from known building properties.

Shielding — With respect to buildings, the tendency of the portions of a structure facing a noise source to attenuate the noise before it reaches portions of the structure not facing the noise source. The shielded building faces can be thought of as an "acoustical shadow."

STC — Abbreviation for Sound Transmission Class, a single-number rating describing the attenuation of wall- or panel-type structures.

TL — Abbreviation for Transmission loss, a rating of the attenuation of a particular type of wall construction.

Chapter 1

INTRODUCTION

1.1 PURPOSE

The purpose of this manual is to provide members of the highway engineering field with the necessary tools to assess the noise insulation requirements of buildings. This analysis will enable the highway engineer to determine the effectiveness of existing buildings in insulating interior spaces against highway noise. It will also allow an evaluation of proposed modifications to the building to increase insulation effectiveness.

1.2 BASIC CONCEPTS OF NOISE INSULATION

When noise strikes a structure such as a wall or a window, most of it is reflected, with the remainder being transmitted through by vibrating the structure, as shown in Figure 1. Since only a small portion appears on the other side of the structure, we say that the noise has been reduced.

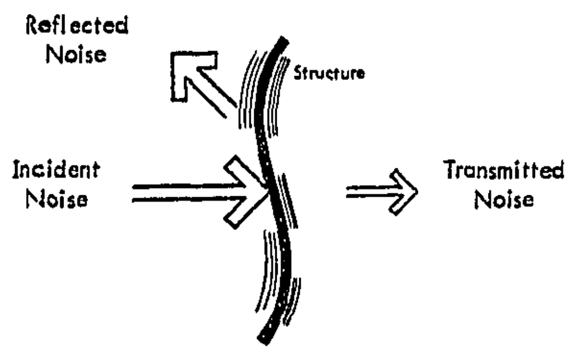

Figure 1. Conceptual illustration of noise being transmitted through a structure. Incident noise vibrates the structure; some of the noise is reflected with the rest being transmitted through.

Two important properties of a wall that contribute to its ability to reduce noise are its weight per unit area, and its stiffness or resistance to bending when a force is applied. In general, the heavier a wall is, the better it will act to reduce noise, as shown conceptually in Figure 2.

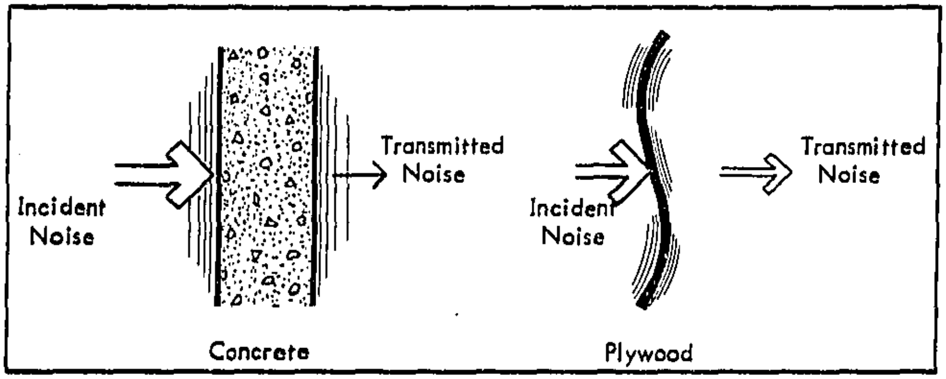

Figure 2. Conceptual illustration of how heavy structures transmit less noise than lightweight structures. The concrete panel does not vibrate easily when noise strikes it so relatively little noise is transmitted through. The light plywood vibrates readily and so it transmits more noise than the concrete structure.

The term noise reduction has been used generally to this point to mean the decrease in level as noise passes through a wall. Once the noise manages to pass through the wall into a room, it may then be partially absorbed by soft materials such as drapes and carpets. Hence, noise reduction is really two separate mechanisms – one due to the blocking properties of the wall, and one due to the acoustic environment on the receiving side of the wall. These two mechanisms are shown conceptually in Figure 3. The exterior noise is first attenuated while passing through the exterior wall, attaining a level which is prevented from further buildup by the absorptive materials normally found in residential buildings. The first mechanism, which is

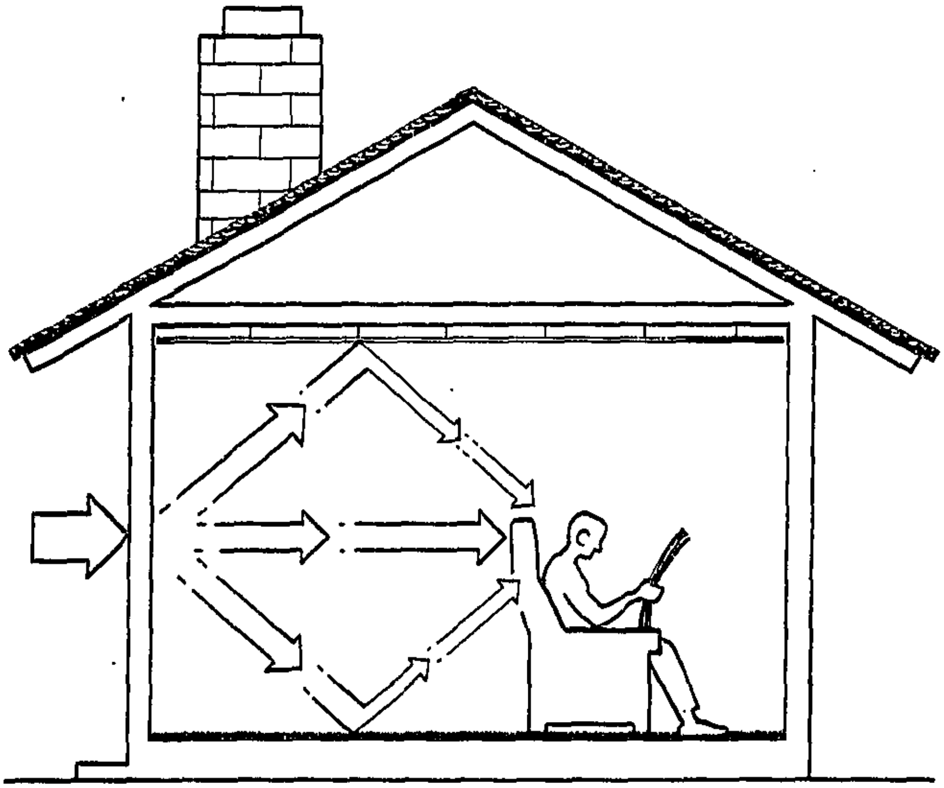

Figure 3. Conceptual Illustration of the Two Mechanisms Comprising Total Noise Reduction.

the reduction due only to the physical properties of the wall, is termed Transmission Loss (TL). The second mechanism, interior absorption, is due to absorption of the noise materials inside the room.

Noise Reduction (NR) may now be defined as the total difference between noise levels existing on two sides of a wall. TL and room absorption are the two properties that contribute to NR.

In this manual, a simplified type of TL - called Exterior Wall Noise Rating (EWNR) will be used.* Thus, in general, NR will be equal to the EWNR adjusted to account for interior absorption.

1.3 USE OF THIS MANUAL

The remainder of this manual is divided into four chapters. Chapter 2 deals with Noise Reduction Calculation Procedures and Chapter 3 contains Noise Measurement Procedures. Chapter 4 discusses Requirements for Ventilation and Energy, and, finally, Chapter 5 presents Procedures for Estimating the Costs of Noise Attenuation Modifications. The organization of the manual is shown graphically in Figure 4. A complete detailed flow diagram is presented in Appendix B along with step-by-step instructions concerning the procedures in the manual.

Following the last chapter, a series of worksheets are included for conveniently working the problems addressed in this manual.

*For a complete discussion of the Exterior Wall Noise Rating, see Appendix A.

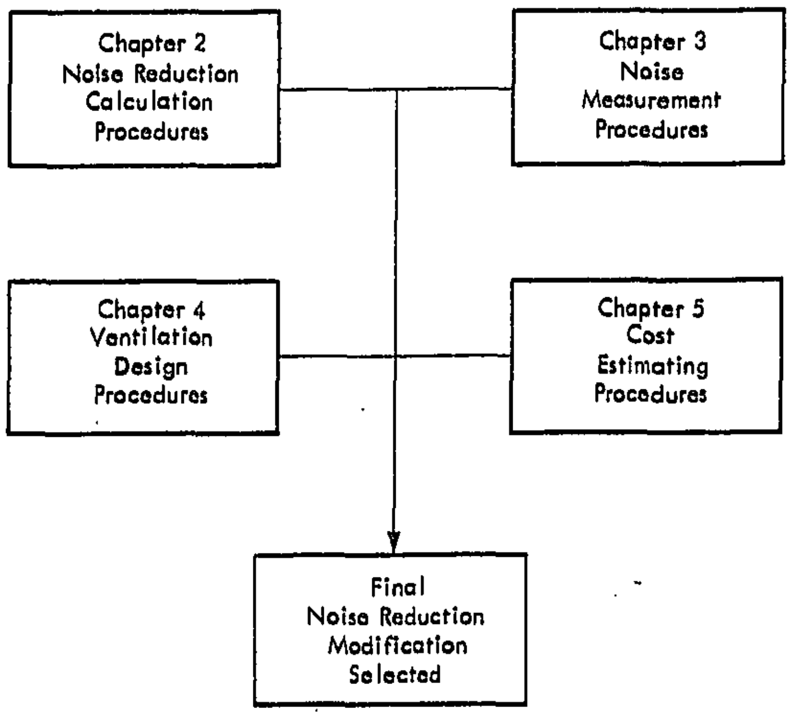

Figure 4. Organization of the Manual by Chapters

CHAPTER 2

NOISE REDUCTION DESIGN PROCEDURES

2.1 INTRODUCTION

When noise enters a building from the outside, it undergoes a reduction in level we have defined as Noise Reduction (NR). The amount of NR obtained depends on the type of construction used for the walls of the building, the sizes and types of windows and doors, the presence of noise leaks such as ventilation openings, and the amount of acoustically-absorptive material inside the building. Noise Reduction can be measured directly (this is discussed in Chapter 3), or it may be calculated from the following relation:

$$NR_c = EWNR - 10 \log S/A - 6, \text{ dB}$$

where:

EWNR = Exterior Wall Noise Rating,

10 log (S/A) = Room Absorption Factor.

S is the area of exterior wall through which the noise is transmitted, and
A is the total room absorption.

The Exterior Wall Noise Rating (EWNR) is a scheme for evaluating the Transmission Loss (TL) of a building element based on a typical highway noise spectrum.* In a typical building, many walls have windows and doors so that the EWNR must be known for these elements. Furthermore, the composite EWNR must be determined for the wall system with windows and doors installed. This chapter contains EWNR values for commonly-used wall constructions, window and door units,

*See Appendix A for details on the development of the Exterior Wall Noise Rating concept.

and miscellaneous elements such as through-the-wall air conditioners. In addition, procedures are included for combining the effects of two or more elements to determine the composite EWNR. Finally, a step-by-step procedure is given to evaluate the Noise Reduction value in the above relation. Material contained in this chapter can also be used to select building modifications to increase Noise Reduction to the desired amount. The steps of the overall manual procedure that will be carried out in this chapter are shown in Figure 5, where L_o is the given highway noise level and L_c is the design noise level.

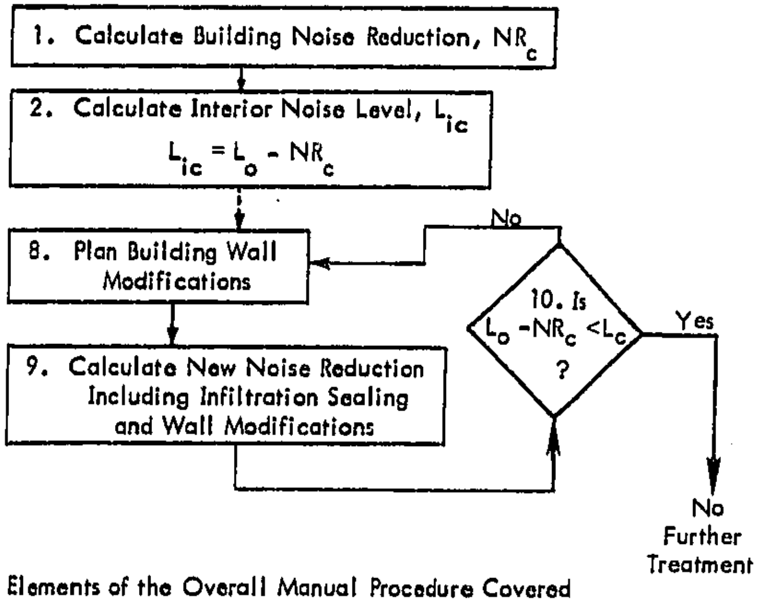

Figure 5. Elements of the Overall Manual Procedure Covered in Chapter 2. (See Appendix B for complete procedure flow diagram.)

2.2 EWNR VALUES FOR WALLS

Table 1 is a matrix presentation of EWNR values of 91 commonly-used basic exterior wall constructions, each made up of an exterior and an interior surface with no absorptive material in the stud space. The matrix may be entered either on the horizontal listing of interior wall surfaces or on the vertical listing of exterior wall surfaces.

Typical constructions found in existing buildings are often a variation of one of the basic constructions listed in Table 1. For example, an existing building may have fiberglass insulation in the stud spaces, or the stud spacing may be 24 inches rather than 16 inches. For this reason, it is convenient to consider standard constructions as having a basic EWNR value with some additional value added to account for construction variations. This approach may also be used to determine the NR benefits that may be expected by modifying an existing construction.

Modifications to basic constructions usually involve changes to the weight per unit area of wall panels, addition of absorption to the stud space, or changes to the limpness of the wall panels. These three modification categories act independently and when modifications are made to different categories, the full benefit of each modification will be realized. Adjustments to be added to the EWNR for basic constructions are given in Table 2 for the three categories. Category 3 contains several different modifications that increase the limpness of a construction. If two or more Category 3 modifications are used, count the value of the largest adjustment plus one-half of the value of the next largest adjustment.

Table 1

Exterior Wall Noise Rating (EWNR) Values in dB For Standard Exterior Constructions (For Use With Highway Noise)

Note: Approximate Metric thicknesses in centimeters may be obtained by multiplying the nominal English-inch units by 2.54

EXTERIORS \ INTERIORS		1 Gypsumboard - 1/2" to 5/8"	2 1/8" to 1/2" Plaster on 3/8" Gypsum Lath	3 1/2" Soundboard on Gypsumboard - 3/8" to 1/2"	4 Plaster - 1/2" to 7/8"	5 Plywood - 1/2"	6* Plywood Paneling - 1/4"	7* Hardboard Paneling - 1/4"	8 Exposed Solid Wall
Alum. Siding on 1/2" Wood	A	28	31	29	32	25	29	31	--
7/8" Stucco	B	36	34	37	30	33	37	38	--
7/8" Stucco on 1/2" Wood	C	37	36	37	32	34	38	39	--
Wood Siding - 1/2" to 3/4"	D	27	29	27	31	24	28	30	--
4-1/2" Brick Veneer	E	44	42	44	39	42	45	46	--
9" Brick	F	47	50	50	45	45	45	45	45
4" Concrete	G	46	47	47	41	40	40	40	40
6" Concrete	H	46	48	48	42	42	42	42	42
6" Hollow Concrete Block	I	38	40	40	34	33	33	33	33
8" Hollow Concrete Block	J	40	42	42	36	35	35	35	35
6" Block w/1/2" Stucco	K	39	41	41	35	34	34	34	34
8" Block w/1/2" Stucco	L	41	43	43	37	36	36	36	36

*Both 1/4" Paneling Interiors (columns 6 and 7) are mounted on 1/2" Gypsumboard only for Exteriors A through E.

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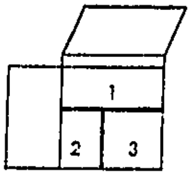


Area 1: Stud-work Constructions – All conventional 2x4 wood studs on 16-inch centers with no insulation in stud spaces.

Area 2: Solid Wall with Furred Interior Surfaces – All interior surfaces mounted on 3/4-inch furring strips on 16-inch centers.

Area 3: Solid Wall with Glued Interior Surfaces – All interior surfaces glued directly to the solid wall.

Table 2

Adjustments To Basic EWNR Values Due To Modifications [1]

Modification Category 1: Mass Increases	Δ EWNR, dB
Double Mass One Side	3
Double Mass Both Sides	4

Modification Category 2: Stud Space Absorption	Δ EWNR, dB
Absorption in Stud Space ②	4

Modification Category 3: Limpness Increases	Δ EWNR, dB
Fiberboard Under Both Panels	8
Resilient Mounting of One or Both Panels	8
Staggered Studs	6
24-inch Stud Spacing	2
Metal Channel Studs	5

Table Instructions

① To obtain the Total EWNR adjustment for multiple modifications: add the adjustments for each of the three categories. If more than one Category 3 modification is used, count the value of the largest adjustment plus one-half of the value of the next largest.

② If fiberboard is used for a Category 3 modification, count Category 2 stud space absorption as only 2 dB.

Example 1: An existing building located near a highway has a solid exterior wall facing the highway. The wall is constructed of standard wood studs 16 inches on center with an interior surface of 1/2 inch thick plaster and an exterior surface of 1/2 inch thick wood siding. What is the EWNR of the wall? What would the EWNR be if the exterior siding were removed, fibrous absorption installed in the stud spaces, and the wood siding reinstalled?

Solution: From Table 1, a standard 16-inch on-center stud wall is located in Area 1 (above the solid line). At the intersection of Exterior Surface Row D and Interior Surface Column 4, an EWNR value of 31 dB for the wall is found. From Table 2, the addition of stud space absorption is determined to provide an adjustment of +4 dB. The modified wall would therefore have an EWNR of 31 +4 = 35 dB.

These calculations should be carried out on Worksheet No. 1, a portion of which is reproduced as follows. (A complete Worksheet No. 1 is included at the end of the manual.)

Portion of Worksheet No. 1

EWNR CALCULATION FOR WALL ELEMENTS

Wall	Basic EWNR (Table 1)		EWNR Adjustment (Table 2)		Total EWNR
#1	31	+	4	=	35 dB
___	______	+	_________	=	___ dB

2.3 EWNR VALUES FOR ROOF-CEILING CONSTRUCTIONS

If the room being evaluated is just below the roof, the EWNR of the Roof-Ceiling Construction must be determined. Two general types of Roof-Ceilings in common use are the Single Joist and Attic Space Type, as shown in Figure 6.

Basic EWNR values for Typical Roof-Ceiling Constructions are given in Table 3 for Single Joist as well as Attic Space Constructions. These basic values must be adjusted to account for attic venting, acoustical absorption in the attic or ceiling joist space, and self-shielding of the roof by the building.

