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A STUDY OF SOUNDPROOFING REQUIREMENTS FOR RESIDENCES ADJACENT TO COMMERCIAL AIRPORTS

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As part of an overall systems program being conducted by the U.S. Environmental Protection Agency to examine options for the reduction of aircraft noise impact, this study was conducted to estimate the costs of soundproofing dwellings within the L_{dn} 65 noise contours at major U.S. commercial airports. The goal of the study is to achieve an interior sound level of L_{dn} 45 dB. The nation was divided into eleven regions, each one incorporating areas of similar dwelling construction. In this way, it was possible to specify the noise reduction of dwellings on a regional basis, taking local features into account. To determine the distribution of dwelling types in each region, and to obtain detailed information on local dwelling characteristics that affect noise reduction, field surveys were conducted at one airport in each region. The airports surveyed were selected on the basis that the local dwelling characteristics were representative of the respective region. The information obtained was used to identify the types of modifications most suitable for soundproofing dwellings in each region. The selection of soundproofing modifications required for construction elements in each dwelling category in each region was made using a computerized cost optimization procedure to achieve the interior noise criteria at the least cost. The costs for adding a ventilation system, required to replace the natural ventilation that occurs through leaks in the dwelling structure, were then added to the costs for structural modifications to provide an overall cost for soundproofing.

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For

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
Arlington, Virginia 22202

(ORI Subcontract No. 7145)

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTORY SUMMARY	1
1.1	Introduction	1
1.2	Methods of Approach	1
1.3	Results	2
2.0	BASIS FOR NOISE REDUCTION ESTIMATES	3
2.1	General Expressions for Noise Reduction	3
2.2	Structural Element Areas	5
2.3	Room Absorption	8
3.0	RESIDENTIAL CONSTRUCTION CHARACTERISTICS	11
3.1	Construction Types	11
3.2	Development of a Classification Scheme	14
4.0	FIELD SURVEY OF RESIDENTIAL TYPES	20
4.1	Survey Design	20
4.2	Survey Results	22
5.0	SOUNDPROOFING MODIFICATIONS AND COSTS	27
5.1	Soundproofing Requirements	27
5.2	Soundproofing Modifications	29
5.3	Ventilation Requirements	32
5.4	Soundproofing Costs	33
5.5	Soundproofing Cost Optimization	34
5.6	Savings Due to Energy Conservation	35
APPENDIX A:	Derivation of Expression For Noise Reduction	A-1
APPENDIX B:	Development of the EWR Rating Scheme	B-1
APPENDIX C:	Dwelling Construction Distribution By Region	C-1
APPENDIX D:	Tables of Multi-Family Dwelling Data	D-1
APPENDIX E:	Tables of Soundproofing Costs By Dwelling Category and Region	E-1
REFERENCES		R-1

LIST OF TABLES

Table No.		Page
1	Housing Configurations	6
2	Baseline Values of Noise Reduction	19
3	Airports Selected For Field Survey	21
4	Percentages of Dwellings in Each Construction Category and Floor Constructions For Each Region	24
5	Miscellaneous Information For Each Region	25
6	Multi-Family Housing Data For Region C	26
7	Required Increase in Noise Reduction For Dwellings	28
8	Average Cost (In 1981 Dollars) To Soundproof Single-Family Dwellings	36
9	Average Cost (In 1981 Dollars) To Soundproof Multiple-Family Dwellings	37
10	Average Costs for Soundproofing Multi-Family Units For All Regions	38
11	Approximate Savings Due to Energy Conservation in Single-Family Dwellings.	41
D-1	Multi-Family Housing Data For Region A	D-2
D-2	Multi-Family Housing Data For Region B	D-3
D-3	Multi-Family Housing Data For Region C	D-4
D-4	Multi-Family Housing Data For Region D	D-5
D-5	Multi-Family Housing Data For Region E	D-6
D-6	Multi-Family Housing Data For Region F	D-7
D-7	Multi-Family Housing Data For Region G	D-8
D-8	Multi-Family Housing Data For Region H	D-9
D-9	Multi-Family Housing Data For Region J	D-10
D-10	Multi-Family Housing Data For Region K	D-11
E-1	Soundproofing Costs for Region A	E-2
E-2	Soundproofing Costs for Region B	E-4
E-3	Soundproofing Costs for Region C	E-6
E-4	Soundproofing Costs for Region D	E-8
E-5	Soundproofing Costs for Region E	E-10
E-6	Soundproofing Costs for Region F	E-12
E-7	Soundproofing Costs for Region G	E-14
E-8	Soundproofing Costs for Region H	E-15
E-9	Soundproofing Costs for Region J	E-17
E-10	Soundproofing Costs for Region K	E-19
E-11	Soundproofing Costs for Region L	E-21

LIST OF FIGURES

Fig. No.		Page
1	Absorption Characteristics of Dwellings	9
2	Average Absorption Versus Floor Area for Living Rooms and Bedrooms	10
3	Regions of Differing Construction Practices	12
4	Frequency of Use of Common Construction For Region D	15
5	Construction Elements For Dwelling Categories	17
6	Residential Worksheet Used In Field Survey	23
7	Conceptual Illustration of the Three Major Types of Paths By Which Noise Is Transmitted to Building Interiors	31
B-1	Conceptual Illustration of Basis for Standard TL Curve For EWR Concept	B-4
B-2	Typical Highway Noise Spectra	B-5
B-3	Standard Highway Noise Spectrum	B-5
B-4	Calculated Shape For Standard Curve	B-6
B-5	Exterior Wall Rating Standard Contour	B-6
B-6	Aircraft Noise Spectrum	B-7
B-7	Conceptual Illustration of Regression Analysis Results Comparing Interior A-Weighted Noise Levels For Aircraft Computed With Single-Number EWR Method or With Classical TL Method at Each Frequency Band	B-8
C-1	Frequency of Use of Common Construction for Region A	C-2
C-2	Frequency of Use of Common Construction for Region B	C-3
C-3	Frequency of Use of Common Construction for Region C	C-4
C-4	Frequency of Use of Common Construction for Regions D and E	C-5
C-5	Frequency of Use of Common Construction for Regions F and G	C-6
C-6	Frequency of Use of Common Construction for Regions H, J, and K	C-7

1.0 INTRODUCTORY SUMMARY

1.1 Introduction

The exposure of communities to noise produced by commercial airport operations represents one of the most severe environmental noise problems faced by this country today. It is a challenging problem because of the diverse interests involved and the many different possible approaches that can be taken in search of a solution. To date, partial solutions have been achieved by introducing modified flight procedures, night curfews, and other aircraft restrictions – solutions directed at the source of noise. The feasibility of land-use controls and protection of the nearby residents by soundproofing dwellings have also been studied at certain airports. This study is designed to estimate the costs of soundproofing dwellings lying within the L_{dn} 65 dB noise contours at major U.S. commercial airports. It forms one part of an overall systems program currently being conducted by EPA to examine all options for environmental noise abatement. The goal of this soundproofing study is to achieve an interior sound level of L_{dn} 45 dB.

1.2 Method of Approach

The costs for soundproofing dwellings to achieve the stated criteria were developed using the following approach. First, the noise reduction of existing dwellings was calculated and combined with the exterior sound levels from airport operations to determine the existing interior levels. The difference between these levels and the stated criteria represents the additional noise reduction to be provided by soundproofing. The modifications necessary to achieve this additional noise reduction were then identified and costed.

The wide range of dwelling types and constructions found in the U.S. made it necessary to develop a series of categories. Single-family dwellings were classified into four main types – one-story, two-story, bi-level, and split-level. Multi-family dwellings were classified in terms of the number of units contained, the categories being 2, 3 to 4, 5 to 9, 10 to 49, and greater than 50 units per structure. For each dwelling category, interior configurations were defined describing the number and size of rooms, and the type of construction elements, i.e., wall, roof, floor, etc., present in each room. This data formed the basis for the calculation of noise reduction provided by existing dwellings.

To calculate the noise reduction, the sound transmission characteristics of each construction element were specified in terms of a single number, called the EWR rating. The EWR ratings of typical dwelling elements were defined using a classification scheme covering all constructions common to the U.S. The scheme uses the exterior wall and roof construction as the basis for classification, treating other elements as subcategories or potential options that may or may not be present in any dwelling type. The nation was divided into eleven regions, each one incorporating areas of similar dwelling construction. In this way, it was possible to specify the noise reduction of dwellings on a regional basis, taking local features into account.

To determine the distribution of dwelling types in each region, and to obtain detailed information on local dwelling characteristics that affect noise reduction, field surveys were conducted at one airport in each region. The airports surveyed were selected on the basis that the local dwelling characteristics were representative of the respective region. The information obtained was used to identify the types of modifications most suitable for soundproofing dwellings in each region.

The selection of soundproofing modifications required for construction elements in each dwelling category in each region was made using a cost optimization technique to achieve the interior noise criteria at the least cost. The costs for adding a ventilation system, required to replace the natural ventilation that occurs through leaks in the dwelling structure, were then added to the costs for structural modifications to provide an overall cost for soundproofing.

1.3 Results

A summary of the national average costs (in 1981 dollars) for soundproofing dwellings in various noise zones are shown below.

L_{dn} Zone	Number of Units in Dwelling					
	1	2	3-4	5-9	10-49	50
65-70 dB	2,500	800	800	700	700	700
70-75 dB	6,600	2,300	1,900	900	800	800
75-80 dB	13,600	5,100	4,100	1,600	1,200	1,000

2.0 BASIS FOR NOISE REDUCTION ESTIMATES

The first step in determining the soundproofing requirements for dwellings exposed to aircraft noise is to calculate the noise reduction provided by a generalized dwelling structure in terms of its component building elements. The method for performing these calculations is presented in this chapter.

2.1 General Expressions for Noise Reduction

When sound generated by aircraft operations impinges on a dwelling, some of the energy is reflected by the exterior surfaces, and some is transmitted through the dwelling structure to the interior where it is absorbed by room surfaces and furnishings. The resulting sound level inside the dwelling is determined by the balance between the amount of sound energy transmitted through the exterior surfaces and the interior absorption. For a given amount of absorption, the interior sound level depends on the amount of sound energy transmitted, which in turn is related directly to the exterior sound level and the transmission properties of the structure. Increasing the absorption in the dwelling reduces the interior sound level. The difference between the exterior and interior sound levels is called the noise reduction of the dwelling structure.

Sound energy is transmitted through the dwelling structure via two main paths – airborne and structureborne. Airborne paths consist of open windows, vents, cracks around windows and doors, etc., that tend to transmit sound energy at high frequencies more readily than at low frequencies. Structureborne paths include the main dewelling construction elements, such as walls, roofs, windows, and doors. The exterior sound generates vibration in these elements, which in turn radiate sound to the interior. In contrast to the airborne paths, construction elements transmit sound more readily at low frequencies than at high frequencies. Moreover, the amount of sound energy transmitted is inversely related to the mass of the structure – the higher the mass, the less energy transmitted to the interior. The ratio of the sound energy transmitted to that incident on the structure is termed the transmission coefficient. The transmission properties of a structure are commonly stated in terms of the transmission loss, R, which is related to the transmission coefficient, τ, by the simple expression:

$$R = -10 \log \tau \text{, dB} \qquad (1)$$

Since the quantity τ is always less than 1, the transision loss R always takes a positive value. The total sound energy transmitted is proportional to the product of the transmission coefficient and the area of the structure.

If the sound is transmitted from outdoors to a room via a single construction element, such as a wall, it is shown in Appendix A that the interior sound level L_2 is given by the following expression:

$$L_2 = L_1 + 10 \log (\tau S) - 10 \log A + 6 , \text{ dB} \quad (2)$$

where L_1 is the exterior free-field sound level, S is the area of the element, and A is the room absorption. The noise reduction, D, is then

$$D = L_1 - L_2 \quad (3)$$

If the sound is transmitted through "n" such construction elements, then

$$L_2 = L_1 + 10 \log \left(\sum_{i=1}^{n} \tau_i \; S_i \right) - 10 \log A + 6 , \text{ dB} \quad (4)$$

where τ_i and S_i are the transmission coefficient and area, respectively, of the i'th construction element.

Since the value of τ (or R) varies with frequency, the interior sound level L_2 and the noise reduction D will also vary with frequency. It is common practice to specify R in octave or one-third octave bands and to compute the interior sound level separately in each band before combining the levels to obtain the A-weighted level. This relatively simple procedure becomes time-consuming if calculations are required for many different construction types. It is more convenient to assign a single-number value to the transmission loss R that can be inserted into Equations (1) and (2) together with the exterior A-weighted sound level L_{A1} to give the interior A-weighted sound level, L_{A2}. The concept and development of a single number value or rating termed the External Wall Rating, R_E,[1] for the transmission loss of a construction element, is explained in detail in Appendix B. Inserting this value into Equation (4), the expression for the A-weighted interior sound level becomes:

$$L_{A2} = L_{A1} + 10 \log \left(\sum_{i} \tau_{Ei} \; S_i \right) - 10 \log A + 12 , \text{ dB} \quad (5)$$

where $\tau_E = 10^{(R_E/10)}$. The noise reduction is then given by the expression:

$$D = L_{A1} - L_{A2} = -10 \log \left(\sum_{i} \tau_{Ei} \; S_i \right) + 10 \log A - 12 , \text{ dB} \quad (6)$$

Note that an additional constant of 6 dB has been included to account for the spectral characteristics of aircraft noise. Different constants must be included to calculate the interior levels produced by other types of exterior noise sources.[1] The validity of this simplified method has been demonstrated by comparing measured and calculated values of noise reduction for several buildings exposed to aircraft noise.[2]

The calculation of the noise reduction, D, for dwellings exposed to aircraft noise was performed using Equation (6). The values of τ_E are dependent on the type and composition of the dwelling, and were determined from the single-number ratings R_E for each structural element. A full discussion of dwelling types and their construction is given in Chapter 3.0. The following sections in this chapter describe the rationale for selecting values of structural element area S, and absorption A.

