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Guidelines for the Sound Insulation of Residences Exposed to Aircraft Operations

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WYLE RESEARCH REPORT

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GUIDELINES FOR THE SOUND INSULATION OF RESIDENCES EXPOSED TO AIRCRAFT OPERATIONS

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

The effect of aircraft noise on communities surrounding airfields concerns airport operators and their neighbors. Since 1973, when the Department of Defense initiated the Air Installation Compatible Use Zones (AICUZ) Program, there has been a systematic attempt to minimize the negative impact of local community growth on air operations and of these operations on communities. Similarly, in 1981 the FAA published Part 150 of the Federal Aviation Regulations establishing a single system of noise measurement appropriate to human response to aviation noise and identifying land uses normally compatible with various levels of noise exposure.

There are substantial mutual benefits in having communities located near airfields. Such benefits include improved economic development for the community and provision of services to the air installation. However, there are also continuing problems associated with having close neighbors, not the least of which is noise impact. Airfield neighbors become annoyed at the noise generated by flight operations and they exert pressure on airfield operators to take appropriate action to minimize the noise.

The need to safeguard military and civilian flight operations must be balanced with the need to protect local residents from excessive aircraft noise exposure. This challenge can be addressed in several ways. Solutions can be directed at the noise source, by developing quieter aircraft and by modifying flight procedures and flight tracks. Because military aircraft are designed for the performance of specific functions, it is not usually feasible to quiet them. Both military and civilian airport operators, however, do consider flight procedure and flight track changes to minimize noise impact.

The alternative is to protect the community members from noise impact where they live – in their homes and other activity centers – through land-use controls and sound insulation. The Navy's AICUZ program and the FAA's Land-Use Compatibility guidelines identify compatible land usage and encourage land-use controls. These recommendations appear in Tables 1-1 and 1-2. This guide provides a project management handbook for studying, initiating, and implementing residential sound insulation programs in neighborhoods around military and civilian airports.

The information presented in this guide is based on fundamental acoustic principles supported by practical experience gained in numerous residential sound insulation projects across the country. The most successful solutions to problems typically encountered in these projects have been incorporated.

The two primary goals of a residential sound insulation project are the improvement of the noise environment for community members and better relations between the installation and its neighbors. These goals, and the methods used to achieve them, must take into account the sometimes conflicting needs of the parties concerned. The existence of federal recommendations for noise exposure provides clear-cut, objective noise goals which can be aimed toward and complied with.

1.2 Use of This Handbook

This handbook is divided into four sections plus appendices. The Executive Summary, Section 1.0, provides an introduction to the Guidelines, this discussion of how to use the text, and a brief discussion of some of the topics covered in the handbook. Specific instructions are highlighted and useful data tables are reproduced from other Guidelines sections. Section 1.3 describes dwelling categories, their noise reduction, and common geographic distribution patterns. Suggested dwelling type modifications are given in Section 1.4. A brief discussion of project costs follows in Section 1.5.

The material in the Executive Summary is a condensed version of some of the topics covered more completely in the body of the handbook. It is intended to provide an overview of the general types of sound insulation and their associated costs. It is not intended to be an adequate substitute for a full explanation of the concepts and practices involved in a home sound insulation program which is provided in the main body of the document.

It is assumed that not all readers will need to study all parts of this document. The guidelines have been structured to make it easy to find topics of particular interest to a wide variety of users. The reader is urged to become familiar with the background material and detailed instructions provided in the sections which apply to his or her specific needs.

Table 1-1[1]

Air Installation Compatible Use Zone Suggested Land-Use Guidelines (Department of Defense)

Land Use		Noise Zones/DNL Levels in L_{dn}						
SLUCM No.	Name	A 0-55	B 55-65	C-1 65-70	C-2 70-75	D-1 75-80	D-2 80-85	D-3 85+
10	**Residential**							
11	Household units.							
11.11	Single units — detached	Y	Y*	25[1]	30[1]	N	N	N
11.12	Single units — semidetached	Y	Y*	25[1]	30[1]	N	N	N
11.13	Single units — attached row	Y	Y*	25[1]	30[1]	N	N	N
11.21	Two units — side-by-side	Y	Y*	25[1]	30[1]	N	N	N
11.22	Two Units — one above the other	Y	Y*	25[1]	30[1]	N	N	N
11.31	Apartments — walk up	Y	Y*	25[1]	30[1]	N	N	N
11.32	Apartments — elevator	Y	Y*	25[1]	30[1]	N	N	N
12	Group quarters	Y	Y*	25[1]	30[1]	N	N	N
13	Residential hotels	Y	Y*	25[1]	30[1]	N	N	N
14	Mobile home parks or courts	Y	Y*	N	N	N	N	N
15	Transient lodgings	Y	Y*	25[1]	30[1]	35[1]	N	N
16	Other residential	Y	Y*	25[1]	30[1]	N	N	N
20	**Manufacturing**							
21	Food and kindred products — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
22	Textile mill products — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
23	Apparel and other finished products made from fabrics, leather, and similar materials — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
24	Lumber and wood products (except furniture) — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
25	Furniture and fixtures — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
26	Paper and allied products — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
27	Printing, publishing, and allied industries	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
28	Chemicals and allied products — manufacturing	Y	Y	Y	Y[2]	Y[3]	Y[4]	N
29	Petroleum refining and related industries	Y	Y	Y	Y[2]	Y[3]	Y[4]	N

*The designation of these uses as "compatible" in this zone reflects individual Federal agencies' consideration of general cost and feasibility factors as well as past community experiences and program objectives. Localities, when evaluating the application of these guidelines to specific situations, may have different concerns or goals to consider. For an indication of possible community reaction to residential environments at various levels of cumulative noise, Table D-1 in Appendix D should be consulted.

NOTES FOR TABLE 2

1. a) Although local conditions may require residential use, it is discouraged in C-1 and strongly discouraged in C-2. The absence of viable alternative development options should be determined and an evaluation indicating that a demonstrated community need for residential use would not be met if development were prohibited in these zones should be conducted prior to approvals.

   b) Where the community determines that residential uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB (Zone C-1) and 30 dB (Zone C-2) should be incorporated into building codes and be considered in individual approvals. Normal construction can be expected to provide a NLR of 20 dB, thus the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. Additional consideration should be given to modifying NLR levels based on peak noise levels.

   c) NLR criteria will not eliminate outdoor noise problems. However, building location and site planning, design and use of berms and barriers can help mitigate outdoor noise exposure particularly from ground level sources. *Measures that reduce noise at a site should be used wherever practical in preference to measures which only protect interior spaces.*

Table 1-2[2]

Federal Aviation Administration Definitions of Land-Use Compatibility With Yearly Day-Night Average Sound Levels

Land use	Yearly day-night average sound level (L_{dn}) in decibels					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential						
Residential, other than mobile homes and transient lodgings.	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware and farm equipment.	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction.	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation.	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

*The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

KEY TO TABLE 1

SLUCM = Standard Land Use Coding Manual.
Y (Yes) = Land Use and related structures compatible without restrictions.
N (No) = Land Use and related structures are not compatible and should be prohibited.
NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35 = Land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure.

NOTES FOR TABLE 1

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.
(2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
(3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
(4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal level is low.
(5) Land use compatible provided special sound reinforcement systems are installed.
(6) Residential buildings require an NLR of 25.
(7) Residential buildings require an NLR of 30.
(8) Residential buildings not permitted.

Section 2.0 covers the basic concepts involved in improving the acoustic performance of residences exposed to aircraft noise. It includes a statement of the goals of a sound insulation project. The terms and metrics used to describe noise levels and sound insulation are defined in this section. The paths by which sound enters a dwelling, the effects of aircraft noise intrusion, and fundamental sound insulation concepts are also described.

Section 3.0 examines project formulation and implementation methods. This section addresses issues concerned with identifying which houses need to be treated and the types of treatment available. Dwelling categories are defined and explained, and a comprehensive nationwide dwelling type data base is provided. Instructions for performing acoustic measurements are given along with the criteria for determining appropriate noise reduction objectives.

Sound insulation techniques useful for the various parts of a dwelling are presented as options to be combined in the total dwelling treatment package. Recommended modification packages are identified along with costs to implement them. A detailed example shows how to develop project costs from the information provided.

Section 4.0 provides guidelines on project management and implementation, discussing program management in greater detail. All aspects of program planning, initiation, implementation, supervision, and follow-up evaluation are covered.

Worksheets for developing detailed cost estimates are provided in Appendix A. Other appendices provide a bibliography, glossary, and sample forms for surveys and inspection.

1.3 Dwelling Category Summary

The sound insulation modifications required to achieve a specific acoustic goal depend on the existing sound insulation characteristics of the dwelling. The existing sound insulation performance of a dwelling is determined by the construction methods and materials used, as well as the condition of the home. Section 3.2 explains how to categorize dwellings based on these acoustically significant building features. Table 1-3, taken from Section 3.2.3 and presented here, shows the External Wall Rating (EWR) of a number of these construction elements. EWR is a measure of sound insulation capability and is explained in Section 2.3.

Because construction practices vary from one geographic region to another, it is desirable to identify those that are typical in different parts of the country. Figure 1-1 shows eleven regions where the housing types near major airports are similar. Section 3.2.2 gives more information on these regions and the dwelling patterns found in them. Table 1-4 presents the results of national housing surveys showing the most typical dwelling categories for each of the 11 regions.

Table 1-5 gives the average house size in each geographical region, which influences the sound insulation cost of a dwelling.

1.4 Recommended Modification and Construction Practices

Section 3.5, Sound Insulation Methods, gives detailed instructions on how to modify an existing house or alter the design of a new house to improve its sound insulation performance. There are many specific techniques used in acoustic treatments which must be performed properly and with careful attention to detail, in order for them to be effective. Acoustic windows, for example, must be installed according to the manufacturer's detailed instructions or their insulation performance will be seriously degraded. In general, acoustic insulation construction requirements are stricter than those necessary for standard home construction. The reader is urged to study the principles and practices of Section 3.5 for a thorough understanding of sound insulation construction.

Summary Tables 1-6 through 1-13 provide guidelines for improving the sound insulation performance of different building elements. They will be useful for easy reference after the reader has become familiar with the supporting information in Section 3.5.

1.5 Dwelling Modification Packages and Costs

Based on the compatible land-use recommendations given in Tables 1-1 and 1-2, it is possible to set sound insulation goals for dwellings exposed to aircraft noise. This involves knowing the external noise environment, the required noise reduction for residences, and the existing noise reduction of the dwelling.

Airport operators can provide mapped noise exposure contours (Sections 2.1 and 2.2) showing

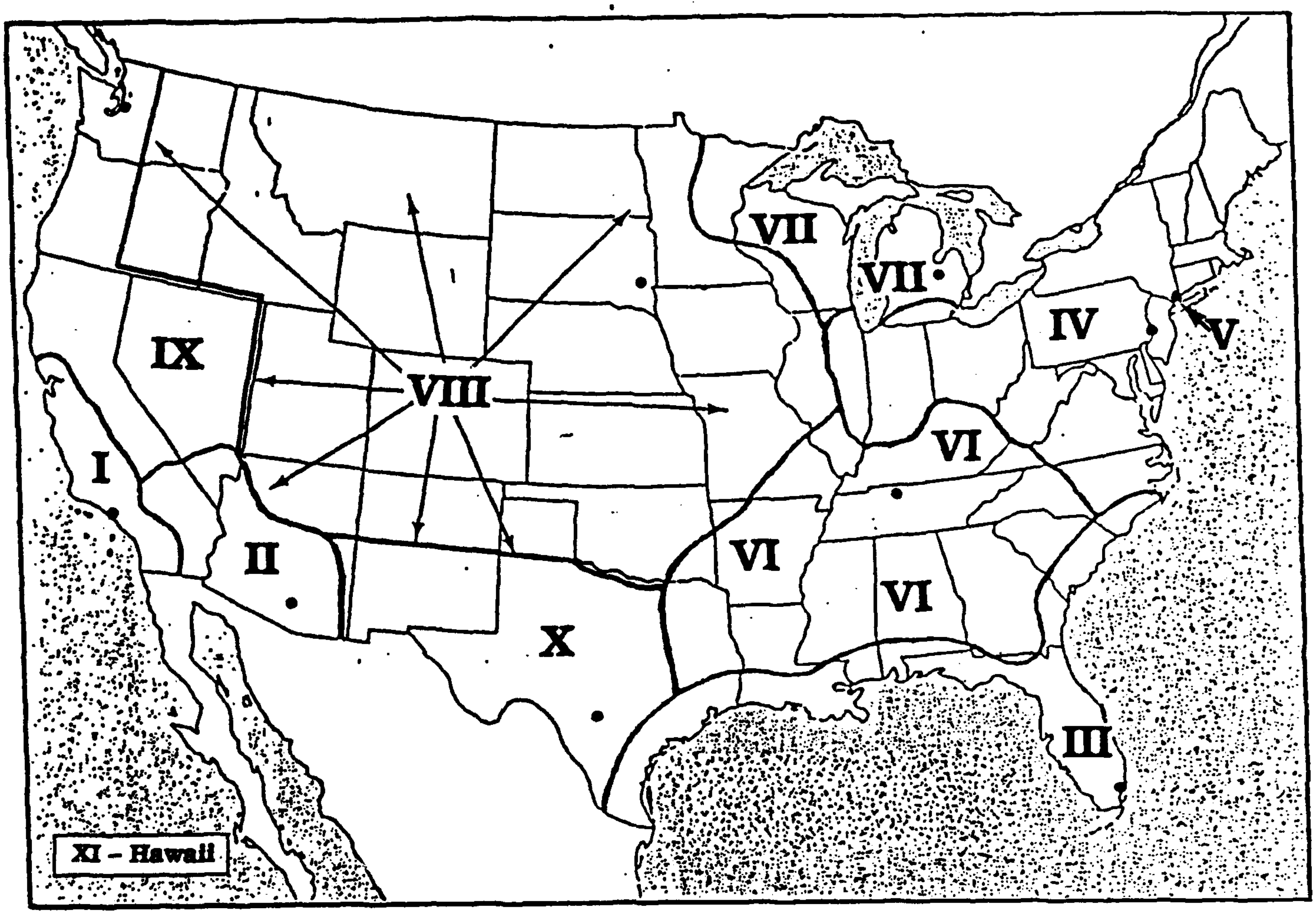
Table 1-3

EWR Ratings for Common Construction Elements

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 Crawlspace	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



- Indicates location of airport used in field survey described in Reference 3.

Figure 1-1. Regions of Differing Construction Practices.

(Repeated as Figure 3-3.)

Table 1-4
(Repeated as Table 3-2)

Percentages of Dwellings in Each Construction Category and Floor Constructions for Each Region

Construction Category*	Region and Airport										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	LAX	TUS	JAX	PHL	LGA	BNA	LAN	FSD	SEA	SAT	HNL
Siding/VA	15	--	35	30	15	15	40	55	70	60	--
" /SJL	--	--	15	35	50	--	45	30	20	--	100
" /ECL	--	--	--	--	--	--	--	--	5	--	--
Stucco/VA	80	5	--	--	--	--	--	--	--	5	--
" /SJL	5	5	--	--	--	--	--	--	--	--	--
Brick/VA	--	80	15	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	--	--	30	--	--	--	--	--	--	--	--
" /SJL	--	--	5	--	--	--	--	--	--	--	--
Slab Floor	50	100	70	15	5	--	10	5	--	90	100
Crawlspace	50	--	30	5	10	15	--	--	70	10	--
Basement	--	--	--	80	85	85	90	95	30	--	

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

LAX =Los Angeles, CA
TUS =Tucson, AZ
JAX =Jacksonville, FL
PHL =Philadelphia, PA
LGA =LaGuardia, New York, NY
BNA =Nashville, TN

LAN = Lansing, MI
FSD = Sioux Falls, SD
SEA = Seattle, WA
SAN = San Antonio, TX
HNL = Honolulu, Oahu, HI

Table 1-5
(Repeated as Table 3-48)

1987 Average Dwelling Size for New Construction

Region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Sq. Ft.	1,765	1,765	1,800	1,815	1,840	1,800	1,795	1,785	1,765	1,800	1,765

Table 1-6
(Repeated as Table 3-8)

Summary of Methods for Improving Window Sound Insulation

1. Increase glazing thickness up to 1/2 inch to increase mass and to reduce vibration. 2. Use laminated glazing, typically two layers of glazing with a 30 mil polyvinyl butyral interlayer, to achieve limpness and provide damping which reduces coincidence effects. For double-lite constructions, place the laminated lite on the warm side of the window because cold climate conditions may result in loss of damping effect for the interlayer. Laminated glazing constructions can result in an increase of 3 dB in the STC rating over monolithic glazing of the same thickness. 3. Use double-lite constructions with at least a 2-inch-wide spacing between the lites. Each doubling of the airspace between the lites results in an increase of 3 dB in the STC rating. Glazing thickness should be in a ratio of 2:1 so lites have different resonance frequencies. 4. Do not use lightweight frames where flanking sound paths may limit window transmission loss performance. Use separate heavy aluminum frames connected together with a thermal break. 5. Mount lites in soft neoprene edge gaskets which wrap around the bottom of the glazing sash channel. This minimizes structureborne sound transmission between the glazing and the window sash. 6. Operable double windows with separate sashes provide greater transmission loss than a single sash with double glazing. Non-operable windows have STC ratings which are 3 dB higher than operable windows of similar construction. 7. Do not evaluate windows needed to isolate low-frequency noise (such as occurs with aircraft overflights) based on STC ratings alone. This is because the STC rating does not include transmission loss performance below 125 Hz, where aircraft noise may be significant. For example, single lites with STC ratings identical to double-lite constructions will generally perform better at low frequencies due to their greater overall weight. Installation is critical in order to maintain the sound isolation performance of the window assembly. 8. Windows need to fit with a minimum perimeter gap between the window frame and opening. All voids need to be caulked and closed off with wood trim and blocking. Ensure that all sound flanking and air infiltration paths have been closed off. Remember, if air can pass through, so can sound.

Table 1-7
(Repeated as Table 3-9)

Summary of Methods for Improving Door Sound Insulation

1. Increase the weight of the door. This results in higher transmission loss characteristics. 2. Use solid-core wood doors or hollow-core metal doors filled with fibrous fill. Special acoustical wood and metal doors are available which can be specified for optimum results. 3. Fill hollow metal door frames with fiberglass or use solid wood door frames. Caulk around door frames at the wall. 4. Door frames and hardware should be reinforced to handle the extra weight of acoustical doors. Use ball-bearing hinges and long screws for attachment to framing members. 5. Provide full seals and weatherstripping at the perimeter of the door jamb and head to minimize perimeter air infiltration. 6. Provide a drop seal at the door bottom which makes full contact with a raised threshold. The drop seal should be adjustable to compensate for misalignment of the door. 7. Vision lites should have similar transmission loss characteristics to the door. Use two layers of 1/4-inch laminated glass separated by an airspace. Provide full seals and gasketing at the window perimeter. 8. Add a second sliding glass door in parallel with the existing sliding glass door. Position the new sliding glass door so it is a minimum of 2 inches from the existing sliding glass door.

Table 1-8
(Repeated as Table 3-12)

Summary of Methods for Improving Attic and Ceiling Sound Insulation

1. Install baffles on attic vents where practical.
2. Add acoustically absorptive material to a thickness equal to R-19 to the attic space to reduce reverberant sound level buildup. Apply material evenly throughout the attic space, taking care to keep it away from eave vents and openings.
3. Add one layer of 5/8-inch fire-code gypsumboard to the interior finish ceiling for dormer, non-attic, lightweight, or deteriorated roofs.
4. For greater noise control in attics add 5/8-inch plywood or gypsumboard to the rafters or add plywood flooring to the joists. Use absorptive material equivalent to R-19 between the rafters or joists.
5. Cover exposed beam ceilings with interior finish ceilings or partial enclosures.
6. For higher noise insulation on non-attic roofs: strip off existing exterior surface, add 3.5-inch rigid insulation assembly, 1/2-inch plywood sheathing, and new roofing material.
7. Remove whole-house attic exhaust fans and repair the interior ceiling to match the existing conditions.

Table 1-9
(Repeated as Table 3-13)

Summary of Methods for Improving Interior Wall Sound Insulation

1. Use heavy gypsumboard such as fire-rated products in 5/8-inch thickness. Adding one layer of 5/8-inch gypsumboard increases the wall STC rating by 3 dB.
2. Use a discontinuous construction between the existing wall and the new wall finish. This can be achieved by adhesive attachment of gypsumboard and sound-deadening board to the existing wall or by furring out a separate wall. Increases of 6 dB and 12 dB, respectively, to the STC rating are achieved.
3. Use light-gauge metal channel studs (25-gauge or lighter) because they are less stiff than wood or load-bearing metal studs. The use of wide (3.5-inch) metal channel studs will increase the transmission loss at low frequencies.
4. Use 3-inch-thick sound-absorbing blankets in the wall cavity. Install blankets tightly between studs using friction fit or with fasteners to the studs to prevent sagging.
5. Cut new gypsumboard so that it fits tightly against walls, floor, and ceiling.
6. Apply acoustical caulking around perimeter of new gypsumboard and around all electrical outlets and switches to eliminate sound flanking.

Table 1-10
(Repeated as Table 3-15)

Components of Ducted Air Heating, Cooling and Ventilation System

1. Circulation fan capable of supplying the required air volume exchange through the ducting in each room.
2. For climates where heating is necessary, forced hot air heating, cooling, and ventilation capabilities through appropriate heating and cooling coils and condenser unit.
3. Fresh air inlet located on the shaded side of the dwelling provided that side is not exposed directly to the flight path. It should also be adjacent to a return air plenum to facilitate mixing the fresh air with the recirculated air.
4. Supply and return air diffusers in each room to circulate the air. The supply air diffusers should be adjustable to allow redirection or shut-off of the airflow. In systems without a furnace, the return plenum should be located near the ceiling to encourage recirculation of rising warm air. Furnaces have return-air plenums as part of the system.
5. Flexible ducting connecting the fan air supply vents and the return plenum to each room and to the exterior. Sheetmetal ducting should be used to provide superior sound insulation in attics and crawlspaces.
6. Control switch with on/off and at least two fan speeds, the lower of which provides the minimum required air circulation. The switch should permit air to be circulated without activating the heating or cooling elements. Existing radiant heat can be used as a "backup" system.