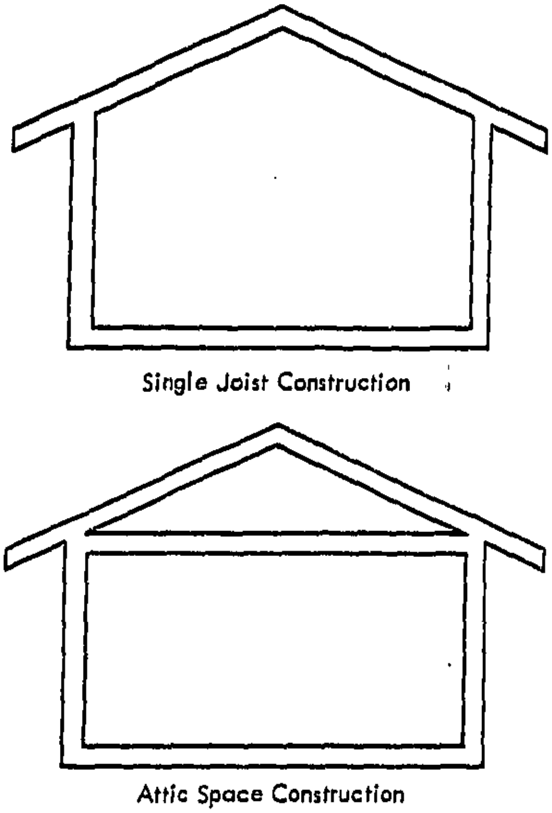
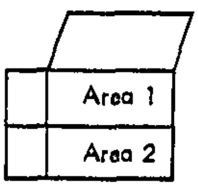


Figure 6. Illustration of Two Commonly-Used Roof-Ceiling Constructions

Table 3

EWNR Values in dB for Basic Roof-Ceiling Constructions[1]
(For Use With Highway Noise)

ROOF CONSTRUCTION	CEILING CONSTRUCTION	1/2" Gypsumboard	3/8" Gypsum Lath on 1/8" Plaster	1/2" Fiberboard	Exposed Framing
		1	2	3	4
Wood Shingles	A	28	28	24	21
Composition Shingles	B	31	34	26	25
Clay or Concrete Tiles	C	39	40	33	32
Built-Up Roofing	D	31	31	26	24
1/2" Wood and Sheet Metal	E	–	–	–	23
Wood Shingles	F	36	39	48	–
Composition Shingles	G	40	43	53	–
Clay or Concrete Tiles	H	45	48	58	–
Built-Up Roofing	I	38	41	50	–
1/2" Wood and Sheet Metal	J	36	39	49	–



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Area 1: Single Joist Constructions

Area 2: Attic Space Constructions

1/8" = .32 cm
3/8" = .95 cm
1/2" = 1.27 cm

If the roof system is not vented and is lined with acoustically-absorptive material (such as fiberglass or mineral wool), add an adjustment from Table 4 to the basic EWNR value.

Table 4

Adjustment to Basic EWNR for Addition of Absorption*in Nonvented Ceiling/Joist Spaces

Description	Adjustment Factor, dB (To be Added)
Single Joist Constructions - All Cases	5
Attic Space Constructions -	
Fiberboard Ceiling	2
Plaster or Gyp Ceiling	6

*A minimum of 4 inches (10.16 cm) is required to count this adjustment.

If the roof system is a vented attic space system, use Table 5 to adjust the EWNR values. Find the row corresponding to the basic EWNR value from Table 3 and read the new EWNR value in the appropriate column to account for the absorptive material. Single joist constructions are not normally vented, so Table 5 does not apply to these systems.

Table 5

Effects of Venting Attic Space Constructions* On EWNR Values With and Without Absorption[1]

Basic Construction EWNR, dB		Vented Attic EWNR, dB (Without Absorption)	Vented Attic EWNR, dB (With Absorption)
Plaster or Gypboard Ceiling	36 to 39	24	31
	40 to 42	25	32
	43 to 45	26	33
	46 to 48	27	34
Fiberboard Ceiling	48 to 58	35	38

*Based on minimum venting requirements of the Uniform Building Code.

Finally, the Roof-Ceiling EWNR values must be adjusted to account for building self-shielding which is a function of the slope of the roof line. The noise level due to an exterior source will not be as great just outside the center of the building roof as it will be just outside the building walls. This self-shielding effect of the building may be accounted for by adding the adjustment factors given in Table 6 to the EWNR values determined in Tables 3, 4, and 5.

Table 6

Adjustment to Basic EWNR to Account for Building Self-Shielding

Roof Line Description	Adjustment Factor, dB (to be added)
Flat Roof	6
Sloped Roof	3

Example 2: An existing building has a sloped roof consisting of composition shingles. The attic space is vented in accordance with the Uniform Building Code and there is no acoustical absorption in the attic space. If the ceiling construction is 1/2 inch gypsumboard, what is the EWNR of the Roof-Ceiling System? What would the EWNR be if the attic space were treated with acoustic absorption?

Solution: The basic EWNR for this Roof-Ceiling System is found at the intersection of Column 1 and Row G of Table 3 - 40 dB. Since the attic space is vented, we must refer to Table 5 which indicates that a gypsumboard construction with a basic EWNR of 40 to 42 dB will have an EWNR of 25 dB with venting. Since the roof line is sloped, we add a final adjustment of 3 dB from Table 6 to account for self-shielding. The resulting EWNR is 28 dB.

If absorption were added to the vented attic space, the use of Table 5 indicates an EWNR of 32 dB. With the adjustment for self-shielding, the resulting EWNR is 35 dB. The absorption has provided a beneficial increase in the EWNR of 7 dB.

These calculations should be carried out on Worksheet No. 1, a portion of which is reproduced as follows. (A complete Worksheet No. 1 is included at the end of the manual.)

Portion of Worksheet No. 1

EWNR CALCULATION FOR ROOF-CEILING ELEMENTS			
Attic Space Construction		**Single Joist Construction**	
Basic EWNR (from Table 3)	40 dB	Basic EWNR (from Table 3)	___dB
New Basic EWNR for vented spaces (from Table 5)	25 dB	Adjustment for absorption (from Table 4)	___dB
Adjustment for self-shielding (from Table 6)	3 dB	Adjustment for self-shielding (from Table 6)	___dB
Total EWNR (Sum of one basic EWNR and adjustment)	28 dB	Total EWNR (Sum of above)	___dB

2.4 EWNR VALUES FOR WINDOWS AND DOORS

If the wall being evaluated has one or more windows or doors, the EWNR values of these elements must be determined. Table 7 lists EWNR values for common window assemblies and Table 8 lists EWNR values for commonly-used doors.

Table 7

EWNR Values for Common Window Assemblies*[1]
(For Use With Highway Noise)

	DESCRIPTION	EWNR, dB
Single Glazed Windows	1/16" glass (.16 cm)	24
	1/8" glass (.32 cm)	24
	1/4" plate glass (.64 cm)	24
	5/16" glass (.79 cm)	28
	3/8" glass (.95 cm)	30
	2-ply glass, 0.53" total (1.35 cm)	38
	3-ply glass, 0.82" total (2.1 cm)	41
Jalousie Window	4-1/2" wide, 1/4" thick louvers with 1/2" overlap - cranked shut	18
Double Glazed Windows	3/32" glass, 4" airspace, 3/32" glass	30
	1/8" glass, 2-1/4" airspace, 1/8" glass	32
	1/8" glass, 2-1/4" airspace, 1/4" glass	36
	1/4" glass, 2-1/4" airspace, 1/4" glass	38
	3/16" glass, 2" airspace, 1/4" glass	39
	1/4" glass, 2" airspace, 3/8" glass	40
	3/16" glass, 2" airspace, 3/8" glass	41
	3/16" glass, 4-3/4" airspace, 1/4" glass	44

3/32" = .24 cm; 3/16 = .48 cm; 1/2" = 1.3 cm; 2" = 5.08 cm; 4" = 10.16 cm

Note: The addition of a storm window to an existing single glazed or jalousie window will increase the EWNR by 5 dB.

*If the window is fully open (such as a fully open jalousie or crank type window) its EWNR value is 4 dB. If the window is not completely open (usually the case for sliding windows) use 4 dB for the open area, the given value for the closed or unopenable area, and combine the two values using the procedures of Section 2.6.

Table 8

EWNR Values for Commonly-Used Doors [1]
(For Use With Highway Noise)

	DESCRIPTION	EWNR, dB
Hollow Core Doors	1-3/4" wood, 1/16" undercut	16
	1-3/4" wood, Weather-Stripped	17
	Steel (3.22 lbs/ft^2, 15.72 kgs/m^2) Magnetic weather-strip	28
Solid Core Doors	1-3/4" wood, 1/16" undercut	18
	1-3/4" wood, Weather-Stripped	26
	1-3/4" wood, Drop seal threshold	35
	1-3/4" wood, weather-strip, and Aluminum storm door, glazed 1/16" glass	31
Sliding Door	Glazed 3/16" (.48 cm) safety glass	26

1-3/4" = 4.45 cm
1/16" = .16 cm

Note: The addition of a weather-stripped single glazed storm door to an existing door will increase the EWNR by 5 dB.

2.5 EWNR VALUES FOR THROUGH-THE-WALL AIR CONDITIONERS

If a through-the-wall-type air conditioning unit is present in an existing wall being evaluated, or if such a unit is being considered, the EWNR values of the air conditioners must be determined. Table 9 lists EWNR values for through-the-wall air conditioners for vents open and vents closed. Treat these units as windows in the remaining analysis in this manual.

Table 9

EWNR Values for Through-the-Wall Air Conditioners for Vents Open and Closed[1]
(For Use With Highway Noise)

	Vent Open	Vent Closed
EWNR, dB	21	24

2.6 COMPOSITE EWNR VALUES FOR TWO OR MORE ELEMENTS

In most typical constructions of interest, there will be one or more windows, doors, and through-the-wall air conditioners existing as part of the walls being evaluated. Two components – such as a single door in a wall – may be combined and treated as one single component with an EWNR value that is less than the EWNR of the higher-rated element. The amount by which the EWNR of the higher-rated element (usually the wall) must be reduced to account for the presence of the lower-rated element (usually the window or door) is a function of the relative areas of both components and the magnitude of the difference between their individual EWNR values.

For more than two components, the following procedure may be repeated as many times as necessary taking the elements two at a time in any order.

PROCEDURE To Combine the EWNR Values of Two or More Elements

1. Determine the surface area of each of two elements to be combined. Note that if two elements have the same EWNR values, combine them directly by considering them as one element with the same EWNR and a combined surface area equal to the total area of both elements.

2. Determine the percentage area of each element to the total area of both elements.

3. Record the EWNR of each element. (This should be the adjusted EWNR where applicable.)

4. Subtract the EWNR of the lower-rated element from the higher-rated element.

5. Enter Figure 7 on the horizontal axis at the value determined in Step 4. (Difference between EWNR values of two elements.)

6. Draw a vertical line up to the curve corresponding to the percentage of the total area occupied by the lower-rated EWNR element. (Interpolate between percentages if necessary.)

7. Draw a horizontal line from this point to the left to intersect the vertical axis to find the difference between the higher-rated element and the composite of both elements.

8. Subtract this value (difference between higher-rated element and composite of both elements) from the higher-rated element to obtain the composite EWNR for both elements in combination.

9. Repeat the procedure as necessary to determine the composite rating of three or more wall components.

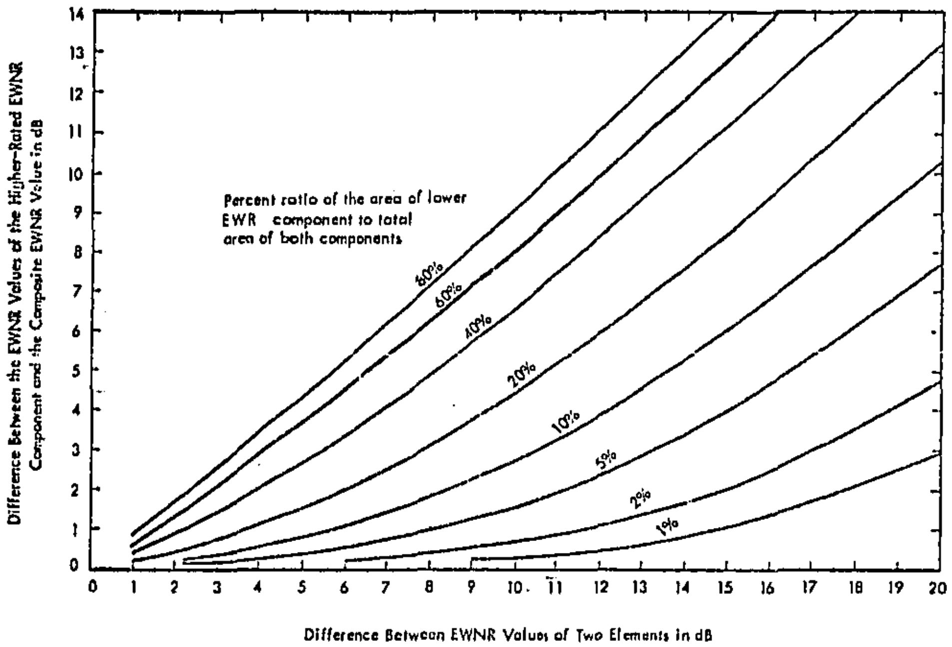


Figure 7. Graph for Determining Composite EWNR for Two Wall Elements for Several Ratios of the Area of One Component to the Total Area of Both Components

Example 3: It is proposed that the solid wall of Example 1 (without absorption) be modified to include a 1-3/4" (4.4 cm) hollow core door (fully weather-stripped). If the wall is 8' 0" x 30' 6" (2.4 x 9.3 m) and the door is 3' 6" x 7' 0" (1.1 x 2.1 m), what will the composite EWNR be for the wall with door installed?

Solution: Following the numbered steps of the described Procedure:

1. The door area is 24.5 square feet (2.3 m^2). The wall area (with door cut out) is 219.5 square feet (20.4 m^2). The total area is 244 square feet (22.7 m^2).

2. The door is 10 percent and the wall 90 percent of the total area.

3. The EWNR of the door is 17 dB (from Table 8). The EWNR of the wall is 31 dB (from Example 1).

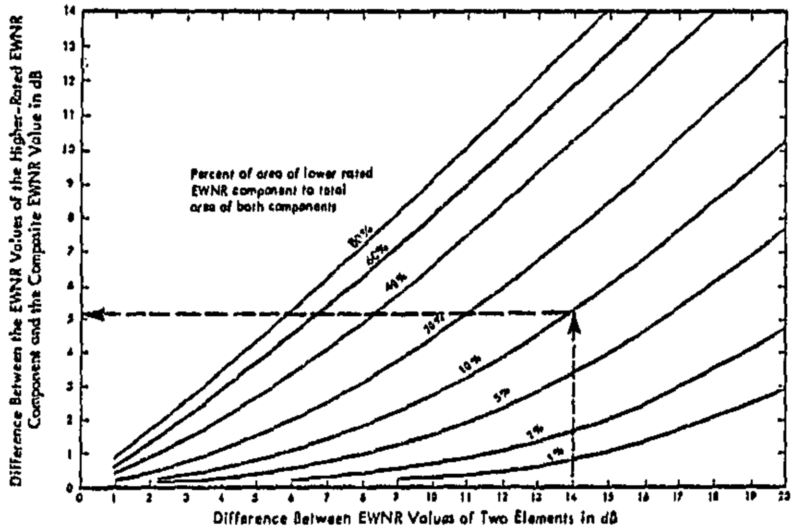
4. The difference between the EWNR values is 14 dB.

5. Enter Figure 7 at 14 dB on the horizontal axis.

6. Draw a line up to the curve marked 10 percent.

7. Draw a line horizontally to the left to intersect the left axis at 5 dB (round off to the nearest integral value).

8. The composite EWNR of the wall with door installed is 31 - 5 = 26 dB.



These calculations should be carried out on Worksheet No. 2, a portion of which is reproduced as follows. (A complete Worksheet No. 2 is included at the end of the manual.)

Portion of Worksheet No. 2

COMPOSITE EWNR CALCULATION FOR TWO ELEMENTS

Step	Element 1	Element 2
1. Enter Total Area	244 ft² ~~(m²)~~	
Enter Element Area	DOOR 24.5 ft² ~~(m²)~~	WALL 219.5 ft² ~~(m²)~~
2. Percent of Total Area (Must sum to 100%)	10 %	90 %
3. Enter EWNR's	17 dB	31 dB
4. Difference of Line 3 EWNR's	14 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	5 dB	
8. Composite EWNR (Larger Line 3 EWNR − Line 5-7)	26 dB	

2.7 INTERIOR ABSORPTION ADJUSTMENT

When exterior noise is transmitted to the interior of a structure, it undergoes absorption due to materials located in the room such as draperies, carpeting, and upholstered furniture which usually provide most of the absorption in typical buildings.

Increasing the interior room absorption in an attempt to reduce noise produced by an exterior source is not usually an effective technique, since a great deal of absorption must be added to an existing interior space to obtain only a small noise reduction benefit.

The presence of normal amounts of interior room absorption must be accounted for, however, when determining the noise reduction of an existing structure. The value of the adjustment for room absorption will depend on the total amount of absorption usually referred to by the term A and the total surface of the exterior wall, S (this is the area of the exterior wall that covers the room being evaluated). It is not necessary to actually determine what S and A are, since the combined room absorption adjustment – 10 log (S/A) – is normally a constant value for various types of rooms in typical structures. (See Appendix C for a detailed discussion of this.) Adjustment factors for room absorption are listed in Table 10 for three types of rooms with either one exterior wall or two exterior walls (corner rooms).

Table 10

Adjustment Factors for Interior Room Absorption

Type of Interior Room	10 log (S/A), dB	
	1 Exterior Wall	2 Exterior Walls (Corner Room)
Living Room	-4	-1
Bedroom	-3	0
Kitchen	-2	+1

2.8 NOISE REDUCTION PROCEDURE

Once the appropriate EWNR values are determined for the structure, the Noise Reduction (NR) can be calculated from the following relationship

$$NR = EWNR - 10 \log (S/A) - 6, \text{ dB}$$

where 10 log (S/A) is the room absorption correction factor given in Table 10. Use the following procedure to determine the NR for an existing structure or for one that is being modified.

PROCEDURE TO CALCULATE NR

1. For each interior room to be evaluated, identify all elements that will transmit noise from outside the structure. These elements will include exterior walls, roof-ceilings, windows, doors, and air conditioners.

2. Determine the area of each element. For roof-ceiling constructions, use the ceiling area of the room being evaluated.

3. Determine the EWNR of all wall elements. Find the basic EWNR in Table 1. Add appropriate adjustments from Table 2.

4. Determine the EWNR of the roof-ceiling if the room being evaluated adjoins the roof. Find the basic EWNR from Table 3. For nonvented ceiling/joist spaces, add an appropriate adjustment for absorption from Table 4. For vented spaces (attics only), use Table 3 and Table 5 to determine the EWNR. Add the appropriate adjustment from Table 6 to account for self-shielding of the structure.

5. Determine the EWNR for all windows, doors, and through-the-wall air conditioners from Tables 7, 8, and 9.

6. Determine the composite EWNR of each wall element that contains a window, door, or air conditioner, using the procedure of Section 2.6. If a wall contains more than one window or door, repeat the procedure as necessary to account for all windows and doors.

7. Combine the composite EWNR of all wall elements if the room has more than one exterior wall. Use the procedure of Section 2.6 as required to determine the EWNR for all composite wall elements.

8. Combine the EWNR for all composite wall elements with the adjusted EWNR of the roof-ceiling construction, if appropriate, to obtain the total EWNR for the structure.

9. Determine the room absorption correction from Table 10 for the type of room being evaluated.

10. Subtract the quantity (10 log S/A + 6) from the total structure EWNR to determine the structure's NR.

Example 4: A single-story residence, located near a highway that is being widened, is being evaluated to determine if acoustical modifications will be required. The exterior walls are constructed of aluminum siding on 1/2" (1.3 cm) wood nailed to 2"x4" (5.1 x 10.2 cm) studs with fiberglass thermal insulation in the stud spaces, and an interior finish of 5/8" (1.6 cm) gypsumboard. The house has a vented attic space with fiberglass thermal insulation installed. The sloped roof is wood shingle, and the interior ceilings are 1/2" (1.3 cm) gypsumboard. The bedroom has one exterior wall 8' 0" x 15' 6" (2.4 x 4.7 m) containing one 1/8" (0.3 cm) window 3' 6" x 3' 6" (1.1 x 1.1 m). The bedroom ceiling is 15' 6" x 12' 0" (4.7 x 3.7 m). Calculate the NR of the structure for the bedroom.