2.2 Structural Element Areas

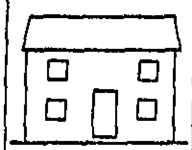
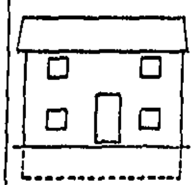
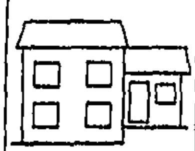
Sound is transmitted from the exterior to the interior via all the structural elements of a dwelling. The amount of sound transmitted by any given element depends on the construction materials and will vary considerably from dwelling to dwelling. Accordingly, to account for all the different types of dwelling common in the United States, it is necessary to include all structural elements as potential paths for sound transmission. These elements are as follows:

- Walls
- Roofs
- Floors
- Windows
- Doors

The noise reduction provided by a given dwelling depends not only on the sound transmission characteristics of each elements, but also on their relative areas – see Equation (6). Since both type of elements and their areas vary from room to room in a dwelling, it follows that the noise reduction is room specific. Therefore, the calculation of noise reduction and subsequent estimates of soundproofing costs must be performed for each room type. Table I shows the configurations of rooms assumed for the four most common types of single-family dwellings – namely, one-story, two-story, bi-level, and split-level. Any of these types have the option of sliding glass doors, so there are eight basic single-family dwelling configurations that must be considered. The remainder of the table indicates the type of elements applicable to each room type. For example, every room in a one-story dwelling has some specified ("Spec." in Table I) roof and floor, but generally only two rooms have doors, one of which may be a sliding glass door. In a two-story dwelling, every upper-level room has a specified roof but no doors. Since the floor

Table I

Housing Configurations

HOUSE TYPE	SGD+	ROOF		FLOOR		DOOR			NO. ROOMS
		Inf.TL	Spec.*	Inf.TL	Spec.*	None	Spec.*	SGD+	
ONE STORY (1500 FT^2) 	Yes		X		X	X			4
			X		X		X		1
			X		X			X	1
	No		X		X	X			4
			X		X		X		2
TWO STORY (2000 FT^2) 	Yes		X	X		X			4
		X			X	X			2
		X			X		X		1
		X			X			X	1
	No		X	X		X			4
		X			X	X			2
		X			X		X		2
BI-LEVEL (1750 FT^2) 	Yes		X	X		X			3
			X	X			X		1
		X		X		X			2
		X		X				X	1
	No		X	X		X			3
			X	X			X		1
		X		X		X			2
		X		X			X		1
SPLIT LEVEL (2000 FT^2) 	Yes		X	X		X			5
			X	X				X	1
		X			X	X			1
		X			X		X		1
	No		X	X		X			5
			X	X			X		1
		X			X		X		1

* Of any specified construction. + Sliding Glass Door.

of an upper-level room is internal to the dwelling, it is not an element for calculation of noise reduction from the exterior and thus is assumed to have an infinite transmission loss. Similarly, the ceiling of a lower-level room is considered to have an infinite transmission loss. The total number of rooms for each type of single-family dwelling were determined from typical dwelling configurations.

The total living areas assigned to each dwelling type in Table I were obtained from statistics developed especially for this study by the National Association of Home Builders (NAHB). The values are averages of over 200,000 single-family dwellings constructed since 1976 – data for earlier years was not available – and may be larger than those for the average dwelling regardless of age. This will tend to result in an underestimate of the noise reduction and a subsequent overestimate of modification costs for soundproofing. Dividing the living areas for each dwelling type by the number of rooms leads to the conclusion that the average room size is about 250 ft^2. Again, this value is large, since it includes an equal pro-rating of the area of corridors, foyers, and other non-assignable space, and assumes that each room is of equal size. To calculate wall areas, it is assumed that each room is 8 feet high and square. The latter assumption introduces an error of less than 5 percent in calculating wall areas for rooms covering a range of reasonable aspect ratios. Thus the dimensions of each room were defined as 16 feet by 16 feet by 8 feet. For single-family dwellings, it was futher assumed that two of the walls, of each room, as well as the roof (where applicable) were exposed to the exterior sound. Using this data together with the configurations shown in Table I, the area of each major construction element was defined. Additional data extracted from NAHB files indicate that average areas for other elements are as follows:

- Windows – 12 percent of wall area
- Doors – 20 ft^2
- Sliding Glass Doors – 40 ft^2

A similar approach was taken in determining configurations and average areas for elements in multi-family dwellings. Each apartment unit in a multi-family dwelling was assumed to consist of four 250-square-foot rooms, representing the living room, kitchen and dining area, and two bedrooms. Units both with and without sliding glass doors in one of the rooms were considered, and combined using a ratio appropriate to the given region. In southern areas a single external entrance door was assumed for each unit in two-story multiple dwellings. In other regions of the country and for all buildings of three or more stories, it was assumed that all entrance doors to the apartment units were internal to the building. Since the basic transmission calculations for a room assume two external walls, correction factors were applied to account for the lesser number of external walls in a multi-family dwelling.

2.3 Room Absorption

The amount of absorption present in a room is determined by the type and number of furnishings, such as carpets, drapes, and furniture, and is specified as the equivalent area, in square feet, of surfaces in the room that absorb all incident sound. To a large extent, the absorption in a room is independent of frequency, as shown by the data in Figure 1 taken in 20 homes of differing sizes in Los Angeles.[1] This is a convenient result, since it allows a straight average value of the absorption to be used in Equation (6) to determine noise reduction. As expected, the data shows that the absorption is greatest in living rooms and least in kitchens, for the reason that living rooms contain many more absorbent furnishings and are larger than kitchens.

For the purposes of this study, it is necessary to determine the average absorption in a room of area 250 ft^2. A search of the published literature was unsuccessful in unearthing any significant body of data on room absorption in dwellings. Accordingly, the average values were based on the data shown in Figure 1. The average value of absorption over the frequency range 250 Hz to 2000 Hz for living rooms and bedrooms (representative of the majority of rooms in a dwelling) is plotted against room size in Figure 2. It can be seen from the regression relationship that there is 300 ft^2 of absorption in a room of size 250 ft^2. Accordingly, the value of $10 \log A$ that is subsequently used in Equation (6) is 25.

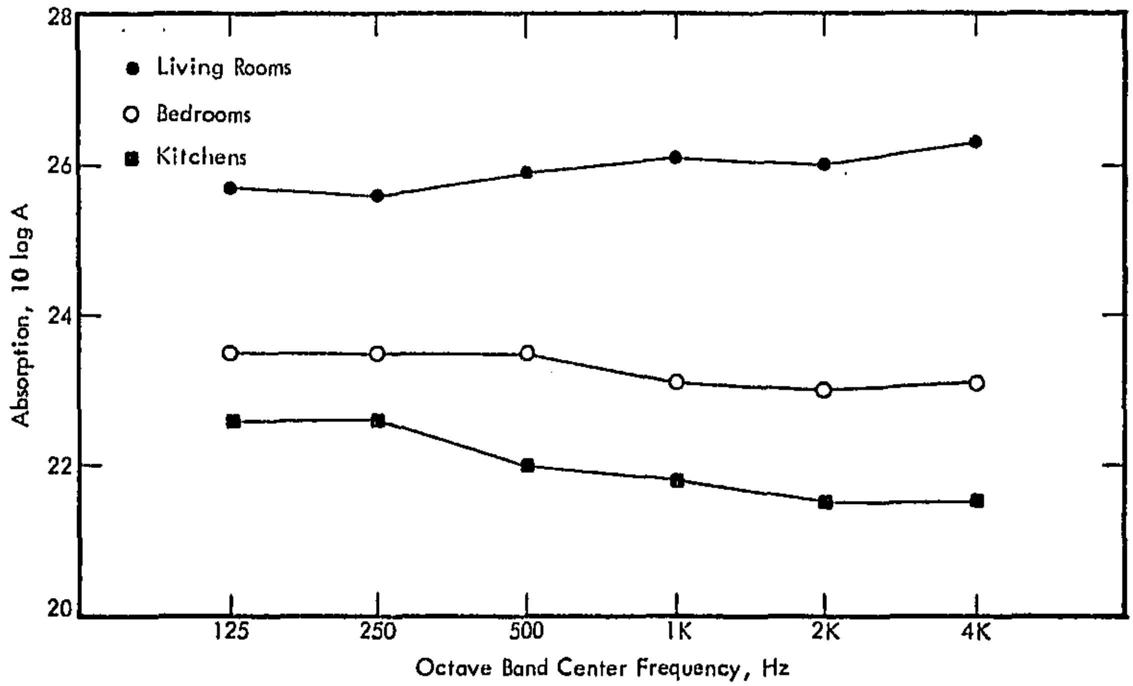


Figure 1. Absorption Characteristics of Dwellings.[1]

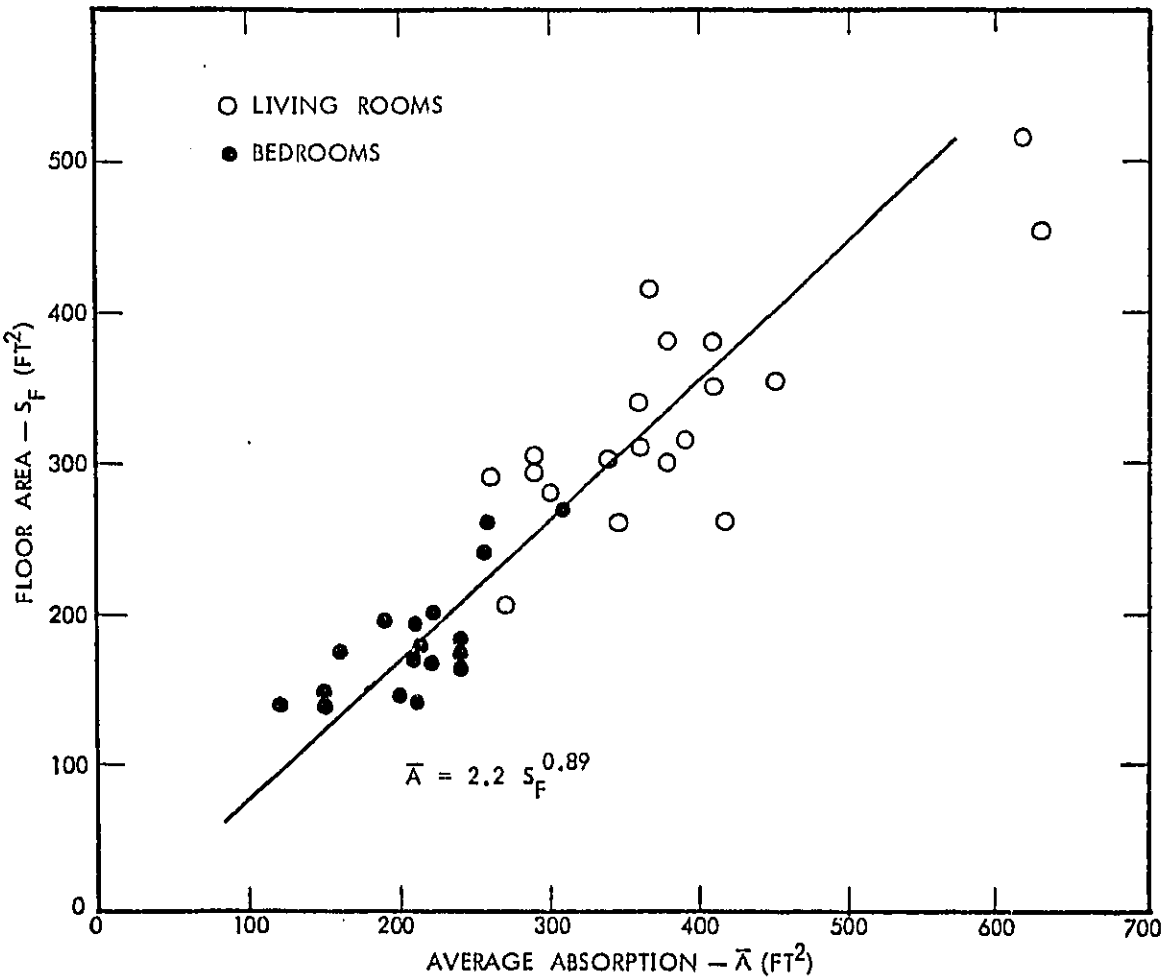


Figure 2. Average Absorption Versus Floor Area for Living Rooms and Bedrooms.

3.0 RESIDENTIAL CONSTRUCTION CHARACTERISTICS

To define the EWR ratings of typical dwelling elements, a classification scheme was developed covering all constructions commonly found in the United States. The scheme uses the exterior/interior wall and roof construction as the basis for classification, treating other elements as subcategories or potential options that may or may not be present in each region. This chapter describes the formation of the scheme, and gives estimates of noise reduction, calculated using Equation (6), for dwellings in each category.

3.1 Construction Types

The patterns for construction of dwellings in different regions of the country are fairly well established and are influenced by factors such as climate conditions, availability of materials and labor, local building codes, design loads (e.g., wind, seismic, or snow), local historical trends, and local economic conditions. In this program, the primary interest is to determine the noise reduction provided by the exterior shells of dwellings. Therefore the construction details required are those that influence the transmission of aircraft noise to the interior of the dwellings. The factors that determine the noise reduction of a dwelling are as follows:

- The type, number, and size of windows and doors;
- The exterior/interior* wall materials;
- The roof/ceiling construction;
- The floor/basement configuration;
- The presence of vents, chimneys, mail slots, etc.;
- The presence of sound leaks at the edges of windows, doors, and other building elements;
- The presence of air-conditioning or ventilation units — central system, through-the-wall, and window units.

In a previous study, an attempt was made to geographically subdivide the nation into six regions in which residential housing construction patterns were fairly homogeneous.[3] Expanding this work to provide a more detailed categorization of construction characteristics, and to include areas outside the contiguous 50 states results in a total of 11 regions as shown in Figure 3. A brief description of each region is given below.

* Interior in this sense means the interior surface material of the exterior wall. Interior walls separating rooms within a residence are not included in this program.

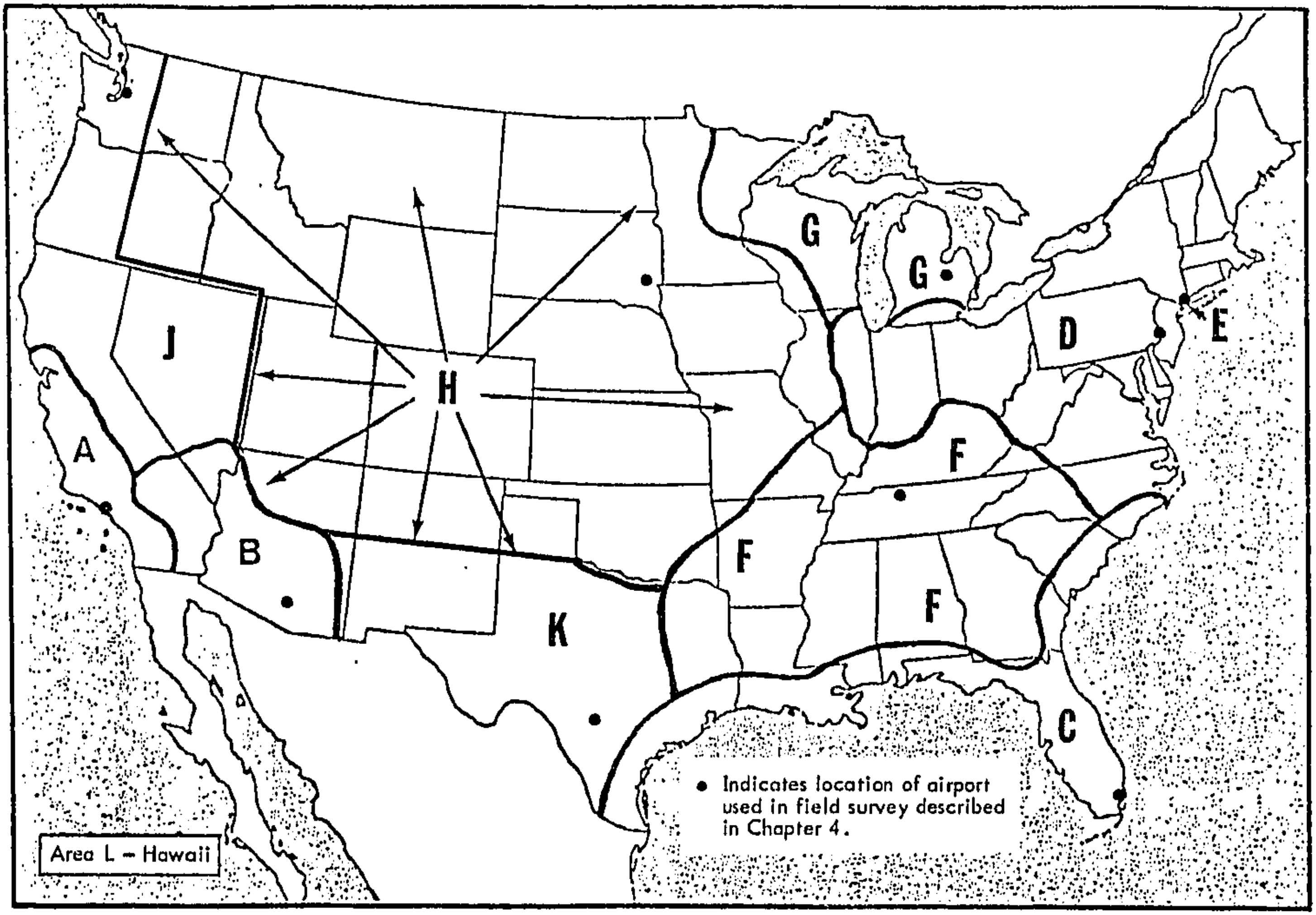


Figure 3. Regions of Differing Construction Practices.