Table 1-11
(Repeated at Table 3-16)

Recommendations for Noise and Vibration Control in Residential HVAC Systems

1. Mount the motor/fan at grade level on factory-supplied vibration isolators to minimize vibration transmitted to the house.
2. If fans or other pieces of equipment are located in the attic, use mounting bases and vibration isolators to reduce structureborne noise and vibration transmission. Due to local building code restrictions it may not be possible in some areas to locate mechanical equipment for heating or cooling in the attic.
3. Install flexible duct connectors to limit vibration transmitted to the ductwork or the dwelling structure.
4. Use of standard sheetmetal ductwork in attics and crawlspaces. Ductwork is exposed to higher levels of aircraft noise in these spaces. Do not use flexible ductwork in attic spaces since it does not have as good sound-insulating properties as standard sheetmetal.
5. Supply grilles in the rooms should be of the opposed-blade type and be designed for low noise.
6. A duct sound trap (muffler) should be installed just inside the fresh-air inlet opening. The sound trap will reduce any aircraft noise that passes through this opening and will eliminate the possibility of aircraft noise being transmitted via the duct path.

Table 1-12
(Repeated as Table 3-18)

Summary of Methods for Improving Noise Reduction in Manufactured Homes

<u>Roofs:</u>

1. Upgrade attic insulation to R-19, or better, where feasible.
2. Remove skylight and repair roof to existing condition.

<u>Walls:</u>

3. Add mass under exterior siding, or under interior decorative finish surface, by mounting sheathing, gypsumboard, or sound-deadening board.

<u>Windows and Doors:</u>

4. Mount secondary windows and sliding glass doors at least 2 inches away from existing elements on the dwelling exterior.
5. Replace existing windows and doors with highest STC rated products available.

<u>Air Infiltration Paths:</u>

6. Seal gaps and openings in external envelope.
7. Baffle vents.
8. Repair or replace weatherstripping.
9. Check and repair seals between modular units in double and triple-wide homes. Re-level home if necessary to prevent recurring problem.

<u>Ventilation:</u>

10. Upgrade existing system, as necessary, to provide air replenishment, circulation, heating and/or cooling to enable homeowner to keep windows and doors closed year-round.

Table 1-13
(Repeated as Table 3-14)

Suggested Guidelines for Design of New Construction

1. Do not build homes where DNL is 75 dB or greater.
2. Orient homes on the lot so noise-sensitive areas, such as TV rooms and bedrooms, are shielded from the flight track.
3. Use more massive external cladding, such as brick or other masonry, in place of siding wherever practical.
4. Where siding is used, or the noise exposure is high, use sound-deadening board, multi-layer gypsumboard, or a furred-out interior wall construction as discussed in Section 3.5.2.4.
5. Use heavy roofing materials, preferably with an attic rather than single-joist construction. Use R-19 or better insulating batts in the attic and R-11 to R-15 insulating batts in the walls. Use open-beam ceilings with extreme caution.
6. Use acoustical windows of an appropriate STC rating, properly installed.
7. Avoid large picture windows and sliding glass doors on sides of the dwelling which face the flight track.
8. Use solid-core doors with storm doors or, preferably, specialty acoustical doors.
9. Give careful attention to weatherstripping and seals.
10. Eliminate unnecessary openings such as through-the-wall air conditioners, vents, chimneys, skylights, and whole-house attic fans. Baffle or shield those that are used.
11. Provide a forced-air HVAC system with fresh air replenishment as described in Section 3.5.3.2.

the expected noise levels in residential communities around airfields. Tables 1-1 and 1-2 define the required noise reduction for each noise impact zone.

The existing noise reduction can be determined either by acoustic field measurements (Section 3.3) at a dwelling, or by using calculations based on the EWR and STC ratings of the building components and materials. The wall ratings in Table 1-3 cannot be used directly for these estimates because they do not account for the presence of windows or doors. STC, or Sound Transmission Class, ratings are conceptually similar to EWR ratings. They are discussed in Sections 2.3 and 3.5. The noise reduction provided by different dwelling categories and various construction schemes is given in Sections 3.2.3, 3.5.1, and 3.5.2.

Twenty-six different housing categories have been identified as representing most of the common types of residences across the country. A computerized cost optimization model has been used to identify the most cost-effective package of dwelling modifications satisfying the noise reduction goals for each house. This design tool was exercised for each of four noise impact zones. The 26 housing types are defined in Table 1-13. Of these 26, the most common types found in each of the 11 geographic regions of the country are listed in Table 1-14. Table 1-15 defines the modification codes used in the tables which follow it. Then Tables 1-16 to 1-41 provide, room by room, suggested modifications for each house. Section 3.6.1 discusses this information and the decisions involved in the design process.

At the bottom of each column in the modifications tables, a cost per square foot is provided to show the expense of implementing the suggested modifications package. This figure can be multiplied by the size of the house, in square feet of living space, to give the total cost of remodeling the dwelling. Table 1-5 provides the average size of homes in different parts of the country.

Construction material costs and labor rates vary from one part of the country to another. For this reason it is desirable to find local costs which are equivalent to the baseline costs given in the modifications tables. Table 1-43 gives geographic cost factors to facilitate calculating the equivalent cost in each region of the country. To use these factors, simply identify the target region, find the appropriate cost multiplier in Table 1-43, and multiply the modification cost by this factor. Either the cost per square foot or the whole house cost can be used for this calculation.

In order to estimate the cost of using these construction features in new construction rather than remodeling, multiply the remodeling cost by 0.70.

A sample cost development sheet is provided here as Figure 1-2. Its use is discussed in Section 3.6.3, where a full example is provided.

To use the Single Noise Zone Modification Cost Worksheet, the following information is needed:

- Geographical Region – if needed to identify typical house types or sizes (Tables 1-4 and 1-15).
- Noise Exposure Zone.
- Number of Houses of each type.
- Cost to modify each type of house in given noise zone (Tables 1-17 to 1-42).
- House size (Table 1-5, if necessary).
- Geographical Cost Factor (Table 1-43).

The cost to modify houses in the specified noise zone can be calculated according to the instructions in Section 3.6.

Table 1-14
(Repeated as Table 3-19)

Table of Housing Configurations Used in EWR Cost Optimization Program

Ident.	Ext. Wall	Roof	Window	Foundation	Door
One-story Houses:					
A	Stucco	VA	AL; 1/8 oper.	Crawl	SC
B	"	SJL	1/8 dual pane	Slab	SC
C	Brick	VA	AL; 1/8 oper.	Slab	SC
D	"	VA	1/8 dual pane	Basement	SC
E	"	VA	1/8 dual pane	Slab	SC
F	"	SJL	1/8 dual pane	Crawl	SC
G	"	SJH	1/8 dual pane	Crawl	SC
H	"	VA	1/8 oper.	Crawl	SC
I	Siding	VA	1/8 dual pane	Basement	SC
J	"	VA	1/8 oper.	Crawl	SC
K	"	VA	1/8 oper.	Slab	SGD
L	"	ECL	Jalousie	Slab	SGD
M	"	VA	1/8 oper.	Slab	SC
N	"	SJL	1/8 dual pane	Slab	SC
O	"	SJL	1/8 oper. w/st.	Basement	SC
P	"	ECL	1/8 dual pane	Crawl	SC
Q	"	SJL	1/8 oper.	Slab	SGD
R	Block	VA	AL; 1/8 oper.	Slab	SC
S	Concrete	VA	1/8 dual pane	Crawl	SC
T	"	SJL	1/8 dual pane	Crawl	SC
Manufactured Home:					
U	Siding	VA	1/8 oper.	Crawl	HC
Two-story Townhouses:					
V	Siding	VA	1/8 dual pane	Basement	SGD
W	Brick	VA	"	"	SGD
End Unit Townhouse:					
X	Siding	VA	1/8 dual pane	Basement	SGD
Two-story Detached Dwelling:					
Y	Siding	VA	1/8 dual pane	Basement	SC
Z	Brick	VA	"	"	SC

Notes:
- Where there is a sliding glass door (SGD), the other exterior door is solid core (SC).
- One side of all dwellings is "shielded", usually the back side.

VA = Vented Attic
SJL = Single Joist, Light
ECL = Exposed Ceiling, Light

SC = Solid Core Door
HC = Hollow Core Door
SGD = Sliding Glass Door

Table 1-15
(Repeated as Table 3-47)

Most Common Dwelling Types in Each Region

Region	I	II	III	IV	V	VI	VIII	VII	IX	X	XI
Dwelling Type*	A B J K M	C E B F U	M R C N U	O I T D F	O I F D N	D I F E J	I O S T M	O I D F N	J I O T D	K E J B D	L Q K N

* Ranked from most to least common.

Table 1-16
(Repeated as Table 3-20)

Housing Modification Description Codes

Door Modifications	Description
SC+SEald	Solid Core + Vinyl Bulb Seal
SC+WSTRP	Solid Core + Weatherstrip
SC+SE+ST	Solic Core + Vinyl Bulb Seal + Storm Door
SG+WSTRP	Sliding Glass + Weatherstrip
RSTC35	Door having an STC Rating of 35
RSTC40	Door having an STC Rating of 40
RSTC45	Door having an STC Rating of 45
HC+STORM	Hard Core + Storm Door
HC+WS+ST	Hard Core + Weatherstrip + Storm Door
Window Modifications	**Description**
8p+STORM	1/8-inch Pane + Storm Window
8p+STC25	1/8-inch pane + Window having an STC Rating of 25
RSTC35	Window having an STC Rating of 35
RSTC40	Window having an STC Rating of 40
RSTC45	Window having an STC Rating of 45
Wall Modifications	**Description**
STUC+GYP	Stucco + 5/8-inch Gypsumboard
STUC+2GY	Stucco + 2 Layers Gypsumboard
STUC+MG	Stucco + Metal Stud + Gypsumboard
STUC+MGA	Stucco + Metal Stud + Gypsumboard + Absorption
WDGY+GYP	Wood/Gyp + 5/8-inch Gypsumboard
WDGY+2GY	Wood/Gyp + 2 Layers Gypsumboard
WDGY+RGA	Wood/Gyp + Resilient Chan. + Gypsumboard + Absorption
WDGY+MG	Wood/Gyp + Metal Stud + Gypsumboard
WDGY+MGA	Wood/Gyp + Metal Stud + Gypsumboard + Absorption
HBLK+GYP	Hollow Block + Gypsumboard
HBLK+2GY	Hollow Block + 2 Layers Gypsumboard
HBLK+RGA	Hollow Block + Resilient Chan. + Gypsumboard + Absorption
HBLK+MGA	Hollow Block + Metal Stud + Gypsumboard + Absorption
BRIK+GYP	4-inch Face Brick + Gypsumboard
BRIK+2GY	4-inch Face Brick + 2 Layers Gypsumboard
BRIK+MG	4-inch Face Brick + Metal Stud + Gypsumboard
BRIK+MGA	4-inch Face Brick + Metal Stud + Gypsumboard + Absorption
Roof Modifications	**Description**
VP+Absrp	Vented Pitched + Absorption
VP+Ab+GY	Vented Pitched + Absorption + Gypsumboard
SJL+GYP	Single Joist (Light) + Gypsumboard
SJL+A+RG	Single Joist (Light) + Resilient Chan. + Gypsumboard
ELt+GYP	Exposed Ceiling (Light Joist) + Gypsumboard
EL+Ab+GY	Exposed Ceiling (Light Joist) + Absorption + Gypsumboard
EL+Spc B	******** Needs Clarification ********
Floor Modifications	**Description**
FB+A+STd	Floorboard + Absorption + Storm Door (Basement)

Table 1-17
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type A

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *			RSTC35	RSTC45
	Wall 1				STUC+MGA
	Wall 2 *				STUC+MG
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.8	24.9	30.4	34.9
Dining Room	NR BEFORE	21.0	21.0	21.0	21.0
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC45	RSTC45
	Wall 1 *				STUC+2GY
	Wall 2				STUC+MGA
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	21.0	25.4	30.0	34.8
Kitchen	NR BEFORE	18.7	18.7	18.7	18.7
	Door 1	SC+SEald	SC+SEald	RSTC40	RSTC40
	Window 1	RSTC35	RSTC40	RSTC45	RSTC45
	Wall 1				
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	24.2	24.7	28.7	29.7
Bedroom #1	NR BEFORE	23.2	23.2	23.2	23.2
	Window 1 *		RSTC35	RSTC35	RSTC35
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *				STUC+GYp
	Wall 2				STUC+MGA
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	23.2	30.1	30.4	34.1
Bedroom #2	NR BEFORE	23.0	23.0	23.0	23.0
	Window 1		RSTC35	RSTC40	RSTC45
	Wall 1				STUC+GYp
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	23.0	30.2	31.0	34.0
Library/Den	NR BEFORE	19.5	19.5	19.5	19.5
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1			STUC+GYp	STUC+GYp
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	19.5	26.7	30.5	31.5
Cost Per Dwelling Sq. Ft.	C/D. Sq.Ft.	$0.34	$6.40	$10.18	$15.65

* 5 dB shielding assumed.

Table 1-18
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type B

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.0	21.0	21.0	21.0
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC35	RSTC35	RSTC45
	Window 2 *		RSTC35	RSTC35	RSTC45
	Wall 1			STUC+GYP	STUC+RGA
	Wall 2 *				STUC+RGA
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.0	25.9	31.8	35.8
Dining Room	NR BEFORE	23.0	23.0	23.0	23.0
	Window 1 *		RSTC40	RSTC35	RSTC45
	Window 2		RSTC40	RSTC35	RSTC40
	Wall 1 *		STUC+GYp		STUC+2GY
	Wall 2				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.0	28.4	30.8	35.0
Kitchen	NR BEFORE	19.4	19.4	19.4	19.4
	Door 1		SC+SE+ST	RSTC40	RSTC40
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1				
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.4	24.8	30.0	30.0
Bedroom #1	NR BEFORE	24.6	24.6	24.6	24.6
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC35	RSTC35	RSTC40
	Wall 1 *				STUC+RGA
	Wall 2				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.6	28.1	31.7	35.3
Bedroom #2	NR BEFORE	24.5	24.5	24.5	24.5
	Window 1		RSTC35	RSTC35	RSTC40
	Wall 1				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.5	28.3	31.9	35.4
Library/Den	NR BEFORE	21.5	21.5	21.5	21.5
	Window 1		RSTC35	RSTC35	RSTC45
	Wall 1			STUC+GYp	STUC+RGA
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.5	26.4	30.1	35.0
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$7.29	$11.33	$17.46

* 5 dB shielding assumed.

Table 1-19
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type C

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		RSTC35	RSTC35	RSTC45
	Window 2 *			RSTC35	RSTC40
	Wall 1				BRIK+GYP
	Wall 2 *				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.0	30.3	35.3
Dining Room	NR BEFORE	21.3	21.3	21.3	21.3
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				
	Wall 2				BRIK+2GYP
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.3	25.9	30.7	36.1
Kitchen	NR BEFORE	19.0	19.0	19.0	19.0
	Door 1	SC+SE+ST	SC+SEald	RSTC35	RSTC40
	Window 1	8P+STorm	RSTC35	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.7	25.1	32.2	35.1
Bedroom #1	NR BEFORE	23.6	23.6	23.6	23.6
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC35	RSTC35	RSTC40
	Wall 1 *				
	Wall 2				BRIK+MGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.6	31.6	32.5	35.8
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.3	27.8	32.4	35.6
Library/ Den	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1		8P+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	24.6	29.4	35.9
Cost Per Dwelling Sq.Ft.	C/D. Sq. Ft.	$0.22	$4.45	$8.33	$12.11

* 5 dB shielding assumed.

Table 1-20
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type D

Room	Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.5	21.5	21.5	21.5
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC40
	Wall 1		BRIK+GYp		BRIK+MGA
	Wall 2 *				BRIK+RGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.5	26.9	32.0	34.6
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC40	RSTC45
	Window 2			RSTC40	RSTC45
	Wall 1 *				
	Wall 2				BRIK+MGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	33.8	36.1
Kitchen	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.6	31.9	34.4
Bedroom #1	NR BEFORE	26.2	26.2	26.2	26.2
	Window 1 *			8G+STC25	RSTC40
	Window 2			8G+STC25	RSTC45
	Wall 1 *				
	Wall 2				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	26.2	26.2	30.7	35.8
Bedroom #2	NR BEFORE	26.0	26.0	26.0	26.0
	Window 1			8G+STC25	RSTC40
	Wall 1				BRIK+MG
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	26.0	26.0	30.5	35.0
Library/Den	NR BEFORE	22.7	22.7	22.7	22.7
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	22.7	27.2	32.8	35.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$3.23	$8.97	$12.96

* 5 dB shielding assumed.

Table 1-21
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type E

Room	Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.6	21.6	21.6	21.6
	Door 1		SC+SE+ST	RSTC35	RSTC35
	Window 1		8G+STC25	RSTC35	RSTC35
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYP		BRIK+2GYP
	Wall 2 *				BRIK+GYP
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	21.6	27.0	32.1	35.4
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	33.1	34.5
Kitchen	NR BEFORE	20.0	20.0	20.0	20.0
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STorm	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	20.0	25.2	27.3	35.8
Bedroom #1	NR BEFORE	26.3	26.3	26.3	26.3
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.3	26.3	33.9	35.6
Bedroom #2	NR BEFORE	26.1	26.1	26.1	26.1
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.1	26.1	34.0	35.7
Library/Den	NR BEFORE	22.8	22.8	22.8	22.8
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.8	27.3	32.2	36.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	\$0.00	\$3.96	\$6.04	\$13.15

* 5 dB shielding assumed.

Table 1-22
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type F

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC45
	Wall 1		BRIK+GYp		BRIK+MGA
	Wall 2 *		BRIK+GYp		BRIK+MGA
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	21.1	26.3	30.9	35.5
Dining Room	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+2GY		BRIK+2GY
	Wall 2		BRIK+GYP		BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	26.6	31.1	35.5
Kitchen	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SC+SE+ST	RSTC40	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	19.6	24.8	31.4	34.7
Bedroom #1	NR BEFORE	25.0	25.0	25.0	25.0
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	25.0	25.0	31.4	35.8
Bedroom #2	NR BEFORE	24.9	24.9	24.9	24.9
	Window 1			RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	24.9	24.9	31.6	35.9
Library/Den	NR BEFORE	22.1	22.1	22.1	22.1
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+2GY		BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	22.1	25.8	30.4	34.9
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$6.71	$9.69	$16.50

* 5 dB shielding assumed.

Table 1-23
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type G

Room	Building Element	Modifications by Noise Zone 60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.4	21.4	21.4	21.4
	Door 1		SC+SE+ST	RSTC35	RSTC35
	Window 1		8G+STC25	RSTC40	RSTC40
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYP	BRIK+GYp	BRIK+2GY
	Wall 2 *				BRIK+2GY
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	21.4	26.3	30.8	34.6
Dining Room	NR BEFORE	23.8	23.8	23.8	23.8
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	23.8	27.7	31.1	35.0
Kitchen	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	19.8	25.5	29.9	35.8
Bedroom #1	NR BEFORE	25.7	25.7	25.7	25.7
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	25.7	25.7	31.4	36.1
Bedroom #2	NR BEFORE	25.6	25.6	25.6	25.6
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	25.6	25.6	31.6	35.6
Library/Den	NR BEFORE	22.5	22.5	22.5	22.5
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	22.5	26.6	30.4	36.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$3.64	$8.05	$15.20

* 5 dB shielding assumed.

Table 1-24
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type H

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8P+STC25	RSTC35	RSTC45
	Window 2 *		8P+STC25	RSTC35	RSTC45
	Wall 1		BRIK+GYp	BRIK+GYp	BRIK+GYp
	Wall 2 *				BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.9	25.1	29.5	36.1
Dining Room	NR BEFORE	21.2	21.2	21.2	21.2
	Window 1 *		8P+STC25	RSTC40	RSTC45
	Window 2		8P+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+GYp	BRIK+GYp	BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	21.2	25.9	30.5	35.2
Kitchen	NR BEFORE	19.0	19.0	19.0	19.0
	Door 1		RSTC40	RSTC35	RSTC40
	Window 1		8P+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.0	26.8	29.5	35.2
Bedroom #1	NR BEFORE	23.5	23.5	23.5	23.5
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+GYp		BRIK+GYp
	Wall 2		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.5	27.9	31.3	35.9
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.3	27.7	31.2	35.9
Library/Den	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1		8P+STC25	RSTC40	RSTC45
	Wall 1		BRIK+GYp		
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.9	24.6	31.9	36.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$7.85	$8.59	$14.73

* 5 dB shielding assumed.

Table 1-25
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type I

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.0	21.0	21.0	21.0
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC45	RSTC45
	Window 2 *		RSTC40	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	21.0	26.0	30.2	35.7
Dining Room	NR BEFORE	22.4	22.4	22.4	22.4
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.4	28.1	30.3	35.2
Kitchen	NR BEFORE	18.9	18.9	18.9	18.9
	Door 1	RSTC35	RSTC35	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.4	24.5	24.7	25.0
Bedroom #1	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC40	RSTC45
	Window 2			RSTC45	RSTC45
	Wall 1 *				WDGY+2GY
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.1	24.1	30.2	35.3
Bedroom #2	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1			RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.1	24.1	29.8	37.0
Library/Den	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1		8G+STC25	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	24.1	29.9	34.7
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.02	$7.62	$13.40	$18.15

* 5 dB shielding assumed.

Table 1-26
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type J

Room	Building Element	Modification by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	17.9	17.9	17.9	17.9
	Door 1	HC+WS+ST	HC+WS+ST	RSTC35	RSTC40
	Window 1	8P+STC25	RSTC40	RSTC45	RSTC45
	Window 2 *	8P+STorm	RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.8	24.9	30.2	35.7
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	25.5	30.3	35.2
Kitchen	NR BEFORE	15.8	15.8	15.8	15.8
	Door 1	HC+WS+ST	RSTC35	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.7	24.5	24.7	25.0
Bedroom #1	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1 *		RSTC35	RSTC40	RSTC40
	Window 2		RSTC40	RSTC45	RSTC45
	Wall 1 *				WDGY+2GY
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	26.9	30.2	34.9
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC40	RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	27.4	29.8	37.0
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	RSTC40	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.4	26.7	29.9	34.7
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$3.34	$9.13	$13.40	$18.06

* 5 dB shielding assumed.