Solution: Following the numbered steps in the procedure of Section 2.8:

1. For the bedroom, noise will be transmitted through one wall, the roof-ceiling, and the window.

2. Window: 12.3 square feet ($1.1 m^2$)
   Wall: 111.7 square feet ($10.4 m^2$)
   Ceiling: 186.0 square feet ($17.3 m^2$)

3. | | |
   |---|---|
   | Basic Wall EWNR (Construction A1 from Table 1) | 28 dB |
   | Adjustment for Stud Space Absorption (from Table 2) | + 4 |
   | Wall EWNR | 32 dB |

4. | | |
   |---|---|
   | Basic Roof-Ceiling EWNR (Construction F1 from Table 3) | 36 dB |
   | New EWNR for Vented Attic (from Table 5) | 31 dB |
   | Adjustment for Slope (from Table 6) | + 3 |
   | Roof-Ceiling EWNR | 34 dB |

5. Window EWNR (from Table 7) 24 dB

6. The window (10 percent of the combined window-wall area) has an EWNR that is 8 dB less than the wall EWNR. Figure 7 indicates that the difference between the wall EWNR and the composite EWNR is 2 dB. The composite wall-window EWNR is, therefore, 32 -2 = 30 dB.

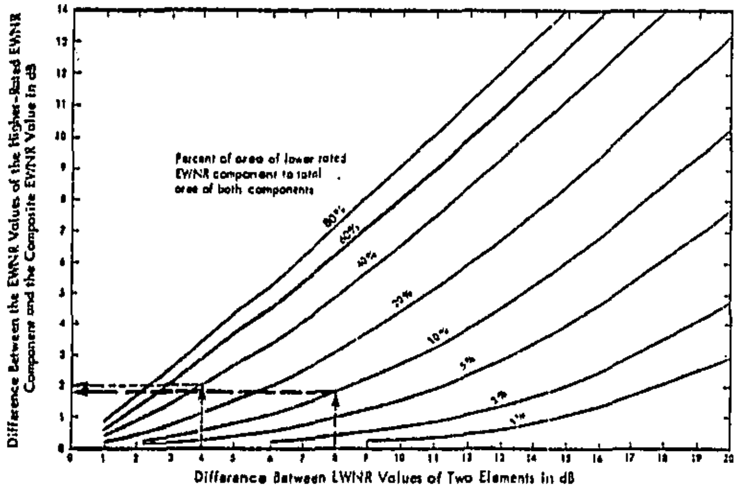
7. This step is not applicable in this case.

8. The roof-ceiling EWNR is 34 dB and the composite wall-window EWNR is 30 dB. The total ceiling and wall-window area is 186 + 124 = 310 square feet ($11.5 + 17.3 = 28.8 m^2$), 40 percent of which is the wall-window (the lower-rated element). Figure 7 indicates that with a difference of 4 dB between the EWNR values of the two elements, the higher-rated element

EWNR exceeds the composite total EWNR by 2 dB. The composite total EWNR for the structure is, therefore, 34 - 2 = 32 dB.

9. The room absorption correction from Table 10 for a bedroom with one wall exposed is -3 dB.

10. The NR is determined by subtracting the absorption correction from the structure's EWNR (NR = EWNR - 10 log S/A -6). Therefore, NR = 32 - (-3) - 6 = 29 dB.



These calculations should be carried out on Worksheet No. 1 and Worksheet No. 2, portions of which are reproduced as follows: (Complete Worksheets are included at the end of the manual.)

Steps 1 to 3 Portion of Worksheet No. 1

EWNR CALCULATION FOR WALL ELEMENTS

Wall	Basic EWNR (Table 1)		EWNR Adjustment (Table 2)		Total EWNR
#1	28	+	4	=	32 dB

Step 4 Portion of Worksheet No. 1

EWNR CALCULATION FOR ROOF-CEILING ELEMENTS

Attic Space Construction		Single Joist Construction	
Basic EWNR (from Table 3)	36 dB	Basic EWNR (from Table 3)	____ dB
New Basic EWNR for vented spaces (from Table 5)	31	Adjustment for absorption (from Table 4)	____
Adjustment for self-shielding (from Table 6)	3	Adjustment for self-shielding (from Table 6)	____
Total EWNR (Sum of one basic EWNR and adjustment)	34 dB	Total EWNR (Sum of above)	____ dB

Steps 5 and 6

Portion of Worksheet No. 2

COMPOSITE EWNR CALCULATION FOR TWO ELEMENTS		
Step	Element 1	Element 2
1. Enter Total Area	124 ft² (m²)	
Enter Element Area	WINDOW 12.3 ft² (m²)	WALL 111.7 ft² (m²)
2. Percent of Total Area (Must sum to 100%	10 %	90 %
3. Enter EWNR's	24 dB	32 dB
4. Difference of Line 3 EWNR's	8 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	2 dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	30 dB	

Step 8

Portion of Worksheet No. 2

COMPOSITE EWNR CALCULATION FOR TWO ELEMENTS		
Step	Element 1	Element 2
1. Enter Total Area	WALL/WINDOW 310 ft² (m²)	ROOF
Enter Element Area	124 ft² (m²)	186 ft² (m²)
2. Percent of Total Area (Must sum to 100%)	40 %	60 %
3. Enter EWNR's	30 dB	34 dB
4. Difference of Line 3 EWNR's	4 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	2 dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	32 dB	

Steps 9 and 10

Portion of Worksheet No. 1

FINAL CALCULATION FOR NOISE REDUCTION				
Structure Composite EWNR.		Interior Absorption Correction from Table 10		Structure Noise Reduction
32 dB	-	-(3) dB → 6	=	29 dB

2.9 MODIFICATIONS TO INCREASE NOISE REDUCTION

When interior noise (from nearby highways) exceeds the Design Noise Level, modifications to increase the building's noise reduction are required. A preliminary selection of modifications can be made by considering the three basic paths by which noise enters a structure. The actual increases in noise reduction which would result from these modifications can then be determined using methods presented earlier in this chapter. If insufficient noise reduction is obtained, the cycle of selection and evaluation should be continued until interior noise no longer exceeds the Design Noise Level.

The three major paths by which noise can be transmitted to the interior of a structure are illustrated conceptually in Figure 8. These paths are:

- Air Infiltration (gaps and cracks)
- Small Wall Elements (Windows and Doors)
- Main Wall Elements

Air infiltration paths are the small gaps and cracks that normally exist around doors and windows. Naturally, the more such leakage paths there are, the lower the noise reduction of the building will be — even if the EWNR of the wall panels themselves is relatively high. This explains why it is often not sufficient simply to calculate the interior noise level using known properties of wall materials, because this method cannot easily take leakage into account. The usual calculated value of interior noise provides the minimum value that can be obtained in the absence of leakage paths. Thus, the principal difference between the calculated and appropriately measured values of interior noise may be attributed to noise leakage. The improvement in NR that can be obtained merely by treating the leakage paths without modifying the windows, doors, or other building elements is shown, in Table 11, to be as high as 4 dB. Thus, the usual first step in increasing the NR of buildings is to

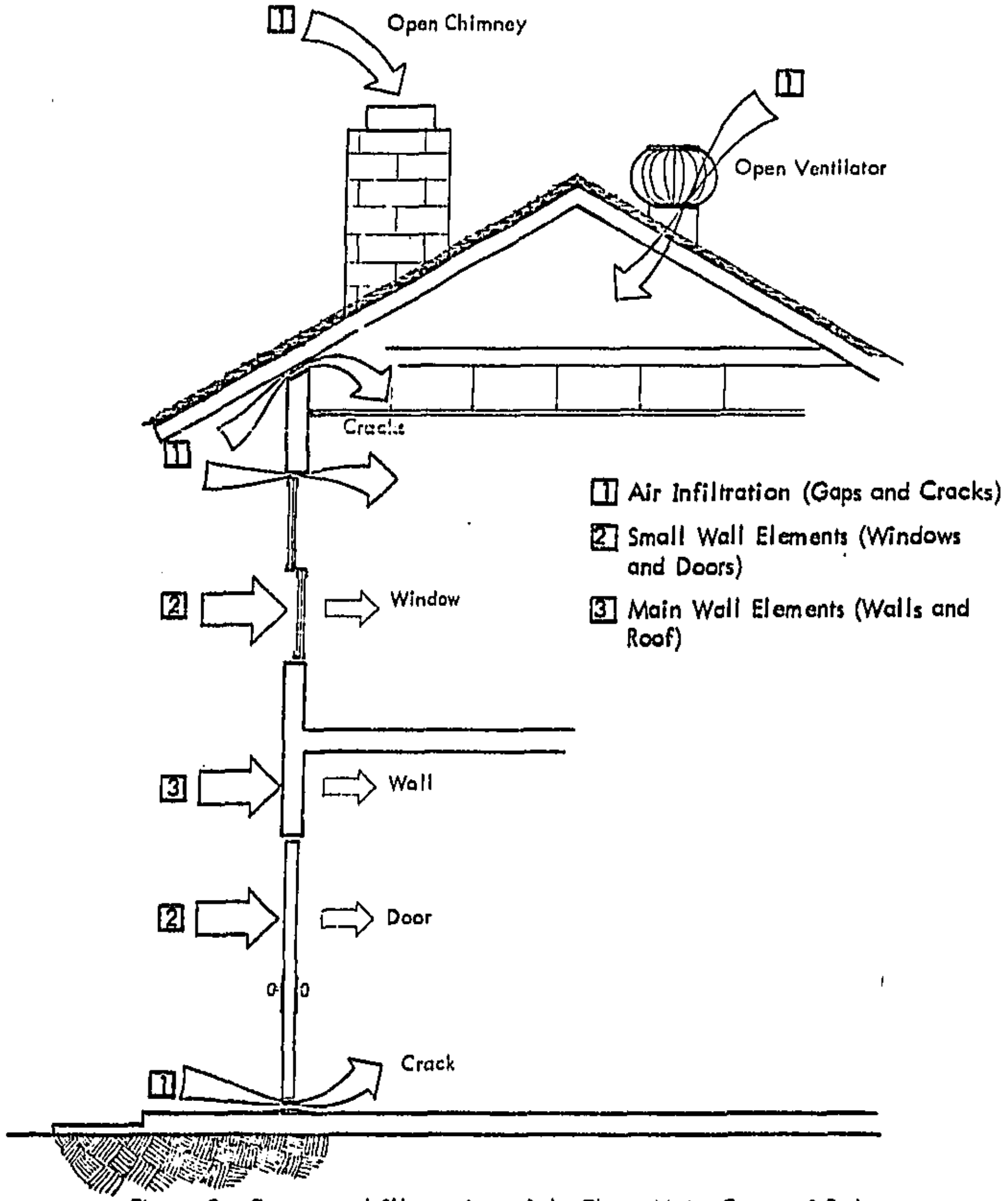


Figure 8. Conceptual Illustration of the Three Major Types of Paths By Which Noise is Transmitted to Building Interiors.

seal all infiltration cracks using weather-stripping, nonhardening caulking, and door threshold seals. If the sealing of cracks and leaks will not add sufficiently to the NR of the building, then modifications of the building elements will be required.

Since small wall elements such as windows and doors usually have EWNR values less than that of the surrounding wall, it is usually beneficial to consider them in the second stage of modifications. This second stage should upgrade small wall elements to an EWNR which approaches that of the surrounding wall. This is usually done by replacement with improved elements and, as shown in Table 11, can result in NR increases of up to 10 dB. One basic small element modification is the installation of storm doors and windows. These can provide substantial increases in door and window EWNR, but these elements must remain in place if the benefits are to be realized year-round.

The final alternative, if the previous two approaches do not provide adequate noise reduction, is modification of the main wall elements, the basic wall and roof construction. This major noise attenuating technique can provide substantial increases in NR but may not be justifiable on a cost/benefit basis. Two of the simpler construction modifications are addition of absorbing material to the stud space, and resilient mounting of the interior wall panels. The NR benefits to be expected from these and more extensive modifications can be obtained from tables presented earlier in this chapter.

Table 11 may be used to select the modification type based on the required increase in NR. Relative modification costs are also included to assist in this selection. Procedures for estimating quantitative changes in heating and ventilation requirements due to the modifications are presented in Chapter 4, and procedures for estimating the actual costs of various modification alternatives are given in Chapter 5.

Table 11

Relative Aspects of Noise Reduction Modifications to External Walls

Noise Reduction Modification	Increase in NR of Structure	Initial Modification Cost	Additional Ventilation Required	Heating and Air Conditioning Energy Savings
SEAL LEAKS Seal all cracks, openings, leaks with caulk, tape, or weather-stripping around door, window, wall joint seams. Provide acoustical baffles for chimneys, ventilators, etc.	Up to 4 dB	Low	High	High
SMALL ELEMENT MODIFICATION For windows, doors, air conditioners, ventilators, install new elements with upgraded EWNR comparable to that of wall structure.	Up to 10 dB over sealing of cracks; typically, 4 to 7 dB.	Moderate	None	Moderate
WALL PANEL MODIFICATION Construction changes to walls, roof, including stud space insulation and resilient mounting of interior surface.	Up to 10 dB over small element modifications; higher for more extensive modifications.	High	None	Moderate

CHAPTER 3

NOISE MEASUREMENT PROCEDURES

3.1 INTRODUCTION

Procedures were given in Chapter 2 to calculate Building Noise Reduction, NR_c. Since the Exterior Noise Level, L_o, is given, the calculated NR may be used to calculate the building's Interior Noise Level, L_{ic}. When L_{ic} is within a 5 dB safety margin of the Design Noise Level, measurements should be made to establish the Measured Interior Noise Level, L_{im}, and the Measured Exterior Noise Level, L_{om}, at the wall (assumed equal to the free field Exterior Noise Level L_o + 5 dB) in order to define the Measured Noise Reduction ($NR_m = L_{om} - L_{im} - 5$).

This chapter discusses the equipment and procedures necessary for measuring noise levels. That portion of the overall Manual procedure dealing with noise measurements is shown in Figure 9.

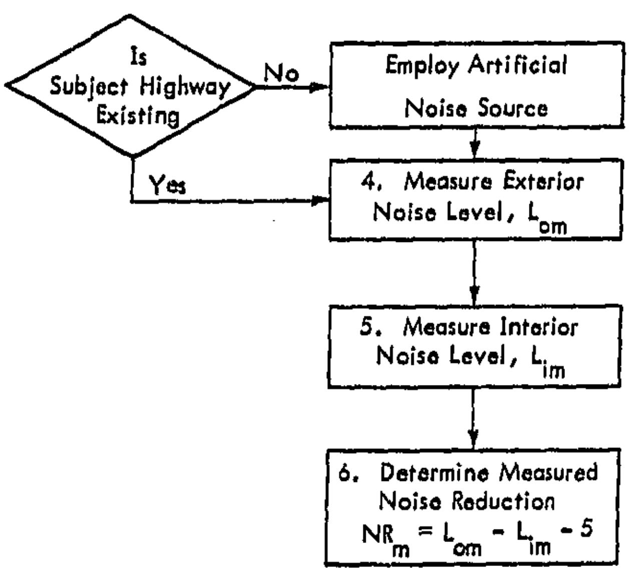


Figure 9. Elements of the Overall Manual Procedure Covered in Chapter 3. (See Appendix B for complete procedure flow diagram.)

3.2 EQUIVALENT NOISE LEVEL

One area of environmental acoustics that has received considerable attention in recent years is the development of new methods to describe the impact of highway noise on the community. Attempts to correlate noise environments with community annoyance have led to the development of several single-number noise descriptors for the assessment of community reaction. To accurately relate to peoples' reactions to noise, a descriptor should describe the fluctuating noise completely by including intensity and frequency characteristics and the variation of both with time. Furthermore, it should describe, in a single number, the known effects of noise on humans.

A descriptor that satisfies these requirements is the Equivalent Noise Level, L_{eq}, which is the constant noise level that contains the same amount of acoustical energy as the actual fluctuating level of interest over the same period of time. L_{eq} values are usually based on A-weighted noise levels. Community response to noise has been widely correlated to A-weighted L_{eq} values, and reliable methods of predicting highway noise levels expressed in L_{eq} have been developed. Procedures are given in this chapter to obtain L_{eq} values from manually-sampled noise level data that may be obtained with a hand-held sound level meter.

3.3 NOISE MEASUREMENT EQUIPMENT

There is a wide range of instrumentation available for the measurement and analysis of highway noise. Some units, such as a hand-held sound level meter (SLM), can provide simple noise level data without the necessity for laboratory data reduction. To obtain records of data representing long periods of time, it is frequently advantageous to have data recorded and analyzed in a laboratory. The highway planner, however, will seldom have available equipment more complex than the hand-held SLM. Thus, the measurement techniques given in this chapter will primarily be concerned with the use of a sound level meter.

In addition to the SLM, a calibrator, microphone windscreen, and stopwatch will be necessary to perform adequate measurements. To insure sufficient precision, the meter should be certified as a Type I or Type II sound level meter according to ANSI Standard S1.4-1971.[1] Further, the meter should be capable of measuring noise levels ranging from 35 to 100 dB. The meter and microphone should be calibrated prior to making the measurements and again when the measurements have been completed. The microphone windscreen is necessary to reduce wind noise and to protect the microphone from moisture and dust. A stopwatch or clock with a readable sweep-second hand will be required to time the meter readings.

3.4 NOISE LEVEL MEASUREMENT PROCEDURE

Specific measurement procedures will depend on whether the highway is existing. If it is still in the planning stage, then an artificial source must be used. This procedure will be discussed later in this chapter.

It is advisable to maintain a Field Data Log similar to that shown in Figure 10. All pertinent information should be entered on the log for each measurement site prior to recording data.

Field Data Log

☐ Indoor
☐ Outdoor

Location ______________________________

Prepared By ______________________ Date ______________

Equipment – Mic. Type ______________ S.N. __________

Recorder ______________ S.N. __________

Sound Level Meter ______________ S.N. __________

Calibrator ______________ S.N. __________

Weather Conditions –

Start: Time _____ Temperature _____ R.H. _____ Wind _____ Meter Cal. _____

Stop: _____ _____ _____ _____ _____

Survey Data (indicate microphone position, traffic volume, major noise sources, etc.)

____

____

____

____

____

____

____

____

____

Site Sketch

Figure 10. Field Measurement Data Log

If traffic flow is fairly constant throughout the measurement period, measurements can be taken — first outside, and then inside the building — with the same meter, since the source noise level will not have changed. A final-check measurement should be made outside to verify that conditions have not changed, however. If traffic conditions do not allow for this, simultaneous exterior and interior measurements must be taken, using a separate SLM for each location.

3.4.1 EXTERIOR MEASUREMENTS

To record exterior noise levels, use the following procedure:

1. Record weather and general data on a Data Log.
2. Turn on SLM and check batteries.
3. Select A-Scale and Slow Meter Response.
4. Calibrate SLM.
5. Install windscreen on microphone.
6. Locate microphone immediately next to — but not touching — center of exterior wall area of room to be measured.
7. Record meter indication every 10 seconds for a period of 15 minutes.

For all noise level measurements made during these procedures, the meter should be set to the "slow" response setting.