Region A: The Pacific Coastline. The climate is relatively mild as far inland as the Sierra Nevada foothills. Additionally, this region contains three major metropolitan sections: San Francisco–Oakland–San Jose complex, Los Angeles–Orange–Riverside–San Bernardino Counties complex, and the San Diego County area. The population concentration is relatively high, bringing with it the influx of skilled trades. Lumber is plentiful as are aggregates for concrete, and most all other standard building materials, explaining the proliferation of stud-and-stucco construction, modified by the higher cost systems such as brick veneers. The higher economic level of a metropolitan and industrialized area permits use of more expensive methods and materials for aesthetic purposes. Seismicity for this region is high and is an important consideration.

Region B: Inland Southern California, Southern Nevada, and Southwestern Arizona. Climate is a prime factor; hot, dry summers and relatively mild winters. Closely spaced metropolitan areas do not exist. Lumber is imported, but sand and aggregates for concrete block are plentiful. Therefore, in this region, buildings will have a greater percentage of concrete masonry. As a further incentive, concrete block structures are cool in the long summers. The common stud-and-stucco combination is also popular, as in this region it is again the most economical and durable. Additionally, maintenance is low for stucco in relation to wood, which needs paint more frequently.

Region C: The Gulf Coast and Atlantic Coastline. This region enjoys a relatively mild climate with high humidity, and is subject to violent tropical storms. Clay for brick is relatively abundant, as is local lumber. Therefore, less stud-and-stucco construction is used as it is more susceptible to moisture, and the brick and concrete block construction is more popular. When wood framing is used, it is often protected by brick veneer. Because of the high humidity and generous rainfall, concrete block is often protected by exterior plaster.

Region D: Eastern Seaboard and inland to Central Illinois. Both climate and concentration of population comprise the prime influence here. The climate is quite cold for half the year and insulation properties are important. Both brick clay and local lumber are available, and the labor availability in all trades is generally good.

Region E: New York City. Single-family dwellings are similar to those found in Region D, but the central urban area consists largely of row houses and high-rise buildings.

Regions F and G: Central South and Great Lakes (Western) States. Although these regions have considerably different climates, the average construction is similar due to economics. Lumber is local and plentiful, as is clay for brick. Away from metropolitan areas, union influences are not so strong, and carpenters are frequently jack-of-all-trades, laying brick and block, installing gypsumboard or plastering.

Regions H, J, and K: Central States. These regions of different climatic conditons are governed more by economics than by climate. Most parts of this region experience below-freezing winters and hot, moderately humid summers. More important, however, is the commonality that, with the exception of very localized spots such as the Seattle-Tacoma area, there is no concentration of urbanization and industrialization. Consequently, the economy of the region is the prime factor, and materials and construction combinations giving best insulation at least cost are predominant. In this region, the carpenter is frequently the general builder. Material influences are again balanced between the easy transportability of lumber and the general local availability of clay for bricks. Thus the construction norms for different parts of the region are similar for different reasons.

Region L: Hawaii. Generally lightweight construction for walls and roofs, with heavy use of wood products. The climate is mild throughout the year so that insulation is not required.

Additional data contained in Reference 3 as well as other sources[2,4] provide informa-tion on the frequency of use of various construction types for each region and the EWR ratings for each construction. As an example, Figure 4 shows a matrix of building elements developed for Region D with the frequency of use of each construction type indicated on a scale from 0 to 5. A "5" indicates a building element which is used very often; a "0" indicates one which is never used in that area of the country. Similar matrices for the other regions are given in Appendix C. This data is sufficient to define the range of residential constructions for single-family and multi-family residences in each of the geographical areas.

3.2 Development of a Classification Scheme

The first step in developing a classification scheme was to examine the construction matrices applicable to each Region, and eliminate the combinations marked "0", "1", and "2", as these are rarely used in typical dwellings. The remaining combinations of exterior and interior wall constructions were then grouped into categories of the same, or essentially the same, EWR ratings using data from References 2 and 4. The criteria used in this step was to combine construction types with EWR ratings lying within a band 4 dB wide. For example, in Figure 4, exterior materials B and C were combined, as were H and I, since their transmission loss characteristics are very much the same. Similarly,

EXTERIORS	INTERIORS	1/2" Gypsumboard 1	3/8" Gypsumboard 2	2 layers 1/2" Gypsumboard 3	2 layers 5/8" Gypsumboard 4	3/8 Gyp Lath/1/2" Plaster 5	3/8 Gyp Lath/1/8" Plaster 6	1/2" Soundboard/ 1/2" Gypsumboard 7	1/2" Soundboard/ 3/8" Gypsumboard 8	1/2" Plaster 9	3/4" Plaster 10	7/8" Plaster 11	1/4" Plywood Paneling 12	1/2" Plywood Paneling 13	1/4" Hardboard Paneling 14	Exposed Solid Wall 15
Alum. Siding/1/2" Wood	A	2	2	3	3	3	3	3	3	0	2	3	2	1	2	0
7/8" Stucco/Paper	B	2	3	3	3	3	3	3	3	0	2	3	2	1	2	0
7/8" Stucco/1/2" Wood	C	3	3	3	3	3	3	3	3	0	2	3	2	1	2	0
1/2" Wood Siding	D	2	2	2	2	2	2	2	2	0	1	2	2	1	2	0
3/4" Wood Siding	E	4	4	4	4	4	4	3	3	0	2	3	3	1	3	0
4-1/2" Brick Veneer	F	3	3	2	2	3	3	2	2	0	2	3	2	2	2	0
9" Brick	G	5	5	3	2	0	3	3	3	5	3	2	5	2	5	4
4" Concrete	H	1	1	0	0	0	1	1	1	1	0	0	1	0	1	0
6" Concrete	I	2*	2*	1	1	0	2*	2*	2*	2*	2*	1*	2*	1*	2*	0
8" Concrete	J	3*	3*	2*	2*	0	2*	2*	1*	2*	2*	1*	2*	1*	2*	0
6" Hollow Concrete Block	K	2	2	1	1	0	2	2	2	2	2	1	2	1	2	0
8" Hollow Concrete Block	L	2	2	2	2	0	2	2	2	2	2	1	2	1	2	0
6" Block w/1/2" Stucco	M	2	2	1	1	0	2	2	2	2	2	1	2	1	2	0
8" Block w/1/2" Stucco	N	2	2	2	2	0	2	2	2	2	2	1	2	1	2	0

* Multi-Family Dwellings.

Figure 4. Frequency of Use of Common Construction for Region D [3]
(5 is most frequently used; 0 is never used).

interior materials 1 and 2 were combined, as were 3 and 4. In this way, it was possible to develop a manageable number of categories representing the range of exterior/interior wall constructions. The range of roof/ceiling constructions, with or without attics, is fairly limited, and generally follows a well-defined pattern in each community. Accordingly, it was possible to identify five primary roof/ceiling constructions that cover the majority of types in any region. The selected constructions and EWR values for walls and roofs are shown in Figure 5. These form the basic residential categories in the classification scheme. Other building elements were considered as subcategories.

Floor systems can be conveniently divided into three categories – concrete slab, wooden floors over a vented crawl space, and wooden floors over a basement. The concrete slab floor is in direct contact with the ground and hence provides no path for sound transmission. Wooden floors do provide a sound transmission path via side vents or basement windows and doors.

In examining the statistics of data measured nationwide, Sutherland and Sharp[5] have shown that the noise reduction of existing dwellings is primarily a function of the number and orientation of windows. Furthermore, the variation in noise reduction for nominally similar dwellings is probably more a function of the differences in the degree of weather stripping around the windows and doors, and in construction quality, than of the other design details. With good weatherstripping, there is little difference in the sound transmission loss of the different types of single-pane windows. Accordingly, only one category of single-pane window was specified, but two categories of condition were specified, namely:

- Good: As new, with weatherstripping and seals in good or fair condition providing a reasonably tight fit between window and frame.
- Poor: Weatherstripping and seals worn and in need of replacement, providing a loose fit between window and frame.

In areas that experience cold winters, weatherstripping will normally be in good condition; in other areas, the poor condition is more prevalent.

In many areas of the nation it is common to install storm windows in the winter months to provide additional heat insulation and conserve energy. By forming a double window system, storms effectively increase the noise reduction of a dwelling, and hence were considered as a window option in the classification scheme. Although they are often removed in the summer months, storms could be considered as a year-round addition and are available for constant use for noise control.

BASIC CATEGORIES:

EXTERIOR WALLS	EWR (dB)
1. Aluminum or Wood Siding	37
2. Stucco	43
3. Brick or Veneer	54
4. Concrete	58
5. Hollow Concrete Block	49
ROOFS	
1. Vented Attic (With / Without Absorption)	50/47
2. Single Joist – Light	41
3. Single Joist – Heavy	44
4. Exposed Roof – Light	33
5. Exposed Roof – Heavy	39

SUBCATEGORIES:

FLOORS	
1. Slab	∞
2. Vented Crawl Space	49
3. Basement	49
WINDOWS	
1. Double-Strength Glazing	25/28*
DOORS	
1. Hollow Core (HC)	20/22*
2. Solid Core (SC)	24/27*
3. Sliding Glass (SGD)	27/31*

* Poor / Good Weatherstripping Condition

Figure 5. Construction Elements For Dwelling Categories.

Exterior doors are either hollow-core, solid-core, or sliding glass. The condition of weatherstripping as described above for windows was also applied to doors. the presence of storm doors was included as an option. The constructions selected for subcategories together with their respective EWR values are also shown in Figure 5.

3.3 Noise Reduction of Dwellings

The EWR data for dwelling categories was combined with the details on dwelling configurations and room absorption developed in Chapter 2, to calculate the noise reduction of dwellings using Equation (6). The calculations were performed for all possible combinations of construction elements incorporated in the classifications scheme, including the effect of poor/good conditions and storms for windows and doors. The resulting values of noise reduction vary very little with the type of wall, roof, and floor construction, but depend mainly on the type of window and door. This is to be expected from the EWR values of the various elements shown in Figure 5 – the values for windows and doors being considerably lower than those for the other elements. As a result, the baseline values of noise reduction for dwellings can be summarized as shown in Table 2. In this table, the effect of window type enters in the "Storms" column since a "Yes" indicates both storm doors and storm windows. The following facts emerge from this analysis:

- The noise reduction of dwellings lies generally in the range 18 to 27 dB depending only on the type of windows and doors.
- The difference between poor and good conditions is on the order of 2 dB. Clearly, there will be individual situations where extremely poor weatherstripping can result in larger differences.
- The effect of adding storm windows is to increase the noise reduction by about 4 dB.
- The noise reduction for rooms with a door is 4 to 6 dB less than that for rooms without a door. This demonstrates the need to consider all the different room configurations shown in Table 1.

Table 2

Baseline Values of Noise Reduction

DOOR	STORMS	CONDITION	
		POOR	GOOD
HC	NO	18	19
SC	NO	20	21
SGD	NO	20	23
NONE	NO	22	24
SC	YES	24	25
NONE	YES	26	27

HC: Hollow Core

SC: Solid Core

SGD: Sliding Glass Door

4.0 FIELD SURVEY OF RESIDENTIAL TYPES

The soundproofing requirements for dwellings will be based on the existing values of noise reduction shown in Table 2 of the previous chapter. These requirements will vary from region to region due to the difference in housing configurations, construction tyes, and window and door types. A field survey was conducted at one airport in each region to define the regional dwelling characteristics and to verify that the residential categories were all-inclusive.

4.1 Survey Design

The purpose of the field survey was to determine the distribution of dwelling types located within the L_{dn} 65 noise contours at selected airports. One airport was assigned to each region, the selection being based on the populated land area encompassed by the L_{dn} 65 contour, and on the requirement that the dwellings in the local area be somewhat representative of those within the region. The selected airports and the region they represent are presented in Table 3. (The location of each airport is indicated on Figure 3.)

The L_{dn} 65, 70, 75, and 80 noise contours for each of the 10 airports were developed by ORI using Version 2.7 of the Integrated Noise Model. These contours were transferred to local USGS maps for each airport to define the boundaries of the field survey. The populated land areas within the L_{dn} 65 contours for the larger airports, i.e., LAX, MIA, PHL, LGA, and SEA, were too extensive to permit a complete survey of dwelling types. Accordingly, the following sampling procedure was established for these airports:

- Sample areas approximately one-half mile square were selected for each area containing a homogeneous distribution of dwelling types.
- Sample areas were selected for populated land areas lying between the L_{dn} 65 and 70, 70 and 75, 75 and 80, and 80 to 85 dB contours.
- Each sample area was assigned to one or more census tracts.
- The distribution data obtained from each sample area were weighted by the number of dwellings in the assigned census tract and then summed to provide the distribution for the entire contour area.

For the remaining smaller airports, the land areas encompassed by the L_{dn} 65 contours were sufficiently small to allow a complete survey of the entire area. No field survey was conducted for Region L – Hawaii: the data for this region were collected by contacting local building departments and contractors.

Table 3

Airports Selected For Field Survey

Airport (Designation)	Region
Los Angeles (LAX)	A
Tucson (TUS)	B
Miami (MIA)	C
Philadelphia (PHL)	D
LaGuardia (LGA)	E
Nashville (BNA)	F
Lansing (LAN)	G
Sioux Falls (FSD)	H
Seattle (SEA)	J
San Antonio (SAT)	K

The data were collected using the worksheet shown in Figure 6. In each sample area, each dwelling was entered onto the worksheet in the appropriate square of the wall/roof matrix, and identified by a number 1 through 4 corresponding to the dwelling type. A separate worksheet was used for each street within the sample area, the information at the bottom of the page being a summary for the particular street.

4.2 Survey Results

The results of the survey for single-family dwellings are given in Tables 4 and 5. Table 4 shows the percentage of dwellings in each construction category together with floor constructions for each airport. Table 5 presents the other relevant data necessary to determine the soundproofing requirements in each region. All percentages have been rounded to the nearest five percent. Similar data for multi-family dwellings is presented in Appendix D. An example of this data for Miami International Airport (Region C) is shown in Table 6. In many cases, the data sheets show blank entries where the field survey showed no dwellings of a certain category.