Table 1-27
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type K

Room	Building Element	Modifications by Noise Zone			
		60–65 dB	66–70 dB	71–75 dB	76–80 dB
Living Room	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1 *		8P+STC25	RSTC45	RSTC45
	Window 2		8P+STC25	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.6	24.9	30.3	34.4
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+MGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	25.6	30.5	37.2
Kitchen	NR BEFORE	18.1	18.1	18.1	18.1
	Door 1	SC+SE+ST	RSTC35	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.2	24.6	24.8	25.0
Bedroom #1	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1 *		RSTC40	RSTC35	RSTC35
	Window 2		RSTC45	RSTC45	RSTC40
	Wall 1 *				WDGY+MG
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.3	27.3	30.1	34.5
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC35	RSTC45	RSTC40
	Wall 1			WDGY+GYp	WDGY+MG
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	26.8	30.0	34.7
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1	WDGY+2GY	WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.6	26.4	30.1	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$2.96	$8.97	$13.30	$17.79

* 5 dB shielding assumed.

Table 1-28
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type L

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	16.2	16.2	16.2	16.2
	Door 1	SG+WStrp	SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1	RSTC35	RSTC45	RSTC45	RSTC45
	Window 2 *	RSTC30	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Wall 2 *			WDGY+RGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	23.2	25.8	29.9	33.6
Dining Room	NR BEFORE	16.5	16.5	16.5	16.5
	Window 1 *	RSTC30	RSTC35	RSTC40	RSTC45
	Window 2	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.5	25.3	30.5	36.0
Kitchen	NR BEFORE	15.7	15.7	15.7	15.7
	Door 1	SC+WStrp	RSTC40	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	20.4	23.4	24.3	25.0
Bedroom #1	NR BEFORE	17.9	17.9	17.9	17.9
	Window 1 *	RSTC30	RSTC30	RSTC40	RSTC40
	Window 2	RSTC35	RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.2	25.2	30.2	35.6
Bedroom #2	NR BEFORE	17.8	17.8	17.8	17.8
	Window 1	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MG
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	23.6	26.4	31.5	35.1
Library/Den	NR BEFORE	15.2	15.2	15.2	15.2
	Window 1	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+MG	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	20.6	25.7	29.5	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$7.39	$10.27	$18.15	$22.77

* 5 dB shielding assumed.

Table 1-29
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type M

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	19.5	19.5	19.5	19.5
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		RSTC40	RSTC45	RSTC45
	Window 2 *			RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MG
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.5	25.0	30.4	35.2
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	20.3	25.6	30.5	35.0
Kitchen	NR BEFORE	18.1	18.1	18.1	18.1
	Door 1	RSTC35	RSTC40	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC40	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	23.0	24.7	24.8	25.0
Bedroom #1	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC40	RSTC45	RSTC45
	Wall 1 *				WDGY+MG
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.3	27.0	30.1	35.6
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.2	26.8	30.0	36.7
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	RSTC40	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	23.5	24.9	30.1	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.72	$8.02	$13.24	$17.00

* 5 dB shielding assumed.

Table 1-30
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft., One-Story House: Type N

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	20.6	20.6	20.6	20.6
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2 *		RSTC35	RSTC35	RSTC45
	Wall 1			WDGY+GYp	WDGY+MG
	Wall 2 *			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.6	26.3	30.7	35.0
Dining Room	NR BEFORE	21.9	21.9	21.9	21.9
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC40	RSTC40	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.9	26.9	29.5	35.2
Kitchen	NR BEFORE	18.6	18.6	18.6	18.6
	Door 1		RSTC40	RSTC40	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	18.6	25.0	25.0	25.0
Bedroom #1	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *		WDGY+GYp	WDGY+GYp	WDGY+MG
	Wall 2			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	28.0	30.1	35.0
Bedroom #2	NR BEFORE	23.4	23.4	23.4	23.4
	Window 1		RSTC40	RSTC40	RSTC40
	Wall 1		WDGY+GYp	WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.4	30.5	30.5	36.1
Library/Den	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1		RSTC35	RSTC40	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.0	26.1	30.6	35.5
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$12.01	$15.45	$18.34

* 5 dB shielding assumed.

Table 1-31
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type O

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	20.6	20.6	20.6	20.6
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+MGA	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	20.6	26.2	30.1	34.9
Dining Room	NR BEFORE	21.9	21.9	21.9	21.9
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2		WDGY+2GY	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	21.9	28.3	30.3	35.4
Kitchen	NR BEFORE	18.6	18.6	18.6	18.6
	Door 1	RSTC35	RSTC40	RSTC40	RSTC40
	Window 1	RSTC45	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.7	24.4	23.9	24.9
Bedroom #1	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		RSTC45	RSTC35	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *		WDGY+GYp	WDGY+GYp	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.3	28.6	30.2	35.4
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.3	28.9	30.3	36.0
Library/Den	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1		RSTC40	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	20.0	25.5	31.1	34.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.10	$13.45	$16.28	$20.34

* 5 dB shielding assumed.

Table 1-32
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type P

Room	Building Element	Modifications by Noise Zone 60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	18.4	18.4	18.4	18.4
	Door 1	SC+SE+ST	RSTC35	RSTC40	RSTC40
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2 *	8G+STC25	WDGY+GYp	RSTC40	RSTC45
	Wall 1				WDGY+MG
	Wall 2 *				WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.8	26.0	29.6	34.8
DiningRoom	NR BEFORE	19.4	19.4	19.4	19.4
	Window 1 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2	8G+STC25	RSTC35	RSTC45	RSTC40
	Wall 1 *		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Wall 2			WDGY+2GY	WDGY+MGA
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.4	26.1	29.7	35.5
Kitchen	NR BEFORE	17.2	17.2	17.2	17.2
	Door 1	SC+SE+ST	RSTC40	RSTC40	RSTC40
	Window 1	8G+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.3	24.3	24.3	25.0
Bedroom #1	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1 *			WDGY+RGA	WDGY+MG
	Wall 2			WDGY+2GY	WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	25.4	26.3	29.8	34.7
Bedroom #2	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1			WDGY+RGA	WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	25.6	26.6	30.5	35.0
Library/Den	NR BEFORE	18.1	18.1	18.1	18.1
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.1	25.3	30.9	35.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$6.74	$11.34	$18.04	$22.80

* 5 dB shielding assumed.

Table 1-33
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type Q

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	19.3	19.3	19.3	19.3
	Door 1		SG+WStrp	SG+WS+SG	SG+WS+SG
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2 *		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.3	25.5	30.3	33.3
Dining Room	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1 *		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.0	25.7	29.5	35.5
Kitchen	NR BEFORE	17.9	17.9	17.9	17.9
	Door 1	RSTC40	RSTC40	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.5	24.9	24.9	24.9
Bedroom #1	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1 *		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.7	26.8	30.3	35.9
Bedroom #2	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1		RSTC35	RSTC40	RSTC40
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.7	27.0	30.0	34.7
Library/Den	NR BEFORE	18.3	18.3	18.3	18.3
	Window 1	8P+STC25	RSTC35	RSTC45	RSTC45
	Wall 1	WDGY+2GY	WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.9	25.1	30.6	34.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$3.08	$7.63	$16.50	$18.37

* 5 dB shielding assumed.

Table 1-34
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type R

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC40	RSTC45
	Window 2 *			RSTC35	RSTC40
	Wall 1				HBLK+MGA
	Wall 2 *				HBLK+GYp
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	24.9	31.9	35.2
Dining Room	NR BEFORE	21.2	21.2	21.2	21.2
	Window 1 *		8P+STC25	RSTC35	RSTC45
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				HBLK+GYp
	Wall 2				HBLK+RGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.2	25.8	30.2	36.4
Kitchen	NR BEFORE	18.9	18.9	18.9	18.9
	Door 1	SC+SE+ST	SC+SE+ST	RSTC35	RSTC40
	Window 1	8P+STC25	8P+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	24.5	24.5	31.2	33.3
Bedroom #1	NR BEFORE	23.5	23.5	23.5	23.5
	Window 1 *		8P+STC25	RSTC35	RSTC35
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				HBLK+GYp
	Wall 2				HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.5	27.8	31.9	35.1
Bedroom #2	NR BEFORE	23.2	23.2	23.2	23.2
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1		HBLK+RGA		HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.2	27.8	31.9	35.4
Library/Den	NR BEFORE	19.8	19.8	19.8	19.8
	Window 1		8P+STC25	RSTC40	RSTC45
	Wall 1				HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.8	24.4	31.6	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.38	$4.66	$8.94	$15.51

* 5 dB shielding assumed.

Table 1-35
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type S

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.5	21.5	21.5	21.5
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC40
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+2GY
	Wall 2 *		BRIK+GYp		BRIK+2GY
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	21.5	26.9	29.5	35.1
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	32.7	36.0
Kitchen	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STorm	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.1	31.1	35.1
Bedroom #1	NR BEFORE	26.2	26.2	26.2	26.2
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.2	26.2	33.4	34.9
Bedroom #2	NR BEFORE	26.0	26.0	26.0	26.0
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.0	26.0	33.5	35.0
Library/Den	NR BEFORE	22.7	22.7	22.7	22.7
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.7	27.2	31.9	35.3
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$4.37	$7.33	$14.08

* 5 dB shielding assumed.

Table 1-36
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type T

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC45
	Window 2 *		8G+STC25	RSTC35	RSTC45
	Wall 1				BRIK+2GY
	Wall 2 *				BRIK+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.1	26.3	32.4	35.5
Dining Room	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+RGA		BRIK+2GY
	Wall 2		BRIK+RGA		BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	26.6	33.5	35.5
Kitchen	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.6	24.8	27.6	34.7
Bedroom #1	NR BEFORE	25.0	25.0	25.0	25.0
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	25.0	25.0	34.4	35.8
Bedroom #2	NR BEFORE	24.9	24.9	24.9	24.9
	Window 1			RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.9	24.9	34.5	35.9
Library/Den	NR BEFORE	22.1	22.1	22.1	22.1
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+MGA		BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.1	25.8	32.5	34.9
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$6.33	$9.32	$16.33

* 5 dB shielding assumed.

Table 1-37
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Manufactured Home: Type U

Room	Building Element	Modifications by Noise Zone			
		MH L65	MH L70	MH L75	MH L80
Living Room	NR BEFORE	18.3	18.3	18.3	18.3
	Door 1	HC+WS+ST	HC+WS+ST	HC+WS+ST	HC+WS+ST
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+2GY	WDGY+2GY
	Wall 2 *		WDGY+2GY	WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	23.2	25.3	25.7	25.8
Kitchen	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *		RSTC45	RSTC45	RSTC45
	Wall 1				
	Wall 2 *				
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	23.3	27.4	27.7	27.7
Bedroom #1	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		HC+WS+ST	HC+WS+ST	HC+WS+ST
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 2		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 3 *			WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	19.8	25.4	27.8	27.8
Bedroom #2	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 2			WDGY+2GY	WDGY+2GY
	Wall 3 *			WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	21.7	25.4	30.4	30.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.38	$11.11	$18.79	$18.79

* 5 dB shielding assumed.

Table 1-38
Noise Reduction, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type V

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	25.5	25.5	25.5	25.5
	Door 1 *			SC+SE+MT	RSTC40
	Window 1 *			RSTC35	RSTC45
	Wall 1 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	25.5	25.5	30.2	35.8
Dining Room	NR BEFORE	24.4	24.4	24.4	24.4
	Window 1			RSTC40	RSTC45
	Wall 1			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.4	24.4	31.6	35.1
Kitchen	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1	SG+WS+SG	SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1	8G+STorm	8G+STorm	RSTC45	RSTC45
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	19.8	26.0	29.2	29.2
Bedroom #1	NR BEFORE	25.0	25.0	25.0	25.0
	Window 1			RSTC35	RSTC45
	Wall 1			WDGY+GY	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	25.0	25.0	30.4	35.3
Bedroom #2	NR BEFORE	28.8	28.8	28.8	28.8
	Window 1 *				RSTC45
	Wall 1 *				WDGY+2GY
	Roof 1				
	Floor 1				
	NR AFTER	28.8	28.8	28.8	34.7
Bedroom #3	NR BEFORE	28.3	28.3	28.3	28.3
	Window 1 *			8G+STC25	RSTC45
	Wall 1 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	28.3	28.3	30.4	35.1
Basement	NR BEFORE	32.7	32.7	32.7	32.7
	Window 1 *				RSTC35
	Window 2 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	32.7	32.7	32.7	43.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.50	$2.95	$6.40

* 5 dB shielding assumed.

Table 1-39
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type W

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	26.2	26.2	26.2	26.2
	Door 1 *			SC+SEald	RSTC35
	Window 1 *			RSTC35	RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	26.2	26.2	31.4	35.7
Dining Room	NR BEFORE	25.7	25.7	25.7	25.7
	Window 1			RSTC35	RSTC35
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	25.7	25.7	34.9	34.9
Kitchen	NR BEFORE	20.0	20.0	20.0	20.0
	Door 1	SG+WS+SG	SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1			RSTC35	RSTC45
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	20.0	24.9	31.1	32.2
Bedroom #1	NR BEFORE	26.7	26.7	26.7	26.7
	Window 1			RSTC35	RSTC40
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	26.7	26.7	34.1	35.1
Bedroom #2	NR BEFORE	30.1	30.1	30.1	30.1
	Window 1 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	30.1	30.1	30.1	35.3
Bedroom #3	NR BEFORE	29.7	29.7	29.7	29.7
	Window 1 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	29.7	29.7	29.7	35.2
Basement	NR BEFORE	32.7	32.7	32.7	32.7
	Window 1 *				RSTC35
	Window 2 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	32.7	32.7	32.7	43.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.41	$1.98	$3.85

* 5 dB shielding assumed.

Table 1-40
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type X

Room	Building Element	Modifications by Noise Zone 60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	24.5	24.5	24.5	24.5
	Door 1 *			RSTC35	RSTC40
	Window 1 *			RSTC35	RSTC40
	Window 2 *			RSTC35	RSTC40
	Wall 1 *				WDGY+RGA
	Wall 2 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.5	24.5	30.1	35.0
Dining Room	NR BEFORE	24.4	24.4	24.4	24.4
	Window 1			RSTC40	RSTC45
	Wall 1			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.4	24.4	31.6	35.1
Kitchen	NR BEFORE	19.2	19.2	19.2	19.2
	Door 1		SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1		8G+STC25	RSTC45	RSTC45
	Wall 1				
	Wall 2				
	Roof 1				
	Floor 1				
	NR AFTER	19.2	24.4	25.5	25.5
Bedroom #1	NR BEFORE	22.0	22.0	22.0	22.0
	Window 1 *		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC45
	Wall 1 *		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Wall 2 *		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	22.0	26.9	30.3	34.7
Bedroom #2	NR BEFORE	25.9	25.9	25.9	25.9
	Window 1 *			RSTC35	RSTC45
	Window 2 *			RSTC35	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MG
	Roof 1				
	Floor 1				
	NR AFTER	25.9	25.9	31.0	35.0
Bedroom #3	NR BEFORE	28.3	28.3	28.3	28.3
	Window 1 *			RSTC35	RSTC45
	Wall 1 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	28.3	28.3	31.5	35.1
Basement	NR BEFORE	32.7	32.7	32.7	32.7
	Window 1 *				RSTC35
	Window 2 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	32.7	32.7	32.7	43.4
Cost/Dwell.Sq.Ft.	C/D. Sq.Ft.	$0.00	$1.96	$6.06	$9.14

* 5 dB shielding assumed.

Table 1-41
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Dwelling: Type Y

Room	Building Element	Modifications by Noise Zone			
		60 - 65 dB	66 - 70 dB	71 - 75 dB	76 - 80 dB
Living Room	NR BEFORE	20.1	20.1	20.1	20.1
	Door 1		RSTC35	RSTC40	RSTC40
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	20.1	26.0	30.2	35.4
Dining Room	NR BEFORE	26.6	26.6	26.6	26.6
	Window 1 *			RSTC35	RSTC40
	Window 2 *			RSTC40	RSTC40
	Wall 1 *			WDGY+GYp	WDGY+RGA
	Wall 2 *			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	26.6	26.6	32.0	35.0
Kitchen	NR BEFORE	24.6	24.6	24.6	24.6
	Door 1 *			RSTC40	RSTC40
	Window 1 *			RSTC40	RSTC45
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	24.6	24.6	29.7	30.4
Family Room	NR BEFORE	24.8	24.8	24.8	24.8
	Window 1			RSTC35	RSTC45
	Wall 1			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.8	24.8	30.9	34.9
Bedroom #1	NR BEFORE	21.8	21.8	21.8	21.8
	Window 1		RSTC40	RSTC45	RSTC40
	Window 2		RSTC40	RSTC40	RSTC40
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+2GY	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	21.8	25.4	30.6	34.9
Bedroom #2	NR BEFORE	24.6	24.6	24.6	24.6
	Window 1			RSTC35	RSTC45
	Wall 1			WDGY+2GY	WDGY+MG
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	24.6	24.6	32.1	36.7

Table 1-41 (Continued)

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Bedroom #3	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC40
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+GYp	WDGY+MGA
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	22.3	27.7	29.9	35.5
Bedroom #4	NR BEFORE	26.5	26.5	26.5	26.5
	Window 1 *			RSTC40	RSTC40
	Window 2 *			RSTC40	RSTC35
	Wall 1 *			WDGY+GYp	WDGY+RGA
	Wall 2 *				WDGY+2GY
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	26.5	26.5	30.7	35.2
Den	NR BEFORE	26.8	26.8	26.8	26.8
	Window 1 *			RSTC40	RSTC40
	Window 2 *			RSTC40	RSTC40
	Wall 1 *			WDGY+GYp	WDGY+2GY
	Wall 2 *			WDGY+GYp	WDGY+2GY
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	26.8	26.8	32.8	35.6
Basement	NR BEFORE	34.6	34.6	34.6	34.6
	Window 1 *				
	Window 2 *				
	Wall 1				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	34.6	34.6	34.6	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$1.85	$6.52	$8.20

* 5 dB shielding assumed.

Table 1-42
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Dwelling: Type Z

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STorm	RSTC40	RSTC40
	Wall 1			BRIK+GYp	BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				
	Floor 1				
	NR AFTER	21.1	26.1	29.5	35.0
Dining Room	NR BEFORE	28.7	28.7	28.7	28.7
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	28.7	28.7	36.1	36.1
Kitchen	NR BEFORE	25.9	25.9	25.9	25.9
	Door 1 *			SC+SE+ST	RSTC35
	Window 1 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	25.9	25.9	32.5	35.6
Family Room	NR BEFORE	26.4	26.4	26.4	26.4
	Window 1			RSTC35	RSTC35
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	26.4	26.4	35.2	35.2
Bedroom #1	NR BEFORE	24.0	24.0	24.0	24.0
	Window 1			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1				
	Floor 1				
	NR AFTER	24.0	24.0	33.7	34.8
Bedroom #2	NR BEFORE	27.0	27.0	27.0	27.0
	Window 1			RSTC35	RSTC40
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	27.0	27.0	34.2	37.6

Table 1-42 (Continued)

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Bedroom #3	NR BEFORE	24.7	24.7	24.7	24.7
	Window 1			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1				
	Wall 2				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.7	24.7	33.2	35.6
Bedroom #4	NR BEFORE	28.4	28.4	28.4	28.4
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	28.4	28.4	34.7	36.8
Den	NR BEFORE	28.8	28.8	28.8	28.8
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	28.8	28.8	34.8	36.9
Basement	NR BEFORE	34.6	34.6	34.6	34.6
	Window 1 *				
	Window 2 *				
	Wall 1				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	34.6	34.6	34.6	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.30	$3.30	$4.52

* 5 dB shielding assumed.

Table 1-43

Cost Multiplier for Each Region

Region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Cost Multiplier	1.03	0.86	0.77	0.88	1.07	0.78	0.87	0.84	0.94	0.79	1.04

SINGLE NOISE ZONE MODIFICATION COSTS WORKSHEET

Region	DNL Zone	House Type	No. of Units	Cost/ Dwelling Sq.Ft.	Size (Sq.Ft.)	Unit Cost	TOTAL COST
		A					
		B					
		C					
		D					
		E					
		F					
		G					
		H					
		I					
		J					
		K					
		L					
		M					
		N					
		O					
		P					
		Q					
		R					
		S					
		T					
		U					
		V					
		W					
		X					
		Y					
		Z					
						Zone Cost:	
						Geographic Cost Factor:	
						Adjusted Zone Cost:	

Figure 1-2. Single Noise Zone Modification Costs Worksheet.
(Repeated as Figure 3-23.)

2.0 BASIC CONCEPTS

2.1 Sound Exposure Metrics

A-Weighted Sound Level

The normal human ear can detect sound frequencies ranging from about 20 Hz to about 15,000 Hz. Hertz is the unit used to indicate frequency and is equal to the number of cycles per second. Low-pitched sounds have low frequencies and high-pitched sounds have high frequencies. People do not hear all sounds over this wide range of frequencies equally well, however. The human ear is most sensitive to sounds in the 1000 to 4000 Hz range.

In order to reflect the differences in hearing sensitivity to different frequencies, sound levels are usually stated in terms of the A-weighted audibility scale. When a sound spectrum is A-weighted, sound levels in the 1000 to 4000 Hz frequency range are *increased* by a specified amount to account for the fact that the ear perceives them as louder compared to other frequencies. Similarly, the loudness at lower frequencies and at much higher frequencies is *reduced* because the ear is less sensitive in those regions. The A-weighting curve in Figure 2-1 shows how much is added to, or subtracted from, a sound level depending on the frequency. For example, at 250 Hz a value of 8.6 dB would be subtracted from a sound level to get the A-weighted one-third octave level. The unit of measure for all noise levels is the decibel (dB) and A-weighted levels are indicated by the unit "dBA".