If the room of interest has more than one exterior wall, choose the one most directly facing the highway for exterior measurements. Locate the microphone or sound level meter as close as possible to the centerpoint (both horizontally and vertically) of the exterior wall area of the room as shown in Figure 11. This location should be adjusted, if required to maintain at least three feet (91 cm) between the microphone and any surfaces perpendicular to the wall such as fences, awnings, or deep window perimeters. An extendable microphone stand may be necessary to hold the microphone at this location for the required measurement duration. Hold the microphone or fix it in a stand as close to the wall surface as possible without touching it. The microphone face should be perpendicular to the wall. If a soft foam microphone windscreen is used, it may be lightly compressed

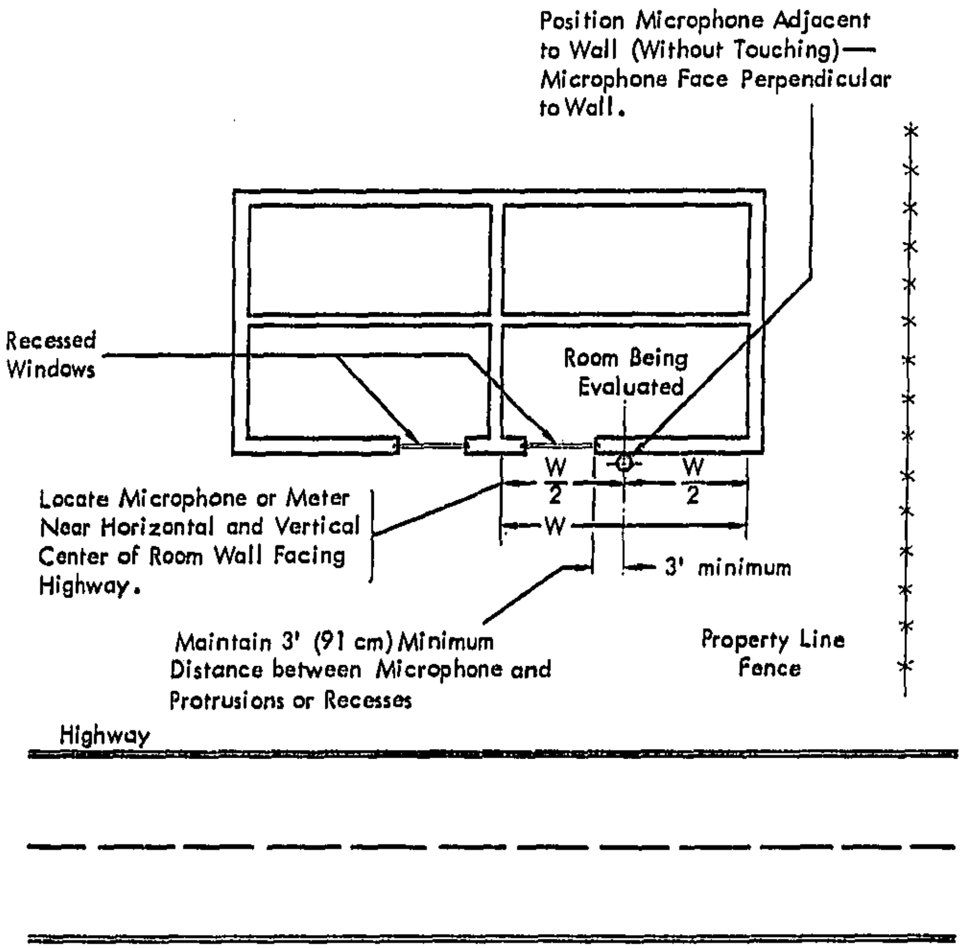


Figure 11. Location of Sound Level Meter and Microphone for Exterior Noise Level Measurements.

against the wall in positioning the microphone as closely as possible. When making measurements with a hand-held SLM, hold the meter at a comfortable arm's length away from the body, with the microphone positioned as above. Never stand between the meter microphone and the noise source.

Because weather and atmospheric conditions can affect noise measurements, data should not be recorded under conditions of precipitation, ground fog, or when wind velocity exceeds 12 mph (19 km/hr). Additionally, measurements should not be made when the highway is covered with rain, snow, or ice.

During the actual measurement, the meter indication should be noted every 10 seconds. These values should be recorded as a check mark in the appropriate 2 dB-interval row on a Field Measurement Data Sheet, such as that shown in Figure 12. Even-numbered readings should be recorded in the higher row; for example, if the meter indicates a reading of exactly 62 dB, a check should be made in the row labeled 62-4. This measurement sampling should be continued for at least 15 minutes at each location. If the readings seem to fluctuate quite a bit, or if traffic flow is moderate-to-light (less than 1200 vehicles per hour total), the measurement sampling period should be increased to 30 minutes.

3.4.2 INTERIOR MEASUREMENTS

To record interior noise levels, use the following procedure:

1. Turn on SLM and check batteries.
2. Select A-Scale and Slow Meter Response.
3. Calibrate SLM.
4. Locate microphone near the center of the room.
5. Position all windows, doors, and vents as they would be normally and note in the Field Data Log any that are left open.
6. Turn off all interior noise sources such as radios and appliances.
7. Record meter indication every 10 seconds for a period of 15 minutes.

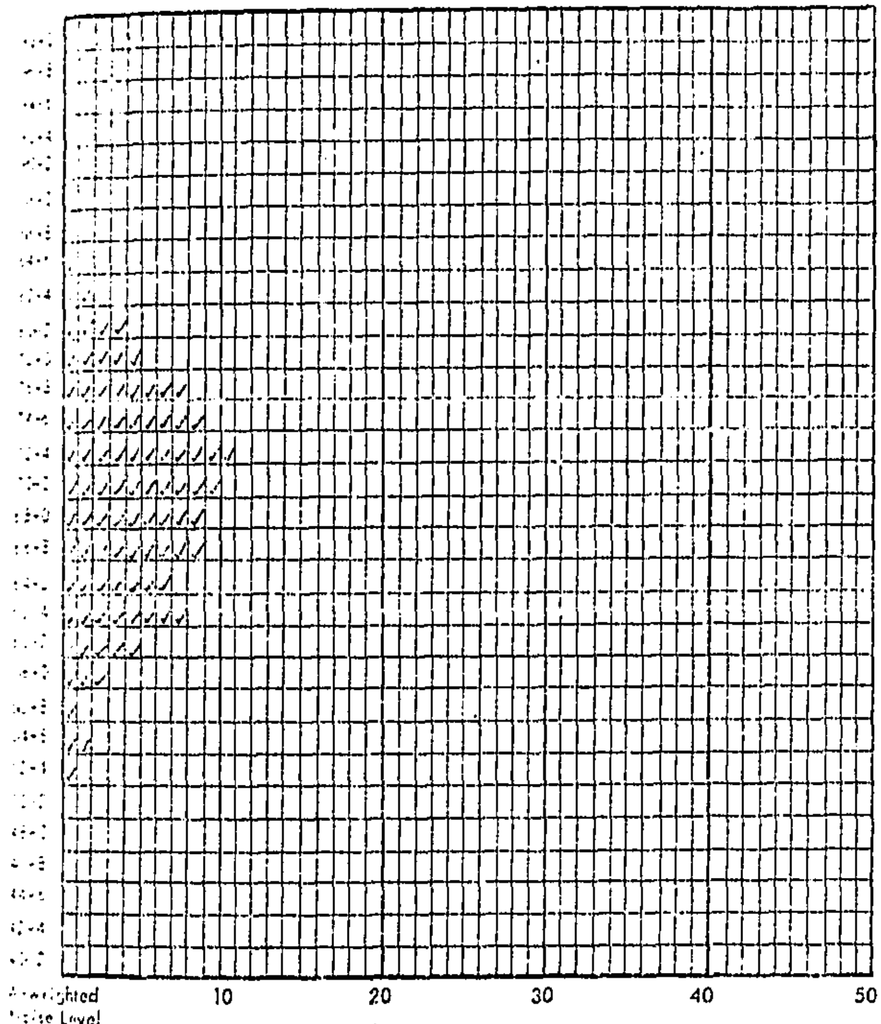


Figure 12. Field Measurement Data Sheet

When making interior measurements, the noise level within the room will normally vary slightly between different locations due to the acoustical characteristics of the walls and room interior. To select a measurement location, quickly survey the room interior with the SLM. Identify a position at about shoulder-height, away from large reflecting surfaces, where the sound level approximately represents the average for the entire room. This point will normally be near the center of the room.

3.4.3 L_{eq} COMPUTATION PROCEDURE

Once the exterior and interior noise levels have been measured by the sampling technique discussed in Sections 3.4.1 and 3.4.2, the next step is to compute an L_{eq} value for both exterior and interior noise. The L_{eq} value may be computed with the use of a calculator, or the computation may be carried out manually.

If a calculator is available, the L_{eq} of a number of discrete A-weighted noise levels for a specified time period is given by:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^{n} \text{antilog}\ (L_i/10)\right]$$

where L_i is the instantaneous noise level for sample i and n is the number of samples in the sampling time period.

Example 5: Find the L_{eq} for the 95 noise samples recorded in Figure 12.

Solution: Taking the median integral value of each 2 dB range to be the values for L_i, we have:

L_i	Number of Samples	Antilog $L_i/10$
85	1	316.2×10^6
83	2	199.5
81	4	125.9
79	5	79.4
77	8	50.1
75	9	31.6
73	11	20.0
71	10	12.6
69	9	7.9
67	9	5.0
65	7	3.2
63	8	2.0
61	5	1.3
59	3	0.8
57	1	0.5
55	2	0.3
53	1	0.2

$$L_{eq} = 10 \log_{10} \Big\{ \Big[316.2 + 2(199.5) + 4(125.9) + 5(79.4) + 8(50.1) + 9(31.6) + 11(20.0) + 10(12.6) + 9(7.9) + 9(5.0) + 7(3.2) + 8(2.0) + 5(1.3) + 3(0.8) + 0.5 + 2(0.3) + 0.2 \Big] \times 10^6/95 \Big] \Big\}$$

$$L_{eq} = 10 \log_{10} 29.6 \times 10^6 = 75 \text{ dB}$$

If a calculator is not available, the worksheet illustrated in Figure 13 may be used to determine L_{eq} values manually. Use the following procedure to complete this worksheet:

A	B		C		D
2dB Range	No. of Counts		Relative Noise Energy		Total Relative Noise Energy
98-100	____	x	79,400	=	____
96-98	____	x	50,100	=	____
94-96	____	x	31,600	=	____
92-94	____	x	20,000	=	____
90-92	____	x	12,600	=	____
88-90	____	x	7,940	=	____
86-88	____	x	5,010	=	____
84-86	____	x	3,160	=	____
82-84	____	x	2,000	=	____
80-82	____	x	1,260	=	____
78-80	____	x	794	=	____
76-78	____	x	501	=	____
74-76	____	x	316	=	____
72-74	____	x	200	=	____
70-72	____	x	126	=	____
68-70	____	x	79.4	=	____
66-68	____	x	50.1	=	____
64-66	____	x	31.6	=	____
62-64	____	x	20.0	=	____
60-62	____	x	12.6	=	____
58-60	____	x	7.94	=	____
56-58	____	x	5.01	=	____
54-56	____	x	3.16	=	____
52-54	____	x	2.00	=	____
50-52	____	x	1.26	=	____
48-50	____	x	.794	=	____
46-48	____	x	.501	=	____
44-46	____	x	.316	=	____
42-44	____	x	.200	=	____
40-42	____	x	.126	=	____
Sum B = ____			Sum D =		____

L_{eq} Table

L_{eq}	Q	L_{eq}	Q
100	100,000	69	74.9
99	79,400	68	63.1
98	63,100	67	50.1
97	50,100	66	39.3
96	39,000	65	31.6
95	31,600	64	25.1
94	25,100	63	20.0
93	20,000	62	15.8
92	15,800	61	12.6
91	12,600	60	10.0
90	10,000	59	7.94
89	7,940	58	6.31
88	6,310	57	5.01
87	5,010	56	3.98
86	3,980	55	3.16
85	3,160	54	7.51
84	2,510	53	2.00
83	2,000	52	1.58
82	1,580	51	1.26
81	1,260	50	1.00
80	1,000	49	.794
79	794	48	.631
78	631	47	.501
77	501	46	.398
76	398	45	.316
75	316	44	.251
74	251	43	.200
73	200	42	.158
72	158	41	.128
71	126	40	.100
70	100		

$$Q = \frac{\text{Sum D}}{\text{Sum B}} = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

L_{eq} = ______ dB

Figure 13. Worksheet for Manual L_{eq} Calculation

1. Enter the total number of counts from the Field Measurement Data Sheet for each 2 dB range into the corresponding line of Column B on the worksheet.

2. Add the total number of counts and record the sum at the bottom of Column B.

3. For each 2 dB range, multiply the number of counts in Column B by the Relative Noise Energy in Column C and enter the products in Column D.

4. Add the total Relative Noise Energy values in Column D and record the sum at the bottom of the column.

5. Divide the sum from Column D by the sum from Column B as indicated to obtain the value Q.

6. From the L_{eq} Table, find the value in Column Q that is closest to Q and read the corresponding L_{eq} in the adjacent column. Record this L_{eq} value at the bottom of the form.

Example 6: Repeat Example 5 for the data recorded in Figure 12 using the manual L_{eq} computation worksheet.

Solution: The recorded data extends from the 52–54 dB range to the 84–86 dB range. The number of counts in these and intervening ranges are recorded as shown on the following page. The products for Total Relative Noise Energy may be rounded off to the nearest integer. Q is 296, which is nearest the number 316, in the Q column of the table. The corresponding L_{eq} value is 75 dB.

Solution To Example 6

A	B		C		D
2dB Range	No. of Counts		Relative Noise Energy		Total Relative Noise Energy
98-100		x	79,400	=	
96-98		x	50,100	=	
94-96		x	31,600	=	
92-94		x	20,000	=	
90-92		x	12,600	=	
88-90		x	7,940	=	
86-88		x	5,010	=	
84-86	1	x	3,160	=	3160
82-84	2	x	2,000	=	4000
80-82	4	x	1,260	=	5040
78-80	5	x	794	=	3970
76-78	8	x	501	=	4008
74-76	9	x	316	=	2844
72-74	11	x	200	=	2200
70-72	10	x	126	=	1260
68-70	9	x	79.4	=	715
66-68	9	x	50.1	=	451
64-66	7	x	31.6	=	221
62-64	8	x	20.0	=	160
60-62	5	x	12.6	=	63
58-60	3	x	7.94	=	24
56-58	1	x	5.01	=	5
54-56	2	x	3.16	=	6
52-54	1	x	2.00	=	2
50-52		x	1.26	=	
48-50		x	.794	=	
46-48		x	.501	=	
44-46		x	.316	=	
42-44		x	.200	=	
40-42		x	.126	=	
Sum B = 95			Sum D =		28,129

L_{eq} Table

L_{eq}	Q	L_{eq}	Q
100	100,000	69	74.9
99	79,400	68	63.1
98	63,100	67	50.1
97	50,100	66	39.3
96	39,000	65	31.6
95	31,600	64	25.1
94	25,100	63	20.0
93	20,000	62	15.8
92	15,800	61	12.6
91	12,600	60	10.0
90	10,000	59	7.94
89	7,940	58	6.31
88	6,310	57	5.01
87	5,010	56	3.98
86	3,980	55	3.16
85	3,160	54	7.51
84	2,510	53	2.00
83	2,000	52	1.58
82	1,580	51	1.26
81	1,260	50	1.00
80	1,000	49	.794
79	794	48	.631
78	631	47	.501
77	501	46	.398
76	398	45	.316
75	316	44	.251
74	251	43	.200
73	200	42	.158
72	158	41	.128
71	126	40	.100
70	100		

$$Q = \frac{\text{Sum D}}{\text{Sum B}} = \frac{28,129}{95} = 296.1$$

L_{eq} = 75 db

3.4.4 USE OF AN ARTIFICIAL NOISE SOURCE

The procedures described so far in this chapter will not be applicable when a yet-to-be-constructed highway is being evaluated, or when the traffic on an existing highway does not produce noise levels that exceed the ambient level by 10 dB. Under these circumstances, some type of artificial source of noise will have to be employed for Noise Reduction measurements. Two types of artificial noise sources will be considered in this section — the use of a diesel truck (or motorcycle), and the use of a loudspeaker system to play back tape-recorded highway noise.

If a truck is selected as an artificial source, it may either be run in neutral at a constant engine speed for separate exterior and interior measurements, or it may be driven past the building. If a moving source is used, simultaneous exterior and interior measurements will be necessary.

If an artificial noise source is used to determine Noise Reduction, the levels measured from the operating source must be at least 10 dB above the ambient noise level without the artificial source. This applies to both interior and exterior measurements.

If a loudspeaker system is desired, the required equipment can usually be rented from electronics or instrumentation dealers. The system will consist of a tape-deck, a power amplifier with a minimum power rating of 30 watts, and the loudspeaker itself, as illustrated in Figure 14. The loudspeaker should have a minimum horizontal dispersion of 60° as indicated in the illustration, and a relatively good frequency response between 50 Hz and 5 kHz. As a guide, a loudspeaker system capable of generating a sound pressure level (SPL) of 100 dB at 50 feet should be adequate. However, in particularly noisy areas, more powerful systems may be required.

The loudspeaker system must be capable of producing a noise level 10 dB above ambient, both inside and outside the building being evaluated. If the source has insufficient power to do this, it may be moved closer to the building, but no closer than one building width away, as indicated in Figure 14. A source that cannot generate a sufficient level at this minimum distance is inadequate and a louder one must be used.

Utilize the following procedure when measuring Noise Reduction with an artificial source:

1. Locate the noise source, as shown in Figure 15.
2. Measure the average room interior ambient noise level with all interior sources (appliances, radios, etc.) and the artificial highway source off, and with all windows, vents, and outside doors in their normally-open or normally-closed positions.
3. Turn on the artificial noise source and measure the resulting interior noise level in the building.
4. If this noise level is not at least 10 dB above the interior ambient level, move the source toward the building until the desired level is obtained. Do not move the source closer than one building width. Repeat this step for exterior noise.
5. Make interior and exterior measurements with the source at Position 1 and Position 2, as indicated in Figure 15. If the NR values measured at these two locations ($NR_m = L_{om} - L_{im} - 5$) are within 5 dB of each other, then average the two values to determine the Noise Reduction for the building. If the two values are not within 5 dB, then repeat the measurements at Positions 3 through 8 in the sequence shown in Figure 15 until the number of measurement positions is equal to one-half of the difference between the maximum and the minimum NR_m.