Comparing the data in Table 4 with the discussion of regional dwelling characteristics in Chapter 3 shows fairly good agreement. One interesting fact that emerged from the survey is that the distribution of dwelling types and the condition of the dwellings was essentially the same in all L_{dn} zones. There was no apparent overall deterioration of dwellings in the higher L_{dn} zones – on the contrary, at several airports, expensive single- and multi-family dwellings were located inside the L_{dn} 65 and 75 contours, some of them currently under construction. Since the survey was limited to areas lying within the L_{dn} 65 contour it is not possible to draw any general comparisons with dwelling types and conditions in other areas of the cities visited.

CITY: ____________ DATE: ________ L_{dn}: 65 70 75 80 85

SAMPLE AREA: ____________ STREET NAME: ________________

COMMENTS: ______________________________________

____

____

ROOF \ WALL		Alum. or Wood Siding	Stucco	Brick Veneer	Concrete	Hollow Concrete Block	Brick Veneer/ Siding
VENTED ATTIC							
SINGLE JOIST	LIGHT						
	HEAVY						
EXPOSED CEILING	LIGHT						
	HEAVY						
STORM DOORS							

House Types:

Type 1: One-Story

Type 2: Two-Story

Type 3: Bi-Level

Type 4: Split-Level

Condition (Good/Poor): ____________

Forced-Air Systems: ________ %

Sliding Glass Doors: ________ %

Window A/C Units: ________ %

Doors (HC/SC): ________ %

Mobil Homes: ____________

Chimneys: ________ %

Average Price: $ ____________

Heating Fuel: Oil ____ Gas ____ Elec ____, %

Figure 6. Residential Worksheet Used in Field Survey.

Table 4

Percentages of Dwellings in Each Construction Category
And Floor Constructions For Each Region

CONSTRUCTION CATEGORY *	REGION AND AIRPORT										
	A	B	C	D	E	F	G	H	J	K	L
	LAX	TUS	MIA	PHL	LGA	BNA	LAN	FSD	SEA	SAT	HI
SIDING / VA	15	--	15	30	15	15	40	55	60	60	--
" / SJL	--	--	--	35	50	--	45	30	30	--	100
" / ECL	--	--	--	--	--	--	--	--	5	--	--
STUCCO / VA	80	5	--	--	--	--	--	--	--	5	--
" / SJL	5	5	--	--	--	--	--	--	--	--	--
BRICK / VA	--	80	--	10	5	80	10	--	5	35	--
" / SJL	--	10	--	10	10	5	5	--	--	--	--
" / SJH	--	--	--	--	15	--	--	--	--	--	--
CONCRETE / VA	--	--	--	5	--	--	--	10	--	--	--
" / SJL	--	--	--	10	5	--	--	5	--	--	--
HC BLOCK / VA	--	--	75	--	--	--	--	--	--	--	--
" / SJL	--	--	10	--	--	--	--	--	--	--	--
SLAB FLOOR	50	100	75	15	5	--	10	5	--	90	100
CRAWL SPACE	50	--	25	5	10	15	--	--	50	10	--
BASEMENT	--	--	--	80	85	85	90	95	50	--	--

* VA – Vented Attic; SJL – Single-Joist Roof, Light; SJH – Single-Joist Roof, Heavy; ECL – Exposed Ceiling, Light.

Table 5

Miscellaneous Information For Each Region
(Numbers Expressed as Percentages)

MISCELLANEOUS INFORMATION	REGION AND AIRPORT										
	A	B	C	D	E	F	G	H	J	K	L
	LAX	TUS	MIA	PHL	LGA	BNA	LAN	FSD	SEA	SAT	HI
CONDITION-- GOOD / POOR	60/40	70/30	75/25	70/30	60/40	85/15	60/40	55/45	65/35	80/20	50/50
SLIDING GLASS DOORS	20	--	10	10	10	10	15	5	30	75	60
DOORS-HC/SC *	25/75	35/65	5/95	-/100	-/100	-/100	5/95	-/100	45/55	25/75	10/90
FORCED AIR SYSTEMS	30	90	40	60	10	70	85	95	60	95	--
STORM WINDOWS	--	--	--	40	80	80	5	85	--	10	--
STORM DOORS	--	--	--	50	80	80	95	95	80	10	--
HEATING FUEL:											
OIL	10	--	--	50	70	--	5	--	30	--	--
GAS	90	80	--	50	20	25	95	100	40	95	--
ELECT.	--	20	100	--	10	75	--	--	30	5	--
WINDOW AIR CONDITIONING	5	10	60	40	40	40	5	10	--	15	10

* Hollow Core / Solid Core

Table 6

Multi-Family Housing Data For Region C
(Numbers Expressed As Percentages)

	NUMBER OF UNITS 2	3–4	5–9	10–49	≥50
NUMBER OF STORIES:					
TWO	100	100	100	50	
THREE				50	20
FOUR OR MORE					80
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA					
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA	20	20	40	40	
CONCRETE / SJL	80	80	60	60	100
CONCRETE / SJH					
SGD	20	20	20	30	80
WINDOW A/C UNITS	60	60	80	80	80
FUEL:	ELECTRICITY: 100 GAS: OIL:				

5.0 SOUNDPROOFING MODIFICATIONS AND COSTS

The criterion established for this soundproofing study required that the interior sound level in dwellings exposed to noise from aircraft operations shall not exceed L_{dn} 45 dB. This chapter describes the analysis performed to define the modifications necessary to satisfy this criteria and presents estimates of the cost of these modifications.

5.1 Soundproofing Requirements

The degree of soundproofing required to satisfy the interior noise criteria depends on the exterior sound level and the dwelling construction characteristics. The minimum sound level to be considered for the soundproofing program is L_{dn} 65; the maximum is L_{dn} 80 since virtually no dwellings were noted in areas exposed to higher levels. For the purpose of defining soundproofing requirements, this range of levels was divided into three 5 dB ranges centered on L_{dn} values of 67.5, 72.5, and 77.5 dB.

Using these exterior sound levels and the baseline noise reduction values for dwellings shown in Table 2, the required increase in noise reduction was calculated. The results are presented in Table 7, for dwellings having different window and door types, without and with storms. The field data on window and door types (see Chapter 4) was averaged over the 10 surveyed airports to provide weighting factors for each configuration shown in Table 7, from which the national average additional noise reduction was determined.

A review of Table 7 shows that only 1 dB of additional noise reduction is required, on average, for dwellings exposed to L_{dn} 67.5 dB, the mid-point of the L_{dn} 65 to 70 dB zone. In fact, no increase at all is required for dwellings with storm windows and doors. At a level of L_{dn} 77.5 dB, however, an average increase of 10 dB is required, with individual rooms requiring up to 15 dB. It should be noted here that the average data presented in Table 7 is for illustrative purposes only. The requirements for each dwelling type included in the field survey were calculated separately to determine the total cost of soundproofing.

The required increases in noise reduction specified in Table 7 assume that the exterior dwelling surfaces are exposed directly to the source of sound – namely, aircraft operations. In many cases, at least one of the four walls of a single-family dwelling will be facing away from the airport and hence will be shielded from the source of sound. Measurements indicate that the sound level on the shielded side of a dwelling is about 10 dB less than that on the exposed side.[3] Accordingly, for rooms on the shielded side, the

Table 7

Required Increase in Noise Reduction For Dwellings

		L_{dn} ZONE MID-POINT, dB		
		67.5	72.5	77.5
NO DOOR	POOR	0.5/0 +	5.5/1.5	10.5/6.5
	GOOD	0/0	3.5/0	8.5/4.5
H C DOOR	POOR	4.5/0.5	9.5/5.5	14.5/10.5
	GOOD	3.5/0	8.5/4.5	13.5/9.5
S C DOOR	POOR	2.5/0	7.5/3.5	12.5/8.5
	GOOD	1.5/0	6.5/2.5	11.5/7.5
SGD	POOR	2.5/0	7.5/3.5	12.5/8.5
	GOOD	0/0	4.5/0.5	9.5/5.5
AVERAGE VALUES *		1	5	10

+ NO STORM WINDOWS / WITH STORM WINDOWS

* National Average

values of increased noise reduction shown in Table 7 can be reduced by 10 dB. Because of the uncertainty involved in predicting the number of shielded rooms in a dwelling, this factor was not included in estimating soundproofing costs.

5.2 Soundproofing Modifications

A selection of the modifications required to achieve L_{dn} 45 dB can be made by considering the three basic paths by which sound enters the building, namely via

- air filtration paths (gaps and cracks);
- small wall elements (windows and doors); and
- main wall elements (walls, roofs, and floors).

These paths are illustrated conceptually in Figure 7.

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 EWR of the walls is relatively high. The calculated values of noise reduction presented in Chapter 3 include both "poor" and "good" conditions, although it is possible to note lower values in extreme cases. The improvement in noise reduction that can be obtained merely by treating the leakage paths without modifying the windows, doors, or other building elements was shown to be on the order of 2 dB, but could be as high as 5 dB depending on the condition of weatherstripping and seals. Thus the first step in increasing the noise reduction of residences is to seal all infiltration cracks using weatherstripping, non-hardening caulking, and door threshold seals. This is termed Stage I soundproofing. If the sealing of cracks and leaks does not achieve the desired interior levels, then modifications of the building elements are required.

Since small wall elements such as windows and doors usually have EWR values less than that of the surrounding wall, they must usually be modified in the second stage of soundproofing. This second stage should upgrade small wall elements to an EWR which approaches that of the surrounding wall. This is achieved by replacement with improved elements and can result in noise reduction 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 EWR values, but they must remain in place if the benefits are to be realized year-round. In this stage of soundproofing, it is usually necessary to install acoustic baffles in the air vents, chimneys, and kitchen ducts.

The final alternative, if the previous two stages do not provide adequate noise reduction, is modification of the main wall elements, the basic wall and roof construction.

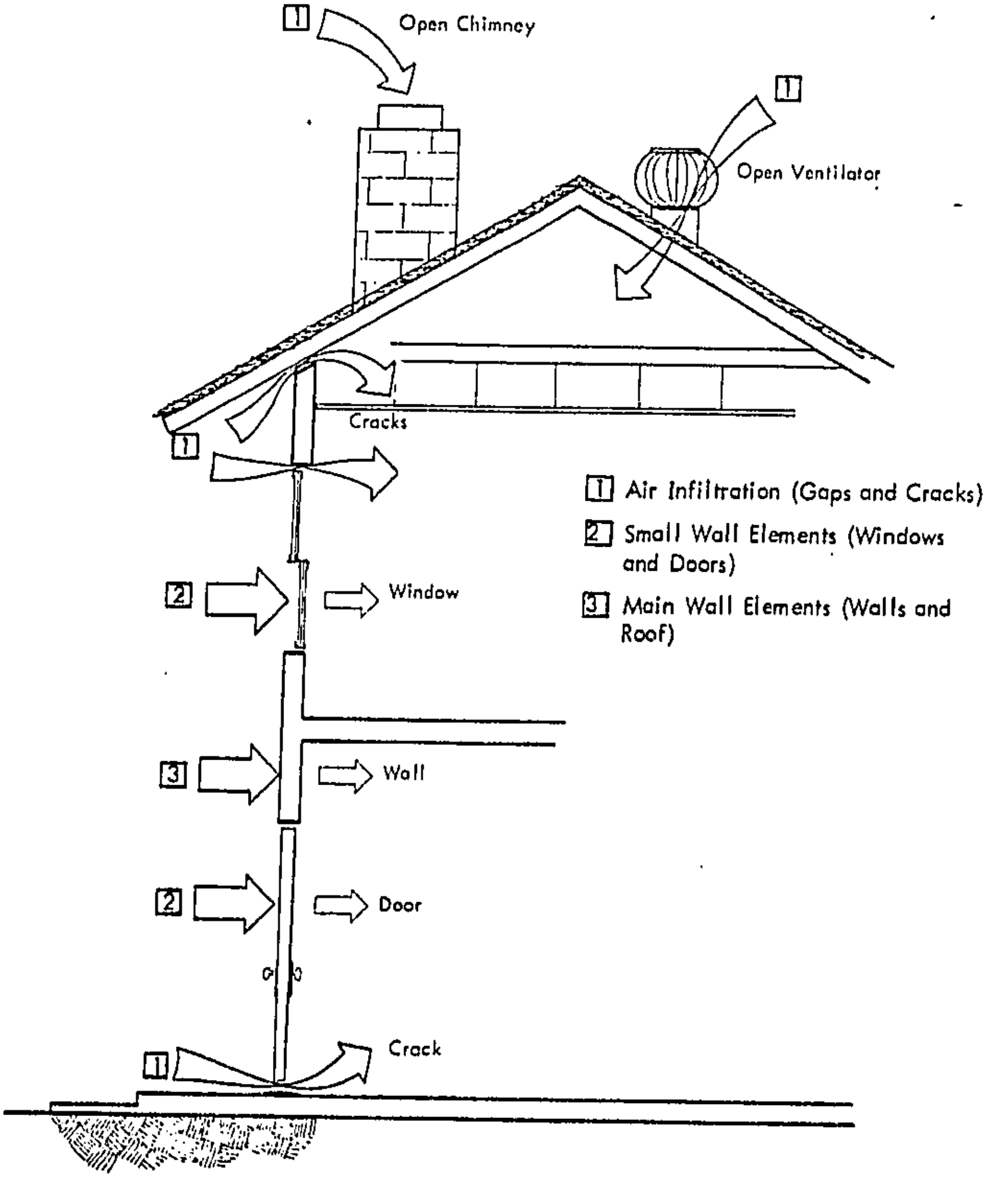


Figure 7. Conceptual Illustration of the Three Major Types of Paths By Which Noise is Transmitted to Building Interiors.

This major noise-attenuating technique can provide the substantial increases in noise reduction that may be required in the noisiest areas. This is termed Stage 3 soundproofing.

The above description of the requirements for soundproofing dewellings is general and thus subject to changes for individual dwelling types. For example, it may be necessary to modify windows, doors, and roofs to achieve a 5 dB increase in noise reduction in cases where the roof forms a major sound transmission path.

The specific modifications considered for soundproofing the various construction elements of single- and multi-family dwellings are as follows:[6,7]

WALLS:

(1) Add a single layer of drywall cemented to the interior surface.

(2) As (1) plus sound-deadening board cemented to the interior surface.

(3) Add a single layer of drywall to the interior surface on resilient channels with absorption in cavity.

(4) Add single layer of drywall to the interior surface on metal studs.

(5) As (4) with absorption in cavity.

ROOFS:

(1) Add insulation to the attic space.

(2) As (1) plus a single layer of drywall applied to the top of the ceiling joists.

(3) As (2) plus seals applied to eave openings and install vents with absorbent linings

(4) Add a single layer of drywall to the underside of the ceiling.

(5) As (4) but apply on resilient channels.

(6) Remove existing ceiling and replace with two layers of drywall on resilient channels.

WINDOWS (BASELINE: SINGLE–STRENGTH GLAZING):

(1) Replace/add weatherstripping.

(2) Add edge seals to openable sections; seal fixed sections.

(3) Add storm windows.

(4) Add edge seals and storm windows.

(5) Add a second window (double strength) at a spacing of 4 inches.

(6) As (5) but use 1/4-inch glazing.