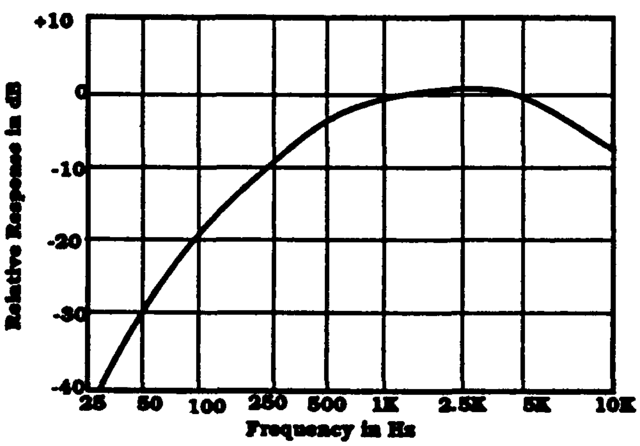


Figure 2.1. A-Weighting Versus Frequency.

Day-Night Average Sound Level (DNL) and Noise Contours

Aircraft noise exposure in a community is usually described in terms of noise contour maps. These indicate bands or zones around airfields where the average noise level can be expected to fall within the ranges specified by the contour lines. Contour maps typically show continuous lines of equal exposure drawn in 5 dB increments. Figure 2-2 shows a sample contour map.

The acoustic metric used is the Day-Night Average Sound Level (DNL or L_{dn}). This is a cumulative measure of the noise exposure during a 24-hour day. A 10 dB penalty is added to noise events occurring between 10:00 p.m. and 7:00 a.m. to reflect their greater intrusiveness and potential for disturbing sleep. The DNL is the result of averaging the A-weighted sound pressure level over 24 hours for aircraft activities throughout a year. This gives an indication of the long-term noise exposure for the community. DNL has proven to be a very reliable predictor of community reaction to noise intrusion.

Noise is generally identified as a problem for noise zones at and above DNL 65 dB. Residential land uses are considered unacceptable when the DNL is 75 dB or greater.

Sound Exposure Level (SEL), the Single-Event Metric

The Sound Exposure Level, SEL, is a single-event sound level often used in addition to DNL to evaluate noise exposure. It measures the total audible energy in a single flyover and presents it as though it took place in one second. Normalizing the sound energy to one second makes it possible to compare events that vary in duration.

Using the SEL gives a better measure of the intrusiveness of individual aircraft noise events as opposed to the long-term exposure which DNL predicts. Both SEL and DNL are derived from A-weighted sound levels. The difference between them is basically one of time averaging. DNL expresses the impact of all flights throughout the day. SEL, on the other hand, focuses on the effect of a single event and shortens the exposure time to one second. Both SEL and DNL are usually available in the form of mapped noise exposure contours. Because SEL expresses sound energy in a short timeframe, while DNL averages it out over many hours, SEL numbers are higher than DNL for the same location.

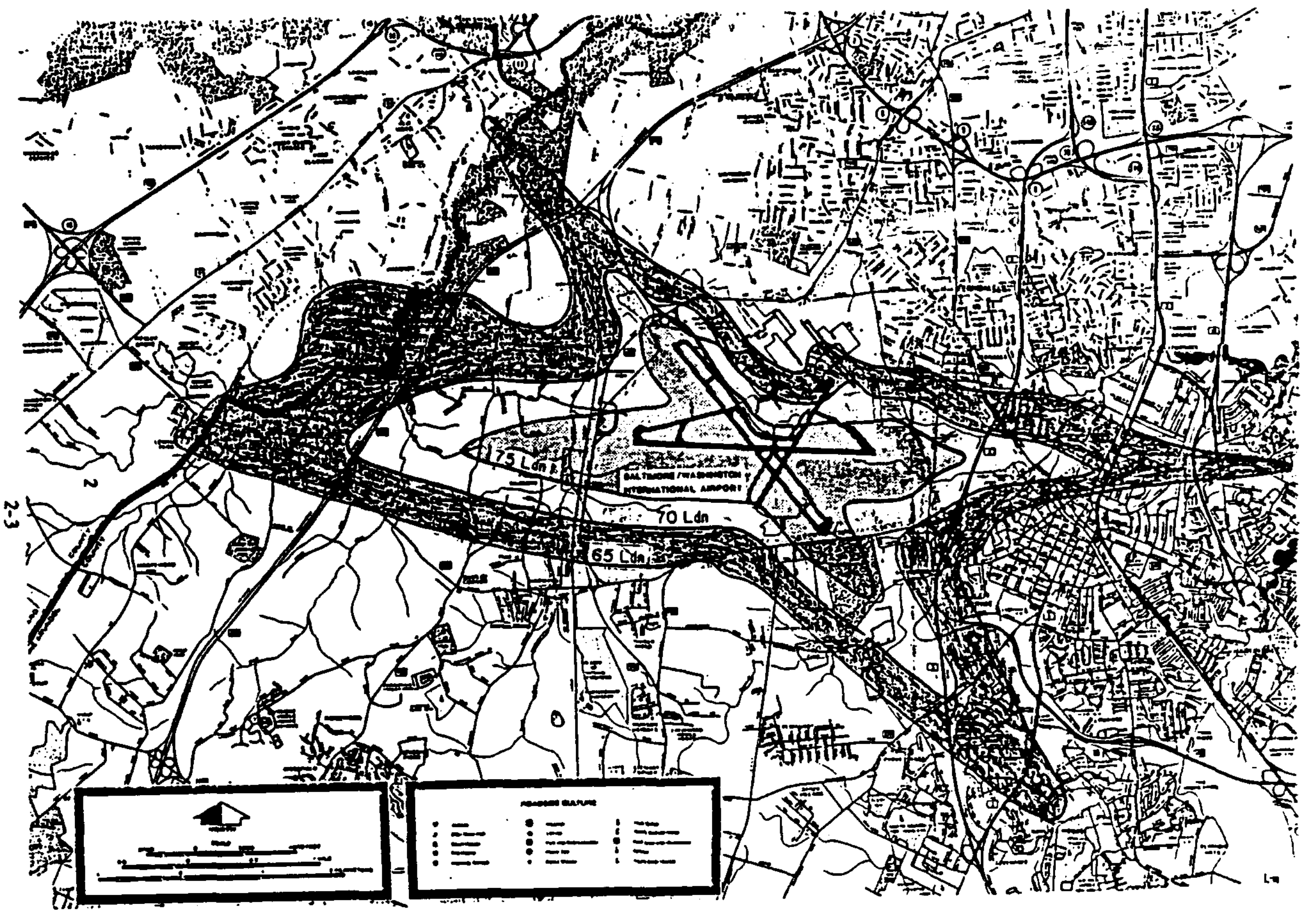


Figure 2-2. Example of Noise Contours at Baltimore/Washington International Airport.

Also, since DNL is a long-term average it cannot be measured directly the way SEL can. SEL measurements are useful for determining the existing and improved noise reduction in a dwelling. These measurements are discussed in Section 3.3.

2.2 Noise Intrusion From Aircraft Operations

Interference With Activities

The problem of aircraft noise has been recognized and studied in this country since the 1950s. While advances have been made in mitigating aircraft noise impact, there is a continuing need to safeguard the public health and welfare as well as to ensure the safety and efficiency of aircraft operations. Opinion surveys indicate that interference with telephone usage, listening to television and radio, and conversation invoke the most complaints. While residents often notice improvements in their ability to fall asleep and to concentrate after their home has been insulated for sound, these are not the activities they complain the most about.

Fears of permanent hearing damage from flyovers have been shown to be unfounded. A large number of studies on the physical, mental, and emotional health effects of aircraft noise exposure have led to the general conclusion that residences near airports are not exposed to high enough sound levels to warrant concern. The principal effect of aircraft noise on airfield neighbors is annoyance, caused by interference with daily activities.

Noise Characteristics

Noise intrusion from aircraft activities is perceived as more disturbing than other kinds of noise because of two characteristics. Unlike many other community noise sources which tend to be fairly constant, aircraft noise consists of sporadic individual noise events with a distinct rise and fall pattern. People do not, in general, respond to these events as just another component of the "background noise" of their day-to-day lives. Each individual flyover event remains recognizable and disturbing.

The second quality that makes aircraft noise more intrusive is its higher level, or loudness. The noise level experienced at a particular dwelling will depend on its location relative to the aircraft flight paths and the mode of ongoing aircraft operations (arrivals or departures).

Aircraft Sound Spectrum

The noise produced by modern aircraft contains acoustical energy over a wide frequency range. The audible noise which results varies from a very low-frequency "rumble" to a very high-frequency "whine", depending on the aircraft type and the operation performed (takeoff, landing, or ground run-up). Low-frequency noise (below 500 Hz) penetrates walls, roofs, doors, and windows much more efficiently than does high-frequency noise. Higher frequencies (above 1000 Hz), however, are carried through cracks and vents better. Also, people hear higher frequency sound better, the human ear being more sensitive above 1000 Hz than below.

Each noise source generates a characteristic sound spectrum. This spectrum can be plotted showing the noise level as a function of frequency. Aircraft noise differs somewhat from other types of community noise. It is important to identify the spectral characteristics of the noise that sound insulation is protecting against. Most materials and construction methods are more effective at insulating in one part of the frequency spectrum than in others. Knowing the noise characteristics helps to choose the best materials for insulation.

Most of the sound energy from aircraft operations is found at lower frequencies. While this energy is below the most sensitive region of people's hearing range, it can be heard well enough to be a problem and it causes disturbing structural vibration in a dwelling. Section 2.5 discusses the process by which sound gets transmitted into a dwelling interior.

2.3 Sound Insulation Metrics

Several metrics have been developed for discussing and specifying sound insulation performance. Each term differs from the others in important ways, but all refer to the ability to inhibit sound transmission. Several nationally (and internationally) recognized organizations have developed standards and specifications for evaluating these quantities. The organizations are identified in this section, and the Glossary (Appendix E) and the List of Organizations (Appendix G) provide more information on them. Standards and specifications are revised from time to time and it is important to keep abreast of these changes. Current versions can be obtained directly from the organizations themselves.

Of the descriptors that we are concerned with, two are determined by laboratory testing procedures: Sound Transmission Loss (TL) and Sound Transmission Class (STC). The Exterior Wall Rating (EWR) uses acoustical analysis based on TL. The others – Noise Reduction (NR) and Noise Level Reduction (NLR) – are determined by field testing of actual built systems. In general, a construction method or component will have a lower performance rating when tested under realistic field conditions than when tested in a laboratory. This is because sound-flanking paths, which can be minimized in a testing laboratory, are not as easily controlled in actual construction. Flanking refers to sound bypassing a wall – through crawlspaces, vents, rigid edge connections, and other means. Also, it is difficult to measure noise only through an isolated, single element such as a window, section of wall, or door in a field installation.

*Sound Transmission Loss (TL)**

This is the physical measure which describes the sound insulation value of a built construction system or component. It is a measure, on a logarithmic scale, of the ratio of the acoustic sound power incident on the tested piece to the acoustic sound power transmitted through it. The TL is expressed in decibels (dB). Generally, TL is measured as a function of frequency in one-third octave frequency bands. The higher the sound insulation, the less sound will be transmitted, resulting in a higher TL value. Values of TL are determined in acoustical laboratories under controlled testing methods prescribed by the American Society for Testing and Materials (ASTM).

*Sound Transmission Class (STC)***

Since working with a series of one-third octave TL measurements can be cumbersome, a single-number descriptor based on the one-third octave TL values has been developed. This rating method is called the Sound Transmission Class (STC). Like TL, the higher the STC rating for a construction method or component, the higher the sound insulation. Originally, STC ratings were developed as a single-number descriptor for the TL of interior office walls for typical office noise and speech spectra. Now, they are used, often incorrectly, for exterior walls as well. Most acoustical materials and components are commonly specified in terms of their STC rating.

*Exterior Wall Rating (EWR)**

EWR is a single-number rating for exterior building elements (such as walls, windows, doors, etc.) and represents the effective sound transmission loss capability, in decibels, of each element. It differs from STC rating in that it is based on aircraft noise rather than office noise spectra. For this reason, EWR is superior to STC for describing the sound-insulating properties of exterior wall elements exposed to aircraft noise. The EWR concept was developed by Wyle Laboratories and has been used extensively in studies of residential sound insulation. It is conceptually similar to the STC rating method. Like TL and STC, the higher the EWR value, the better the noise reduction.

Commercial products are usually specified in terms of STC. Therefore, when designing dwelling modifications, required EWR values for building elements are accompanied by the equivalent STC value, for specification purposes.

*Noise Reduction (NR)****

The quantitative measure of the sound isolation between spaces is called Noise Reduction (NR). The NR between two spaces, such as from the exterior to the interior of a dwelling, depends on the TL of the various components in the separating wall, the area of the separating wall, and the acoustical absorption in the receiving room. This value takes more into account than just the sound transmission characteristics of the wall material. Generally, values of NR are determined in one-third octave bands. A higher NR gives a lower noise level in the receiving room, indicating greater noise insulation.

Noise Level Reduction (NLR)

NLR is used to describe the reduction of environmental noise sources, such as aircraft. It is a single-number metric based on values of A-weighted noise reduction (NR). The greater the sound insulation in a wall, the lower the noise level in the receiving room, giving a higher NLR. The NLR is useful because it is a simpler metric to

* Typical tests to determine TL are described in ASTM E-90.

** STC is described in ASTM E-413.

*** Values of NR can be determined in built constructions under controlled field conditions described in ASTM E-336 and E-966.

use than NR; one number is easier to apply than a set of numbers in one-third octave bands. However, some building materials and components are more effective at reducing low-frequency noise than other materials or components. Since aircraft noise contains a lot of low-frequency sound, it is important to ensure that insulating materials and components perform well at low frequencies. NLR is a good indicator of overall wall performance but may not be appropriate when designing modifications for aircraft noise reduction, especially if a good NLR value disguises poor low-frequency insulation.

2.4 Sound Insulation Objectives

The goal for residential sound insulation is to reduce the dwelling interior noise levels due to aircraft operations. Total "soundproofing" of the dwelling, such that aircraft operations are inaudible, is economically infeasible. Modest improvements over the existing characteristics (i.e., less than 5 dB) may not provide a noticeable improvement for the homeowner and hence are not cost effective. The ideal solution is to provide sound insulation which lies between these two extremes.

FAA Regulations and the Department of Defense Air Installation Compatible Use Zone (AICUZ) Studies address the issue of aircraft noise infringement on communities surrounding airfields. Both identify the normally acceptable levels of exposure outside dwellings for residential use. Tables 1-1 and 1-2 show the land-use compatibility definitions of the AICUZ program and the FAA, respectively.

Interior Noise Objectives

The DNL is the best predictor of overall long-term community reaction to noise from aircraft as well as other activities. Exterior noise exposure less than DNL 65 dB is normally considered compatible with residential land use. Noise exposure is normally incompatible above 65 dB unless stated noise reductions are achieved within the dwellings. A 25 dB NLR is required in the noise zone from 65 to 70 dB. From 70 to 75 dB, a 30 dB NLR is required. Above 75 dB, residential land use is generally deemed incompatible and should be discouraged by local officials.

Sometimes, the DNL noise reduction goal in habitable rooms is supplemented by a single-event noise level criteria. This Sound Exposure Level (SEL) reflects the annoyance associated with individual flyovers because of activity interference. The SEL goal is 65 dB in general living spaces and 60 dB in bedrooms and television viewing rooms. These criteria are only applied to homes within the DNL-defined noise impact area, not to homes outside the 65 dB DNL contour boundary.

To use the SEL interior noise criteria, the outside noise exposure level is compared to the interior goal. For example, if the dwelling is between the SEL contour boundaries of 85 to 90 dB, then the required NLR to achieve 60 dB in a bedroom would be 30 dB. (The conservative upper bound of the noise zone is normally used to set NLR goals.)

Room Variations

The noise level of different rooms in a house depends on the absorption within the room, as well as on the noise entering from outside. Upholstered furniture, drapes, and carpeting absorb sound while hard surfaces do not. In addition, different categories of room vary on how predictable their sound environments are. Living rooms, for example, tend to be consistent from one house to another because they almost always have the same types of furnishings in them. Bedrooms vary because some are guest rooms with less furniture, and some have been converted to other uses. Kitchens tend to vary widely due to the use of different wall coverings, such as cabinets and appliances, or floor coverings, such as tile or carpet. These room variations act in addition to variation in exterior sound level and sound transmission through the outside wall.

Geographical Differences

Climate influences housing construction in ways that affect the sound insulation. In warm climates, construction may be lighter weight, especially in the roof, windows, and doors. Conversely, in cold climates, especially where snow is likely, the roof tends to be thicker and heavier, as do the windows and doors. A heavier roof, especially if there is an attic present, improves the noise insulation of a home. While thermal windows are not as effective at reducing noise as they are at reducing heat loss, they offer minimal additional protection. Solid-core doors reduce noise better than hollow-core doors. Perhaps most significantly, good weatherstripping and sealing eliminate noise entering the home through air infiltration paths. Good sealing practices are more common in colder areas of the country.

Availability and local cost of materials exert an influence on construction decisions also. These variations all affect the noise reduction performance of homes.

Existing Conditions and Expected Improvements

An acoustically well-insulated home that is kept closed can provide 30 dB of noise attenuation. A more typical, unmodified dwelling might provide 20 to 25 dB of noise reduction. Experience has proved the objectives discussed here to be reasonable and effective for typical dwelling construction. In addition, the FAA has recognized that in order for a homeowner to perceive any improvement in the home's sound environment, there must be a minimum of 5 dB improvement in noise reduction in each room. It is not usually practical to try to provide more than 40 dB of NLR in a dwelling. Of course, no amount of noise reduction will have any effect on outdoor activities. The advantage of sound insulation is that it provides a refuge from high external aircraft noise levels.

2.5 Sound Insulation Concepts

Sound Transmission

In order to effectively examine noise control measures for dwellings it is helpful to understand how sound travels from the exterior to the interior of the house. This happens in one of two basic ways: through the solid structural elements and directly through the air. Figure 2-3 illustrates the sound transmission through a wall constructed with a brick exterior, stud framing, interior finish wall, and absorbent material in the cavity.

The sound transmission starts with noise impinging on the wall exterior. Some of this sound energy will be reflected away and some will make the wall vibrate. The vibrating wall radiates sound into the airspace, which in turn sets the interior finish surface vibrating, with some energy lost in the airspace. This surface then radiates sound into the dwelling interior. As the figure shows, vibrational energy also bypasses the air cavity by traveling through the studs and edge connections.

Openings in the dwelling which provide air infiltration paths – through windows, vents, and leaks – allow sound to travel directly to the interior. This is a very common, and often overlooked, source of noise intrusion.

Flanking is a similar concept and usually refers to sound passing around a wall. Examples of common flanking paths include: air ducts, open ceiling or attic plenums, continuous side walls and floors, and joist and crawlspaces.

The three different major paths for noise transmission into a dwelling – air infiltration through gaps and cracks, secondary elements such as windows and doors, and primary building elements such as walls and the roof – are displayed in Figure 2–4.

Low-frequency sound is most efficiently transmitted through solid structural elements such as walls, roof, doors, and windows. High frequencies travel best through the air gaps. Within these broad categories, different building materials have different frequency responses to sound and varying abilities to insulate against sound.

Reducing Transmitted Sound

The amount of sound energy transmitted through a wall, roof, or floor can be limited in several ways. First, all air infiltration gaps, openings, and possible flanking paths must be eliminated wherever possible. This is the single most important, but occasionally overlooked, step in noise reduction. This includes keeping windows and doors closed and putting baffles on open air vents.

Some materials reflect more of the incident sound, converting less of it into vibrational energy. The mass of the exterior and interior panels influences how much sound will pass through them. The more mass a structural element has the more energy it takes to set it into vibration, so adding weight to a wall or ceiling by attaching a gypsumboard layer will make the assembly pass less sound. Then, absorption in the air cavity and resilient mounting of interior finish panels can further reduce the sound transmitted to the room.

The primary approaches for improving sound isolation are:

1. Elimination of openings and flanking paths (when accessible).
2. Improvement of windows and doors.
3. Massive construction (build a wall 3 feet thick and 40 feet high around the whole house);
4. Isolation of panel elements through separation or resilient mounting;
5. Absorption.

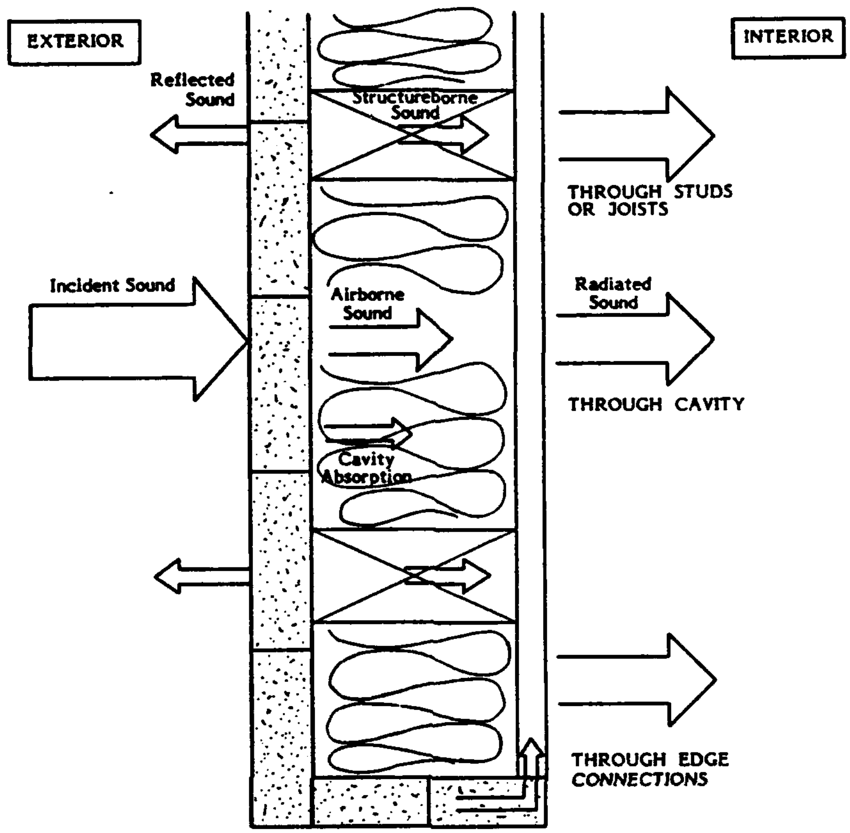


Figure 2-3. Pictorial Representation of Sound Transmission Through Built Construction.