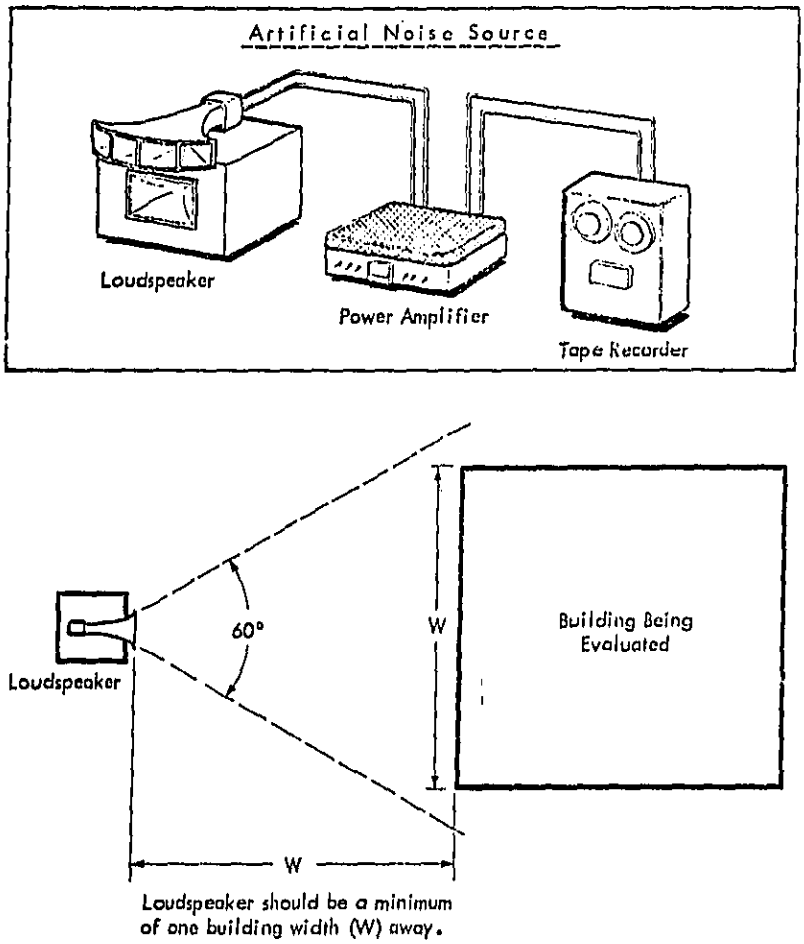


Figure 14. Illustration of Correct Placement of Artificial Noise Source

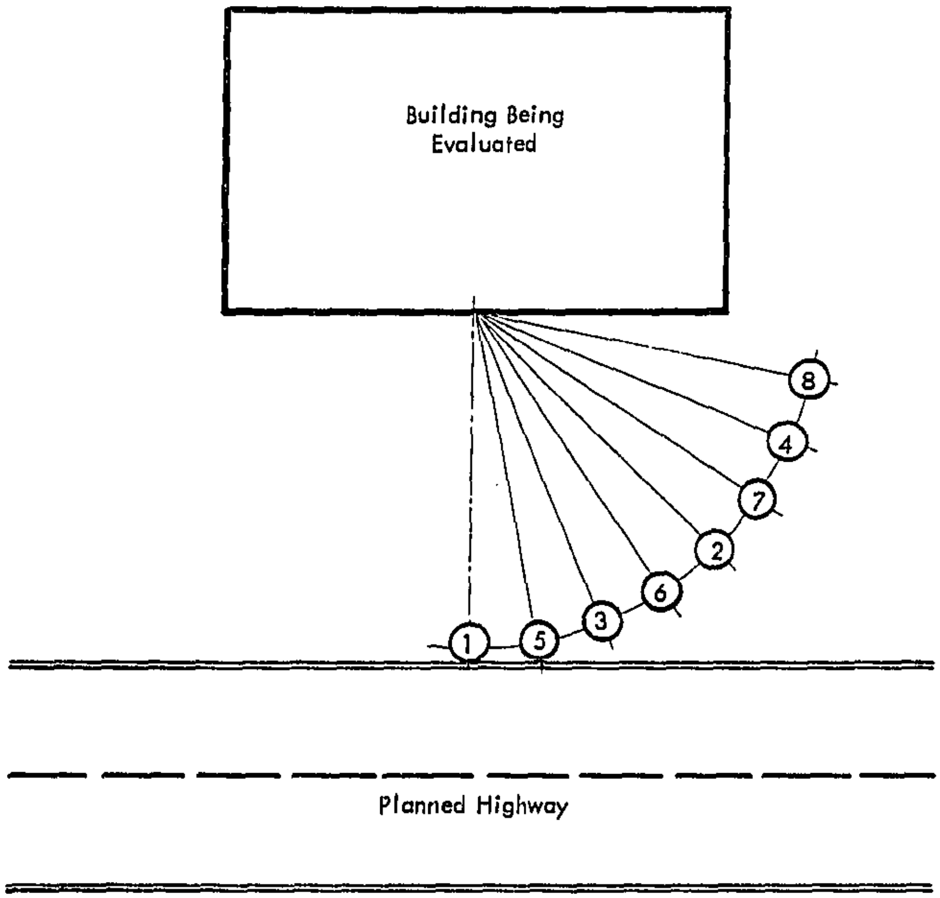


Figure 15. Measurement Locations for an Artificial Noise Source

CHAPTER 4

VENTILATION DESIGN PROCEDURES

4.1 INTRODUCTION

In some situations it may be necessary to close the windows of buildings to provide sufficient Noise Reduction. With the loss of natural ventilation, mechanical ventilation must be provided to meet interior ventilation requirements. This additional mechanical ventilation then becomes a residential energy consumption directly attributable to highway noise, and in some cases will add its own noise to that produced by the highway. Some building modifications, however, can provide increased Noise Reduction and also result in an energy savings. This chapter will discuss general ventilation requirements as well as energy consumption and noise levels due to ventilation equipment. Additionally, energy savings that can result from some building modifications will be discussed. The procedures discussed in this chapter comprise Box 11 of the flow diagram shown in Appendix B.

4.2 VENTILATION REQUIREMENTS

Minimum residential ventilation requirements are often specified in local building codes for purposes of health and for the provision of draft air for small combustion appliances. Accepted general ventilating practice suggested by the American Society of Heating, Refrigeration, and Air Conditioning Engineers calls for a minimum of one air change per hour and can be as much as 40 cubic feet (1.13 cubic meters) per minute per person in areas of heavy smoking.[3] This ventilation is provided either by infiltration of outside air through small cracks, natural ventilation through open windows and doors or by mechanical ventilating systems. A rule of thumb in the air conditioning industry is that a one ton air conditioner (12,000 BTU/hr or 3024 Kg-cal/hr) will adequately cool and ventilate 450 square feet of floor space.[23] Window or through-the-wall air conditioning units are available with capacities up to 3 tons, which would ventilate up to approximately 1350 square feet of floor area. For ventilation of areas larger than this, central or unitary type air conditioning units must be installed.

4.3 VENTILATION SYSTEM NOISE LEVELS

In Chapter 2 it was determined that the first step in increasing Noise Reduction in many cases would be the closing of windows and sealing of infiltration cracks. Eliminating infiltration of outside air and natural ventilation through open windows, however, necessitates the use of mechanical ventilation equipment that introduces additional noise. This must be considered when determining building modifications necessary to meet interior Design Noise Levels. Central air conditioners, such as unitary roof-mounted or stand-alone outdoor types, operate through interior ducting and can cause A-weighted interior noise levels as high as 60 dB a few feet from duct outlet diffusers. Measurements have shown that the much simpler window type air conditioner, which will provide adequate ventilation for a limited number of rooms, can generate interior noise levels as high as 62 dB. Table 12 indicates that the noise level introduced by a new ventilating system must be at least 10 dB below the non-ventilated level in order not to cause a significant increase of total noise in the building.

Table 12

Table for Combining Noise Levels in 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

Guidance for the selection of quiet ventilation units can be found in a single number rating called the Sound Rating Number (SRN) utilized by the manufacturers of ventilating and air conditioning equipment.[4] SRN values, which are published for most available air conditioner models, are a form of sound power level generated at the

.nit which may be related to noise levels the units will produce in typical installations. ~ese noise levels can be greatly modified by the unit installation, however. The most -portant consideration in providing quiet new ventilating or air conditioning units is :ention to installation details as follows:[5]

- In general, the basic central unit should be installed as far away from the interior space as possible and the ventilation air should be ducted to the desired location.
- Supply and return air ducts should be lined with fiberglass insulation to reduce the noise generated by fans. This treatment should be applied to the entire length of large return air ducts and at least 5 feet (1.5 m) of the supply duct, preferably on the discharge end of the duct.
- Units installed on the roof of a building should be mounted on concrete slabs with stable, open-coil steel spring isolation mounts between the unit and the slab.
- In central closet installations, open-cell neoprene rubber pads should be used to isolate the unit from the floor and nearby walls. Flexible boot-type connectors should be used on supply and return ducts.
- Fans should be properly sized to operate near peak efficiency for any particular installation. In general, the blowers should be large diameter, low-speed, belt-driven types.
- Window type air conditioners should be mounted on open-cell neoprene rubber pads at least 1/2 inch (1.27 cm) thick and preferably 1 inch (2.54 cm) thick. Additionally, neoprene rubber should be used to gasket the entire perimeter of the unit. Although the installation of fiberglass sound absorbing baffles inside these units is sometimes helpful, it is usually preferable to purchase units that feature large-diameter low-speed blowers, streamlined air-flow passages, and motor/compressor units that have factory designed vibration mounts.

4.4 ENERGY CONSIDERATIONS

The elimination of natural ventilation to increase Noise Reduction usually results in increased energy consumption due to operation of ventilation equipment. However, there may be an overall savings in the form of less heat loss when infiltration is eliminated or wall/window systems are modified. These two mechanisms may be summarized as follows for infiltration heat loss and conductive heat loss:

$$q_i = CV$$

$$q_c = UA\Delta T$$

where q_i and q_c are the infiltration heat loss and conductive heat loss respectively in Btu/hr, C is an infiltration constant, U is a constant called thermal transmittance, V is building volume, A is wall area and ΔT is the difference between the inside design temperature and the average outside temperature. The infiltration constant C depends on ΔT, so that ΔT must be known in order to calculate either q_i or q_c.

Approximate ΔT values may be determined for a given location from the concept of degree-days for the same location. Degree-days are based on the difference between 65°F (18°C) and the average outdoor air temperature for that day. The base temperature of 65°F (18°C) is used for residential buildings maintained in the temperature range 68° to 70°F (20° to 22°C) to account for miscellaneous heat sources in the building such as people, lights and appliances. Yearly degree-days are tabulated for metropolitan areas in Table 13. These yearly degree-day values divided by 365 will give the average daily temperature difference, ΔT, that may be used in calculations to determine yearly heat loss values.

Table 13

Yearly Degree-Days For Various Cities Based on 65°F, (18°C)[6]

City	Yearly Degree-Days
Atlanta, GA	2983
Austin, TX	1711
Baltimore, MD	4654
Boston, MA	5634
Buffalo, NY	7062
Chicago, IL	6155
Cincinnati, OH	5265
Cleveland, OH	6195
Dallas, TX	2363
Denver, CO	6283
Detroit, MI	6516
Houston, TX	1676
Kansas City, KS	4711
Los Angeles, CA	1799
Miami, FL	214
Milwaukee, WI	7635
Minneapolis, MN	8382
New York, NY	4871
Philadelphia, PA	5101
Phoenix, AZ	1765
Pittsburgh, PA	5291
Rochester, NY	6748
St. Louis, MO	4900
San Francisco, CA	3012
Seattle, WA	5145
Washington, DC	4224

Table 14 lists the infiltration constants, C, for typical residential buildings for several ranges of temperature differences, ΔT. For temperature differences other than those given, interpolate between the values of the infiltration constants.

Table 14

Infiltration Constant, C, for Typical Residential Buildings [7]

Infiltration Constant	Temperature Difference, ΔT °F		
	10	25	50
C	.23	.57	1.13

Example 7: Determine the annual energy savings in Btu due to the elimination of infiltration by sealing all cracks and leaks in a 2000-square-foot house with 8-foot ceilings located in Minneapolis.

Solution: From Table 13 it is seen that the number of annual Degree-Days is 8382 for Minneapolis. Therefore, the temperature difference, ΔT, is 8382/365 = 23°F. The building volume is 2000 ft^2 x 8 ft = 16,000 ft^3. For a ΔT of 23°F, the infiltration constant is approximately .57 (from Table 14) so q_i = .57 x 16,000 = 9120 Btu/hr. The annual energy savings is therefore 9120 x 24 x 365 = 7.99 x 10^7 Btu/yr. (2 x 10^7 kg-cal/yr).

(Note that the degree-day concept is based on Fahrenheit degrees. To calculate the energy savings in metric units convert the answer in Btu/year to kilogram-calories/year by multiplying by 0.252.)

These calculations should be carried out on Worksheet No. 3, a portion of which is reproduced as follows: (A complete worksheet is included at the end of the manual.)

WORKSHEET FOR FUEL SAVINGS DUE TO ACOUSTICAL MODIFICATIONS

Local Yearly Degree Days (Table 13)		Temperature Difference Δt		Infiltration Constant, C (Table 14)
8382	÷ 365 =	23	⇨	0.57

Infiltration Constant, C (From Above)		Building Volume		Hours Per Year		Heat Savings
0.57	×	16,000 ft^3	×	24 × 365	=	7.99×10^7 Btu/Yr.

7.99×10^7 Btu/Yr. × .252 = 2×10^7 kg-cal/Yr.

Noise Reduction modifications beyond the sealing of infiltration cracks usually involve modifications to windows or to the walls of the building. These modifications usually affect the conductive heat loss by decreasing the thermal transmittance, thereby providing an energy savings.

The relationship presented above for conductive heat loss is for the loss through a single element of area A. If more than a single element is modified, the relationship must be applied to each element separately and the decreases in heat flow through each element then added to determine the total heat savings.

Thermal transmittance values (U-Factors) for commonly used basic constructions are given in Table 15. The U-Factors for the stud-work constructions of Area 1 that range from .59 to .23 will be decreased if fibrous absorption is added to the stud-space. The effect of added absorption on the wall's U-Factor may be determined from Table 16. To obtain a U-Factor for walls with stud-space absorption, first find the basic U-Factor in Table 15, then read the adjusted U-Factor in the appropriate column of Table 16.

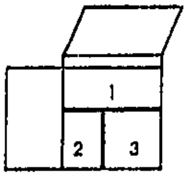
Table 15

Coefficients of thermal Transmittance, (U-Factors) for Common Constructions In Btu/hr ft^2 ^oF (Multiply by 4.9 to Obtain Values in kg-cal/hr m^2 ^oC)

Note: Approximate Metric thicknesses in centimeters may be obtained by multiplying the nominal English-inch units by 2.54

EXTERIORS	INTERIORS	1 Gypsumboard - 1/2" to 5/8"	2 3/8" Gyp Lath on Plaster - 1/6" to 1/2"	3 1/2" Soundboard on Gypsumboard - 3/8" to 1/2"	4 Plaster - 1/2" to 7/8"	5 Plywood - 1/2"	6* Plywood Paneling - 1/4"	7* Hardboard Paneling - 1/4"	8 Exposed Solid Wall
Alum. Siding on 1/2" Wood	A	.34	.34	.24	.34	.32	.31	.30	--
7/8" Stucco	B	.39	.39	.27	.40	.37	.35	.35	--
7/8" Stucco on 1/2" Wood	C	.32	.31	.23	.32	.30	.29	.28	--
Wood Siding - 1/2" to 3/4"	D	.33	.33	.24	.33	.31	.30	.29	--
4-1/2" Brick Veneer	E	.36	.35	.25	.55	.50	.59	.57	--
9" Brick	F	.31	.31	.22	.43	.40	.46	.44	.53
4" Concrete	G	.32	.33	.23	.50	.43	.50	.49	.60
6" Concrete	H	.29	.29	.21	.40	.37	.42	.41	.48
6" Hollow Concrete Block	I	.27	.27	.20	.36	.37	.38	.37	.43
8" Hollow Concrete Block	J	.25	.25	.19	.33	.31	.34	.34	.38
6" Block w/1/2" Stucco	K	.26	.26	.20	.34	.33	.36	.36	.41
8" Block w/1/2" Stucco	L	.24	.25	.19	.32	.30	.33	.32	.37

*Both 1/4" Paneling Interiors (columns 6 and 7) are mounted on 1/2" Gypsumboard only for Exteriors A through E.



LEGEND

Area 1: Stud-work Constructions -- All conventional 2x4 wood studs on 16-inch centers with no insulation in stud spaces.

Area 2: Solid Wall with Furred Interior Surfaces — All interior surfaces mounted on 3/4-inch furring strips on 16-inch centers.

Area 3: Solid Wall with Glued Interior Surfaces — All interior surfaces glued directly to the solid wall.

Table 16

Adjusted U-Factors in Btu/hr ft^2 °F for Walls With Stud-Space Absorption[9]

U-Factor With No Absorption*	New U-Factor with Absorption*	
	2" to 2.5" (5.08 to 6.35 cm)	3" to 4" (7.62 to 10.16 cm)
.60	.12	.09
.50	.12	.09
.40	.11	.09
.30	.10	.08
.20	.09	.07

*Multiply U values by 4.9 to obtain values in kg-cal/hr m^2 °C

Thermal transmittance values (U-Factors) for commonly used windows are given in Table 17 and values for commonly used doors are given in Table 18.

Table 17

Values of Thermal Transmittance (U-Factor) in Btu/hr ft^2 °F for Commonly Used Windows[10]

Window	U-Factor*
Single Pane Glass	1.13
Double Pane (1/2" or 1.3 cm air space)	.58
Storm Windows	.56

*Multiply U values by 4.9 to obtain values in kg-cal/hr m^2 °C

Table 18

Values of Thermal Transmittance (U-Factor) in Btu/hr ft^2 °F For Commonly Used Solid Core Exterior Doors[11]

Door Thickness	U-Factor*		
	No Storm Door	With Storm Doors	
		Wood with Window	Metal with Window
1" (2.54 cm)	0.64	0.30	0.39
1.25" (3.18 cm)	0.55	0.28	0.34
1.5" (3.81 cm)	0.49	0.27	0.33
2" (5.08 cm)	0.43	0.24	0.29

* Multiply U values by 4.9 to obtain values in kg-cal/hr m^2 °C

The heat flow through an area A may be determined from the relation $q_c = UA\Delta T$. Note that for the same area, A and same temperature difference ΔT, the change in heat flow due to a modified wall element may be determined from the relation: $\Delta q = (U_2 - U_1) A \Delta T$ where U_1 and U_2 are the U-Factors before and after the modification.

Example 8: On the Minneapolis house of Example 7, it has been determined that the wall facing a planned highway will require the following modifications:

1. The addition of 4" (10.16 cm) of stud-space absorption.

2. Replacement of two single pane 3' x 5' (.9 x 1.5 m) windows with double pane (.5" or 1.3 cm air space) windows of the same size.

The wall construction is 4.5" (11.43 cm) brick veneer with a 3/4" (1.9 cm) plaster interior finish. The wall is 35' (10.7 m) long and 8' (2.4 m) high. Determine the annual heat energy that will be saved due to the acoustical modifications.

Solution: The U-Factor for the wall with no absorption is .55 (from Table 15). The effect of the added absorption will be to decrease the wall's U-Factor to .09 (from Table 16). The change in U-Factor, (U_2-U_1), for the wall is .55 - .09 = .46.

The U-Factor for the original single pane window is 1.13 (from Table 17). The U-Factor of the new double pane windows will be .58. The change in U-Factor (U_2-U_1), for the windows is 1.13 - .58 = .55.

The total window area is 2 x 3' x 5' = 30 ft^2 (2.8 m^2). The wall area less the windows is 8' x 35' - 30 = 250 ft^2 (23 m^2). The yearly degree-days for Minneapolis is found in Table 13 to be 8382. Therefore the temperature difference, ΔT, is 8382/365 = 23°F.

Therefore the change in heat flow through the windows will be .55 x 30 x 23 = 380 Btu/hr, and the change in heat flow through the wall will be .46 x 250 x 23 = 2645 Btu/hr.

The total heat flow change due to the modifications will be 380 + 2645 = 3025 Btu/hr. To find the heat loss change for a full year, multiply the heat flow in Btu/hr by 8,760 (24 x 365 = 8,760). The total annual heat energy saved will be 3025 x 8,760 = 2.65 x 10^7 Btu/yr (6.68 x 10^6 kg - cal/yr).

(Note that this calculation is based on degree-days for Fahrenheit degrees. To calculate the energy savings in metric units, convert the answer in Btu/yr to kilogram-calories/year by multiplying by 0.252.)

These calculations should be carried out on Worksheet No. 3 a portion of which is reproduced as follows: (A complete worksheet is included at the end of the manual.)

Energy Savings Due to Wall/Window/Door Modifications

Modified Wall Element	Original U-Factor (From Tables)		Modified U-Factor (From Tables)		U-Factor Change		Wall or Element Area		Local Yearly Degree-Days (From Table 13)		Heat Savings Btu/yr
WINDOWS	1.13	−	0.58	=	0.55	×	30 ft^2	×	8382	× 24 =	3.32×10^6
WALL	0.55	−	0.09	=	0.46	×	250 ft^2	×	8382	× 24 =	2.31×10^7
										Total =	2.65×10^7

2.65×10^7 Btu/yr × .252 = 6.68×10^6 kg-cal/yr

To convert the heat energy savings in Btu (kg-cal) calculated above, to actual dollars, the amount of heating fuel saved must first be determined. Table 19 gives typical characteristics of commonly used heating fuels.

Table 19

Characteristics of Heating Fuels [12, 13, 14]

Fuel / Factor	Coal [1]	Oil [2]	Gas [3]
Typical Heating Value	13,000 Btu/lb	140,000 Btu/gal	1,025 Btu/ft^3
Typical Furnace Efficiency Factor	0.6	0.7	0.8
Heating Value Efficiency Product	7,800 Btu/lb	98,000 Btu/gal	820 Btu/ft^3

[1] Multiply values in Btu/lb by .56 to obtain values in kg-cal/kg.