DOORS (BASELINE HOLLOW-CORE DOOR):

(1) Replace/add weatherstripping.
(2) Add a storm door.
(3) As (1) plus add a storm door.
(4) Replace with solid-core door and vinyl bulb edge seal.
(5) As (4) plus a storm door.
(6) Replace with an acoustical door.
(7) As (6) plus a storm door.

FLOORS:

(1) Add absorption to the underfloor surface.
(2) Add absorbent lined vents to the crawl space openings.
(3) As (1) plus (2).
(4) Replace weatherstripping on basement door and windows.
(5) As (4) plus add storm windows.

5.3 Ventilation Requirements

As noted above, air leakage paths are the controlling factor for noise reduction in dwellings. Attempts to achieve benefits by structural modifications are wasted if air leakage paths are not first treated. However, once air leaks are sealed, ventilation must be provided by other means in order to preserve the interior air quality. In warm or humid climates, air conditioning may also be required, and energy must be expended to move and condition the air.

The exchange of the air inside a building with fresh outside air is a natural and necessary process. It is necessary in order to rid the building of air which has a high density of carbon dioxide, to clear the air of contaminants such as smoke from cigarettes, cooking and heating by-products, dust, etc., in order to make the inside space more comfortable for the inhabitants. Currently, residential buildings in the U.S. have air infiltration rates of one to two air changes per hour.[8] An accepted general ventilating practice suggested by the American Society of Heating, Refrigeration, and Air Conditioning Engineers calls for a minimum of one change per hour and greater in areas of heavy smoking. However, homes have been built in Canada, Sweden, and the U.S. with air infiltration rates on the order of one-quarter air change per hour. While reducing the air infiltration rate to this low level does indeed lower the energy usage, there are health hazards associated with it which must be taken into account.[9] These problems include increased odors from human activity, increased humidity in the building, and increased chemical contamination such as formaldehyde and Radon produced from the outgassing of the building materials—especially masonry products—i.e., bricks, blocks, etc.

For the purposes of this study the criteria for ventilation has been selected at two air-changes per hour to provide adquate removal of smoke and odors. A mechanical system with a fan is required to achieve this criteria — natural ventilation via ducts being much less reliable for obtaining the required air flow. The most effective way to provide ventilation is by means of a forced-air system, consisting of a central fan and plenum with ducts to each room and one or two central return ducts. Fresh air is introduced through a duct from the dwelling exterior, and stale air is exhausted through a second duct. A damper is installed to control the proportion of fresh air introduced. Such a system is preferable to individual ventilation units in each room, since the single inlet and exhaust can be located on the shielded side of the dwelling to reduce sound transmission along the ducts to the interior. It is, of course, necessary to line the ducts with acoustic absorbing material to minimize sound transmission. Dwellings with existing forced-air systems require only the addition of the inlet and exhaust ducts and a plenum.

In many older dwellings, window- or wall-mounted air-conditioner units have been installed to provide cooling in the summer months. It is possible to install baffled vents lined with acoustic absorbing material to achieve adequate noise reduction from exterior sound levels up to L_{dn} 70 dB. At higher exterior levels, the units must be removed and replaced with a central system.

5.4 Soundproofing Costs

The costs associated with each modification were estimated in 1981 dollars using the following references:

- 1981 Residential Cost Manual – New Construction, Remodeling and Valuation.[10]
- Building Construction Cost Data, 1981.[11]

For each element, the costs per square foot were determined from the quoted subcontractor's prices that include overhead and profit. Included are the costs for preparation, temporary removal of furniture, etc., modification, finishing, and clean-up. Material and labor prices are based on national averages. No account has been made for bulk purchase of materials.

In addition to the basic costs for materials and labor, the following mark-ups are included:

• Cost of architectural drawings, permits, etc.[12]	=	10%
• Miscellaneous costs for sealing leaks, modifications to kitchen vents, chimneys, etc., and minor repairs to existing structure[12]	=	10%
• Contractor's contingency[10,11]	=	10%
Total Mark-up	=	30%

5.5 Soundproofing Cost Optimization

Having determined the amount and stage of soundproofing required for each residential category in each L_{dn} noise zone, the next step was to define the details of the necessary modifications so that the costs can be determined. There are, of course, many combinations of modifications that are suitable to achieve a given increase in overall noise reduction. For example, in the case of a structure containing a wall and window, it may be possible to achieve the noise reduction goal by increasing the transmission loss of either the wall or the window, or both elements. The most efficient modification will be the one with the lowest overall cost. Usually, when developing the soundproofing requirements for one or two dwelling types, the cost optimization is performed manually by trying various options and selecting the one that is least costly. In this program, such a procedure is impractical because of the large number of residential categories, room elements, modifications, and noise zones. It was therefore necessary to develop computerized methods for determining the least cost soundproofing design. A cost optimization model recently developed by the National Bureau of Standards was examined for use in this program.[13] The model contains a series of linear regression lines, one for each building element, relating the cost of the element to its STC* rating. By introducing the area of each element and the desired overall value for STC, the model provides the STC values for the room elements that result in the minimum cost for the overall structure.

In its current form, the model performs a cost optimization for satisfying a given STC requirement. As the STC rating is appropriate only for interior walls and floor/ceilings, it would be necessary to develop new regression lines relating the cost of building elements to the EWR value. In addition, the model assumes a linear relation

* Sound Transmission Class.[14]

between STC increase and cost – a rather dubious assumption at best. Because of the effort required in developing non-linear relationships between EWR changes and cost would be greater than that needed to deveop a more straightforward technique, it was decided to design an alternate computerized cost optimization algorithm.

Basically, a "brute force" technique was chosen to minimize modification costs for each room element (e.g., window, door, wall, ceiling, and floor). The EWR increases and associated costs of up to 10 possible modifications of up to 15 existing element constructions were determined. Computer software was then developed to calculate the total EWR increase for all possible combinations of these modifications for a given set of existing room element constructions. The least expensive combination of modifications which produced a total EWR increase equal to or greater than that required was identified by the computer program and printed out. This program was then exercised for all combinations of existing room element constructions to develop a minimum room cost matrix as a function of present construction. A sequence of such matrices were computed providing noise reductions to an interior level of 45 dB from exterior levels of 67.5, 72.5, and 77.5 dB.

Once this data base of minimum room costs was obtained, additional computer software was developed to combine rooms of various construction into larger units such as apartments in multiple unit dwellings and single-family homes. Weighted averages of these dwelling units over construction type for each area of the country were computed using weighting functions derived from field survey data. The result was a single average cost for each dwelling type for each of the three noise zones in each of the regions of the country. The costs for adding ventilation systems, where necessary, were added to the costs for soundproofing, and the total multiplied by the factor of 1.3 to account for mark-ups. The final overall costs are listed by construction category for each region in Appendix E. Summaries of the average costs for each region, weighted by the distribution of construction categories, are presented in Tables 8, 9, and 10.

5.6 Savings Due to Energy Conservation

A review of energy considerations in buildings shows that modifications of structural elements to increase the noise reduction generally reduces energy losses.[15] The steps involved in soundproofing a building against exterior noise are the same as those for reducing energy losses – namely, first to eliminate air leaks, second to modify windows and doors, and third to modify the main structural elements. Therefore it is expected that the soundproofing requirements identified in Section 5.3 will have added benefits in conserving energy and reducing operating costs.

Table 8

Average Cost (In 1981 Dollars) Per Dwelling
To Soundproof Single-Family Dwellings

L_{dn} ZONE	REGION										
	A	B	C	D	E	F	G	H	J	K	L
65–70 dB	2,600	1,400	2,300	2,500	4,800	1,800	2,500	1,100	2,700	2,100	3,800
70–75 dB	5,800	3,100	5,400	7,400	9,500	3,800	8,500	5,000	7,700	6,000	10,400
75–80 dB	12,800	8,200	11,000	15,100	18,000	10,000	16,100	13,600	14,900	11,700	18,200
Additional Cost For Air-Conditioning	1,500	800	400	1,000	1,600	400	1,300	1,700	2,500	700	2,600

Table 9

Average Cost (In 1981 Dollars) Per Dwelling
To Soundproof Multiple-Family Dwellings

TWO DWELLING UNITS

L_{dn} ZONE	REGION										
	A	B	C	D	E	F	G	H	J	K	L
65-70 dB	800	900	800	700	700	800	800	700	800	800	800
70-75 dB	2,900	1,900	2,000	1,200	1,200	3,400	3,400	1,200	2,600	2,600	2,500
75-80 dB	7,000	5,000	5,100	3,000	3,000	6,500	6,500	3,000	5,600	5,700	5,200

THREE TO FOUR DWELLING UNITS

L_{dn} ZONE	REGION										
	A	B	C	D	E	F	G	H	J	K	L
65-70 dB	800	900	800	700	700	700	700	700	800	800	800
70-75 dB	2,200	1,700	1,700	1,000	1,000	2,700	2,700	1,000	2,200	2,200	2,200
75-80 dB	5,300	4,200	4,200	2,500	2,500	5,100	5,100	2,300	4,500	4,800	4,800

Average Cost For Additional Air Conditioning = $400 Per Unit

Table 10

Average Costs (in 1981 Dollars) for Soundproofing
Multi-Family Dwellings (5 Units Per Structure)
For All Regions

L_{dn} ZONE	NO. OF UNITS		
	5–9	10–49	>50
65–70	700	700	700
70–75	900	800	800
75–80	1,600	1,200	1,000

Average Cost for Additional Air Conditioning
= $400 Per Unit

The methods for estimating the potential cost savings attributable to the soundproofing treatment involve analyses of the balance from heat energy losses and gains by convection and conduction. The former are defined by the net heat flow of the natural and/or forced ventilation and air leakage. The second part, heat losses by conduction through the structural surfaces, utilizes well-defined data on thermal conductances through all types of building structure.

To estimate the net energy and cost savings from soundproofing dwellings, Wyle has developed a standard worksheet which is used with a series of accompanying data tables.[4] The procedure involves adding the energy savings (in Btu/year) due to sealing air leaks to the savings due to modifications of structural elements, and then to convert the total savings to the amount of fuel saved per year. The net cost savings due to soundproofing were then determined using fuel prices, subtracting the energy costs for mechanical ventilation units (if any). The data necessary for these calculations have been obtained and developed by Wyle, and are available in tabular form.

The costs for fuel vary considerably within each region, and hence the values used in this analysis were national averages for April 1981 obtained from the National Energy Information Center. The costs are as follows:

- Oil – $1.24 per gallon
- Gas – $4.22 per 1000 cubic feet
- Electricity – $0.06 per kWh.

The cost savings were determined for typical dwellings in each of the cities representing the eleven regions, using the data collected in the field surveys. The general soundproofing modifications for dwellings included in the analysis were as follows:

- L_{dn} 65 to 70 dB: Sealing leaks and improving weatherstripping.
- L_{dn} 70 to 75 dB: As above, plus installation of storm windows, storm doors, and roof insulation, where necessary.
- L_{dn} 75 to 80 dB: As above, plus modification of walls to include addition of insulation, where necessary.

The estimated cost savings due to energy conservation in single-family dwellings are shown in Table 11. Because of the considerable variation in fuel costs in different areas of the nation, and within each region, the breakdown in Table 11 should be considered as only approximate. However, the national average value may be taken as an indication of the savings resulting from soundproofing modifications. The variation from region to region reflects the difference in climate, and estimates of the insulation already existing in dwellings. The cost savings for multi-family dwellinngs are approximately one-half, one-third, and one-quarter of those for single-family dwellings located in L_{dn} zones 65–70, 70–75, and 75–80 dB, respectively.

Table 11

Approximate Savings (In 1981 Dollars)
Due to Energy Conservation in Single-Family Dwellings

LOCATION OF DWELLING L_{dn} ZONE	AVG. NR * (dB)	REGION											AVG.*
		A	B	C	D	E	F	G	H	J	K	L	
65–70 dB	1	0	10	(20)	70	90	80	50	30	90	10	(20)	40
70–75 dB	5	70	50	0	190	170	180	160	50	320	80	(20)	130
75–80 dB	10	170	70	10	520	440	320	420	110	620	170	(20)	290

Numbers in parentheses indicate negative savings.

* National average noise reduction (see Table 7).

REFERENCES

1. Mange, G.E., Skale, S.R., and Sutherland, L.C., "Background Report on Outdoor–Indoor Noise Reduction Calculation Procedures Employing the Exterior Wall Noise Rating (EWR) Method", U.S. Department of Tansportation Report FHWA-TS-77-220, prepared by Wyle Research, March 1978.

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14. American Society for Testing & Materials, "Standard Classification for Determination of Sound Transmission Class", ASTM Standard E-413-73, Annual Book of ASTM Standards, 1979.

15. Sharp, B.H., Kasper, P.K., and Montroll, M.L., "Sound Transmission Through Building Structures – Review and Recommendations for Research", National Bureau of Standards Report NBS-GCR-80-250, prepared by Wyle Laboratories, July 1980.

APPENDIX A

Derivation of Expressions For Noise Reduction

When a sound wave impinges on an interface between air and a solid, as it does in the case of a structural wall, some of the acoustic power is transmitted through the structure and the rest is reflected. The fraction of acoustic power that is transmitted is called the transmission coefficient, τ. Since τ is always less than 1, it is convenient to use its reciprocal in logarithmic notation as follows to define the transmission loss (TL):

$$TL = 10 \log_{10} (\tau)^{-1} \text{ , dB} \qquad \text{(A1)}$$

The sound intensity I_1 produced at a distance from a source, such as an aircraft, assuming free, progressive, plane wave propagation, can be expressed as follows:[A1]

$$I_1 = \frac{p_1^2}{\rho c}$$

where p_1^2 is the exterior free-field mean square sound pressure, and ρc is the characteristic impedance of the air. The sound power W incident on a dwelling surface of area S is given simply by $W_1 = I_1 S$.

The sound power W_2 transmitted to the interior of the dwelling through the surface of area A is

$$W_2 = \tau I_1 S = \tau S \frac{p_1^2}{\rho c} \qquad \text{(A2)}$$

The steady-state intensity I_2 inside the dwelling, assuming a reverberant sound field, can be written as:[A1]

$$I_2 = \frac{W_2}{A} = \frac{p_2^2}{4\rho c} \qquad \text{(A3)}$$

where A is the absorption in the dwelling, and p_2^2 is the space-averaged mean square sound pressure in the dwelling.

Combining Equations (A1), (A2), and (A3) results in the following expression for the noise reduction D:

$$\begin{aligned} D &= L_1 - L_2 \\ &= 10 \log (p_1^2 / p_2^2) \\ &= 10 \log (A / 4\tau S) \\ &= -10 \log (\tau S) + 10 \log A - 6 \qquad \text{(A4)} \end{aligned}$$

APPENDIX B

Development of the EWR Rating Scheme[B1]

The purpose of the EWR scheme for rating the transmission loss of dwelling elements is to provide a simplified method for calculating the interior A-weighted sound level by merely subtracting the EWR value from the exterior A-weighted sound level and applying a single-number correction for absorption. Such a procedure eliminates the need for tedious calculations in each octave or one-third octave bands.

B-1 The EWR Concept

In developing the single-number EWR rating, two basic principles were employed: (1) restrict the outdoor noise spectrum to a constant shape varying only in level, and (2) approximate the actual transmission curve for a structure in terms of an ideal TL curve which would filter the outdoor spectrum such that the resulting interior spectrum has the inverse shape of the A-weighting curve. Then when the interior spectrum is A-weighted, each one-third octave band would contain equal energy and therefore be equally important in determining the interior A-weighted noise level. This facilitates the prediction of interior A-weighted noise levels and noise reduction.