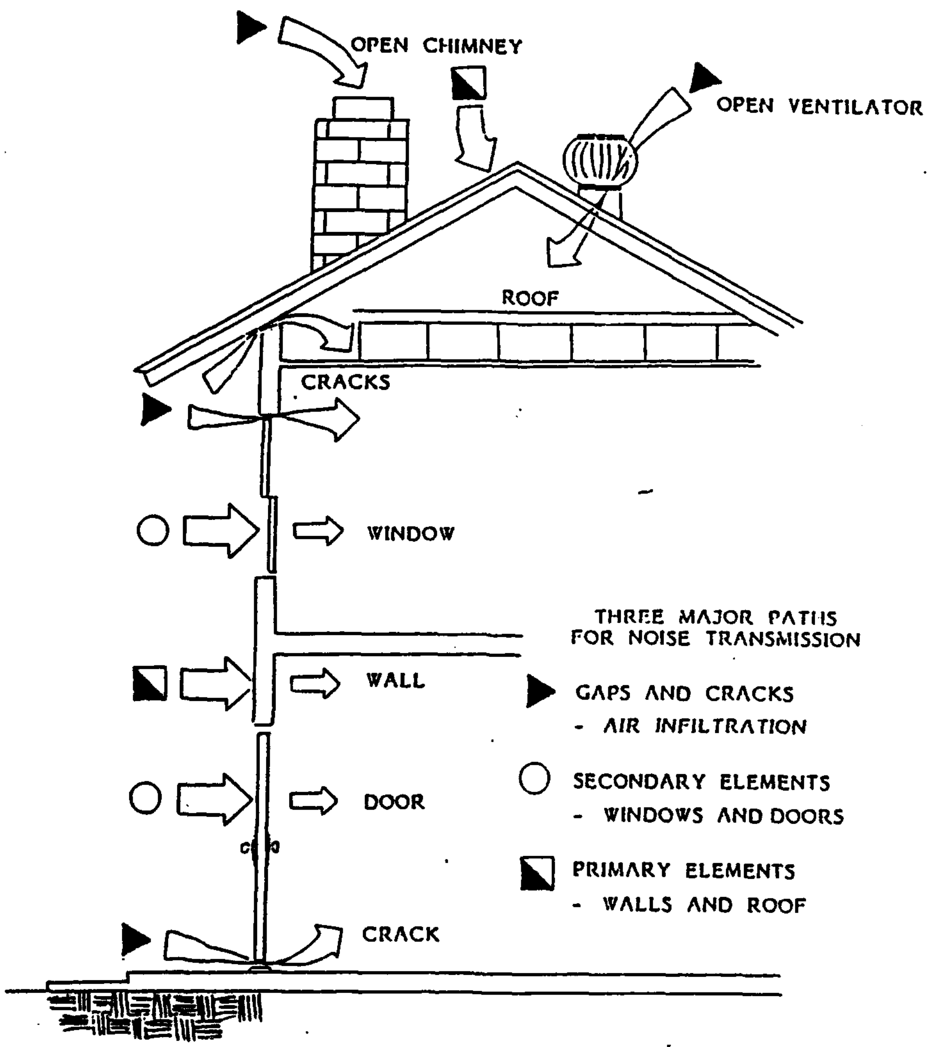


Figure 2-4. Sound Transmission Paths Into Dwelling Interiors.

Balanced Acoustical Design

The most important, or controlling, sound paths must be identified in order to know how to modify a dwelling to meet a specified noise criteria. The ideal sound insulation design would achieve a condition where all the important sound paths transmit the same amount of acoustical energy. This eliminates any weak links in the building's insulation envelope and is commonly referred to as a *balanced acoustical design*.

As an example of the importance of a balanced acoustical design, Figure 2-5 illustrates the effect of introducing windows with poor sound insulation properties to a siding wall. The sound level in decibels (dB) is noted at the outside and the inside and the transmission loss (TL), or drop in sound power, is given in the right-hand column (see Section 2.3 for further discussion of TL). As more of the wall area is taken up with windows, the overall noise protection decreases.

This effect is significant even for massive wall materials, such as the brick wall shown in Figure 2-6. Intuition suggests that this wall would protect better against sound than the siding. In this example, however, the brick construction performs poorly because of the use of low sound insulation windows (STC 25) compared to a siding wall with acoustic windows (STC 30). The STC rating, defined in Section 2.3, is a measure of the material's ability to insulate against sound; the higher the STC rating, the better the insulator. Proper use of STC ratings will be discussed in more detail in Section 3.5.1.

In most cases, after leaks and gaps are sealed, the windows are the controlling sound path. Replacing them with acoustical windows typically does more to improve the sound insulation performance than any other architectural modifications. Once this is done the other elements may become important in meeting specific noise reduction goals. Exterior doors often require improved sound insulation. Ceilings and walls which face the exterior may require modification as well, particularly in the higher DNL noise zones. Treatments for these paths and others are discussed in Section 3.5.2 of this handbook.

Problem Areas

Sound intrusion problems are commonly caused by:

1. Building construction components and configurations not providing sufficient sound insulation.

2. Structural elements, such as windows, doors, walls, roofs, and floors chosen and combined in an unbalanced way so that some parts are much weaker sound insulators than others.

3. Unintended openings or sound-flanking paths caused by deterioration or improper installation of construction elements.

New Construction Versus Old

Dwellings can vary in their sound isolation performance. Generally, air infiltration, and therefore sound infiltration, around windows and doors tends to be worse for older dwellings. This is usually caused by inadequate or deteriorated weatherstripping and misaligned framing. On the other hand, most older construction techniques and materials tend to be more massive than newer lighter-weight construction. As a result, many older buildings tend to perform better with regard to sound transmission through walls, roofs, and floors than do new houses. Homeowner modifications can also degrade the dwelling's sound insulation performance. Examples include home improvements such as skylights, whole-house attic fans, through-the-wall air conditioners, and solariums.

In general, it is much more efficient, and cost effective, to take acoustic performance into account when designing and building a home at the start. Remodeling an already built home is more costly and time consuming than anticipating and building for good sound insulation. Most of the insulation methods discussed in Section 3.5 can be used directly in new construction. Section 3.5.3 gives some specific suggestions.

Thermal Insulation

While homes which are well insulated thermally often perform well acoustically, thermal insulation is not always a good indicator of sound insulation. Many thermal windows, installed in new construction or added as a homeowner upgrade, provide little sound insulation when compared to walls or acoustical windows and are frequently the weak link in the building envelope. However, thermal treatments usually eliminate air infiltration and may serve to improve the acoustical

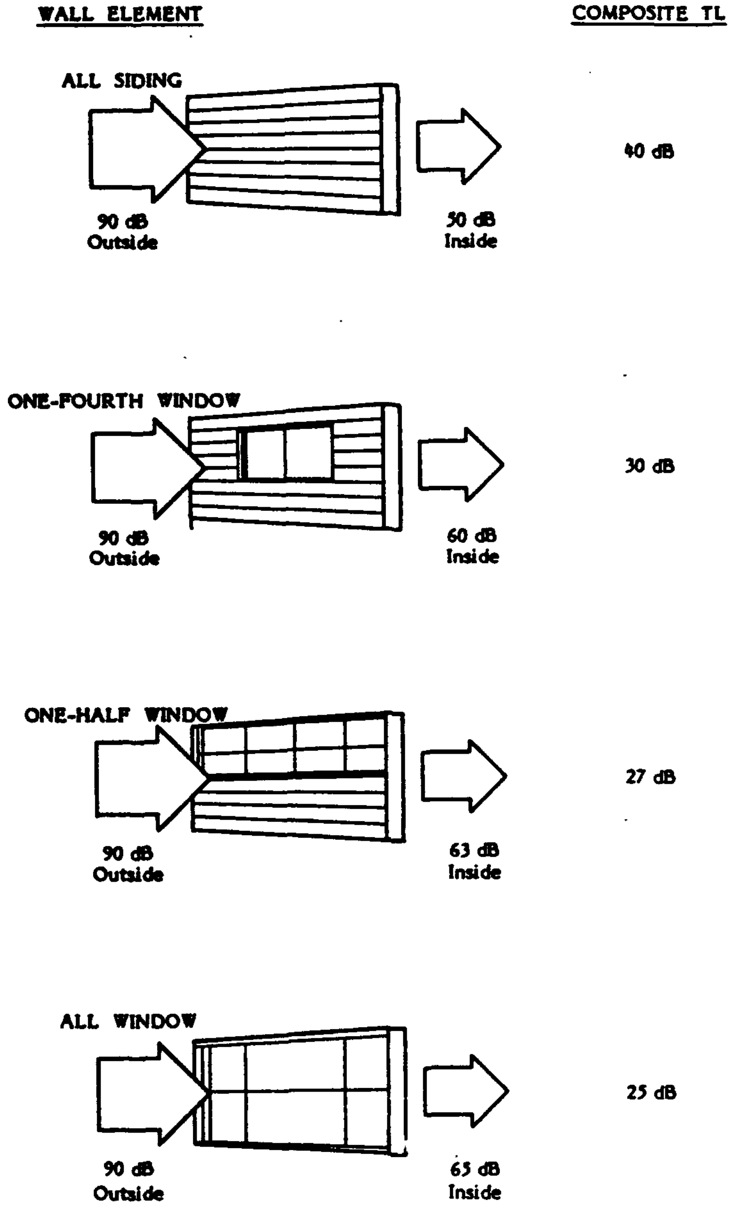


Figure 2-5. Effects of Window in Lowering the Composite TL in Complex Constructions.

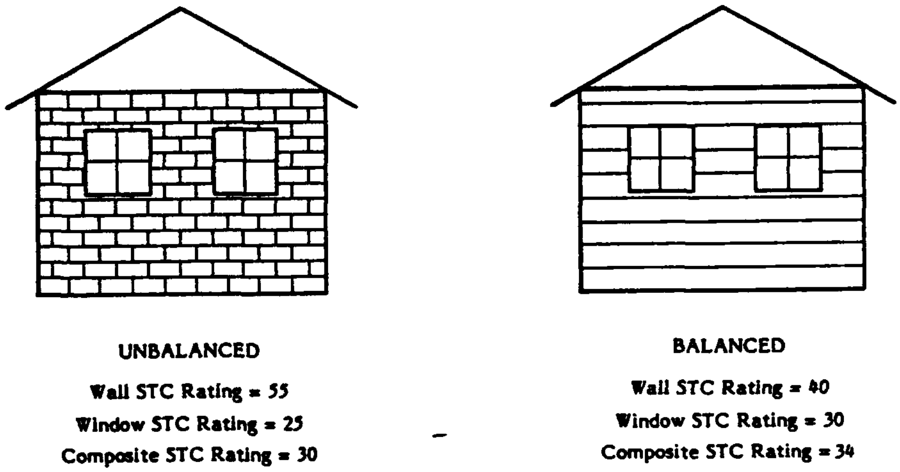


Figure 2-6. Conceptual Illustration of Unbalanced and Balanced Constructions.

performance of a dwelling. And, as Section 3.5.2 discusses, thermal insulation batts are often useful in the wall cavities and attic spaces to absorb some sound.

Shielding

The last concept to consider is shielding. This refers to the fact that the side of the dwelling which faces away from the flight path and does not have an open line-of-sight to it will be protected somewhat from the noise. Figure 2-7 displays this concept. Other sides of the house, facing directly toward the flight path, are unshielded. Sides which face the flight track at an angle may benefit from some shielding effects. Sometimes, however, sound is reflected off nearby buildings in such a way as to counteract the shielding benefits. The shielding may be as much as 10 dB[5] in some cases, though values on the order of 5 dB are more common. Shielding must be examined on a case-by-case basis and the possibility of aircraft straying from the flight path must be taken into account before assuming a consistent shielding effect.

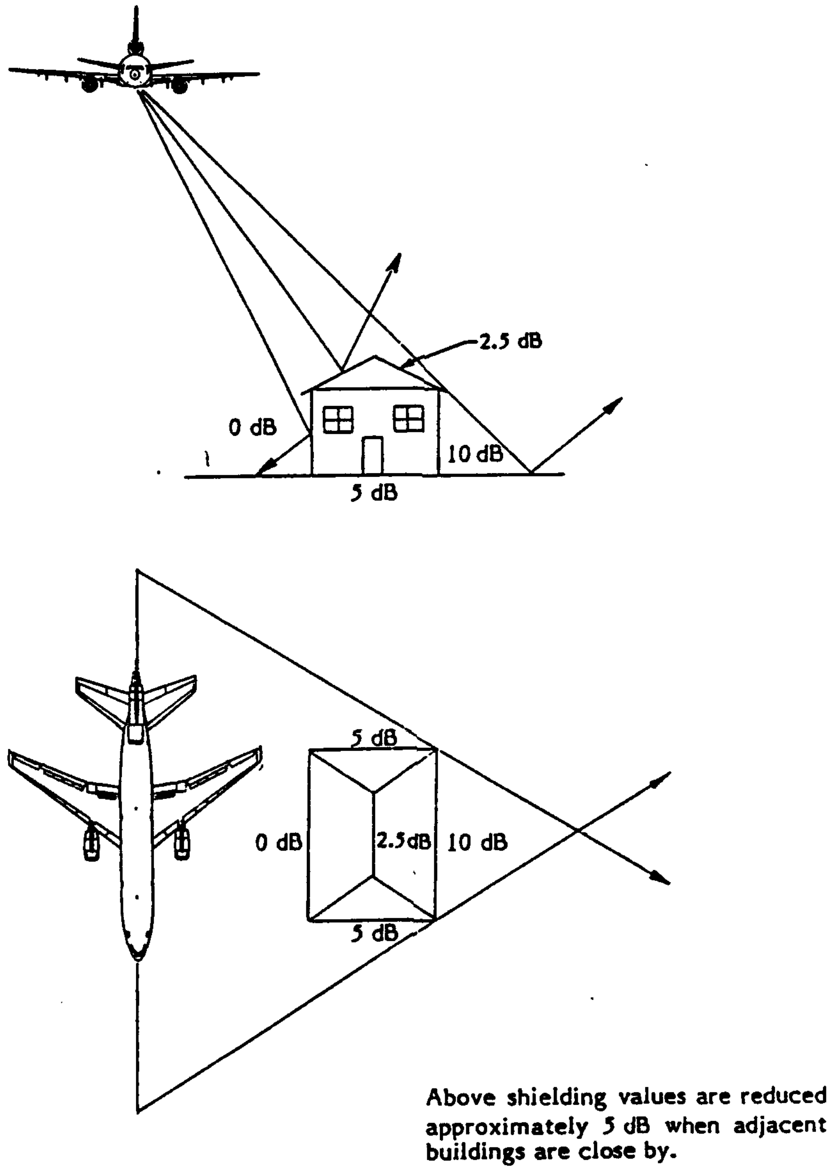


Figure 2-7. Measured Values for Acoustical Shielding Due to Aircraft Noise.

3.0 PROJECT FORMULATION AND METHODS

This section addresses deciding which houses to insulate, performing the modifications, and estimating the construction costs.

The project outline in Section 3.1 provides an overview of the phases of a residential sound insulation program and the general tasks involved. Section 3.2, Dwelling Categories, describes how to identify acoustically significant construction features and how to group homes according to them. It also presents a breakdown of the most common dwelling types in different geographical regions of the country.

Standard methods for measuring pre- and post-modification noise reduction are discussed in detail in Section 3.3. Measurement equipment descriptions and specifications are also provided along with guidelines for choosing a representative sample of homes to test.

Section 3.4, Noise Reduction Objectives, gives criteria for assessing how much improvement is needed in the sound insulation performance of a dwelling.

Methods of improving the sound insulation performance of a home are given in Section 3.5. This section is broken down into four parts: the first part, Section 3.5.1, entitled Evaluating Construction Materials and Methods, discusses metrics used to describe the sound attenuation ability of various construction components and systems. The next part, Section 3.5.2 gives detailed information on the options for improving specific building elements such as windows, doors, walls, roofs, and floors. A subsection is devoted to each one of these components. Specific suggestions for designing new construction are given in Section 3.5.3.

Miscellaneous Features, Section 3.5.4, contains important information on the significance of ventilation in the overall noise reduction effort. While ventilation systems, in themselves, do not contribute to the noise reduction, they determine how livable the home is with all the doors and windows closed – a prerequisite to the effectiveness of the other modifications. At the end of this last section, specific measures for treating open air paths in kitchens, bathrooms, and fireplaces are suggested. Section 3.5.5 addresses the sound insulation performance of Manufactured Homes and the options for improving it.

Making use of results from a computerized cost optimization model, Section 3.6 presents a package of modifications for 26 typical house types. Each case is examined for four noise impact zones. Cost estimates are provided for each of these modification packages. Since there are usually several different modification packages which would achieve the interior noise goals, this section discusses how to choose between them. A detailed example shows how to estimate the costs involved in modifying groups of homes in a community.

3.1 General Project Outline

A residential sound insulation project proceeds through several readily identifiable phases. Within the two basic divisions of program planning and project implementation there are four major stages, as indicated in the Figure 3–1 flowchart. These are: project initiation, contractor selection and bidding, project management, and installation of the modifications. Each of these steps is discussed below in greater depth.

The first task at a local level is to determine the intended scope of the program by reference to an inventory of eligible dwellings. This may be a particular residential subdivision, an entire community, or a selection of one or more heavily impacted dwellings. The flowchart in Figure 3–1, and much of the program management material in this guide, assumes a project of about 20 to 200 homes. The tasks are broken down for an organized team of implementing agency staff, consultants, architects, and project coordination staff. Enough information is given, however, here and in Section 4, so that these guidelines can be applied in a flexible way depending on the project size.

The four major stages outlined in the flowchart are:

- Project Initiation. This will include the selection of dwellings (with alternates) and obtaining agreements with the property owners, preparation of the design plans and specifications for each dwelling, obtaining approvals of these plans and specifications, and developing the program schedule.

- Contractor Selection/Bid Process. This particular stage of the project includes the development of bid procurement documents, advertising for contractor bids, conducting pre-bid meetings and site visits (for the bidders) to any or all of the dwellings;

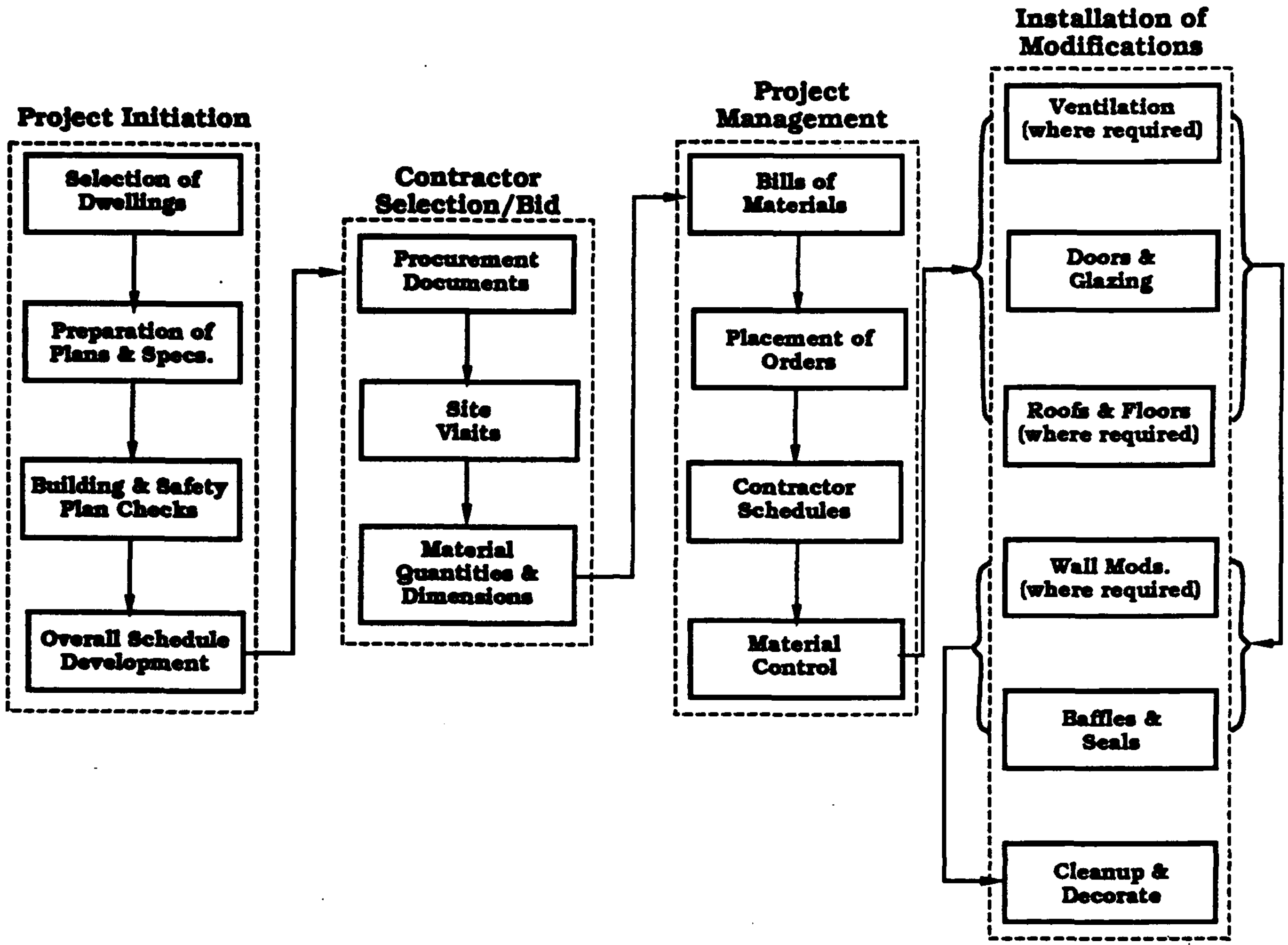


Figure 3-1. Project Implementation Flowchart.

receiving and scrutinizing the bids received for compliance with all technical, administrative, and contractual requirements; checking the potential contractor's listing of materials, quantities (and dimensions) for suitability to the project dwellings; and, finally, awarding a contract to the successful bidder.