[2] Multiply values in Btu/gal by .067 to obtain values in kg-cal/liter.

[3] Multiply values in Btu/ft^3 by 8.9 to obtain values in kg-cal/m^3.

The total annual heat energy savings in Btu/yr (kg-cal/yr) when multiplied by the Heating Value Efficiency Product for the appropriate fuel (as given in Table 19) will result in the total annual fuel saved in pounds, gallons or cubic feet (kilograms, liters or cubic meters).

The savings in annual heat energy due to Noise Reduction modifications should be compared with the increased energy consumed by ventilation equipment if mechanical ventilation is made necessary by implementation of Noise Reduction modifications.

Ventilation equipment energy consumption may be determined from the following relationship:

$$HP = 2\,(cfm)\,(TP)/6356$$

where HP is the required ventilation fan horsepower, cfm is the air flow rate and TP is the total pressure head in inches of water.[15,16]

[redacted] then the air flow rate in ft^3/minute may be determined by dividing the volume of the ventilated space (in ft^3) by 60. Typical residential duct pressure may be assumed to be .25 inches of water. Hence the ventilation fan power is given by:

$$\text{Power} = \frac{2(V/60)\,(.25)}{6356}$$

The ventilation fan power may be converted to kilowatts (kw) by multiplying by the factor .746. [redacted] the rest of the year, the heating system will supply ventilation air), the number of hours in a 6-month period may be multiplied by the fan power in kw to obtain kilowatt-hours. The result is as follows:

$$\text{Energy in kwh} = \frac{2\,(V/60)\,(.25)}{6356} \times .746 \times 4380 = \frac{V}{233}$$

Therefore, the required energy in kwh may be determined simply by dividing the volume of the ventilated space, V in ft^3, by the factor 233. To determine the required energy in kilogram-calories, multiply the value in kilowatt-hours by 860.5 or simply divide the volume of the ventilated space, V, in m^3 by the factor .00766. These relationships may be summarized as follows:

<u>Ventilation Fan Energy Requirements</u>

Volume of Space in $ft^3/233$ = Required kilowatt-hours

Volume of Space in $m^3/.00766$ = Required kilogram-calories

Example 9: Determine the total amount of heating fuel that will be saved when the Noise Reduction modifications of Example 7 and 8 are implemented. Assume that fuel oil is the local fuel. Compare this with the increased energy consumed for ventilation if the double-pane windows are non-operable. Assume that ventilation is required for 6 months out of the year.

Solution: From example 8, the heat energy saved due to decreased conductive heat loss is 2.65×10^7 Btu/yr (6.68×10^6 kg-cal/yr). From Example 7, the heat energy saved due to the elimination of infiltration is 7.99×10^7 Btu/yr (2.01×10^7 kg-cal/yr). The total energy saved is $2.65 \times 10^7 + 7.99 \times 10^7 = 1.06 \times 10^8$ Btu/yr (2.68×10^7 kg-cal/yr).

From Table 19, fuel oil has a Heating Value Efficiency Product of 98,000 Btu/gal (6,566 kg-cal/liter). Therefore the amount of fuel oil that will be saved is:

$$\frac{1.06 \times 10^8 \text{ Btu/yr}}{98,000 \text{ Btu/gal}} = 1086 \text{ gal/yr } (4116 \text{ liters/yr}).$$

The volume of the building is 16,000 ft^3 (453.1 m^3) so the energy required annually for ventilation will be:

$$\frac{16{,}000\ ft^3}{233} = 68.7\ kwh/yr$$

or

$$\frac{453.1\ m^3}{.00766} = 59{,}150 \quad kg\text{-}cal/yr$$

Therefore, 1,086 gallons of fuel oil will be saved every year and an extra 68.7 kwh will be consumed. The procedures of Chapter 5 may be used to determine the actual dollar costs of this energy.

These calculations should be carried out on Worksheet No. 3 a portion of which is reproduced as follows: (A complete worksheet is included at the end of the manual.)

Fuel Savings Due to Noise Reduction Modifications

Fuel (circle one): Coal (lb)
Oil (gal)
Gas (ft^3)

Heat Energy Savings		Heating Value Efficiency Product		Fuel Saved
1.06×10^8 Btu/yr	÷	98,000	=	1086 lb / gal / ft^3 per yr

______ lb x .454 = ______ kg

1086 gal x 3.79 = 4116 liters

______ ft^3 x .0283 = ______ m^3

Added Ventilation Energy

Building Volume				Energy Required
16,000 ft^3	÷	233	=	68.7 kwh per year

68.7 kwh x 860.5 = 5.91×10^4 kg-cal

CHAPTER 5

COST ESTIMATING PROCEDURES

5.1 INTRODUCTION

The modification of an existing building to reduce interior noise may be carried out in several different ways with the same end result. To be able to select the most cost-effective alternative, data on noise reduction benefits and costs for each alternative must be known. The noise reduction provided by various alternatives may be determined using the procedures of Chapter 2. It is the purpose of this chapter to develop a methodology for predicting meaningful costs for each alternative.

The most meaningful basis for quantitatively analyzing alternative building modifications is to define a single number in constant dollars for the combined costs of each alternative that includes the time value of money.

Costs incurred immediately are more significant than costs incurred in later years because of interest, which is the cost involved in the use of money. Interest must be considered on all funds in use, since the selection of one alternative necessarily commits money which otherwise could be invested in another opportunity. Some method must therefore be used to adjust cost figures on the basis of the year in which they occur. The process we shall use in this manual is referred to as <u>discounting</u> with a representative discount rate of 10 percent. We will primarily be concerned with Initial Investment Costs (IC) which are those immediate costs necessary to effect an alternative and Replacement Costs (RC) which occur each time the original modification must be replaced.

5.2 PRESENT VALUE CALCULATIONS

The current value of money is called its Present Value (PV). Present value is the sum of anticipated future cash outflows (or inflows) discounted back to the current date at the appropriate interest rate.

The first step in any cost analysis is to decide what time frame will be utilized. The most accurate choice would be the remaining economic life of the structure. This is the period over which improvements to real estate contribute to the value of the property. For the purposes of this manual, 30 years will be used as a time frame for the analysis.

Table 20 is an annual compound interest table (based on an effective discount rate of 10 percent) to be utilized for calculating the discounted PV of Replacement Costs. To simplify PV calculations of replacement costs, the factors listed in the Table for the appropriate replacement years should be added and then multiplied by the initial investment. For example, for our assumed 30-year analysis of an alternative which requires replacement every 10 years, the factors for years 10, 20, and 30 (the years in which replacement occurs) would be added (.386 +.149 +.057 = .592). If the initial investment is $1,000, the present value of replacement costs is $1,000 x .592 = $592.

Example 10: Assume that three noise reduction alternatives (X, Y and Z) are under consideration. Costs for these alternatives are as follows:

	Alternatives		
	X	Y	Z
Initial Investment	$500	$750	$2,000
Replacement Costs	$500 (every 5 yrs)	$750 (every 15 yrs)	$2,000 (every 30 yrs)

Table 20

Factors for Calculating Present Value (PV) of Replacement Costs (RC)
Based on a 10% Discount Rate*

Years	Factors for RC
1	.909
2	.826
3	.751
4	.683
5	.621
6	.564
7	.513
8	.467
9	.424
10	.386
11	.350
12	.319
13	.290
14	.263
15	.239
16	.218
17	.198
18	.180
19	.164
20	.149
25	.092
30	.057

*For discount rates other than 10%, see Ellwood, L.W. Ellwood Tables for Real Estate Appraising and Financing, Third Ed., Chicago: American Institute of Real Estate Appraisers (1974).

Cost Category	Alternatives		
	X	Y	Z
IC	\$500	\$750	\$2,000
RC (from Table 20)	\$500 (.621 +.386 +.239 +.149 +.092 +.057) = \$772	\$750 (.239 +.057) = \$222	\$2,000 x .057 = \$114
Total PV	\$1,272	\$972	\$2,114

When the Initial Costs and Replacement Costs of each alternative are added, it is found that Alternative Y has the lowest Present Value.

5.3 OPERATING COSTS

In addition to Initial Investment and Replacement Costs, Operating Costs, OC, of Noise Reduction modifications should be considered where appropriate. Once the operating costs of a modification are determined, the Present Value of these costs should be calculated by multiplying the value of the annual OC by the factor 9.427. This factor is based on our assumed 30-year analysis.

5.4 SOURCES OF COST DATA

Unit cost data (hourly labor rate, cost per square foot) can be obtained from many sources, depending on the degee of detail required. The data sources utilized must permit a cost estimate under current, local market conditions. Three particularly valuable data sources are described below.

- <u>Local Contractors and Builders</u>

  These represent a very significant source of cost data since they are constantly in touch with the market. They can provide data on wage rates, materials and equipment prices, and categories of indirect costs. In particular, they are important sources of cost differentials for different types of structures.

- <u>Cost Estimators</u>

  The use of a professional cost estimator might be necessary for highly specialized structures.

- <u>Cost Services</u>

  These provide detailed unit costs for structural components and items of equipment. Three such national services are listed in Table 21. These services publish monthly or quarterly supplements to bring cost studies up-to-date with new construction methods and materials, and to provide area and time adjustment factors in index form so that the base figures can be utilized in the local market area.

Table 21

Cost Services

<u>Boeckh Building Cost Manual</u>. Milwaukee: Boeckh Division, American Appraisal Co., 1967. Vol. I: "Residential and Agricultural," Vol. II: "Commercial," Vol. III: "Industrial and Institutional." <u>Monthly Building Cost Modifier</u>.
<u>Dow Building Cost Calculator and Valuation Guide</u>. New York: McGraw-Hill Information Systems Co., quarterly.
<u>Marshall Valuation Service</u>. Los Angeles: Marshall and Swift Publication Co., Monthly.

5.5 WORKSHEET FOR COST ANALYSIS

Cost worksheets provide a convenient checklist to ensure that all necessary and appropriate elements of cost are included in the final estimate of Noise Reduction costs. Direct costs will consist of labor and materials. The primary category of indirect costs includes architectural, engineering and consulting fees. Operating costs (or savings) result from increased mechanical ventilation costs and heat energy savings.

Figure 16 shows a worksheet format for deriving cost estimates. This enables an equitable comparison of alternatives by formulating a single total cost for each alternative.

	Architectural, Engineering, & Consulting Fees (A)	Material			Labor			Recurring Energy Costs/(Savings)*				Replacement Cost	
Alternative X components		sq. ft.	x cost/sq. ft.	= Cost (B)	hrs.	x wage rate	= Cost (C)	unit energy changes (annual)	x unit cost	x 9.427 =	Cost (D)	initial direct cost (BIC) x factor from Table 20 = Cost (E)	(A + B + C + D + E) x (no. of units being treated) = Total Discounted PV
Alternative Y components													
Alternative Z components													

Compare Total Discounted Present Values

*Savings would be a negative entry.

Figure 16. Worksheet for Cost-Estimating Noise Reduction Alternatives

WORKSHEETS

The following pages contain the worksheets listed below.

EWNR Calculation for Wall Elements

Wall	Basic EWNR (Table 1)		EWNR Adjustment (Table 2)		Total EWNR
#1	____ dB	+	____ dB	=	____ dB
#2	____ dB	+	____ dB	=	____ dB

Composite Wall EWNR

From Worksheet 2 Including All Windows, Doors, etc.

	Wall 1	Wall 2	Total Walls
Composite EWNR, dB including windows, doors, etc.	____ dB	____ dB	____ dB
Total Area, Sq Ft	____ ft^2	____ ft^2	____ ft^2

EWNR Calculation for Roof-Ceiling Elements

Attic Space Construction		Single Joist Construction	
Basic EWNR (from Table 3)	____ dB	Basic EWNR (from Table 3)	____ dB
New Basic EWNR for vented spaces (from Table 5)	____ dB	Adjustment for absorption (from Table 4)	____ dB
Adjustment for self-shielding (from Table 6)	____ dB	Adjustment for self-shielding (from Table 6)	____ dB
Total EWNR (Sum of one basic EWNR and adjustment)	____ dB	Total EWNR (Sum of above)	____ dB

Structure Composite Wall/Roof-Ceiling EWNR

(from Worksheet 2)

	Walls	Roof-Ceiling	Total Structure
Composite EWNR, dB	____ dB	____ dB	____ dB
Area, Sq Ft	____ ft^2	____ ft^2	____ ft^2

Final Calculation for Noise Reduction

Structure Composite EWNR		Interior Absorption Correction from Table 10		Structure Noise Reduction
____ dB	-	____ dB - 6	≈	____ dB

Figure 17. Worksheet No. 1 – Calculation of Building Noise Reduction

Step	Element 1	Element 2
1. Enter Total Area	____ $ft^2 (m^2)$	
Enter Element Area	____ $ft^2 (m^2)$	____ $ft^2 (m^2)$
2. Percent of Total Area (Must sum to 100%)	____ %	____ %
3. Enter EWNR's	____ dB	____ dB
4. Difference of Line 3 EWNR's	____ dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	____ dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	____ dB	

Element 1	Element 2	Element 1	Element 2
____ $ft^2 (m^2)$		____ $ft^2 (m^2)$	
____ $ft^2 (m^2)$	____ $ft^2 (m^2)$	____ $ft^2 (m^2)$	____ $ft^2 (m^2)$
____ %	____ %	____ %	____ %
____ dB	____ dB	____ dB	____ dB
____ dB		____ dB	
____ dB		____ dB	
____ dB		____ dB	

Figure 18. Worksheet No. 2 - Composite EWNR Calculation for Two Elements

Energy Savings Due to Infiltration Sealing

Local Yearly Degree Days (Table 13)		Temperature Difference, ΔT		Infiltration Constant, C (Table 14)
______	$\div$ 365 =	______	⇨	______

Infiltration Constant, C (From Above)		Building Volume		Heat Savings
______	x	______ ft^3	x 24 x 365 =	______ Btu/yr

Energy Savings Due To Wall/Window/Door Modifications

	Modified Wall Element	Original U-Factor (From Tables)		Modified U-Factor (From Tables)		U-Factor Change		Wall or Element Area, ft^2		Local Annual Degree-Days (From Table 13)		Heat Savings Btu/yr
1.	____	____	-	____	=	____	x	____	x	____	x 24 =	____
2.	____	____	-	____	=	____	x	____	x	____	x 24 =	____
3.	____	____	-	____	=	____	x	____	x	____	x 24 =	____
4.	____	____	-	____	=	____	x	____	x	____	x 24 =	____
5.	____	____	-	____	=	____	x	____	x	____	x 24 =	____

____ Btu/yr x .252 = ____ kg-cal/yr Total = ____

Fuel Savings Due to Noise Reduction Modifications

Fuel (circle one): Coal (lb), Oil (gal), Gas (ft^3)

Heat Energy Savings		Heating Value Efficiency Product (From Table 19)		Fuel Saved
______ $\frac{Btu}{yr}$	$\div$	______ $\frac{Btu}{gal}$	=	______ lb / gal / ft^3 per year

____ lb x .454 = ____ kg

____ gal x 3.79 = ____ liters

____ ft^3 x .0283 = ____ m^3

Added Ventilation Energy

Building Volume		Energy Required
______ ft^3	$\div$ 233 =	______ kwh per year

____ kwh x 860.5 = ____ kg-cal

Figure 19. Worksheet No. 3 - Fuel Savings Due to Acoustical Modifications

A	B		C		D
2dB Range	No. of Counts		Relative Noise Energy		Total Relative Noise Energy
98-100	____	x	79,400	=	____
96-98	____	x	50,100	=	____
94-96	____	x	31,600	=	____
92-94	____	x	20,000	=	____
90-92	____	x	12,600	=	____
88-90	____	x	7,940	=	____
86-88	____	x	5,010	=	____
84-86	____	x	3,160	=	____
82-84	____	x	2,000	=	____
80-82	____	x	1,260	=	____
78-80	____	x	794	=	____
76-78	____	x	501	=	____
74-76	____	x	316	=	____
72-74	____	x	200	=	____
70-72	____	x	126	=	____
68-70	____	x	79.4	=	____
66-68	____	x	50.1	=	____
64-66	____	x	31.6	=	____
62-64	____	x	20.0	=	____
60-62	____	x	12.6	=	____
58-60	____	x	7.94	=	____
56-58	____	x	5.01	=	____
54-56	____	x	3.16	=	____
52-54	____	x	2.00	=	____
50-52	____	x	1.26	=	____
48-50	____	x	.794	=	____
46-48	____	x	.501	=	____
44-46	____	x	.316	=	____
42-44	____	x	.200	=	____
40-42	____	x	.126	=	____
Sum B =	____		Sum D =		____

L_{eq} Table

L_{eq}	Q	L_{eq}	Q
100	100,000	69	74.9
99	79,400	68	63.1
98	63,100	67	50.1
97	50,100	66	39.3
96	39,000	65	31.6
95	31,600	64	25.1
94	25,100	63	20.0
93	20,000	62	15.8
92	15,800	61	12.6
91	12,600	60	10.0
90	10,000	59	7.94
89	7,940	58	6.31
88	6,310	57	5.01
87	5,010	56	3.98
86	3,980	55	3.16
85	3,160	54	7.51
84	2,510	53	2.00
83	2,000	52	1.58
82	1,560	51	1.26
81	1,260	50	1.00
80	1,000	49	.774
79	794	48	.631
78	631	47	.501
77	501	46	.398
76	398	45	.316
75	316	44	.251
74	251	43	.200
73	200	42	.158
72	158	41	.126
71	126	40	.100
70	100		

$$Q^* = \frac{\text{Sum D}}{\text{Sum B}} = \underline{\qquad\qquad} = \underline{\qquad\qquad}$$

L_{eq} = __________ dB

Figure 20. Worksheet No. 4 – L_{eq} Calculation

APPENDIX A

Development and Evaluation of EWNR Rating Scheme

Background

Transmission loss in a given structure is a property which is frequency dependent. Therefore, evaluation of transmission loss of walls requires analysis of noise levels in each of eight octave bands, or 16 one-third octave bands, covering a frequency range from 125 Hz to 4000 Hz. Performance of the necessary noise measurements for every wall in every building constructed would prove to be a costly and time-consuming procedure. As an effective alternative, spectral data can be weighted (e.g., using an A-weighted filter) in order to obtain a single-number rating which, in turn, may be cataloged as a function of wall design and composition.

The most common single-number rating for the transmission loss of walls is the Sound Transmission Class (STC). This method utilizes a standard contour to which the transmission loss values in 16 one-third octave bands are compared. Use of the STC rating, however, is limited to interior wall structures. While there have been some efforts in the past to extend STC to evaluate exterior walls, no precise methodology has been developed.

A new single-number rating system, termed the Exterior Wall Noise Rating (EWNR), has been chosen for use in this manual. The rationale behind the development of the EWNR, and the evaluation of this and other exterior wall single-number rating schemes, is presented here.

Development of EWNR Rating Scheme

Development of the EWNR rating is based on the rationale that the interior noise spectrum should take on the characteristics of a 40 dB equal loudness contour which is an inverse A-weighted response curve. Knowing this, the transmission loss characteristics of an exterior wall may be evaluated if the exterior noise spectrum is identified.

The problem is conceptualized in Figure 21. Consider, for the moment, that the exterior noise spectrum exhibits a shape similar to that shown in the figure. As will be discussed, this in fact is the nominal average spectrum for typical highway noise. It follows, then, that the transmission loss characteristic of the wall must act as a shaping "filter" to the prescribed exterior noise spectrum so as to produce an interior noise spectrum similar in shape to the inverse A-weighted response curve.

To identify the precise shape of this special transmission loss curve, an assumption must be made as to the frequency characteristics of the exterior noise level. For this study, exterior noise will be that generated by highway traffic. Figure 22 presents the typical range of highway spectra averaged over a 24-hour period for a single location near a heavily-traveled freeway. Using this data, the nominal average spectrum for highway noise was calculated, with the results illustrated in Figure 23. Note that the octave band levels are relative to the equivalent noise level, L_{eq}, in dBA.