The problem is conceptualized in Figure B-1. Consider, for the moment, that the exterior noise spectrum exhibits a shape similar to that shown in the figure. It is desired, then, that the transmission loss characteristic of the wall 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 of the A-weighted response curve. Interior absorption, having been shown to be independent of frequency,* will not affect the shape of the interior noise spectrum.

To identify the precise shape of this standard transmission loss curve, an assumption must be made as to the frequency characteristics of the incident exterior noise. For the initial development of EWR, the characteristics chosen were those of highway traffic noise. Figure B-2 presents the typical range of highway spectra averaged over a 24-hour period for a single location near a heavily travelled freeway. Using these data, the nominal average spectrum for highway noise was calculated, with the results illustrated in Figure B-3. Note that the octave band levels are relative to the overall energy-average A-weighted sound level.

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* See Chapter 2.

Knowing the characteristics of the exterior noise spectrum, the shape of the special transmission loss curve shown in Figure B-4 was computed according to the concepts of Figure B-1. Several straight-line approximations to the curve were investigated and the curve shown in Figure B-5 was chosen as the EWR standard contour. This contour can be used in a manner similar to an STC contour to determine the EWR rating for a given wall or construction element based on its TL curve. To do this, the standard contour is adjusted vertically to the highest position relative to the TL curve until, over the frequency range of 125 to 4000 Hz, the sum of the deficiencies in the 16 one-third octave bands (that is, deviations of the TL curve below the contour) is 32 or less. The EWR is then arbitrarily taken as the value of the standard curve level at 500 Hz.

The fact that the actual EWR value is arbitrarily taken as the level of the EWR contour at 500 Hz implies that an EWR value obtained using the above procedures may require final adjustment by a constant to better approximate the reduction in A-weighted noise levels for the structure. Also, EWR values assume an incident noise frequency spectrum similar to that of typical highway noise. Therefore the spectral shape of the EWR standard contour, and hence actual EWR values, are dependent upon this highway noise spectrum. To use EWR values for predicting building attenuation of aircraft noise, which has a different frequency spectrum, an additional correction is needed.

B-2 EWR Accuracy and Regression Constants

The most important criterion for application of EWR to this study is that it should give better accuracy in calculating the interior A-weighted noise level for a variety of exterior wall structures than any other single-number rating scheme. To evaluate the accuracy of EWR for the prediction of structure noise reduction of incident aircraft noise, a large-scale comparison was made between noise reduction based on EWR and a more accurate noise reduction calculated in a classical manner with TL values at each frequency band. That is, the exterior noise level spectrum for aircraft shown in Figure B-6 was applied along with frequency-dependent transmission loss data for many commonly used exterior walls to predict interior spectra. These spectra were then A-weighted to determine an accurate interior A-weighted noise level for each wall type. The EWR of each wall was also determined and applied to the exterior A-weighted level to obtain an estimate of the interior A-weighted noise level. A linear regression analysis was then conducted to determine the correlation between the two resulting interior levels. Combinations of 225 wall constructions and 33 window constructions in area ratios of 0, 10, 15, and 20 percent of total wall area were used for a total of 22,500 separate cases. In each case, interior levels based on composite octave band transmission loss values and on composite EWR values were determined.

The aircraft noise spectrum of Figure B-6 used in this comparison was derived from sound level measurements of commercial aircraft operations. Two noise measurements were utilized – one under the landing path and one under the takeoff path located approximately within the NEF 40 contour of Los Angeles International Airport. Approximately one hour of data was reduced for each site and the energy-equivalent noise level in each octave band was determined. These were time-averaged spectra which were dominated by the noise spectra of the aircraft flyovers. The frequency spectra for takeoff and landing were similar in shape (both decreasing in level with increasing frequency) so they were combined into the single average aircraft noise spectrum shown in Figure B-6.

An initial linear regression analysis was carried out using each pair of interior A-weighted noise levels calculated using (1) the classical method with TL values for each frequency band, and (2) the approximate single-number method with EWR. Since the slope of this regression was very close to unity, an additional regression forcing the slope to be unity was performed. A conceptual illustration of this regression is shown in Figure B-7. The correlation coefficient for the unity slope regression is about 0.98 and the 90-percent confidence interval (calculated based on the assumption that the overall distribution was Gaussian) is less than ±2 dB. As illustrated, the regression line has an intercept of 5.8 dB for this case of aircraft noise as a source requiring that a constant of 5.8 dB (or 6 dB) be subtracted from Equation (A4) in Appendix A. A similar regression analysis was performed using the highway noise spectrum shown earlier in Figure B-3. Applying the same technique of a forced unity slope, the 90-percent confidence interval was ±0.6 dB and the intercept corresponded to a constant of 3.5 dB to be subtracted from Equation (A4).

REFERENCE TO APPENDIX B

B1. Mange, G.E., Skale, S.R., and Sutherland, L.C., "Background Report on Outdoor-Indoor Noise Reduction Calculation Procedures Employing the Exterior Wall Noise Rating (EWR) Method", U.S. Department of Tansportation Report FHWA-TS-77-220, prepared by Wyle Research, March 1978.

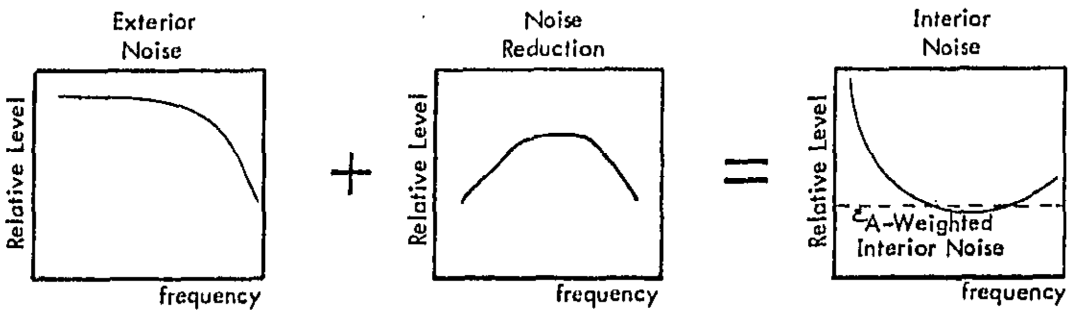

Figure B-1. Conceptual Illustration of Basis for Standard TL Curve for EWR Concept.

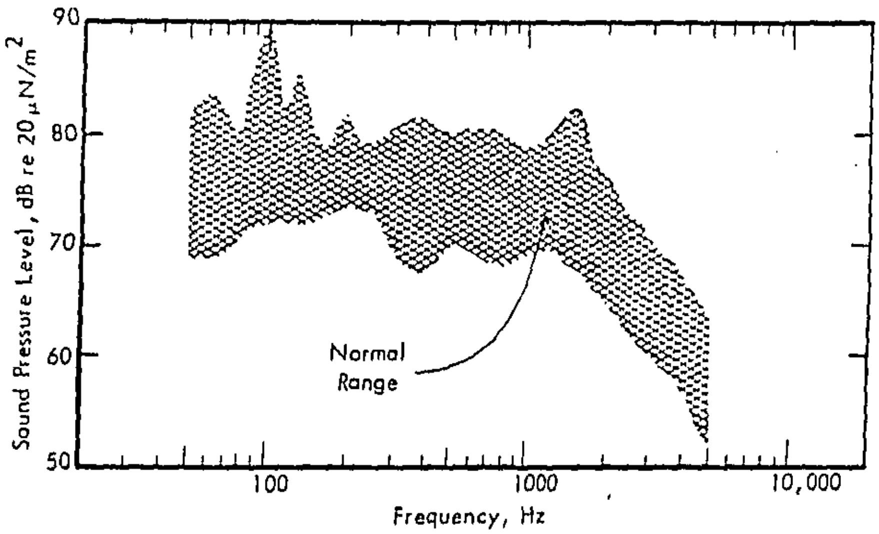

Figure B-2. Typical Highway Noise Spectra.

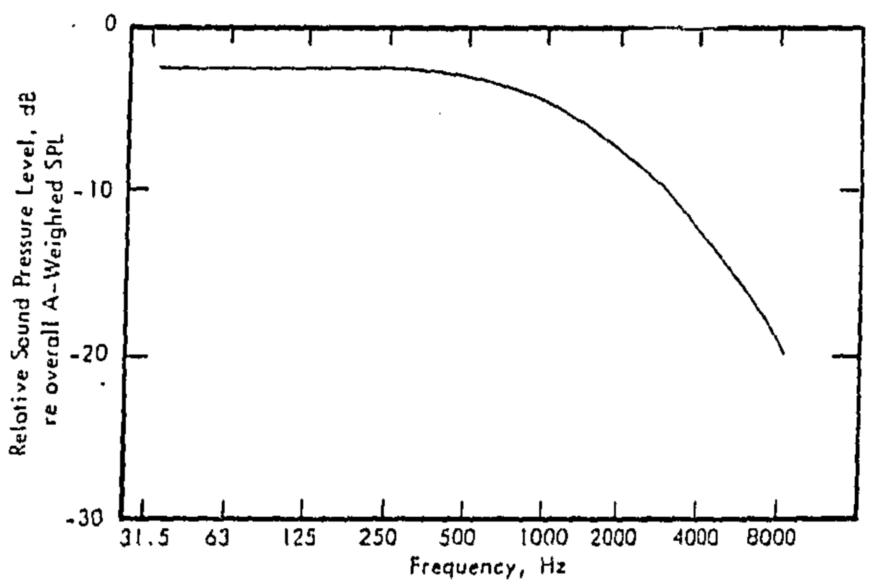

Figure B-3. Standard Highway Noise Spectrum.

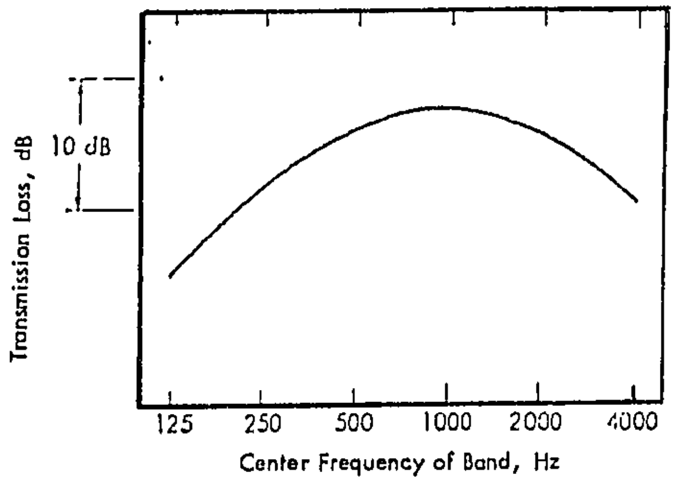

Figure B-4. Calculated Shape For Standard Curve.

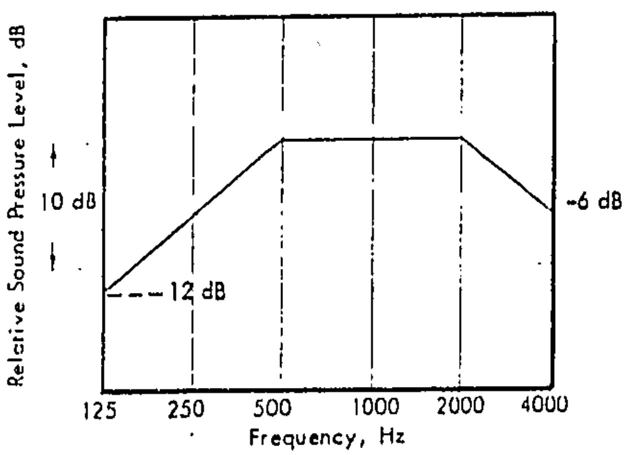

Figure B-5. Exterior Wall Rating Standard Contour.

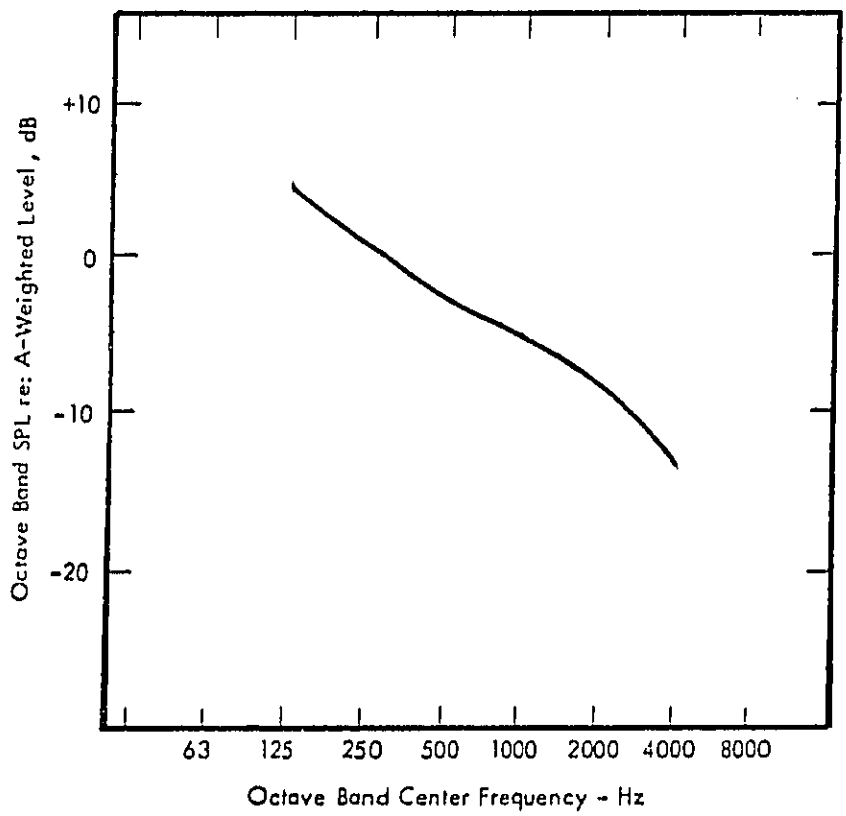

Figure B-6. Aircraft Noise Spectrum.