- Project Management. This is a function normally shared by as many as three parties: *the General Contractor*, who will be responsible for construction management; *the installing agency* (e.g., the city), who will be responsible for financial and contract administration; and *the consultant or architect* who will be responsible for ensuring that the contractor complies with the technical specifications. The normal work flow in this stage requires the contractor to compile a bill of materials and place orders for those materials, organize the work force (e.g., subcontractors) in preparation for the installation, and prepare a detailed work schedule for each dwelling and each trade. The schedule would be submitted to the installing agency for negotiation and approval prior to being finalized. As materials are delivered to the project site, these will be inspected and checked by the contractor and the consultant or architect to ensure they are exactly as specified. This material control function is not as simple as it may seem, since it may require checks on window glazing types and thicknesses; door weights and suitability for exterior use (since many acoustically rated doors are suitable only for interior use); and other items of specific importance to the success of the sound insulation project.

- Installation of Modifications. The installation stage is the eventual culmination of all the planning and organization and follows various levels of overview and approval. The installation process will be subject to further inspections during its performance to satisfy building inspectors, the project administrators, and the consultant/architect that this work is completed properly.

A further task is usually added to the program to evaluate the success of the project. This task can involve:

- Technical Evaluations by means of acoustical measurement of the sound insulation of the dwellings prior to and after the installation of the modifications to each dwelling; and

- Subjective Evaluations by means of pre- and post-modification opinion surveys to the residents of all of the project dwellings.

Dwelling categorization and modification installation are addressed in Section 3. The other project stages are all discussed in Section 4.

3.2 Dwelling Categories

3.2.1 Category Definition

Dwelling construction features vary considerably in their sound transmission properties. For this reason they have a major impact on the amount of work required to meet sound insulation goals and on the resultant cost of projects. One of the most important tasks in the first stages of a project, therefore, is to determine the number and types of homes in the noise impact zones around the airfield. The primary interest is to estimate the noise reduction provided by the existing dwelling shells. This enables planners to develop housing categories, form "ballpark" cost estimates, and select representative homes for in-depth testing, if needed.

Housing Surveys

For a small project, less than 20 homes, information on the home construction types may be readily available and a comprehensive housing survey will probably be unnecessary. Each house can be looked at individually and costed on a case-by-case basis. For large projects, which range from 50 to several thousand homes, it has proven beneficial to survey all the eligible dwellings. From this survey a representative subset can be chosen for more in-depth examination. This information can be used to develop a rough estimate of the total project cost.

Neighborhood housing surveys are simple to perform. Survey members need only to drive through all eligible communities street by street and note the significant characteristics of each house. Figure 3-2 gives an example of a typical housing survey data sheet. A blank copy of the data sheet is given in Appendix D. Each tic mark indicates one home of that type. A new sheet is used for each street or each segment of a street. The construction elements noted play a significant part in determining the overall sound insulation

HOUSING INVENTORY WORKSHEET

City: Whidbey Island Observer: MB Date: 2/15/89

Community: Oak Harbor Ldn Zone: < 60 65 70 75 >

Street: 40th NE Side: N S E W

CATEGORY								COUNT
Type	Wall	Roof	Wndw	Floor	Size	Storms?	Chim?	
1S	SD	VA	AL	CR	1K	✓	✓	|||
"	"	"	"	"	"	—	✓	~~||||~~ ~~||||~~ |||
1S	BS	VA	AL	CR	1K	✓	✓	~~||||~~ ~~||||~~ |
1S	SD	VA	WD	BA	1K	✓	✓	|||
1S	SD	VA	CA	CR	1K	✓	—	~~||||~~
"	"	"	"	"	"	✓	✓	~~||||~~ ~~||||~~
1S	BR	VA	WD	BA	1K	✓	✓	|||
1S	BR	FC	WD	CR	1K	—	✓	||

HOUSE TYPE:
- One Story: 1S
- Two Stories: 2S
- Three Stories: 3S
- Split Level: SL
- Duplex (or row end): DU
- Row, Townhouse: TH

WALL:
- Alum. or Wood Siding: SD
- Brick Veneer: BR
- Brick Veneer + Siding: BS
- Stucco: ST
- Block: BL
- Poured Concrete: CN

ROOF:
- Vented Attic: VA
- Single Joist, Light: SJL
- Single Joist, Heavy: SJH
- Exposed Ceiling, Light: ECL

WINDOW:
- Wood Frame: WD
- Alum. Frame: AL
- Jalousie: JA
- Casement: CA

FLOOR:
- Basement: BA
- Crawlspace: CR
- Concrete Slab: CO

SIZE:
- Small: 0K
- Medium: 1K
- Large: 2K

STORMS:
- All: ✓
- Some: S
- None: –

CHIMNEY:
- Yes: ✓
- No: –

Figure 3-2. Housing Inventory Worksheet.

properties of the home. The factors that determine the noise reduction and/or modification costs of a dwelling are as follows:

- The noise impact zone;
- The number of stories;
- The exterior/interior wall materials;
- The roof/ceiling construction;
- The type of windows (and doors);
- The floor/foundation configuration;
- The size in sq.ft. of the house "footprint";
- The use of storm windows and doors;
- The presence of vents, chimneys, mail slots, etc.;
- Orientation with respect to the flight path.

Also, where discernible:

- The presence of sound leaks at the edges of windows, doors, and other building elements. This usually requires close inspection but may be estimated from the general condition of the home.

- The presence of air-conditioning or ventilation units – central system, through-the-wall, and window units.

3.2.2 Geographic Distribution

3.2.2.1 Regions of Similar Dwelling Types

The patterns for dwelling construction in different regions of the country are fairly well established and are influenced by factors such as climate, availability of materials and labor, local building codes, design loads (e.g., wind, seismic, or snow), local historical trends, and local economic conditions. The nation has been geographically subdivided into 11 regions, shown in Figure 3-3, in which residential housing construction patterns are fairly homogeneous.[3] Below is a brief description of the prevailing construction characteristics in each region.

Region I: The Pacific Coastline. All building materials such as lumber, concrete, and other standard types are used. Stud-and-stucco construction is common, 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 II: Inland Southern California, Southern Nevada, and Southwestern Arizona. Sand and aggregates for concrete block and bricks are plentiful. Therefore, in this region, buildings will have a greater percentage of concrete masonry. The common stud-and-stucco combination is also popular.

Region III: The Gulf Coast and Atlantic Coastline. All types of siding – wood, aluminum, and vinyl – are common. Less stud-and-stucco construction is used as it is more susceptible to humidity, 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 IV: Eastern Seaboard and inland to Central Illinois, except for New York City (see Region V). The climate is quite cold for half the year and insulation properties are important. Brick and various types of siding are common, often in combination. This area typically has more storm doors and windows and heavy roofs.

Region V. 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 VI and VII: Central South and Great Lakes (Western) States. The climates in these two regions differ but other factors encourage similar housing types. Siding of all kinds and brick are most common.

Regions VIII, IX, and X: From Central States to the Pacific Northwest and Central California. Siding, including wood, aluminum, and vinyl, is by far the most common exterior material. Brick is used more frequently than concrete.

Region XI: 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. Roofs, windows, and doors are all of lighter than average construction.

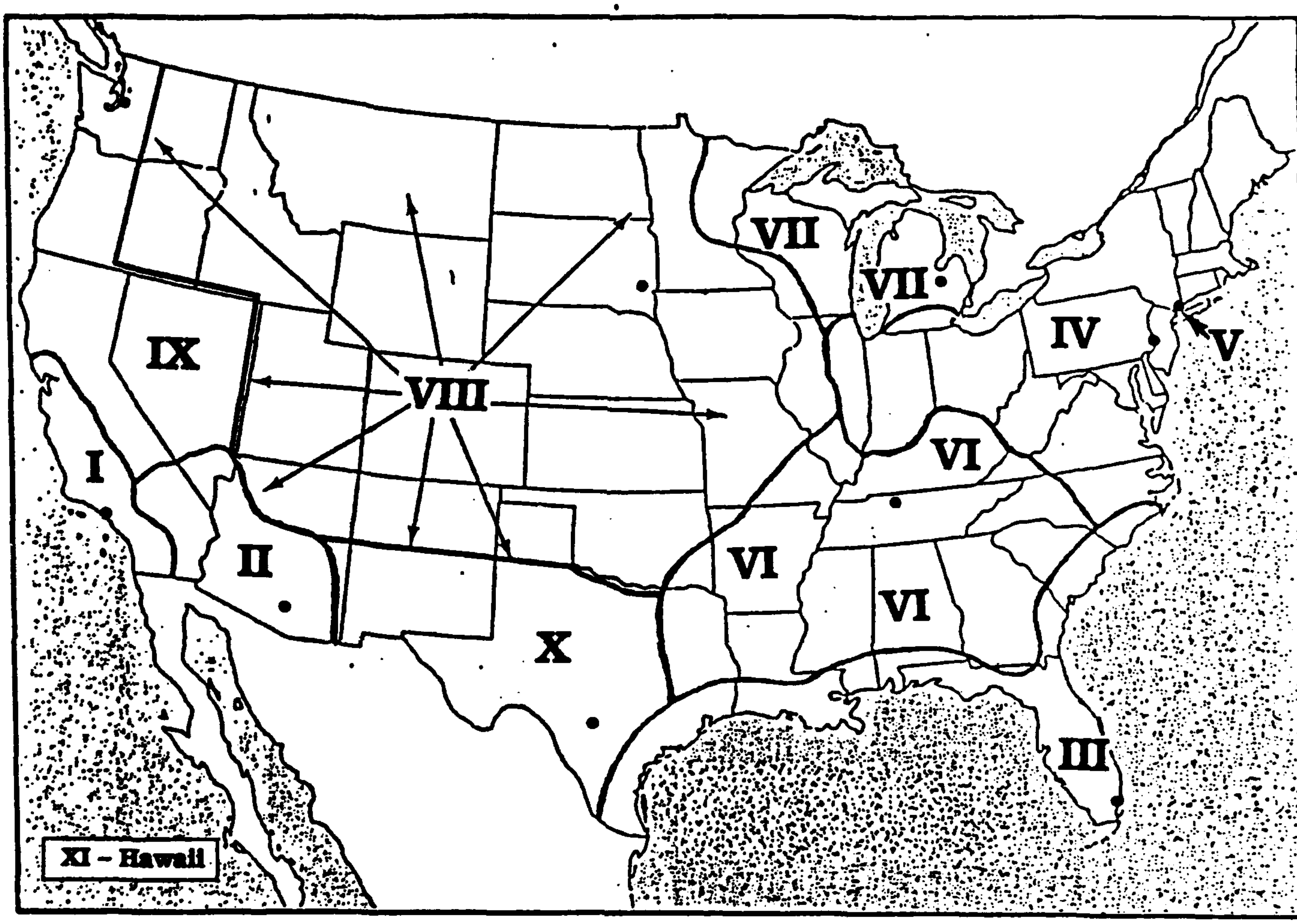


Figure 3-3. Regions of Differing Construction Practices.

For this data base one airport was selected in each of the 11 regions. The list of airports is given in Table 3-1. Housing surveys were conducted in the vicinity of these airports and the results are presented in Tables 3-2 and 3-3.

3.2.2.2 1989 Housing Surveys in Selected Areas

Additional surveys were conducted in February 1989 to validate and supplement the existing data base which was established in 1981. The results are incorporated into Tables 3-2 and 3-3. These newer surveys were conducted in:

1. Oahu, Hawaii
2. Whidbey Island, Washington
3. Corpus Christi, Texas
4. Jacksonville, Florida

During the housing surveys, field personnel drove through all neighborhoods exposed to aircraft noise levels of 60 dB DNL or greater generated by operations at a nearby air field. A "windshield survey" was taken of homes in the area to identify the size, type, exterior cladding, foundation, roof type, etc. These are the factors which affect the sound transmission into the dwelling the most. Survey forms like the sample in Figure 3-2 were used. The homes were categorized to develop rough estimates of their existing noise reduction. This helps approximate the cost of remodeling them to improve their acoustic performance. The most common construction materials and methods were identified for each area studied, as discussed below for the four survey sites.

Oahu, Hawaii: This area falls within Region XI, noted in Figure 3-3. The region surveyed is on the island of Oahu, west of Honolulu. In addition to existing housing, plans have been approved for extensive new residential development. In particular, future housing in the neighborhoods of Ewa Gentry, Ewa Marina, and Kapolei Village might be affected by noise from nearby air traffic.

Observations of existing dwellings on the island show that, because the climate is mild year-round, homes have light construction roofs and walls without insulation. Single-joist ceilings are typical and attics are uncommon. Many homes have jalousie (louvered) windows, and natural ventilation, with open windows, is preferred to air conditioning. Very light, single wall construction predominates.

Information from the local planning authorities and developers indicates that the majority of new homes built will use hardboard siding, be built on concrete slabs, and have light construction sloping roofs. Some will have attics but few will have wall or roof insulation. The newer construction methods use double-layer walls typical of the rest of the country but feature jalousie windows and light roof structures. Air conditioning will not be standard and windows are expected to be kept open much of the time.

Because the area surveyed is still under development, a detailed housing inventory was not performed. However, the structural features observed in existing homes elsewhere on Oahu and the specific details of proposed dwellings suggest very poor sound insulation in the homes – both existing and planned.

Whidbey Island, Washington: Whidbey Island lies in Puget Sound north of Seattle and is part of Region IX shown in Figure 3-3. The housing survey included part of the town of Oak Harbor and much of the scattered housing to the east and north. The community around Coupeville, south of Oak Harbor, was also inventoried. The neighborhoods observed provided information on a representative sample of the homes on Whidbey Island.

The housing inventory included 2,900 homes. The following basic categories were identified:

Siding (wood, aluminum, etc.)	68%
Manufactured Homes (MH)	26%
Brick/Brick & Siding	3%
Concrete Block	1.5%
Other	1.5%

For these, further categorization showed:

Roof Structures:	
Vented Attic	63%
Light Vented Attic (MH)	26%
Single Joist (Light)	9%
Exposed Ceiling (Light)	2%
Foundation:	
Crawlspace (incl MH)	89%
Basement	7%
Slab	4%
Windows:	
Aluminum (incl MH)	90%
Wood	10%
Storm Windows & Doors:	15%

Table 3-1

Airports Selected for Field Survey

Region	Airport (Designation)
I	Los Angeles (LAX)
II	Tucson (TUS)
III	Jacksonville (JAX)
IV	Philadelphia (PHL)
V	LaGuardia (LGA)
VI	Nashville (BNA)
VII	Lansing (LAN)
VIII	Sioux Falls (FSD)
IX	Seattle (SEA)
X	San Antonio (SAT)
XI	Honolulu (HNL)

Table 3-2

Percentages of Dwellings in Each Construction Category and Floor Constructions for Each Region

Construction Category*	Region and Airport										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	LAX	TUS	JAX	PHL	LGA	BNA	LAN	FSD	SEA	SAT	HNL
Siding/VA	15	--	35	30	15	15	40	55	70	60	--
" /SJL	--	--	15	35	50	--	45	30	20	--	100
" /ECL	--	--	--	--	--	--	--	--	5	--	--
Stucco/VA	80	5	--	--	--	--	--	--	--	5	--
" /SJL	5	5	--	--	--	--	--	--	--	--	--
Brick/VA	--	80	15	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	--	--	30	--	--	--	--	--	--	--	--
" /SJL	--	--	5	--	--	--	--	--	--	--	--
Slab Floor	50	100	70	15	5	--	10	5	--	90	100
Crawlspace	50	--	30	5	10	15	--	--	70	10	--
Basement	--	--	--	80	85	85	90	95	30	--	

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

LAX =Los Angeles, CA
TUS =Tucson, AZ
JAX =Jacksonville, FL
PHL =Philadelphia, PA
LGA =LaGuardia, New York, NY
BNA =Nashville, TN

LAN = Lansing, MI
FSD = Sioux Falls, SD
SEA = Seattle, WA
SAN = San Antonio, TX
HNL = Honolulu, Oahu, HI

Table 3-3

Miscellaneous Information for Each Region
(Numbers Expressed as Percentages)

Construction Category	Region and Airport										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	LAX	TUS	JAX	PHL	LGA	BNA	LAN	FSD	SEA	SAT	HNL
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: Gas Electricity	 10 90 --	 -- 80 20	 -- -- 100	 50 50 --	 70 20 10	 -- 25 75	 5 95 --	 -- 100 --	 30 40 30	 -- 95 5	 -- -- --
Window Air Conditioning	5	10	60	40	40	40	5	10	--	15	10

* Hollow Core/Solid Core

Chimneys:	60%
Dwelling Size: *	
0–1,000 sq.ft.	23%
1,000–2,000 sq.ft.	76%
over 2,000 sq.ft.	1%

Corpus Christi, Texas: Corpus Christi is on the Texas coast of the Gulf of Mexico, in Region III shown in Figure 3-3. The housing survey included neighborhoods east of the City of Corpus Christi and some housing on North Padre Island. In all, 1,900 homes were cataloged. The following basic categories were identified:

Brick/Brick & Siding	40%
Siding (wood, aluminum, etc.)	34%
Manufactured Homes (MH)	12%
Stucco	11%
Concrete Block	2%
Other	1%

For these, further categorization showed:

Roof Structures: Vented Attic	71%
Single Joist (Light)	16%
Light Vented Attic (MH)	12%
Exposed Ceiling (Light)	1%
Foundation:	
Slab	72%
Pilings	16%
Crawlspace (MH)	12%
Windows:	
Aluminum (incl MH)	77%
Wood	21%
Jalousie	2%
Storm Windows & Doors:	0%
Chimneys:	26%
Dwelling Size: **	
0–1,000 sq. ft.	21%
1,000-2,000 sq. ft.	72%
over 2,000 sq. ft.	7%

* Field observation indicates approximately two-thirds of the manufactured homes surveyed were under 1,000 square feet. The other one-third, usually double-wide units, were from 1,000 to 2,000 square feet.

** Field observations indicate that approximately 90 percent of the manufactured homes in this area are less than 1,000 square feet. The other 10 percent are between 1,000 and 2,000 square feet.

Jacksonville, Florida: Jacksonville and its surrounding communities fall within Region III in Figure 3-3. The homes here are typical of the southeast Atlantic Coastline. The housing survey included the Ortega Hills subdivision in southern Jacksonville, and the communities of Mayport to the east and Whitehouse to the west. A new, large residential community on the west side was surveyed, including the subdivisions of Argyle Forest and Cheswick Oaks.

During the survey, 2,530 homes were cataloged. The following basic categories were identified:

Manufactured Homes (MH)	29%
Siding (wood, aluminum, etc.)	27%
Brick/Brick & Siding	19%
Block/Block & Brick/ Block & Siding	18%
Stucco/Stucco & Siding	7%

For these, further categorization showed:

Roof Structures:	
Vented Attic	57%
Light Vented Attic (MH)	29%
Single Joist (Light)	12%
Exposed Ceiling (Light)	2%
Foundation:	
Crawlspace (incl MH)	59%
Slab	36%
Pilings	5%
Windows:	
Aluminum (incl MH)	80%
Jalousie	16%
Wood	4%
Storm Windows & Doors:	0%
Chimneys:	40%
Dwelling Size:***	
0–1,000 sq. ft	32%
1,000–2,000 sq. ft.	68%

** Field observations indicate that approximately 80 percent of the manufactured homes in this area are less than 1,000 square feet. The other 20 percent are between 1,000 and 2,000 square feet. In the Jacksonville area there was clear evidence of the use of manufactured homes as temporary shelter while a conventional dwelling is under construction. This accounts for about 10 percent of the manufactured homes noted.

Comparison to Existing Data Base

This data has been analyzed and combined with data collected for the same regions in 1981. Table 3-2 incorporates these latest findings into the earlier data base. A comparison of the 1989 survey data to that collected in 1981 revealed some agreement and some differences. The recent survey of Hawaii gave strong validation to the earlier data. Homes there are very much like the typical dwellings defined in the 1981 report.

On Whidbey Island, which is lightly populated, the construction methods differ slightly from those around Seattle, the site of the 1981 survey. In general, both surveys showed a heavy reliance on siding construction, but Whidbey Island homes are more likely to have attics than Seattle homes. Conversely, more houses in Seattle are built with basements.

Both Corpus Christi and Jacksonville lie within Region III shown in Figure 3-3. The original data for Region III was collected around Miami and differs significantly from the housing types seen in the more recent surveys. For example: most homes in the Miami area are of concrete block construction while siding is most common in Corpus Christi and Jacksonville. On the other hand, very few homes in Miami use brick exteriors, which almost 20 percent of the homes in Jacksonville and 40 percent of those in Corpus Christi have. Concrete slab foundations are very common throughout Region III. Information for all three locations has been combined to give a more representative sample of homes.

Manufactured homes were not accounted for in the earlier housing surveys. As the recently collected data shows, they are quite common in some areas of the country. It is beyond the scope of these guidelines to predict their popularity nationwide, but they should nct be overlooked in a noise assessment. It is very difficult to improve their sound insulation performance significantly so they present special problems in community noise control. Manufactured home construction and options for acoustic treatment are discussed in detail in Section 3.5.5. Because data for them was only available for two regions (III and IX), they are *not* included in Tables 3-2 or 3-3.

3.2.3 Noise Reduction of Category Types

EWR Ratings of Construction Types

The Exterior Wall Rating (EWR), defined in Section 2.3, gives a single-number rating for exterior building elements (such as walls, windows, doors, etc.) and represents the effective sound transmission loss capability, in decibels (dB), of each element. EWRs have been measured for each of the basic construction schemes. This information is presented in Table 3-4. Table 3-5 gives a further breakdown of the noise reductions for various configurations of external doors.

Factors Affecting Noise Reduction

Previous studies have used these noise reduction figures to determine the overall sound insulation performance of various types of existing dwellings. This work has confirmed that the noise reduction varies only slightly with the type of wall, roof, and floor construction. The windows and doors have overwhelmingly proven to be the deciding factors in home sound insulation. 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 an exterior door is 4 to 6 dB less than that for rooms without a door. This demonstrates the need to consider different room configurations.

Table 3-4

EWR Ratings for Common Construction Elements

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 Crawlspace	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**

* A higher EWR value indicates greater sound insulation.
** Poor/Good Weatherstripping Condition.