Knowing the characteristics of the exterior noise spectrum, the shape of the special transmission loss curve was evaluated, resulting in the curve shown in Figure 24. This contour is then utilized in a manner similar to the STC curve in that it is adjusted vertically to the highest position relative to the TL curve where the sum of the one-third octave band deficiencies (that is, deviations below the contour) is 32 or less. The Exterior Wall Noise Rating (EWNR) is then the value of the standard curve at 500 Hz minus a constant value of 4 dB. The rationale for this constant is discussed fully in the section on Evaluation of Single-Number Rating Schemes.

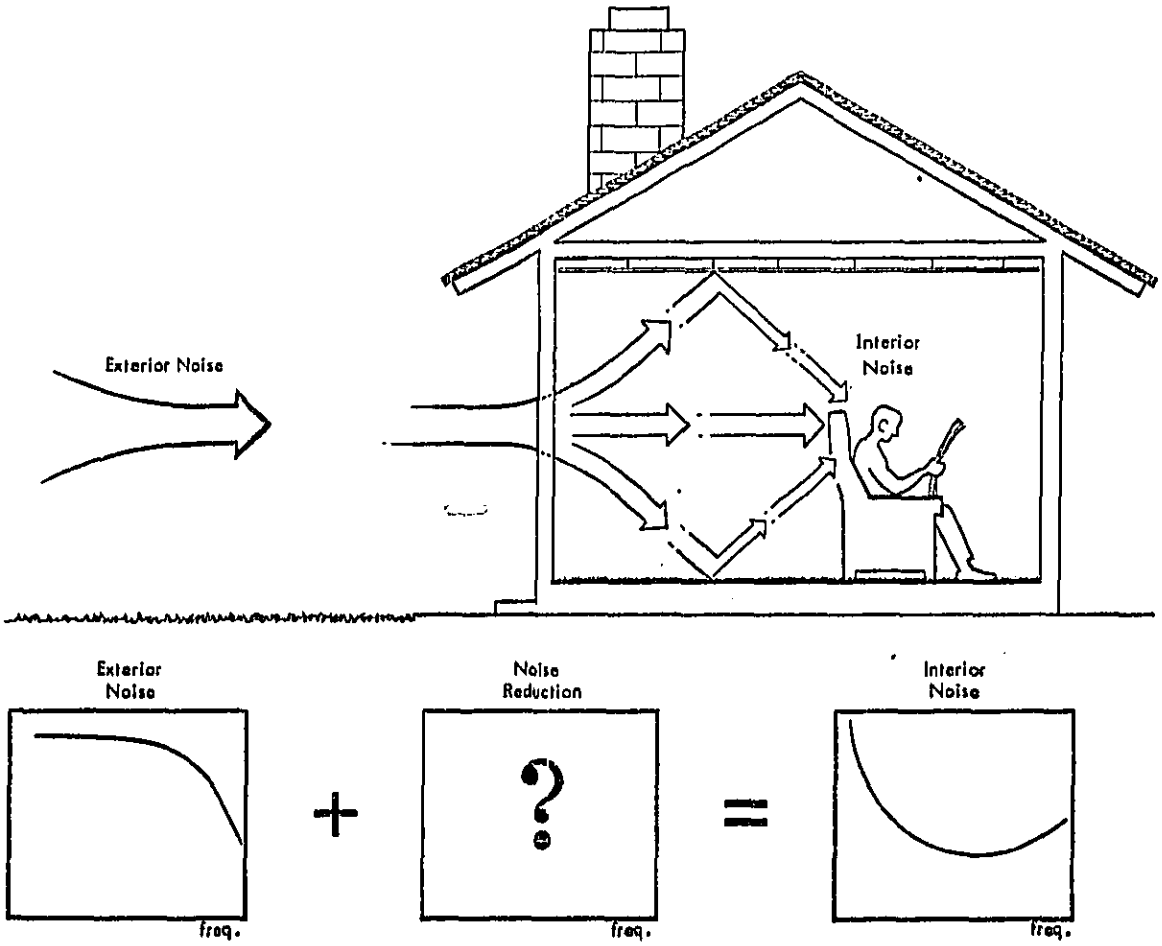


Figure 21. Conceptual Illustration of Noise Reduction Effect of a Building

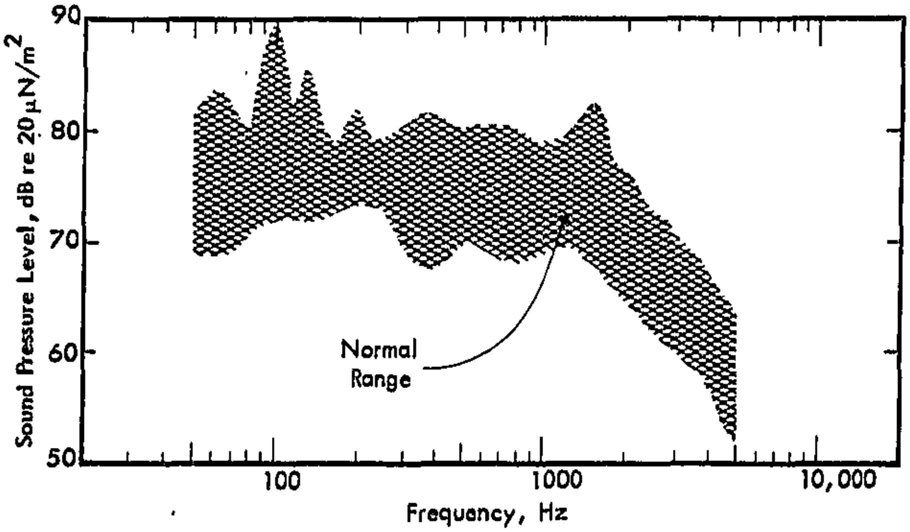


Figure 22. Typical Highway Noise Spectra[17]

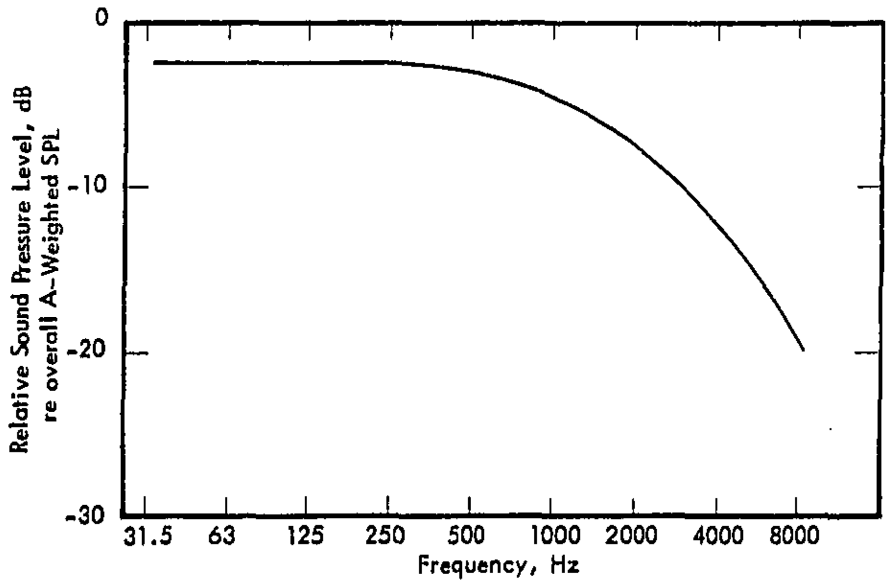


Figure 23. Standard Highway Noise Spectrum[18]

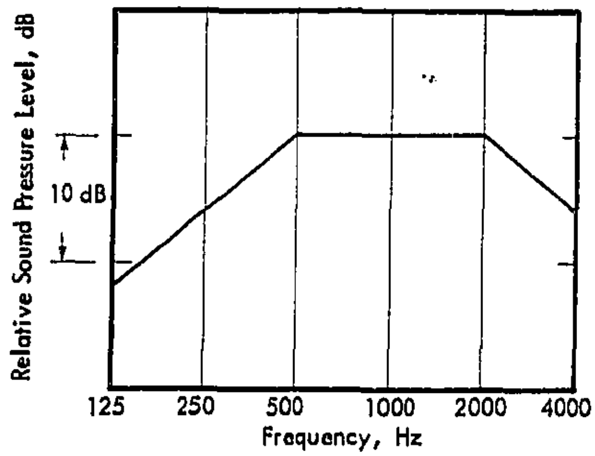


Figure 24. Exterior Wall Noise Rating Curve Designed to Relate to Interior A-Weighted Noise Levels for Highway Noise Levels

The EWNR values were developed assuming an incident noise frequency spectrum similar to that of typical highway noise. Therefore, the spectral shape of the EWNR Standard Contour, and hence the actual EWNR values, were determined by this highway noise spectrum. To use the given EWNR values in the prediction of building attenuation of aircraft noise, which presents a different frequency spectrum, a constant of 6 dB, rather than 4, must be subtracted from graphically determined EWNR values.

EWNR for Composite Walls

When a window or door is part of an exterior wall, the transmission loss rating of the composite wall must be determined. Standard procedure entails calculating the composite transmission loss in each one-third octave band, from which a single-number rating such as EWNR may then be determined from this transmission loss curve. However, the results of sample calculations indicate that a composite transmission loss value may be determined with little error by taking the EWNR of all the wall elements and combining them independently of frequency by the following ratio:

$$\mathrm{EWNR}_{\mathrm{composite}} = 10 \log_{10} \frac{\sum_i S_i}{\sum_i \tau_i' S_i}$$

where τ_i' is the transmission coefficient corresponding to the EWNR of the i^{th} element of area S . This, in fact, is the procedure followed in this manual.

Evaluation of Single-Number Rating Schemes

Numerous single-number rating schemes were evaluated here as potential methods for characterizing the transmission loss of exterior walls. Initial analyses focused on 11 individual rating schemes, including:

1. Exterior Wall Noise Rating (EWNR). Applied in a manner analogous to that described previously.

2. Speech Interference Level Transmission Loss (SILTL). The SILTL is the arithmetic average of the one-third octave band transmission loss values in the speech interference frequency range (400 Hz to 2500 Hz).

3. Average Transmission Loss (AVETL). The AVETL is the arithmetic average of the 16 one-third octave band transmission loss values.

4. Sound Transmission Class (STC). The STC method uses a standard contour against which the transmission loss values in 16 one-third octave bands are compared in the frequency range between 125 Hz and 4000 Hz. The standard contour is shifted vertically relative to the test curve until (1) the sum of the deficiencies does not exceed 32 dB, and (2) the maximum deficiency at a single test point does not exceed 8 dB. The STC rating is then the transmission loss value at the intersection of the contour and the 500 Hz ordinate.

5. Modified STC Ratings. These ratings are similar to STC, but the standard STC curve is replaced with a curve with positive slope rising at a rate of 0, 1, 2, 3, 4, 5 and 6 dB per octave, indicated in Table 22 as Mod 0 through Mod 6. These standard curves are adjusted vertically to the highest position where the sum of the one-third octave band deficiencies is 32 dB or less. The rating is then the value of the standard curve at 500 Hz.

Table 22

Correlation Coefficients and 90 Percent Confidence Intervals for Prediction of Interior A-Weighted Noise Levels for 11 Single Number Transmission Loss Rating Schemes

Single Number Rating	Correlation Coefficients	90% Confidence Intervals, dB
STC	0.962	±2.7
SILTL	0.960	±2.8
AVETL	0.981	±1.9
Mod 0	0.978	±2.1
Mod 1	0.987	±1.7
Mod 2	0.988	±1.5
Mod 3	0.985	±1.8
Mod 4	0.975	±2.2
Mod 5	0.956	±2.9
Mod 6	0.927	±3.8
EWNR	0.998	±0.6

The most important criteria for a single number scheme is that it should give sufficient accuracy in calculating the interior A-weighted noise level for a variety of wall structures. A high speed digital computer was utilized to evaluate and rank the 11 single number ratings listed in Table 22. The computer utilized combinations of TL input data for walls and windows of various sizes for a total of more than 20,000 scenarios for each exterior spectrum.

For each scenario, one-third octave band composite transmission loss values were calculated for each wall-window configuration. These TL values were subtracted from exterior levels to obtain the interior one-third octave band noise levels. The interior octave band levels were A-weighted to obtain the actual interior A-weighted noise level.

Each of the 11 single number wall ratings was then subtracted from the exterior A-weighted noise level to obtain an approximation of the interior level based on single-number calculations. A linear regression analysis was carried out for the actual A-weighted noise level and each of the single number approximations using all of the scenarios. The standard error was then calculated for each of the single number wall ratings. As shown in Table 22, the EWNR concept is the most accurate single number prediction scheme of the 11 analyzed.

The Y-intercept from the regression analysis of the EWNR scheme had a value of 4 dB for highway noise (6 dB for aircraft noise). This represented a constant difference between the A-weighted structure attenuation predicted by the EWNR scheme and the actual attenuation as calculated using one-third octave bands. This constant value of 4 has been incorporated into all data tabulated in this manual, and thus the tabulated EWNR values may be applied directly to predict the attenuation of highway noise. However, 4 dB must be subtracted from the value of the EWNR contour at 500 Hz when determining EWNR values by graphical means from TL data.

Additional analyses of single number rating schemes were then conducted utilizing various other highway noise spectra. Based on the preceding evaluation, the five most feasible rating schemes were selected for further analysis: EWNR, STC, Mod 0, Mod 3, and SILTL. The extended evaluation of these rating schemes centered on the utilization of two additional highway noise spectra based upon octave band data identified as TSC and NCHRP 78 data. Each of these spectra were considered in-light-of both a one and five percent truck mix, thereby resulting in four highway noise spectra test cases.

Commonly-used wall constructions were again combined with various window types in area ratios of 20, 15, 10 and 0 percent. A total of 192 different wall constructions and 16 windows were used in this analysis. Linear regression analyses were conducted for each test case to compare the accuracy of the single number rating schemes against A-weighted interior noise levels as calculated from the frequency-dependent data. The tabulated 90 percent confidence intervals are shown here in Table 23. For all four highway noise spectra, the EWNR provided the most accurate single number rating of transmission loss values. The EWNR was therefore selected for use in this manual.

Table 23

Ninety Percent Confidence Intervals for Comparison of Single Number Calculations With Third Octave Band Calculations

Single Number Rating	TSC		NCHRP 78	
	1 Percent Trucks	5 Percent Trucks	1 Percent Trucks	5 Percent Trucks
EWNR	±0.9	±0.9	±1.1	±1.1
Mod 0	±2.3	±2.3	±1.6	±1.5
Mod 3	±1.2	±1.2	±1.4	±1.4
STC	±2.1	±2.0	±2.6	±2.6
SILTL	±4.2	±4.1	±4.8	±4.8

Identification of EWNR Adjustment Factors

To facilitate the calculation of EWNR values for commonly-used wall constructions, a computer algorithm was devised and implemented based upon the theory of ideal transmission loss for structures.[21] However, so as to more accurately predict the transmission loss characteristics of a wall under actual field test conditions, the algorithm must be extended to account for cavity absorption as well as other anomalies due to leaks, gaps, or flanking paths.

For wall constructions, absorption in the wall cavities was included in the calculations for both the stud construction and the furred interior surface. To account for this, a 4 dB absorption factor was subtracted from each stud wall EWNR, while a 3 dB factor was subtracted for furred wall values, to arrive at the Basic Wall EWNR values tabulated in the manual.

The calculated EWNR values relate to ideal walls which might be tested under laboratory conditions; that is, with no leaks, gaps or flanking paths existent. However, the EWNR value for a wall built under field conditions will be, on the average, 4 dB lower than laboratory values. Therefore, this correction factor has been subtracted in determining the EWNR values for Basic Wall constructions.

Similar corrections to the EWNR values for roof-ceiling constructions must be introduced. For the single joist construction, the computer algorithm for calculating EWNR values assumed absorption to exist in the joist space. For attic space construction, a reverberant field was assumed to exist in the attic space, with no additional absorption considered. Determination of EWNR values for roof-ceiling systems as found in the field requires, in all cases, subtraction of 4 dB to account for inefficiencies due to leaks, gaps and flanking paths. Further, 5 dB must additionally be subtracted from EWNR algorithm values for single joist construction with no absorption in the joist space. These adjustments have been included in the tabulated data or manual procedures.

With appropriate consideration given to each of the above correction factors, EWNR values for basic constructions were calculated and compiled, and appear in the manual. Those correction factors which apply universally to all constructions have been accounted for in Tables 1 and 3 of the text, while those factors whose application is case-specific have been compiled for appropriate application within the manual.

Appendix B

USE OF THE MANUAL

This manual contains various procedures for identifying residential highway noise problems and selecting building modifications as solutions. The flowchart of Figure 25 shows a step-by-step procedure which applies this information directly to the problem of determining building modifications necessary to adequately insulate a building against the noise from an existing or proposed highway. The procedures of this manual can most effectively be applied by following the steps shown in the flowchart. A short explanation of each step is given below.

<u>Step 1</u> Calculate Building Noise Reduction (NR_c) using the methods of Chapter 2. Use normally open or closed conditions for the windows.

<u>Step 2</u> Calculate Interior Noise Level using the relation $L_{ic} = L_o - NR_c$.

<u>Step 3</u> Check to see if the Calculated Interior Noise Level, L_{ic}, plus 5 dB, is greater than the Interior Design Noise Level, L_c. The calculated level is increased by 5 dB to allow for uncertainty in the calculated interior level. If the calculated interior level plus 5 dB is greater than the Design Noise Level, measurements must be made.

<u>Step 4</u> Measure the Exterior Noise Level, L_{om}, using the procedures of Chapter 3. If the subject highway is not in use, an artificial source must be employed.

<u>Step 5</u> Measure the Interior Noise Level, L_{im}, using the procedures of Chapter 3. Use normally open or closed condition for the windows.

<u>Step 6</u> Determine the Measured Noise Reduction using the relationship $NR_m = L_{om} - L_{im} - 5$.

Step 7 If the Given Highway Noise Level, L_o, minus the quantity (NR_m) is less than the Design Noise Level, then the building attenuation is sufficient. If not, building wall modifications must be planned.

Step 8 Plan Building Wall modifications using the procedures of Chapter 2.

Step 9 Calculate New Noise Reduction using the procedures of Chapter 2 for the additional building modifications selected.

Step 10 If the Given Noise Level, L_o, minus the Calculated Noise Reduction, NR_c, is less than the Design Noise Level, then the building attenuation is sufficient. If not, additional modifications must be planned and Steps 8, 9, and 10 repeated until the condition of Step 10 is satisfied.

Step 11 Select Compatible Ventilation System: If ventilation has been restricted by the sealing of cracks and forced closing of windows in order to reduce interior noise levels, mechanical ventilation must be provided. This is discussed in Chapter 4.

Step 12 Determine Modification Costs: The costs of necessary modifications can be determined for comparative planning purposes using the methods of Chapter 5.