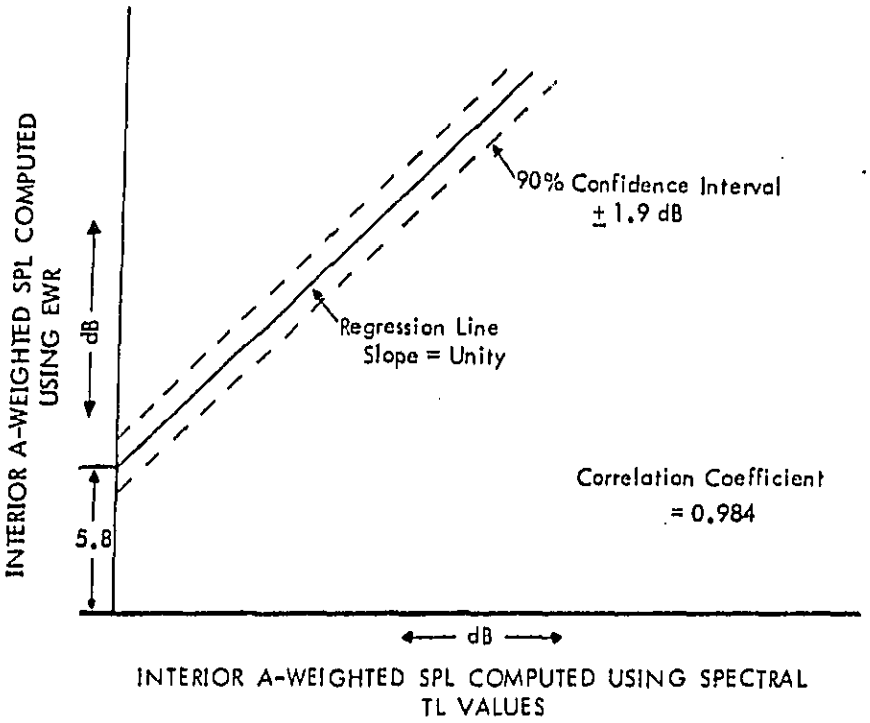

Figure B-7. Conceptual Illustration of Regression Analysis Results Comparing Interior A-Weighted Noise Levels For Aircraft Computed With the Single-Number EWR Method or With the Classical TL Method at Each Frequency Band.

APPENDIX C

Dwelling Construction Distribution By Region

EXTERIORS	INTERIORS	1/2" Gypsumboard 1	3/8" Gypsumboard 2	2 layers 1/2" Gypsumboard 3	2 layers 5/8" Gypsumboard 4	3/8 Gyp Lath/1/2" Plaster 5	3/8 Gyp Lath/1/8" Plaster 6	1/2" Soundboard/ 1/2" Gypsumboard 7	1/2" Soundboard/ 3/8" Gypsumboard 8	1/2" Plaster 9	3/4" Plaster 10	7/8" Plaster 11	1/4" Plywood Paneling 12	1/2" Plywood Paneling 13	1/4" Hardboard Paneling 14	Exposed Solid Wall 15
Alum. Siding/1/2" Wood	A	2	1	0	0	2	2	2	1	1	1	1	1	1	1	0
7/8" Stucco/Paper	B	5	3	1	0	3	2	1	1	2	4	4	3	1	3	0
7/8" Stucco/1/2" Wood	C	2	3	2	2	2	2	2	2	1	2	3	2	1	2	0
1/2" Wood Siding	D	2	3	2	2	2	2	3	3	1	2	2	2	1	2	0
3/4" Wood Siding	E	4	4	2	2	2	3	3	3	1	2	2	2	1	2	0
4-1/2" Brick Veneer	F	4	4	3	2	3	3	2	2	2	3	3	4	3	4	0
9" Brick	G	3	3	0	0	0	1	1	1	3	2	1	3	0	3	2
4" Concrete	H	1	1	0	0	0	1	1	1	1	0	0	1	0	1	1
6" Concrete	I	2*	2*	0	0	0	1*	0	0	2*	0	0	1*	0	1*	2*
8" Concrete	J	2*	2*	0	0	0	1*	0	0	2*	0	0	2*	0	2*	2*
6" Hollow Concrete Block	K	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1
8" Hollow Concrete Block	L	3	3	0	0	0	3	1	1	3	0	0	3	1	3	3
6" Block w/1/2" Stucco	M	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1
8" Block w/1/2" Stucco	N	2	2	0	0	0	2	1	1	2	0	0	2	1	2	2

* Generally over two stories in height.

Figure C-1. Frequency of Use of Common Construction for Region A (5 is most frequently used; 0 is never used).

EXTERIORS \ INTERIORS		1 1/2" Gypsumboard	2 3/8" Gypsumboard	3 2 layers 1/2" Gypsumboard	4 2 layers 5/8" Gypsumboard	5 3/8 Gyp Lath/1/2" Plaster	6 3/8 Gyp Lath/1/8" Plaster	7 1/2" Soundboard/ 1/2" Gypsumboard	8 1/2" Soundboard/ 3/8" Gypsumboard	9 1/2" Plaster	10 3/4" Plaster	11 7/8" Plaster	12 1/4" Plywood Paneling	13 1/2" Plywood Paneling	14 1/4" Hardboard Paneling	15 Exposed Solid Wall
Alum. Siding/1/2" Wood	A	4	4	1	1	3	4	1	1	1	1	1	2	1	2	0
7/8" Stucco/Paper	B	5	5	1	1	3	3	1	1	1	1	1	2	1	2	0
7/8" Stucco/1/2" Wood	C	2	2	1	1	2	2	1	1	1	1	1	2	1	2	0
1/2" Wood Siding	D	3	3	1	1	2	2	1	1	1	1	1	2	1	2	0
3/4" Wood Siding	E	4	4	1	1	2	3	1	1	1	1	1	2	1	2	0
4-1/2" Brick Veneer	F	2	2	1	1	2	2	1	1	1	1	1	2	1	2	0
9" Brick	G	2	2	0	0	0	1	1	1	2	0	0	2	1	2	1
4" Concrete	H	1	1	0	0	0	1	1	1	1	0	0	1	0	1	1
6" Concrete	I	2*	2*	0	0	0	2*	1*	0	2*	0	0	1*	0	1*	2*
8" Concrete	J	2*	2*	0	0	0	1*	1*	0	2*	0	0	1*	0	1*	2*
6" Hollow Concrete Block	K	2	2	0	0	0	1	1	0	2	0	0	1	0	1	0
8" Hollow Concrete Block	L	4	4	0	0	0	2	2	0	3	0	0	3	0	2	3
6" Block w/1/2" Stucco	M	1	1	0	0	0	1	1	0	1	0	0	1	0	1	0
8" Block w/1/2" Stucco	N	3	3	0	0	0	2	2	0	1	0	0	1	0	1	1

* Generally over two stories in height.

Figure C-2. Frequency of Use of Common Construction for Region B (5 is most frequently used; 0 is never used).

EXTERIORS	INTERIORS	1 1/2" Gypsumboard	2 3/8" Gypsumboard	3 2 layers 1/2" Gypsumboard	4 2 layers 5/8" Gypsumboard	5 3/8 Gyp Lath/1/2" Plaster	6 3/8 Gyp Lath/1/8" Plaster	7 1/2" Soundboard/ 1/2" Gypsumboard	8 1/2" Soundboard/ 3/8" Gypsumboard	9 1/2" Plaster	10 3/4" Plaster	11 7/8" Plaster	12 1/4" Plywood Paneling	13 1/2" Plywood Paneling	14 1/4" Hardboard Paneling	15 Exposed Solid Wall
Alum.Siding/1/2" Wood	A	2	2	1	1	1	2	1	1	2	1	1	2	1	2	0
7/8" Stucco/Paper	B	3	3	1	1	2	3	1	1	2	1	1	2	1	2	0
7/8" Stucco/1/2" Wood	C	2	2	1	1	1	2	1	1	1	2	2	2	1	2	0
1/2" Wood Siding	D	2	2	2	2	1	2	1	1	1	2	2	2	1	2	0
3/4" Wood Siding	E	3	3	2	1	2	2	1	1	1	2	3	3	1	3	0
4-1/2" Brick Veneer	F	4	4	1	1	3	3	1	1	1	2	3	3	1	3	0
9" Brick	G	4	4	1	1	3	4	1	1	1	2	3	3	1	3	2
4" Concrete	H	1	1	0	0	0	1	0	0	1	0	0	1	0	1	1
6" Concrete	I	2	2	0	0	0	1	0	0	2	0	0	1	0	1	2
8" Concrete	J	2*	2*	0	0	0	2*	0	0	2*	0	0	2*	0	2*	2*
6" Hollow Concrete Block	K	3	3	0	0	0	3	1	1	3	1	0	3	1	3	3
8" Hollow Concrete Block	L	5	5	0	0	0	5	2	2	5	1	1	4	1	4	3
6" Block w/1/2" Stucco	M	3	3	0	0	0	3	1	1	3	1	0	3	1	3	3
8" Block w/1/2" Stucco	N	4	4	0	0	0	4	1	1	4	1	0	3	1	3	3

* Generally over two stories in height.

Figure C-3. Frequency of Use of Common Construction for Region C (5 is most frequently used; 0 is never used).

EXTERIORS	INTERIORS	1 1/2" Gypsumboard	2 3/8" Gypsumboard	3 2 layers 1/2" Gypsumboard	4 2 layers 5/8" Gypsumboard	5 3/8 Gyp Lath/1/2" Plaster	6 3/8 Gyp Lath/1/8" Plaster	7 1/2" Soundboard/ 1/2" Gypsumboard	8 1/2" Soundboard/ 3/8" Gypsumboard	9 1/2" Plaster	10 3/4" Plaster	11 7/8" Plaster	12 1/4" Plywood Paneling	13 1/2" Plywood Paneling	14 1/4" Hardboard Paneling	15 Exposed Solid Wall
Alum. Siding/1/2" Wood	A	2	2	3	3	3	3	3	3	0	2	3	2	1	2	0
7/8" Stucco/Paper	B	2	3	3	3	3	3	3	3	0	2	3	2	1	2	0
7/8" Stucco/1/2" Wood	C	3	3	3	3	3	3	3	3	0	2	3	2	1	2	0
1/2" Wood Siding	D	2	2	2	2	2	2	2	2	0	1	2	2	1	2	0
3/4" Wood Siding	E	4	4	4	4	4	4	3	3	0	2	3	3	1	3	0
4-1/2" Brick Veneer	F	3	3	2	2	3	3	2	2	0	2	3	2	2	2	0
9" Brick	G	5	5	3	2	0	3	3	3	5	3	2	5	2	5	4
4" Concrete	H	1	1	0	0	0	1	1	1	1	0	0	1	0	1	0
6" Concrete	I	2*	2*	1	1	0	2*	2*	2*	2*	2*	1*	2*	1*	2*	0
8" Concrete	J	3*	3*	2*	2*	0	2*	2*	1*	2*	2*	1*	2*	1*	2*	0
6" Hollow Concrete Block	K	2	2	1	1	0	2	2	2	2	2	1	2	1	2	0
8" Hollow Concrete Block	L	2	2	2	2	0	2	2	2	2	2	1	2	1	2	0
6" Block w/1/2" Stucco	M	2	2	1	1	0	2	2	2	2	2	1	2	1	2	0
8" Block w/1/2" Stucco	N	2	2	2	2	0	2	2	2	2	2	1	2	1	2	0

* Generally over two stories in height.

Figure C-4. Frequency of Use of Commmon Construction for Regions D and E (5 is most frequently used; 0 is never used).

EXTERIORS	INTERIORS	1/2" Gypsumboard (1)	3/8" Gypsumboard (2)	2 layers 1/2" Gypsumboard (3)	2 layers 5/8" Gypsumboard (4)	3/8 Gyp Lath/1/2" Plaster (5)	3/8 Gyp Lath/1/8" Plaster (6)	1/2" Soundboard/ 1/2" Gypsumboard (7)	1/2" Soundboard/ 5/8" Gypsumboard (8)	1/2" Plaster (9)	3/4" Plaster (10)	7/8" Plaster (11)	1/4" Plywood Paneling (12)	1/2" Plywood Paneling (13)	1/4" Hardboard Paneling (14)	Exposed Solid Wall (15)
Alum.Siding/1/2" Wood	A	2	2	3	3	3	2	3	3	1	2	3	2	2	2	0
7/8" Stucco/Paper	B	2	3	3	3	3	3	3	3	1	2	3	2	2	2	0
7/8" Stucco/1/2" Wood	C	3	3	4	4	3	3	4	4	0	2	3	2	2	2	0
1/2" Wood Siding	D	0	1	3	3	2	3	3	3	0	2	3	2	2	2	0
3/4" Wood Siding	E	1	2	3	3	3	3	4	4	0	2	3	2	2	2	0
4-1/2" Brick Veneer	F	3	3	4	4	4	4	4	4	0	2	3	2	2	2	0
9" Brick	G	5	5	4	4	0	5	4	4	3	4	2	2	2	2	0
4" Concrete	H	1	1	0	0	0	1	1	1	1	0	0	1	1	1	0
6" Concrete	I	2*	2*	0*	0*	0	2*	1*	1*	1*	1*	0	1*	1*	1*	1*
8" Concrete	J	3*	3*	0*	0*	0*	3*	1*	1*	1*	0	0	1*	1*	1*	1*
6" Hollow Concrete Block	K	3	3	0	0	0	3	1	1	1	1	0	1	1	1	0
8" Hollow Concrete Block	L	3	3	0	0	0	3	1	1	1	1	0	1	1	1	0
6" Block w/1/2" Stucco	M	3	3	0	0	0	3	1	1	1	1	0	1	1	1	0
8" Block w/1/2" Stucco	N	3	3	0	0	0	3	1	1	1	1	0	1	1	1	0

* Generally over two stories in height.

Figure C-5. Frequency of Use of Common Construction for Regions F and G (5 is most frequently used; 0 is never used).

EXTERIORS	INTERIORS	1/2" Gypsumboard (1)	3/8" Gypsumboard (2)	2 layers 1/2" Gypsumboard (3)	2 layers 5/8" Gypsumboard (4)	3/8 Gyp Lath/1/2" Plaster (5)	3/8 Gyp Lath/1/8" Plaster (6)	1/2" Soundboard/ 1/2" Gypsumboard (7)	1/2" Soundboard/ 3/8" Gypsumboard (8)	1/2" Plaster (9)	3/4" Plaster (10)	7/8" Plaster (11)	1/4" Plywood Paneling (12)	1/2" Plywood Paneling (13)	1/4" Hardboard Paneling (14)	Exposed Solid Wall (15)
Alum.Siding/1/2" Wood	A	2	3	3	3	3	3	2	2	0	3	3	3	2	3	0
7/8" Stucco/Paper	B	3	3	3	3	3	3	2	2	0	3	3	3	2	3	0
7/8" Stucco/1/2" Wood	C	3	3	3	3	3	3	2	2	0	3	3	3	2	3	0
1/2" Wood Siding	D	0	1	2	2	2	1	2	2	0	2	2	1	1	1	0
3/4" Wood Siding	E	3	5	5	4	4	4	4	4	0	2	3	4	2	4	0
4-1/2" Brick Veneer	F	2	3	3	3	3	3	2	2	0	2	2	2	1	2	0
9" Brick	G	2	2	0	0	0	2	0	0	2	1	0	2	0	2	1
4" Concrete	H	1	1	0	0	0	1	0	0	1	0	0	1	0	1	1
6" Concrete	I	2*	2*	0	0	0	2*	0	0	2*	0	0	2	0	2*	1*
8" Concrete	J	2*	2*	0	0	0	2*	0	0	2*	0	0	2	0	2*	1*
6" Hollow Concrete Block	K	2	2	0	0	0	2	1	0	2	0	0	2	0	2	1
8" Hollow Concrete Block	L	3	3	0	0	0	3	1	0	2	0	0	2	0	2	1
6" Block w/1/2" Stucco	M	2	2	0	0	0	2	1	0	2	0	0	2	0	2	1
8" Block w/1/2" Stucco	N	2	2	0	0	0	2	1	0	2	0	0	2	0	2	1

* Generally over two stories in height.

Figure C-6. Frequency of Use of Common Construction For Regions H, J, and K (5 is most frequently used; 0 is never used).