Table 3-5

EWR Reductions (dB) of Doors

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

3.3 Sample Noise Monitoring

In order to obtain reliable estimates of the noise reduction provided by a dwelling structure it is necessary to measure the noise level outside and inside the dwelling simultaneously. These measurements are performed while an aircraft is passing nearby, either taking off or landing. Such measurements are taken prior to making modifications to determine the "as-is" level of noise reduction. This enables the acoustic consultant or architect to determine the need for additional noise reduction and to design an appropriate scheme of modifications. Later the measurements are repeated, under identical conditions, to determine how effective the modifications have been.

Experience in making community noise measurements indicates that the most effective testing methods are those discussed in Section 3.3.1. Section 3.3.2 describes the sound measurement equipment necessary to perform the task.

If all homes are not being audited, measurements should be taken in a representative sample of the eligible homes in the community. Rather than just picking the test sites at random, these homes must be chosen carefully. This choice of how many and which homes to measure is discussed in Section 3.3.3.

Names and addresses of the organizations which develop and publish standards for sound measurement methods, equipment calibration, and performance are provided in Appendix G.

3.3.1 Testing Methods

Auditing the Noise Level Reduction (NLR) in a dwelling before and after making insulation modifications guides the selection of those modifications and provides valuable information on the effectiveness of the sound insulation scheme. The NLR is the difference between the aircraft noise measured outside the dwelling and inside each major room of the house.

Basic Considerations

Basic considerations for conducting the measurements include:

1. The noise level measurements should include only aircraft noise, not other external or household noise sources since these will tend to confuse the analysis.
2. The exterior and interior noise levels of aircraft flights should be measured simultaneously for each flight event. Later, after enough consistent measurements have been obtained, these exterior and interior values may be averaged.
3. The windows and doors must be kept closed during all measurements, both before and after modifications have been made. If windows or doors are even partially open the results will be unreliable.
4. There should be the same amount and type of furniture in a given room during all the measurements. The room furnishings help determine the sound-absorption characteristics of the room. If furniture is removed or added the results may be unreliable for that room.
5. Before-and-after measurements should compare arriving flights to arriving flights and departing flights to departing flights. Mixing the type of flights confuses the analysis since the noise characteristics of takeoffs differ somewhat from landings.

Sound Measurement Systems

Several different types of sound level measurement systems are available which can be used for monitoring aircraft noise reduction in residences. Measurements can be performed by one person if the appropriate equipment is available. One such configuration consists of a sophisticated computerized data acquisition system that can be set up and operated so that much of the sampling is performed automatically. Similarly, Sound Level Meters (SLMs) that are equipped with automatic recorders can be programmed to monitor the noise level and save data pertaining to levels that exceed a specified threshold. Typical SLMs, however, do not come equipped with recorders. If this simpler type is used, the measurements outlined here will require two people.

A single microphone, usually mounted on the roof or in the yard, measures the exterior noise level. The interior noise level in each major room is determined by averaging individual sound level measurements made simultaneously at two locations within the room. In most cases room levels are taken in only one or two rooms at a time to minimize the number of microphones, SLMs, and operators needed. Detailed instructions for the placement and operation of the microphones and noise measurement devices are provided below. Figure 3-4 shows a basic measurement configuration.

SEL and LAmax

For each aircraft event the Sound Exposure Level (SEL) is measured simultaneously at each location. SEL, defined in Section 2.1, is a single-event level which gives the cumulative audible energy of the whole flyover. Sometimes the Maximum A-weighted Sound Level (LAmax) will be measured in addition to, or instead of, the SEL. LAmax is used primarily as a check if the SEL results for one or two events are questionable. SEL can not be compared directly to LAmax, however, without further analysis. Both SEL and LAmax are given in units of decibels, dBA.

Using the Measured Data

The difference between the exterior SEL and the average SEL inside each room gives the noise reduction for that room. This noise reduction is then subtracted from the long-term average DNL taken from the AICUZ or airport mapped contours to determine the existing interior DNL. Section 2.1 discusses the correlation between SEL and DNL. Briefly, DNL is concerned with long-term average noise exposure, while SEL looks at the noise from a single aircraft flyover. The noise reduction is the same for either metric. SEL is used to determine the NR because it is not practical to measure DNL.

For example: Say the SEL drops an average of 27 dB from the exterior of the house to the interior of the master bedroom. If the mapped noise contours show the house to have an exterior DNL of 75 dB then this 27 dB noise reduction indicates an interior DNL of 75 - 27 = 48 dB. Since the NR criteria for the 75 dB noise zone is 30 dB, this bedroom needs sound insulation treatment that will increase the noise insulation properties by 3 dB. In practice, however, modifications should increase the noise insulation by 5 dB in order for the change to be perceptible to the residents. (Section 2.4 discusses using an SEL criteria as well, but this discussion will focus just on DNL for simplicity.)

Continue this procedure for each room in the house with enough events recorded to ensure a reliable average noise reduction for each room. Five or more clear events (not confused with other noise) should be obtained in each room.

Data to be Recorded

The recorded data should include:

For each set of measurements:

1. Dwelling address
2. DNL contour zone
3. Date
4. Location (exterior or room identifier)
5. Microphone number

For each event:

6. Time (may be recorded automatically)
7. Type of aircraft operating
8. Takeoff or Landing
9. Measured SEL (or LAmax) for each microphone

Placement of Microphones

1. Exterior Location: Since the exterior noise measurements are intended to be representative of those contributing to the DNL value indicated on the mapped contours, the measurement location should comply with the requirements for airport noise monitoring. This means that the exterior microphone location should be chosen so that:

   a. There should be no obstructions between the microphone and the flight path which significantly influence the sound field from the aircraft. A free zone in the shape of a cone should be open from the microphone up to the flight path.

   b. If this is not practical, the microphone should be placed at least 10 feet above neighboring buildings with a clear line-of-sight to the flight track. One way to do this is by mounting the microphone on a 10-foot pole or tripod and installing it at the apex of the roof. An alternative is to mount the microphone on a pole in the yard, provided there is an unobstructed area between it and the flight track.

2. Interior Locations: There is no specific standard which addresses the placement of interior microphones but knowledge of

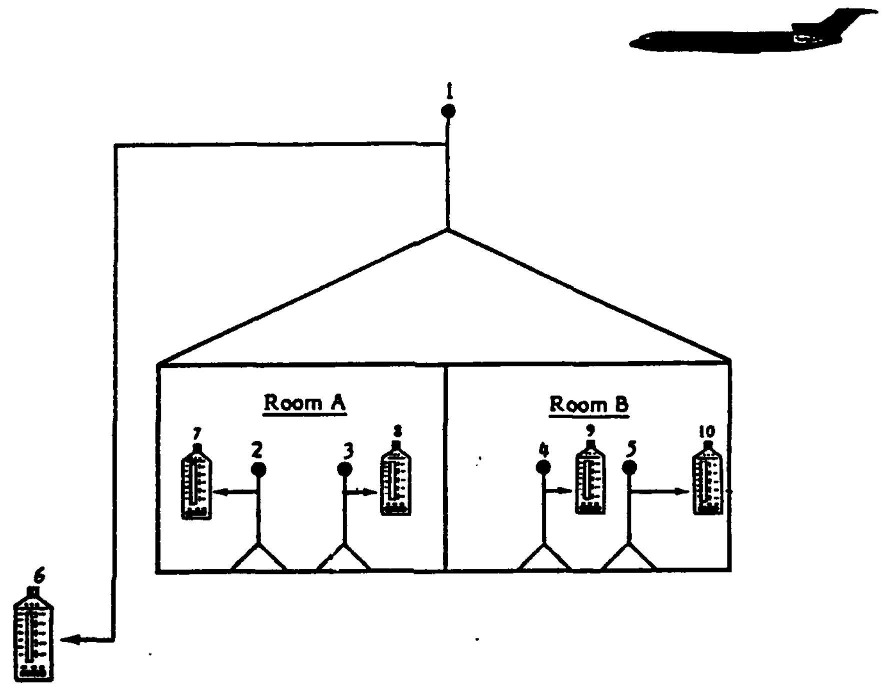


Figure 3-4. Schematic of Sound Measurement Instrumentation.

room acoustics and experience suggest the following guidelines:

a. Whenever possible, and for at least a representative sample of the project measurements, two or more microphones should be used simultaneously in a room to provide the average room interior noise level.

b. Each microphone should be mounted on a tripod at least 4 feet from any major reflective surface such as a wall, ceiling, or uncarpeted floor. One microphone, especially if only one is used, should be placed opposite the major sound-transmitting element in the room such as a window which faces the aircraft traffic. Other microphones should be distributed within the central area of the room but not at the geometric center of the room.

c. If open floor space is not available, the microphones may be mounted above soft furnishings such as sofas, beds, soft chairs, etc., but not above hard furniture such as tables.

d. The microphones must be placed away from household noise sources such as ticking clocks, refrigerators, etc. Whenever possible these items should be temporarily deactivated during the measurements. These noise sources will be quieter than the aircraft flyover but may be loud enough to trigger the measuring threshold (see below) of the sound level meter.

Measurement Units and Threshold Settings

The SEL is a time-integrated value of the A-weighted Sound Level measured to include the loudest part of the flyby. This measurement, which is the one recommended for sound insulation studies, requires equipment that can use an appropriate threshold and which can integrate the noise sample. During SEL measurements the SLM chooses a cutoff threshold based on the peak level for each event. Only noise above this cutoff threshold is included in the integration.

There is an alternative to SEL measurements which may be chosen, depending on the type of measuring equipment available. This measure, SENEL, uses an operator-set threshold for all events. Before starting the SENEL measurements, a few test runs will indicate the proper threshold to use for each location. The threshold should be chosen so that:

a. It is at least 10 dB below the highest A-weighted Sound Level to be recorded. If the SLM only provides SENEL and not LAmax, then choose a level approximately 20 dB below the average SENEL obtained in preliminary tests.

b. It is high enough to filter out other extraneous noise sources in the area.

Both SEL and SENEL require time-integration of the noise sample within the SLM. If an integrating SLM is not available, LAmax can be measured instead. Several samples should be recorded and then averaged. Noise reduction measurements taken using LAmax will give results which agree very well with the SEL data. The maximum A-Weighted Sound Levels are best used, however, when automatic recording SLMs are available. Automatic measurement reduces errors.

All measurements should be taken with the SLM dynamic meter response set on "slow". This allows careful reading of the meter response without the needle or digital display jumping too quickly. The "slow" setting complies with the standards for this type of measurement.* If "peak hold" is available it should be used. Careful technique and an increased number of samples should give a reasonably accurate average noise reduction value.

For any measurement system, the microphone must be calibrated in compliance with the applicable standard.**

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* ANSI E1014.84, "Standard Guide for Measurement of Outdoor A-weighted Sound Levels".

** ANSI S1.10-1966 (Revised 1986), "Standard Method for the Calibration of Microphones".

3.3.2 Sound Measurement Equipment

Standards Compliance

Most Sound Level Meters are designed to comply with the requirements of American National Standards Institute* for precision (Type 2) sound measurements in the field and laboratory. The equivalent International (IEC) Standard** can also be used. Any noise measurement task should specify instrumentation compliance with one of these standards.

A microphone is considered part of the Sound Level Meter system, so when SLMs are used it is sufficient to specify compliance with their ANSI or IEC standard. If the microphone is used to provide a signal to be recorded on magnetic tape without an SLM, the measurement system should satisfy the Society of Automotive Engineers, Inc., standard.† Here the microphone must meet the microphone characteristics described by ANSI†† and the tape recorder and RMS converter and indicator requirements are defined by SAE.

Equipment Capabilities

Some equipment will be capable of storing a succession of noise event data within the unit (for later interrogation and/or printout on a computer) or will provide an automatic printout of data after the event is complete. Another method involves tape-recording the event sound history on a high-quality recorder and performing LAmax or SEL evaluations at a later date.

3.3.3 Choosing a Representative Sample

For large home insulation projects, it is neither feasible nor necessary to perform noise reduction measurements in every house eligible for treatment. The most cost-effective use of measurements, however, requires careful consideration of the homes chosen for measurement.

Around any airfield there will be a variety of housing types and construction materials and methods. The houses will be oriented at different angles with respect to the flight path, giving some of them shielding on the front of the house where the living room might be located, some on the back of the house where the bedrooms are usually located, and so on. In addition, there will usually be houses spread through several noise exposure zones. All of these factors affect the sound insulation requirements of the dwellings and must be taken into account when choosing the homes in which to perform measurements.

Housing Survey and Categorization

Early in the project planning, a comprehensive survey must be conducted of the neighborhoods in the noise impact zone within the DNL 65 dB and higher contours. Information on the actual, observed number and types of eligible homes forms the basis for selecting a representative sample. The first step in processing this data should be to group homes into common categories – usually by the number of stories, the exterior construction material used, the type of roof in place, the kind of floor or foundation, and the type of windows. This should indicate how homogeneous the community is: if there are just a handful of repeated dwelling types or if nearly every house is different in significant ways. In most communities there will be neighborhoods where there are, perhaps, five or six readily identifiable dwelling types. Then there will usually be other areas where each house seems unique.

Determining the Sample Size

It is generally sufficient to measure sound levels in two or three similar homes of each different category of dwelling. So, for a neighborhood comprised of five different house types, measurements would be performed in 10 to 15 dwellings. In areas where it is more difficult to identify a manageable number of dwelling categories, an expert, such as an acoustical consultant or architect experienced in sound insulation practices, should be called in to assist in the choice of sample residences. The decision on how many homes to choose in each noise zone should be based on the number of eligible houses in that zone. For example, if two-thirds of all homes are found between the DNL 70 and 75 contours, then two-thirds of the sample homes should be there, too.

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* "Specifications for Sound Level Meters", ANSI S1.4-1983.

** IEC Standard for Integrating Sound Level Meters, Publication 651.

† SAE J184a, "Qualifying a Sound Data Acquisition System".

†† ANSI S1.4.

Most of the time, budgetary constraints restrict the number of dwellings which can be measured. Program managers and technical consultants reach a compromise between performing measurements in an acoustically representative sample, and keeping costs down by limiting the number of dwellings audited.

3.4 Noise Reduction Objectives

3.4.1 Criteria

The objective of a residential acoustic insulation program is to achieve the noise level reductions recommended in Tables 1-1 and 1-2. This objective applies to every major habitable room in the dwelling such as the living room, dining room, kitchen, den or recreation room, and all bedrooms. Bathrooms, hallways, and unfinished basements are not included.

Existing Noise Reduction Capability

The current noise reduction capability of the dwelling can be determined in one of two ways. Performing field measurements using the methods described in Section 3.3 gives a reliable value for the noise reduction. It may, however, be impractical to take measurements in each dwelling included in the project. Proprietary computerized models are an alternative, and equally valid, tool. In most home sound insulation projects the field measurements are primarily used to provide input data for calibrating the model and to validate the model predictions. The field measurements and model predictions usually agree to within 2 or 3 dB. In general, the more conservative noise reduction value should be used in setting the insulation goals and designing the modification package.

Determining the Required Noise Reduction Improvements

The noise reduction improvement goals are determined by comparing present noise reduction capabilities with the attenuation required to bring the existing exterior sound level down to the noise level reductions specified in Tables 1-1 and 1-2. The exterior levels are taken from mapped DNL contours which show current DNL levels in 5 dB increments. In determining the required noise reduction, the higher end of the noise zone range is always used.

For example, in the DNL 65–70 dB contour zone, the noise level outside the house is taken to be 70 dB. In Table 1–1, this noise zone requires an NLR of 25 dB. Subtract the existing NLR from the required NLR. This simple calculation indicates the required noise reduction improvement.

Exterior Noise Level = 70 dB
(Taken from DNL contour map)

Required Noise Reduction = 25 dB
(Taken from Table 2-1)
Existing Noise Reduction = 17 dB
(Subtract measured interior SEL
from measured exterior SEL
as described in Section 3.3)
Required Improvement = 8 dB

Additional Considerations

In order for a resident to perceive any improvement in noise reduction, experience shows that there must be at least a 5 dB increase in the sound insulation performance.

It should be noted for homes in high noise zones that it has proven infeasible to try to provide more than 40 dB of noise reduction in a dwelling.

3.5 Sound Insulation Methods

3.5.1 Evaluating Construction Materials and Methods

The basic metrics for describing the noise reduction performance of a building component or method are defined in Section 2.3. The Sound Transmission Loss (TL) tells how a material or component performs under laboratory tests. TL is given as a set of one-third octave frequency band values. Often a single-number descriptor is used instead of TL. Sound Transmission Class (STC) and Exterior Wall Rating (EWR) are both single-number measures of TL capability.

Informed Use of STC Ratings

While EWR is the most accurate descriptor of the aircraft noise reduction performance of construction elements and methods, STC ratings are still the most common measures given by manufacturers of building materials. For this reason, it is important to understand how to use

STC ratings effectively for evaluating the acoustic performance of the construction materials and systems commonly used for residential noise reduction. If an EWR rating is unavailable, STC may be used instead.

The STC rating scheme has limitations of which the reader should be aware. Two different construction methods or components may have identical STC ratings and yet have different one-third octave TL values. This means one method or component may perform better than another at some important frequencies. Selecting a construction method or component from a group only on the basis of the highest STC rating may not provide the intended sound insulation. This is because the STC rating is weighted for noise sources other than aircraft and does not take into account the strong low-frequency nature of aircraft noise. Efforts have been made in this guide to take into account the aircraft noise insulation performance of the building components and methods with the recommended STC ratings.

Combining Building Elements

When more than one building construction method or component has been incorporated in an assembly, the composite transmission loss must be determined. This is because each element comprising the assembly has different TL characteristics. The resultant performance depends on these characteristics and the relative areas of the elements. If any of the components has poor insulation properties the overall performance can be seriously weakened. This is why providing a balanced acoustical design is essential when different components are used in combination.

3.5.2 Window, Door, Roof, Wall, and Floor Modifications

3.5.2.1 Windows for Sound Insulation

Options Overview

The exterior windows are usually one of the weakest links in the dwelling's sound insulation performance. Even after all gaps and leaks have been sealed, the windows typically need to be modified or, preferably, replaced. Improving the transmission loss properties of the windows is one of the simplest ways of lowering the overall sound transmission into the house. Three options for window treatment include:

- Repairing and resealing the existing window;
- Adding a storm or secondary window;
- Replacement.

Decision Factors

The decision whether to modify existing windows, replace them with new standard windows, replace them with specially designed acoustic windows, or leave them as is depends on a number of factors, including:

- The noise exposure on the side of the building containing the windows. Windows on the shielded side of the house will often need different treatment from windows directly exposed to noise from the flight path.

- The type of window: fixed or openable, size, etc. Fixed windows usually have a higher STC rating because they are sealed shut and have fewer potential leakage paths.

- The thickness and type of glass in the existing window.

- The type and condition of the existing window frame: Framing materials such as wood or aluminum have different transmission loss capabilities. Settling of the dwelling, effects of weathering, normal wear and tear, aging of the sealant or weatherstripping, and air infiltration around the sash all degrade the sound insulating performance.

- Whether the window meets current local building codes: requirements for ease of escape in emergencies, for example.

Existing Noise Reduction

A typical existing window is rated at STC 25-29. Old windows in poor condition may provide less attenuation than this. Standard single-pane windows, even with storm assemblies, do not normally reduce aircraft noise to the recommended interior levels. They are usually insufficient whether they are fixed or openable. This includes the use of single panes in skylights.

Double-pane thermal windows, used in newer homes and installed as improvements to older homes, do not substantially improve the transmission loss characteristics. Thermal windows are ineffective for reducing sound because the air gap between the panes is too narrow. In order to reduce sound transmission the panes must be separated by a space of at least 2 inches so they vibrate independently of one another. Most dual-pane thermal windows provide less than 1/2 inch spacing so the two panes are coupled together acoustically and vibrate as one.

Specific Modification Options

Modification design options include repairing or replacing existing windows and installing secondary windows. Restoring the windows includes sealing any gaps or leaks and repairing or replacing the weatherstripping. The most common treatment is replacement with specially designed acoustic windows of the necessary STC rating, as discussed below.

The third alternative is adding a secondary window to the existing window, making sure to keep at least 2 inches between the panes. The secondary window can be mounted on the exterior or the interior. It is possible to achieve STC 35–40 with this type of combination. In general, primary replacement windows must have an STC rating of at least 30 dB unless combined with a secondary or existing window.

Table 3–6 gives typical STC ratings for various window systems and Table 3–7 suggests some "rule-of-thumb" improvements in STC rating provided by a number of modifications. Table 3–8 summarizes the requirements for improving window sound insulation.

Weatherstripping

Weatherstripping and caulking around windows (and doors) can improve the noise isolation by limiting air and sound infiltration at the perimeter of the building element. Limiting such perimeter infiltration will typically improve the STC rating of the overall assembly by 2 to 4 dB. This is especially important for STC ratings of 40 dB or better. For these assemblies, any perimeter leakage will seriously degrade the window's performance and will be the controlling factor in the noise isolation.

For acoustical purposes, compressible neoprene weatherstripping is preferred over felt or other fibrous types. Neoprene is not as porous and compresses better against the window or door frame. Also, felt and fibrous weatherstripping materials tend to deteriorate more quickly than neoprene and have to be replaced more often.

Acoustical Windows

Acoustical windows differ significantly from ordinary residential windows. The design of an acoustical window has a greater frame depth, the glass lites are heavier, and the weatherstripping and seals are more substantial. All of these measures are necessary to provide the high degree of sound insulation required for the window assembly. Figure 3–5 shows schematically the features of an acoustical window. Figures 3–6 and 3–7 show some typical acoustical windows. Proprietary windows with STC ratings of 35, 40, and 45 are available in a variety of styles and finishes.

Thermal Performance

Because of the above-mentioned design features, plus the common inclusion of thermal barriers at the frames, acoustical windows perform exceptionally well as thermal barriers. They allow approximately one-tenth the air infiltration of a typical 20-year-old double-hung wood window with single lites. The R-value (a measure of thermal resistance) for acoustical windows is R-4. For comparison, the R-values of most single-lite and thermal double-lite windows are R-1 and R-3, respectively.

Building Code Requirements

Often, the existing windows do not comply with current Uniform Building Code (UBC) requirements in relation to Light and Ventilation, Section 1205(a), and/or Exit Facilities, Section 1204. These requirements for habitable rooms refer to minimum window area (for day lighting or escape), minimum net width and height of openable area, and maximum height of openable sill above the floor (for escape access). Modifications to such windows which include bringing the window into conformity with the UBC specifications, will involve additional project costs.