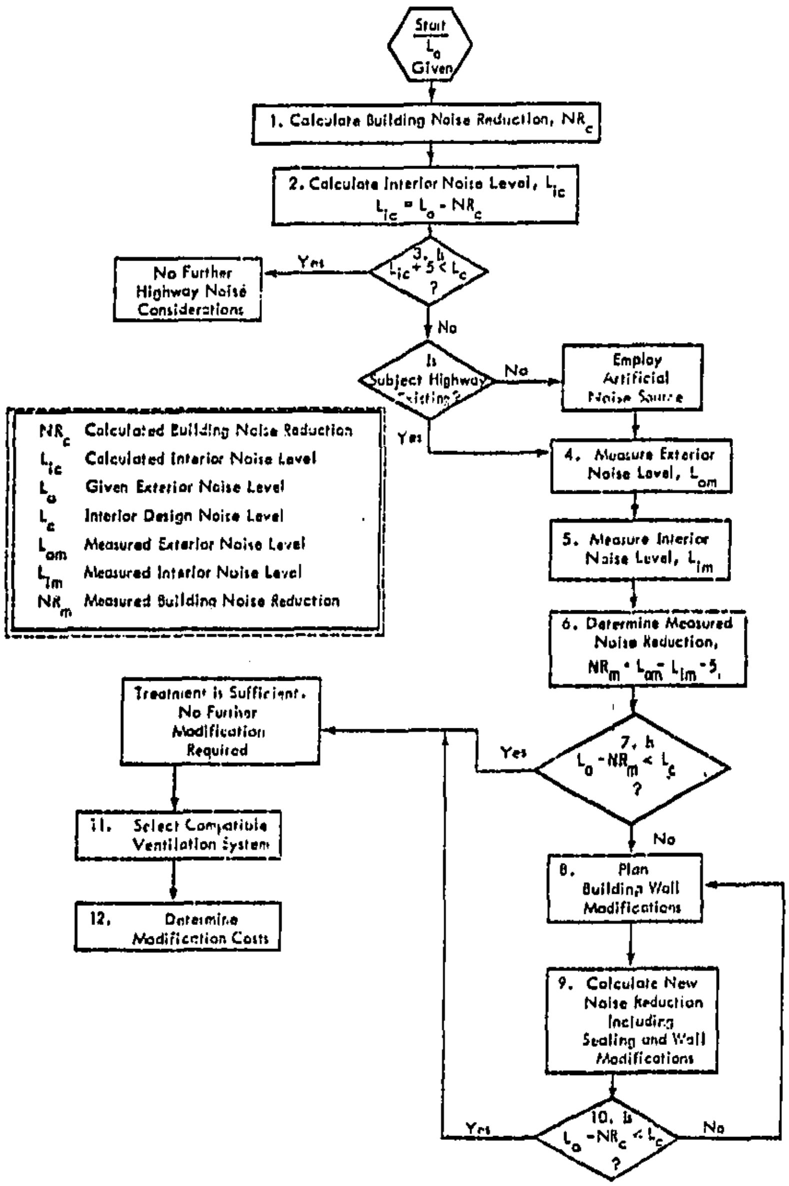


Figure 25. Flow Diagram for the Design of Noise Insulation of Buildings

Example 11: It is desired to determine whether design modifications will be necessary for a 2100 ft^2 (195 m^2) house located adjacent to a heavily travelled highway. Because of local terrain, the only exterior building walls directly exposed to the highway are two living room walls, and the rest of the structure appears to be well shielded. The exterior unshielded noise level in the vicinity of the house is 67 dB. The living room walls and roof have the following characteristics:

- Wall #1 - Constructed of standard wood studs, 16" (41 cm) on center, with an interior surface of 3/8" (1 cm) gypsum lath on 1/2" (1.3 cm) plaster, and an exterior surface of 3/4" (1.9 cm) wood siding. There is thermal insulation in the stud space. The wall measures 16' 6" x 8'0" (4.9 x 2.4 m) with a 1-3/4" (4.4 cm) solid core wood door with drop threshold seal. The door measures 6'8" x 3'0" (2 x .9 m).
- Wall #2 - Constructed of furred interior surface finished with 1/2" (1.3 cm) gypsum board on an exterior of 6" (15.2 cm) block with 1/2" stucco. The wall measures 24'0" x 8' 0" (7.3 x 2.4 m) with a single glazed 1/8"(.3 cm) glass window measuring 8'0" x 5'0" (2.4 x 1.5 m).
- Roof - This single story house has nonvented single joist ceiling construction with thermal insulation under a flat roof. Clay tiles cover the roof's exterior, with 1/2" (1.3 cm) fiberboard covering the interior ceiling.

The house is located in Los Angeles and has a central heating/air conditioning unit which operates on gas. Assuming the living room to be the most critical room, determine whether modifications will be necessary to achieve an interior design noise level of 32 dB.

Solution: Following the steps of the Flow Diagram in Figure 25:

Step 1: Calculate Building Noise Reduction

EWNR Calculation for Wall Elements

Wall	Basic EWNR (Table 1)		EWNR Adjustment (Table 2)		Total EWNR
#1	29 dB	+	4 dB	=	33 dB
#2	39 dB	+	0 dB	=	39 dB

Composite Wall EWNR

From Worksheet 2 Including All Windows, Doors, etc.

	Wall 1	Wall 2	Total Walls
Composite EWNR, dB including windows, doors, etc.	33 dB	30 "	31 dB
Total Area, Sq Ft	132 ft^2	192 ft^2	324 ft^2

EWNR Calculation for Roof-Ceiling Elements

Attic Space Construction		Single Joist Construction	
Basic EWNR (from Table 3)	dB	Basic EWNR (from Table 3)	33 dB
New Basic EWNR for vented spaces (from Table 5)	dB	Adjustment for absorption (from Table 4)	5 dB
Adjustment for self-shielding (from Table 6)	dB	Adjustment for self-shielding (from Table 6)	6 dB
Total EWNR (Sum of one basic EWNR and adjustment)	dB	Total EWNR (Sum of above)	44 dB

Structure Composite Wall/Roof-Ceiling EWNR

(from Worksheet 2)

	Walls	Roof-Ceiling	Total Structure
Composite EWNR, dB	31 dB	44 dB	34 dB
Area, Sq Ft	324 ft^2	396 ft^2	720 ft^2

Final Calculation for Noise Reduction

Structure Composite EWNR		Interior Absorption Correction from Table 10		Structure Noise Reduction
34 dB	-	(-1) dB - 6	=	29 dB

Figure 17. Worksheet No. 1 - Calculation of Building Noise Reduction

Step 1 (Continued)

Step	Element 1 DOOR	Element 2 WALL 1
1. Enter Total Area	132 ft^2 (m^2)	
Enter Element Area	20 ft^2 (m^2)	112 ft^2 (m^2)
2. Percent of Total Area (Must sum to 100%)	15 %	85 %
3. Enter EWNR's	35 dB	33 dB
4. Difference of Line 3 EWNR's	2 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	2 dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	33 dB	

Element 1 WINDOW	Element 2 WALL 2	Element 1 WALL 1	Element 2 WALL 2
192 ft^2 (m^2)		324 ft^2 (m^2)	
40 ft^2 (m^2)	152 ft^2 (m^2)	132 ft^2 (m^2)	192 ft^2 (m^2)
21 %	79 %	41 %	59 %
24 dB	39 dB	33 dB	30 dB
15 dB		3 dB	
9 dB		2 dB	
30 dB		31 dB	

Figure 18. Worksheet No. 2 - Composite EWNR Calculation for Two Elements

Step 1 (Continued)

Step	Element 1 WALLS	Element 2 ROOF
1. Enter Total Area	720 $ft^2 (m^2)$	
1. Enter Element Area	324 $ft^2 (m^2)$	396 $ft^2 (m^2)$
2. Percent of Total Area (Must sum to 100%)	45 %	55 %
3. Enter EWNR's	31 dB	44 dB
4. Difference of Line 3 EWNR's	13 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	10 dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	34 dB	

Element 1	Element 2	Element 1	Element 2
____ $ft^2 (m^2)$		____ $ft^2 (m^2)$	
____ $ft^2 (m^2)$	____ $ft^2 (m^2)$	____ $ft^2 (m^2)$	____ $ft^2 (m^2)$
____ %	____ %	____ %	____ %
____ dB	____ dB	____ dB	____ dB
____ dB		____ dB	
____ dB		____ dB	
____ dB		____ dB	

Figure 18. Worksheet No. 2 - Composite EWNR Calculation for Two Elements

Therefore: $NR_c = 29$ dB, Calculated Noise Reduction (From end of Step 1, p. 98)

Step 2 - Calculate Interior Noise Level L_{ic}

L_o = Predicted outdoor noise level = 67 dB

$L_{ic} = L_o - NR_c = 67 - 29 = 38$ dB

Step 3 - Is $L_{ic} + 5 < L_c$?

Design Interior Noise Level = L_c = 32 dB

Is 38 + 5 < 32 ? No.

Thus proceed to Step 4.

Step 4 - Measure Exterior Noise Level

Subject Highway is existing:

Exterior L_{eq} is determined from measurements to be 71 dB = L_{om}

Step 5 - Measure Interior Noise Level

Interior L_{eq} is determined from measurements to be 39 dB = L_{im}

Step 6 - Determine Measured Noise Reduction

$L_{om} - L_{im} - 5 = 71 - 39 - 5 = 27$ dB = NR_m

Step 7 - Is $L_o - NR_m < L_c$?

Is 67 - 27 < 32? (L_o is given in Step 2)

No. Thus proceed to Step 8.

Step 8 - Plan Modifications

Begin with a simple modification. Treatment of leakage paths in windows, door, etc. will result in a structure EWNR increase of 4 dB.

Step 9 - Calculate New Noise Reduction

New Calculated Noise Reduction will be:

NR_c (from Step 1) + 4 = 29 +4 = 33 dB.

Step 10 - Is $L_o - NR_c < L_c$?

Is 67 -33 < 32 ? No.

Thus return to Step 8 and select additional modifications to give the needed Noise Reduction.

Step 8 - Plan Additional Modifications

In surveying all existing wall elements, the large window appears to be the weakest. Thus, it is specified that this window be double-glazed with panes of 3/16 inch and 1/4 inch separated by a 2-inch airspace.

Step 9 - Calculate New Noise Reduction

Worksheets No. 1 and No. 2 are again used. The new window, from Table 7, will have an EWNR of 39 dB.

Step 9

EWNR Calculation for Wall Elements

Wall	Basic EWNR (Table 1)		EWNR Adjustment (Table 2)		Total EWNR
#1	29 dB	+	4 dB	=	33 dB
#2	39 dB	+	0 dB	=	39 dB

Composite Wall EWNR

From Worksheet 2 Including All Windows, Doors, etc.

	Wall 1	Wall 2	Total Walls
Composite EWNR, dB including windows, doors, etc.	33 dB	39 dB	36 dB
Total Area, Sq Ft	132 ft^2	192 ft^2	324 ft^2

EWNR Calculation for Roof-Ceiling Elements

Attic Space Construction		Single Joist Construction	
Basic EWNR (from Table 3)	___ dB	Basic EWNR (from Table 3)	33 dB
New Basic EWNR for vented spaces (from Table 5)	___ dB	Adjustment for absorption (from Table 4)	5 dB
Adjustment for self-shielding (from Table 6)	___ dB	Adjustment for self-shielding (from Table 6)	6 dB
Total EWNR (Sum of one basic EWNR and adjustment)	___ dB	Total EWNR (Sum of above)	44 dB

Structure Composite Wall/Roof-Ceiling EWNR

(from Worksheet 2)

	Walls	Roof-Ceiling	Total Structure
Composite EWNR, dB	36 dB	44 dB	39 dB
Area, Sq Ft	324 ft^2	396 ft^2	720 ft^2

Final Calculation for Noise Reduction

Structure Composite EWNR		Interior Absorption Correction from Table 10		Structure Noise Reduction
39 dB	-	(-1) dB -6	=	34 dB

Figure 17. Worksheet No. 1 – Calculation of Building Noise Reduction

Step 9

Step	Element 1 WALL 2	Element 2 WINDOW
1. Enter Total Area	192 $ft^2 (m^2)$	
Enter Element Area	152 $ft^2 (m^2)$	40 $ft^2 (m^2)$
2. Percent of Total Area (Must sum to 100%)	79 %	21 %
3. Enter EWNR's	39 dB	39 dB
4. Difference of Line 3 EWNR's	0 dB	
5-7 Difference of Higher Element and Composite EWNR (from Figure 7)	0 dB	
8. Composite EWNR (Larger Line 3 EWNR - Line 5-7)	39 dB	

Element 1 WALL 1	Element 2 WALL 2
324 $ft^2 (m^2)$	
132 $ft^2 (m^2)$	192 $ft^2 (m^2)$
41 %	59 %
33 dB	39 dB
6 dB	
3 dB	
36 dB	

Element 1 WALLS	Element 2 ROOF
720 $ft^2 (m^2)$	
324 $ft^2 (m^2)$	396 $ft^2 (m^2)$
45 %	55 %
36 dB	44 dB
8 dB	
5 dB	
39 dB	

Figure 18. Worksheet No. 2 - Composite EWNR Calculation for Two Elements

Thus the new NR_c = 34 dB +4 dB from sealing = 38 dB

Step 10 - Is $L_o - NR_c < L_c$?

Is $67 - 38 < 32$? Yes.

Thus, the interior noise level criterion will be satisfied if the building sides facing the highway are well sealed and the specified double pane window is installed.

Step 11 - Select Compatible Ventilation System

Due to the high exterior noise levels, it is expected that the door and window would be kept shut at all times, relying on infiltration and mechanical ventilation throughout the year. Infiltration for the house will be greatly reduced by sealing the living room, however, placing a heavier ventilation demand on the HVAC system. This extra ventilation energy requirement is therefore a consequence of Noise Reduction modification.

The sealing and improved window will also result in heat energy savings. Proceed to Step 12 to calculate these energy changes.

Step 12

Energy Savings Due to Infiltration Sealing

Local Yearly Degree Days (Table 13)		Temperature Difference, ΔT		Infiltration Constant, C (Table 14)
1799	÷ 365 =	4.93	⇨	~0.1

Infiltration Constant, C (From Above)		Building Volume				Heat Savings
0.1	x	16,800 ft^3	x 24	x 365	=	1.47×10^7 Btu/yr

Energy Savings Due To Wall/Window/Door Modifications

	Modified Wall Element	Original U-Factor (From Tables)		Modified U-Factor (From Tables)		U-Factor Change		Wall or Element Area, ft^2		Local Annual Degree-Days (From Table 13)		Heat Savings Btu/yr
1.	Window	1.13	-	.58	=	.55	x	40	x	1799	x 24 =	9.5×10^5
2.			-		=		x		x		x 24 =	
3.			-		=		x		x		x 24 =	
4.			-		=		x		x		x 24 =	
5.			-		=		x		x		x 24 =	

_____ Btu/yr x .252 = _____ kg-cal/yr Total = 9.5×10^5

Fuel Savings Due to Noise Reduction Modifications

Fuel (circle one): Coal (lb), Oil (gal), Gas (ft^3)

Heat Energy Savings		Heating Value Efficiency Product (From Table 19)		Fuel Saved
$1.47 \times 10^7 + 9.5 \times 10^5$ Btu/yr	÷	820 Btu/gal	=	1.91×10^4 lb/gal/ft^3 per year

_____ lb x .454 = _____ kg

_____ gal x 3.79 = _____ liters

_____ ft^3 x .0283 = _____ m^3

Added Ventilation Energy

Building Volume		Energy Required
16,800 ft^3 ÷ 233 =		72 kwh per year

_____ kwh x 860.5 = _____ kg-cal

Figure 19. Worksheet No.3 - Fuel Savings Due to Acoustical Modifications

APPENDIX C

Calculation of Internal Absorption Adjustment Factors

Exterior noise transmitted to the interior of a structure undergoes absorption due to the existence of materials such as drapes, carpeting, and upholstered furniture. Since internal absorption may significantly affect the actual Noise Reduction of a building, it is necessary to evaluate the absorption adjustment term 10 log S/A, where S is the area of the exterior wall through which noise is transmitted to the room being evaluated, and A is the total absorption in the room. The difficulty arises due to the fact that internal absorption is frequency-dependent – usually increasing with frequency.

In a recent study of the noise attenuation properties of residential buildings, the absorption of typical rooms in 20 separate houses was measured.[22] These data were used along with dimensions taken from plans for the houses to calculate the term 10 log S/A in each case. The results are given in Figure 26 for Living Rooms, Kitchens, and Bedrooms. As can be seen in this figure, average values for each type of room are reasonably independent of frequency and differ from each other by a small but significant amount.

Additional analysis for typical room dimensions indicated that with two walls exposed (as in the case of a corner room) to the noise source, the 10 log S/A term will increase by 3 dB. The 10 log S/A corrections resulting from this analysis are tabulated in Table 24.

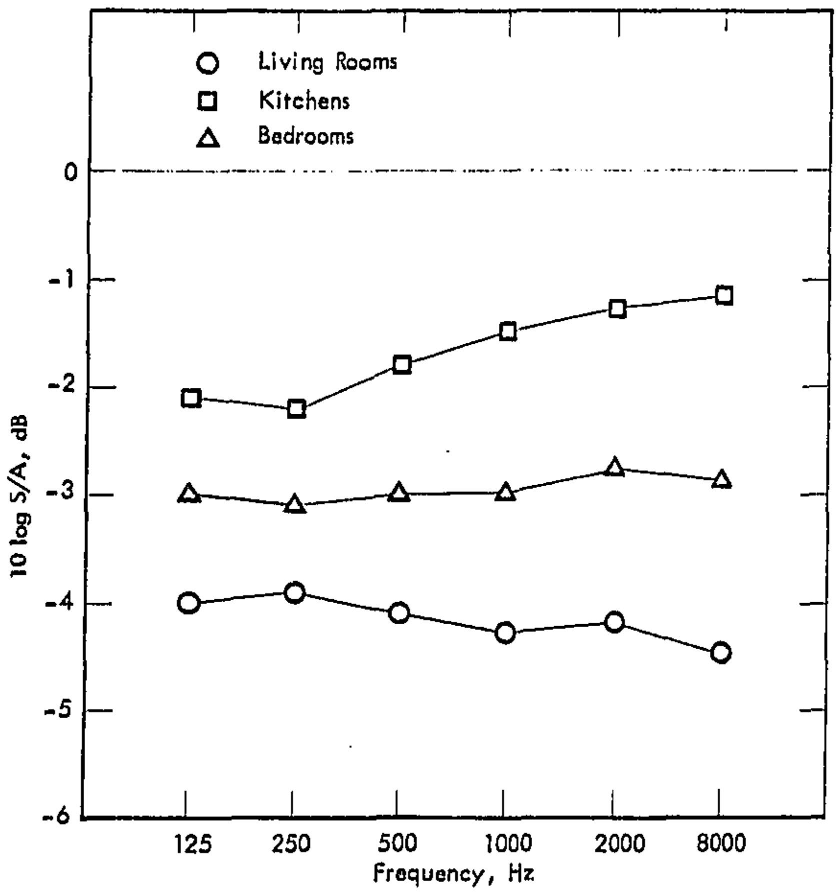


Figure 26. Values of 10 log S/A for Living Rooms, Kitchens and Bedrooms in Residential Buildings With One Wall Exposed to Noise Source.

Table 24

Values of 10 log S/A in dB for Residential Building Rooms With One and Two Walls Exposed

Interior Space	One Wall Exposed	Two Walls Exposed
Living Rooms	-4	-1
Bedrooms	-3	0
Kitchens	-2	+1

REFERENCES TO NOTES IN TEXT

1. EWNR Values Calculated According to the Procedures Given in Appendix A.

2. American National Standards Institute, "Sound Level Meters."

3. American Society of Heating, Refrigeration, and Air Conditioning Engineers, ASHRAE Handbook of Fundamentals.

4. Air Conditioning and Refrigeration Institute, "Directory of Certified Unitary Air Conditioners."

5. See, for example, Berendt, R.D., "A Guide to Airborne, Impact, and Structure-Borne Noise Control in Multifamily Dwellings."

6. Conway, H.M., and L.L. Liston, The Weather Handbook.

7. American Society of Heating, Refrigeration, and Air Conditioning Engineers, ASHRAE Handbook of Fundamentals, Chapter 20, Table 7.

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9. American Society of Heating, Refrigeration, and Air Conditioning Engineers, ASHRAE Handbook of Fundamentals, Chapter 20, Table 5a.

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18. Plotkin, K.J., "The Assessment of Noise at Community Development Sites," Appendix A, Noise Models. Wyle Laboratories.

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23. Private communications with HVAC specialists in the Los Angeles area.

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