APPENDIX D

Tables of Multi-Family Dwelling Data

Table D-1

Multi-Family Housing Data For Region A
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3-4	5-9	10-49	50
NUMBER OF STORIES:					
TWO	100	100	100	90	50
THREE				10	50
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA		40	40	40	
STUCCO / SJL	100	60	60	60	100
BRICK / VA					
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH					
SGD	30	30	30	30	80
WINDOW A/C UNITS	10	10	10	10	10
FUEL:	ELECTRICITY: 100 GAS: OIL:				

Table D-2

Multi-Family Housing Data For Region B
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3-4	5-9	10-49	50
NUMBER OF STORIES:					
TWO					
THREE				100	
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL				25	
BRICK / VA				50	
BRICK / SJL				25	
BRICK / SJH					
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH					
SGD				25	
WINDOW A/C UNITS					
FUEL:	ELECTRICITY: 20 GAS: 80 OIL:				

Table D-3

Multi-Family Housing Data For Region C
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO	100	100	100	50	
THREE				50	20
FOUR OR MORE					80
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA					
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA	20	20	40	40	
CONCRETE / SJL	80	80	60	60	100
CONCRETE / SJH					
SGD	20	20	20	30	80
WINDOW A/C UNITS	60	60	80	80	80
FUEL:	ELECTRICITY: 100 GAS: OIL:				

Table D-4

Multi-Family Housing Data For Region D
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO		100	50	50	50
THREE			50	50	50
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA		100	100	80	50
BRICK / SJL					
BRICK / SJH				20	50
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH					
SGD				20	20
WINDOW A/C UNITS		20	20	30	50
FUEL:	ELECTRICITY: 30 GAS: 50 OIL: 20				

Table D-5

Multi-Family Housing Data For Region E
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO	100	100	50	10	
THREE			50	45	
FOUR OR MORE				45	100
CONSTRUCTION:					
SIDING / VA					
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA					
BRICK / SJL					
BRICK / SJH	100	100	100	90	90
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH				10	10
SGD			30	30	40
WINDOW A/C UNITS			40	40	30
FUEL:	ELECTRICITY: 10 GAS: 20 OIL: 70				

Table D-6

Multi-Family Housing Data For Region F
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO		100		50	60
THREE				50	40
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA		100		50	50
SIDING / SJL				50	50
STUCCO / VA					
STUCCO / SJL					
BRICK / VA					
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH					
SGD		10		20	40
WINDOW A/C UNITS		10		50	50
FUEL:	ELECTRICITY: 100 GAS: OIL:				

Table D-7

Multi-Family Housing Data For Region G *
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO	100	100	50	25	
THREE			50	25	50
FOUR OR MORE				50	50
CONSTRUCTION:					
SIDING / VA	60	60	40	20	
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA	40	40	60	60	50
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA					
CONCRETE / SJL					
CONCRETE / SJH				20	50
SGD	10	10	10	25	25
WINDOW A/C UNITS	20	20	20	30	30
FUEL:	ELECTRICITY:		GAS: 95	OIL: 5	

* Multi-Family housing units were not sampled in this area. This data is estimated for this region.

Table D-8

Multi-Family Housing Data For Region H
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO	100	100	80	20	
THREE			20	80	100
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA			20	20	80
SIDING / SJL				10	20
STUCCO / VA					
STUCCO / SJL					
BRICK / VA			20	10	
BRICK / SJL			20	10	
BRICK / SJH					
CONCRETE / VA	100			10	
CONCRETE / SJL					
CONCRETE / SJH		100	40	40	
SGD			70	70	70
WINDOW A/C UNITS	60	60	80	80	100
FUEL:	ELECTRICITY: GAS: 100 OIL:				

Table D-9

Multi-Family Housing Data For Region J
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3–4	5–9	10–49	50
NUMBER OF STORIES:					
TWO	100	100	100	50	
THREE				50	100
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA	40	40	40	40	40
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL					
BRICK / VA	20	20	20	20	20
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA	20	20	20	20	20
CONCRETE / SJL					
CONCRETE / SJH	20	20	20	20	20
SGD	50	50	50	50	50
WINDOW A/C UNITS	10	10	10	10	10
FUEL:	ELECTRICITY: 30 GAS: 40 OIL: 30				

Table D-10

Multi-Family Housing Data For Region K
(Numbers Expressed As Percentages)

	NUMBER OF UNITS				
	2	3-4	5-9	10-49	50
NUMBER OF STORIES:					
TWO		100	100	100	100
THREE					
FOUR OR MORE					
CONSTRUCTION:					
SIDING / VA		25	25	25	25
SIDING / SJL					
STUCCO / VA					
STUCCO / SJL		15	15	15	15
BRICK / VA		10	10	10	10
BRICK / SJL					
BRICK / SJH					
CONCRETE / VA		10	10	10	10
CONCRETE / SJL					
CONCRETE / SJH		40	40	40	40
SGD		45	45	45	45
WINDOW A/C UNITS		15	15	15	15
FUEL:	ELECTRICITY: GAS: 100 OIL:				

APPENDIX E

Tables of Soundproofing Costs
By Dwelling Category And Region

Table E-1

Soundproofing Costs for Region A

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	15	2,700	7,700	14,600								
SIDING / SJL												
SIDING / ECL												
STUCCO / VA	80	2,600	5,300	12,200	100	800	2,900	7,000	40	800	1,800	4,800
STUCCO / SJL	5	2,600	7,900	16,000					60	800	2,500	5,700
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		2,600	5,800	12,800		800	2,900	7,000		800	2,200	5,300
COSTS FOR A.C. ADDITION		1,500	1,500	1,500		500	500	500		500	500	500

Table E-1 (Region A) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA	40	700	900	1,400	40	700	800	1,200				
STUCCO / SJL	60	700	900	1,400	60	700	800	1,200	100	700	800	1,000
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		500	500	500		500	500	500		500	500	500

Table E-2

Soundproofing Costs for Region B

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA	5	1,600	3,600	10,300								
STUCCO / SJL	5	1,600	6,200	13,800	25	900	2,900	6,900	25	900	2,300	5,600
BRICK / VA	80	1,400	2,700	7,400	50	800	1,400	4,000	50	800	1,300	3,400
BRICK / SJL	10	1,600	4,300	11,100	25	800	2,000	5,200	25	800	1,700	4,300
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		1,400	3,100	8,200		900	1,900	5,000		900	1,700	4,200
COSTS FOR A.C. ADDITION		800	800	800		200	200	200		200	200	200

Table E-2 (Region B) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL	25	700	900	1,400	25	700	800	1,000	25	700	800	1,000
BRICK / VA	50	700	900	1,400	50	700	800	1,000	50	700	800	1,000
BRICK / SJL	25	700	900	1,400	25	700	800	1,000	25	700	800	1,000
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,000		700	800	1,000
COSTS FOR A.C. ADDITION		200	200	200		200	200	200		200	200	200

Table E-3

Soundproofing Costs for Region C

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	15	2,500	7,900	14,600								
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA	75	2,300	4,700	9,900	20	800	1,600	4,200	20	800	1,400	3,500
HCB / SJL	10	2,300	6,400	13,800	80	800	2,100	5,300	80	800	1,800	4,400
HCB / SJH												
WEIGHTED AVERAGE		2,300	5,400	11,000		800	2,000	5,100		800	1,700	4,200
COSTS FOR A.C. ADDITION		400	400	400		100	100	100		100	100	100

Table E-3 (Region C) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA	40	700	900	1,400	40	700	800	1,200	0	700	800	1,000
HCB / SJL	60	700	900	1,400	60	700	800	1,200	100	700	800	1,000
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		100	100	100		100	100	100		100	100	100

Table E-4

Soundproofing Costs for Region D

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	30	2,500	7,700	15,600								
SIDING / SJL	35	2,700	9,900	18,900								
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	10	2,300	4,200	9,600	100	700	1,200	3,000	100	700	1,000	2,500
BRICK / SJL	10	2,500	5,100	12,000								
BRICK / SJH												
CONCRETE / VA	5	2,300	4,200	9,400								
CONCRETE / SJL	10	2,500	5,200	12,100								
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		2,500	7,400	15,100		700	1,200	3,000		700	1,000	2,500
COSTS FOR A.C. ADDITION		1,000	1,000	1,000		300	300	300		300	300	300

Table E-4 (Region D) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	100	700	900	1,400	80	700	800	1,200	50	700	800	1,000
BRICK / SJL												
BRICK / SJH					20	700	800	1,200	50	700	800	1,000
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		300	300	300		300	300	300		300	300	300

Table E-5

Soundproofing Costs for Region E

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	15	4,800	9,600	18,500								
SIDING / SJL	50	4,800	11,600	21,200								
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	5	4,700	6,200	11,700								
BRICK / SJL	10	4,700	6,900	14,200								
BRICK / SJH	15	4,700	6,200	12,400	100	700	1,200	3,000	100	700	1,000	2,500
CONCRETE / VA												
CONCRETE / SJL	5	4,700	6,600	14,200								
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		4,800	9,500	18,000		700	1,200	3,000		700	1,000	2,500
COSTS FOR A.C. ADDITION		1,600	1,600	1,600		400	400	400		400	400	400

Table E-5 (Region E) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH	100	700	900	1,400	90	700	800	1,200	90	700	800	1,000
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH					10	700	800	1,200	10	700	800	1,000
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		400	400	400		400	400	400		400	400	400

Table E-6

Soundproofing Costs for Region F

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	15	1,800	6,400	15,000	100	800	3,400	6,500	100	700	2,700	5,100
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	80	1,800	3,300	9,100								
BRICK / SJL	5	1,800	3,600	10,400								
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		1,800	3,800	10,000		800	3,400	6,500		700	2,700	5,100
COSTS FOR A.C. ADDITION		400	400	400		100	100	100		100	100	100

Table E-6 (Region F) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	50	700	900	1,400	50	700	800	1,200	50	700	800	1,000
SIDING / SJL	50	700	900	1,400	50	700	800	1,200	50	700	800	1,000
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		100	100	100		100	100	100		100	100	100

Table E-7

Soundproofing Costs for Region G

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	40	2,500	8,100	15,500								
SIDING / SJL	45	2,700	10,100	18,600								
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	10	2,200	4,200	9,400								
BRICK / SJL	5	2,200	5,000	11,700								
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		2,500	8,500	16,100								
COSTS FOR A.C. ADDITION		1,300	1,300	1,300								

Table E-8

Soundproofing Costs for Region H

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	55	1,000	4,800	13,400								
SIDING / SJL	30	1,200	6,900	16,800								
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA	10	1,000	1,700	7,300	100	700	1,200	3,000				
CONCRETE / SJL	5	1,000	2,100	8,700								
CONCRETE / SJH									100	700	1,000	2,300
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		1,100	5,000	13,600		700	1,200	3,000		700	1,000	2,300
COSTS FOR A.C. ADDITION		1,700	1,700	1,700		400	400	400		400	400	400

Table E-8 (Region H) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	20	700	900	1,400	20	700	800	1,200	80	700	800	1,000
SIDING / SJL					10	700	800	1,200	20	700	800	1,000
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	20	700	900	1,400	10	700	800	1,200				
BRICK / SJL	20	700	900	1,400	10	700	800	1,200				
BRICK / SJH												
CONCRETE / VA					10	700	800	1,200				
CONCRETE / SJL												
CONCRETE / SJH	40	700	900	1,400	40	700	800	1,200				
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	900	1,400		700	800	1,200		700	800	1,000
COSTS FOR A.C. ADDITION		400	400	400		400	400	400		400	400	400

Table E-9

Soundproofing Costs for Region J

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	60	2,500	7,000	14,000	40	900	4,000	7,700	40	900	3,300	6,100
SIDING / SJL	30	2,700	9,400	17,200								
SIDING / ECL	5	4,900	10,700	17,600								
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	5	2,200	3,400	8,200	20	800	1,700	4,200	20	800	1,400	3,500
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA					20	800	1,700	4,200	20	800	1,400	3,500
CONCRETE / SJL												
CONCRETE / SJH					20	800	1,700	4,200	20	800	1,400	3,500
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		2,700	7,700	14,900		800	2,600	5,600		800	2,200	4,500
COSTS FOR A.C. ADDITION		2,500	2,500	2,500		700	700	700		700	700	700

Table E-9 (Region J) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	40	700	1,000	1,600	40	700	900	1,200	40	700	800	1,200
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA	20	700	1,000	1,600	20	700	900	1,200	20	700	800	1,200
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA	20	700	1,000	1,600	20	700	900	1,200	20	700	800	1,200
CONCRETE / SJL												
CONCRETE / SJH	20	700	1,000	1,600	20	700	900	1,200	20	700	800	1,200
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	1,000	1,600		700	900	1,200		700	800	1,200
COSTS FOR A.C. ADDITION		700	700	700		700	700	700		700	700	700

Table E-10

Soundproofing Costs for Region K

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	60	2,100	7,300	13,700	25	900	4,000	7,800	25	900	3,300	6,400
SIDING / SJL												
SIDING / ECL												
STUCCO / VA	5	2,000	4,800	11,300								
STUCCO / SJL					15	900	3,300	7,700	15	800	2,700	6,000
BRICK / VA	35	2,000	4,000	8,200	10	800	1,800	4,400	10	800	1,600	3,800
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA					10	800	1,800	4,400	10	800	1,000	3,800
CONCRETE / SJL												
CONCRETE / SJH					40	800	1,800	4,400	40	800	1,600	3,800
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		2,100	6,000	11,700		800	2,600	5,700		800	2,200	4,800
COSTS FOR A.C. ADDITION		700	700	700		200	200	200		200	200	200

Table E-10 (Region K) -- Continued

CONSTRUCTION CATEGORY	5 TO 9 UNITS				10 TO 49 UNITS				>50 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA	25	700	1,200	1,800	25	700	900	1,300	25	700	900	1,300
SIDING / SJL												
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL	15	700	1,200	1,800	15	700	900	1,300	15	700	900	1,300
BRICK / VA	10	700	1,200	1,800	10	700	900	1,300	10	700	900	1,300
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA	10	700	1,200	1,800	10	700	900	1,300	10	700	900	1,300
CONCRETE / SJL												
CONCRETE / SJH	40	700	1,200	1,800	40	700	900	1,300	40	700	900	1,300
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		700	1,200	1,800		700	900	1,300		700	900	1,300
COSTS FOR A.C. ADDITION		200	200	200		200	200	200		200	200	200

Table E-11

Soundproofing Costs for Region L

CONSTRUCTION CATEGORY	1 UNIT				2 UNITS				3 TO 4 UNITS			
	%	L_{dn} Zone			%	L_{dn} Zone			%	L_{dn} Zone		
		65–70	70–75	75–80		65–70	70–75	75–80		65–70	70–75	75–80
SIDING / VA												
SIDING / SJL	100	3,800	10,400	18,200								
SIDING / ECL												
STUCCO / VA												
STUCCO / SJL												
BRICK / VA												
BRICK / SJL												
BRICK / SJH												
CONCRETE / VA												
CONCRETE / SJL												
CONCRETE / SJH												
HCB / VA												
HCB / SJL												
HCB / SJH												
WEIGHTED AVERAGE		3,800	10,400	18,200								
COSTS FOR A.C. ADDITION		2,600	2,600	2,600								