Miscellaneous Considerations

For the windows to provide the transmission loss required they must remain tightly closed. Ways to maintain ventilation will be discussed in Section 3.5.4. It is important to note, however, that this requirement precludes the use of jalousie or louvered windows in a sound insulation design. These will almost always have to be replaced.

Other considerations when preparing window specifications include maintainability, warranty,

Table 3-6

Typical STC Ratings of Acoustical Windows

Window Type (Openable Only)	Frame/Sash	STC Rating Range, dB
Primary Windows (STC >30 dB)		
Double-Hung, Horizontal Slider	Aluminum (2.5-inch separation of glazing)	30–45 30–40
Double-Hung, Casement, Awning	Wood (1-inch separation of glazing)	30–35 30–33
Secondary Windows (STC 25–30 dB)		
Double-Hung, Horizontal Slider	Aluminum (0.25-inch separation of glazing)	25–29

NOTES:

Windows with depth equivalent to wall thickness of typical wood frame structures.

Fixed-pane windows are available from most suppliers with STC ratings of up to 50 dB.

Table 3-7

Adjustments in STC Rating for
Different Glazing Configurations

Glazing Type	Modification	STC Adjustment
Monolithic	Replace monolithic lite with laminated glass lite of equal weight	+3
Thermal Insulating	Replace one monolithic lite with laminated glass lite of equal weight	+4
	Double each glass lite weight	+1
	Double airspace cavity between glass lites	+3
	Change from operable to fixed window configuration	+3
Laminated Insulating	Replace monolithic lite with laminated glass lite of equal weight for double-laminated configuration	+3
	Double each glass lite weight:	
	- Airspace cavity between lites less than 1 inch	+3
	- Airspace cavity between lites greater than 1 inch	+1
	Double airspace cavity between glass lites	+3
	Change from operable to fixed window configuration	+3

NOTE:
To use this table, start with the STC rating of the unmodified window. Then find the improved STC rating by identifying the value of the increase for the chosen modification and adding it to the existing STC value.

Table 3-8

Summary of Methods for Improving Window Sound Insulation

1. Increase glazing thickness up to 1/2 inch to increase mass and to reduce vibration.
2. Use laminated glazing, typically two layers of glazing with a 30 mil polyvinyl butyral interlayer, to achieve limpness and provide damping which reduces coincidence effects. For double-lite constructions, place the laminated lite on the warm side of the window because cold climate conditions may result in loss of damping effect for the interlayer. Laminated glazing constructions can result in an increase of 3 dB in the STC rating over monolithic glazing of the same thickness.
3. Use double-lite constructions with at least a 2-inch-wide spacing between the lites. Each doubling of the airspace between the lites results in an increase of 3 dB in the STC rating. Glazing thickness should be in a ratio of 2:1 so lites have different resonance frequencies.
4. Do not use lightweight frames where flanking sound paths may limit window transmission loss performance. Use separate heavy aluminum frames connected together with a thermal break.
5. Mount lites in soft neoprene edge gaskets which wrap around the bottom of the glazing sash channel. This minimizes structureborne sound transmission between the glazing and the window sash.
6. Operable double windows with separate sashes provide greater transmission loss than a single sash with double glazing. Non-operable windows have STC ratings which are 3 dB higher than operable windows of similar construction.
7. Do not evaluate windows needed to isolate low-frequency noise (such as occurs with aircraft overflights) based on STC ratings alone. This is because the STC rating does not include transmission loss performance below 125 Hz, where aircraft noise may be significant. For example, single lites with STC ratings identical to double-lite constructions will generally perform better at low frequencies due to their greater overall weight. Installation is critical in order to maintain the sound isolation performance of the window assembly.
8. Windows need to fit with a minimum perimeter gap between the window frame and opening. All voids need to be caulked and closed off with wood trim and blocking. Ensure that all sound flanking and air infiltration paths have been closed off. Remember, if air can pass through, so can sound.

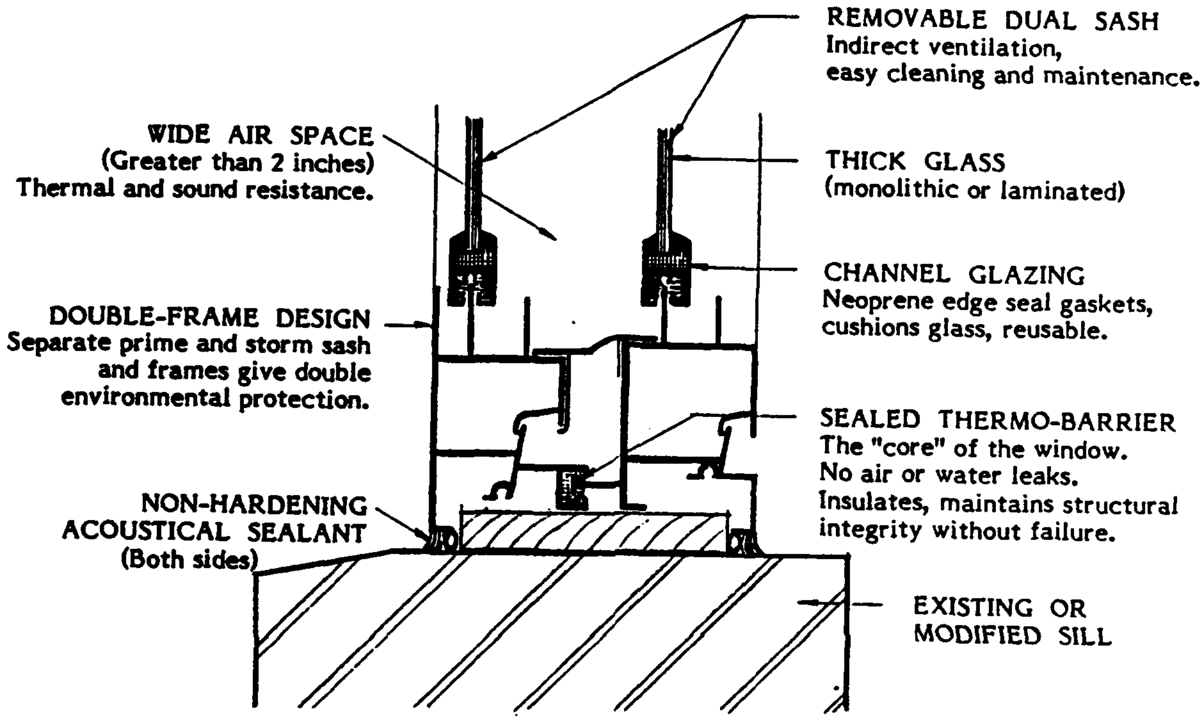


Figure 3-5. Construction Features of Acoustical Window.

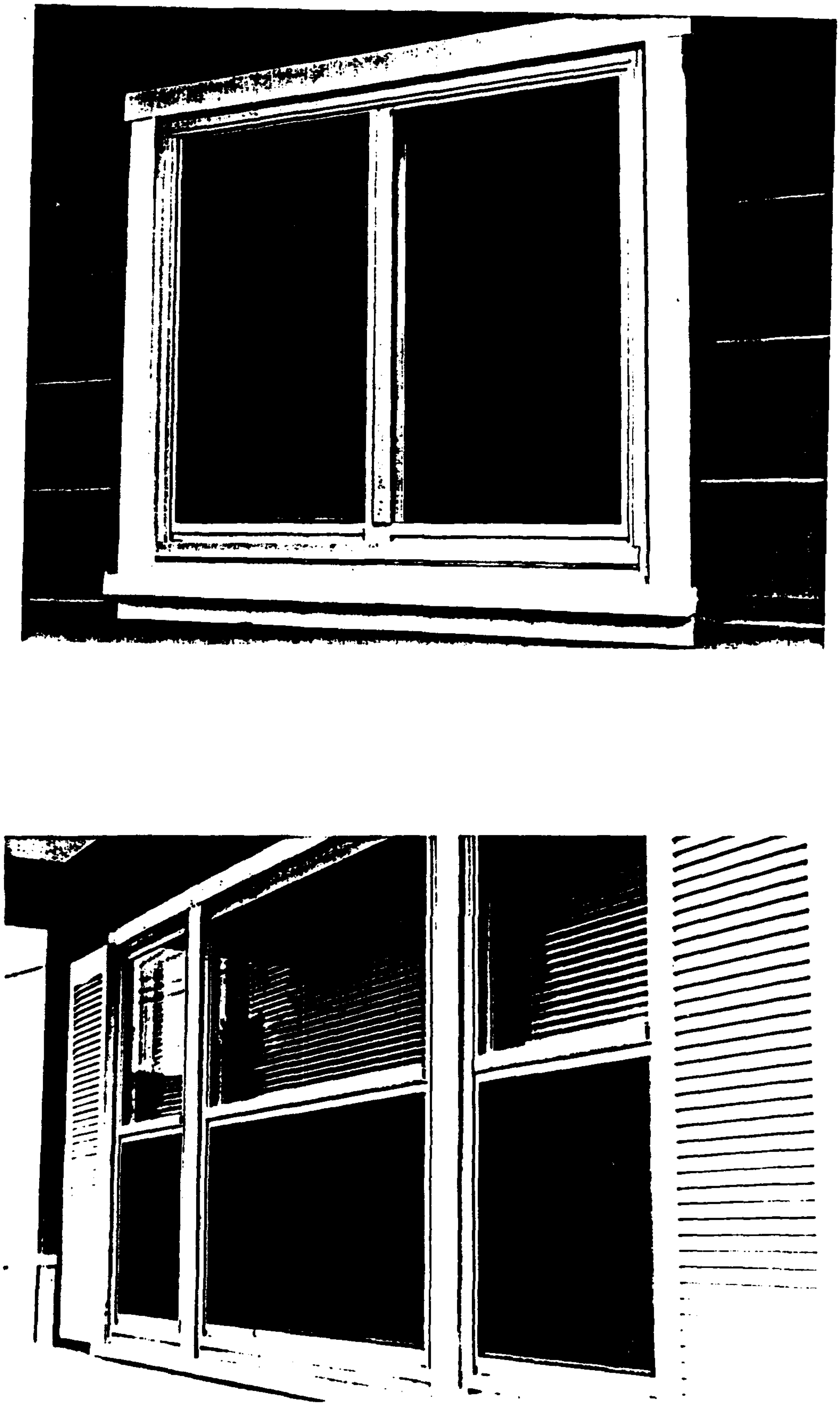


Figure 3-6. Typical Acoustical Windows in Place.

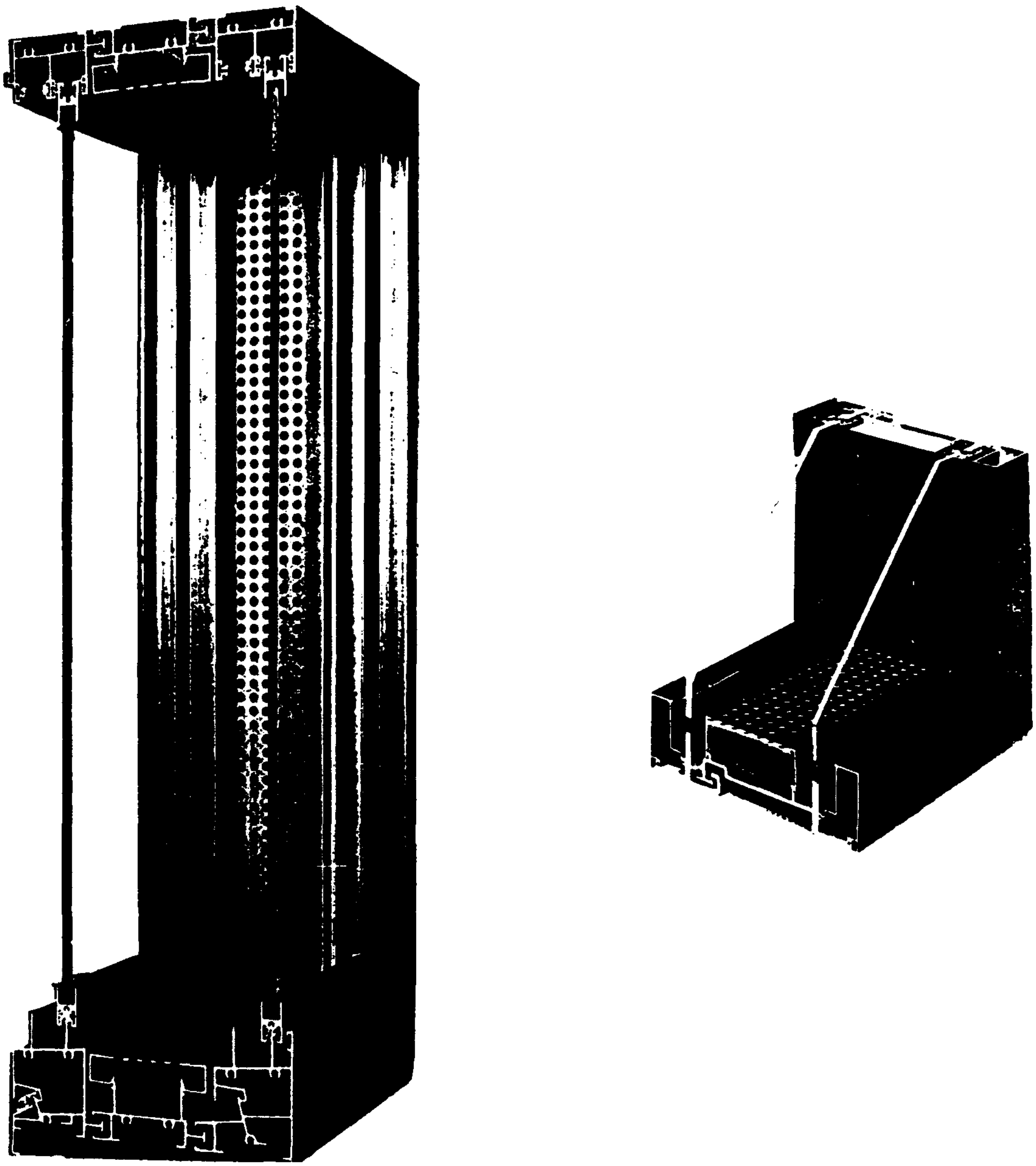


Figure 3-7. Examples of Double-Glazed Window Constructions. (DeVac: #653, STC 44; and #720, STC 48.)

manufacturer's service, and proper installation. It is possible to install the best acoustical window improperly. If it does not fit tightly enough, air infiltration will significantly reduce the effectiveness. Starting with a too-small window unit and filling in the void around the window with a penetrable material such as fiberglass is unacceptable. Wood blocking infill is, however, acceptable.

Replacement windows should be chosen to conform to what the homeowner is accustomed to in the way of style and operation. Windows should be mounted in a way which facilitates cleaning.

3.5.2.2 Doors for Sound Insulation

Options Overview

Doors compete with windows for the role of the weakest link in the dwelling's sound insulation performance. Almost all typical residential doors require modification or replacement to provide the necessary protection from aircraft noise. Several factors are important in evaluating doors for sound insulation:

- Door composition: hollow core, solid core, sliding glass, core material, additional internal insulation, etc.;
- Door weight (can be estimated by pull-weight);
- Presence of fixed window panels;
- Condition of seals and weatherstripping, fit of door to frame, jamb.

The options for improving the noise reduction of residential doors include:

- Repair of the existing door and weatherstripping;
- Replacement with a proprietary acoustical door or a superior standard door;
- Installation of a secondary door or storm door.

Existing Noise Reduction

Standard entrance doors can be expected to fall in the STC range 21 to 27 or the EWR range 19 to 27. Table 3-5 shows several of these. Sliding glass and french doors, however, provide less sound attenuation: approximately STC 23. The worst case – the ordinary, hollow-core wood door – offers only 17 to 19 dB of noise reduction. In some cases, if the door is a substantial weight solid core or a heavy glazing sliding glass door, it may be adequate for sides of the house shielded from the aircraft noise. This would require weight greater than 8 lbs per square foot. For comparison, a standard wood solid-core door weighs approximately 6 lbs per square foot.

External storm doors are common in many parts of the country and can improve the STC rating by 3 to 5 dB. Glass panels in the primary door, however, can reduce the sound insulation by 3 to 5 dB, depending on the thickness of the lite and the area it covers. The thinner the glass and the larger the area it covers, the more it degrades the sound insulation of the door. As with windows, it is of critical importance to ensure that the door fits well, all gaps and leaks are sealed, and the door remains closed.

Improving Existing Doors

Sound transmission loss through existing doors can be increased by fitting them with special acoustical seals, including drop seals mounted to the back. If, because of settling or warping, the existing door or replacement door does not fit squarely into the frame it will not seal properly. This condition must be corrected by repairing and squaring up the door frame and installing new seals and weatherstripping. All openings such as mail slots must be sealed or provided with back-to-back slots. Where repair and reinforcement are not feasible, a prehung door should be used.

Acoustical Replacement Doors

Acoustical doors, with a typical STC rating of 30–40, are similar in appearance to standard entrance doors. Because of their specialized construction and superior sealing design they provide a very noticeable improvement in noise reduction. While metal doors are available, wood doors are preferred since they match the original door more closely. Whether metal or wood, the internal construction of acoustical doors differs substantially from standard doors. Layering of materials, along with added absorption and mass, increase the weight to approximately 12 to 14 lbs per square foot. Figure 3-8 shows these construction details schematically.

To eliminate sound flanking between the closed door and the jamb, acoustic doors are designed with special fixed acoustical seals at the sides and top. A drop seal along the bottom is activated by a cam rod when the door is closed to make tight contact with the threshold. An acoustical

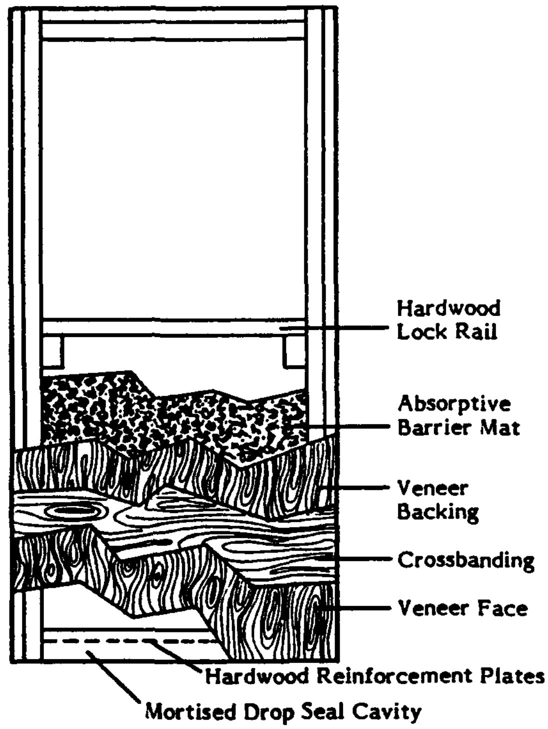


Figure 3-8. Wood Acoustical Door Construction.

replacement door should be ordered of the proper thickness, usually 1 $^3/_4$ inches, so that it fits in the existing frame. Also, because of their extra weight, acoustical doors usually require reinforcement of the door frame and heavy-duty mounting hardware and ball-bearing hinges. Acoustical doors often come with their own frames. Replacement doors, whether acoustical or standard, must be suitable and warranted for exterior use.

Secondary Doors for Sliding Glass and French Doors

The options for improving the sound insulating properties of sliding glass doors and french doors are limited. No replacement doors are available with high enough STC ratings to satisfy noise reduction requirements. Most of the time, a secondary door must be installed. This second sliding glass door can be mounted on the inside or the outside of the existing door, whichever is more practical and convenient. The only alternative to this is to remove the sliding glass or french door completely and replace it with a much smaller area window and a solid core door. Homeowners usually prefer adding a secondary door to closing up the existing one.

Installing a secondary sliding glass door requires building a new frame positioned to mount the door approximately 2 to 3 inches away from the existing door. This dual-door assembly has proven successful in that it raises the STC rating by 5 to 7 dB and it is more acceptable to homeowners than closing up the area with a standard door and window. As with other doors and windows, all possible leakage paths must be sealed. Figure 3-9 shows a system of two sliding glass doors with the secondary door mounted using a 2x4 stud frame outside of the original door.

Table 3-9 gives a summary of the requirements for improving door sound insulation.

3.5.2.3 Roof and Attic Treatments

Options Overview

Where window and door treatments will not provide sufficient noise reduction improvements, it may be necessary to modify the roof, attic, or ceiling of a home. The modification options include:

- Installing baffles in the vents;
- Adding insulation to absorb sound reverberating in the attic space;
- Mounting gypsumboard or plywood barriers to the rafters, joists, or ceiling.
- Improve exterior roofing.

The final design will depend on the type of roof in place and the noise reduction needs.

Sound Transmission Paths

Sound enters through the roof in two paths: by vibrating the roof itself, which then radiates this acoustical energy into the air within the dwelling, and directly through vents and leaks. If there is no attic the sound passes immediately into the living space under the roof. This is why homes with open beam ceilings often have very limited noise reduction through the roof. Where there is an attic, the sound enters and reflects back and forth off of the attic surfaces, reverberating in the space. Then the sound passes through the finished ceiling to the room below.

Attic Vents

Attics typically have open air vents at the ends (for a gabled roof) or under the eaves. The sound entering through these vents may be significant. Acoustical louvers can be applied to baffle the sound passing through such openings. Unfortunately, many attics have triangular-shaped vents and most noise control baffles are rectangular. The exterior wall can be modified to accommodate the baffle but this is rarely the most cost-effective solution. One of the other alternatives, such as adding insulation or installing barriers, can be used instead. Vents under the eaves can be left unmodified when other measures are implemented since they are somewhat shielded from direct exposure to the aircraft noise.

Attic Insulation

When considering the application of thermal insulation to reduce noise levels it is important to understand what the insulation will do. Thermal insulation materials will act to absorb sound that is reverberating in the attic or in the space between flat panels. It does not prevent noise from entering the space. That is, it has no appreciable acoustic "insulating" properties. To keep sound out, barriers must be used which increase the mass of the roof. As a sound absorbent, fiberglass batts and blown-in fiberglass or mineral fiber can be applied between the rafters, between the ceiling joists, or in conjunction with a plywood or gypsumboard

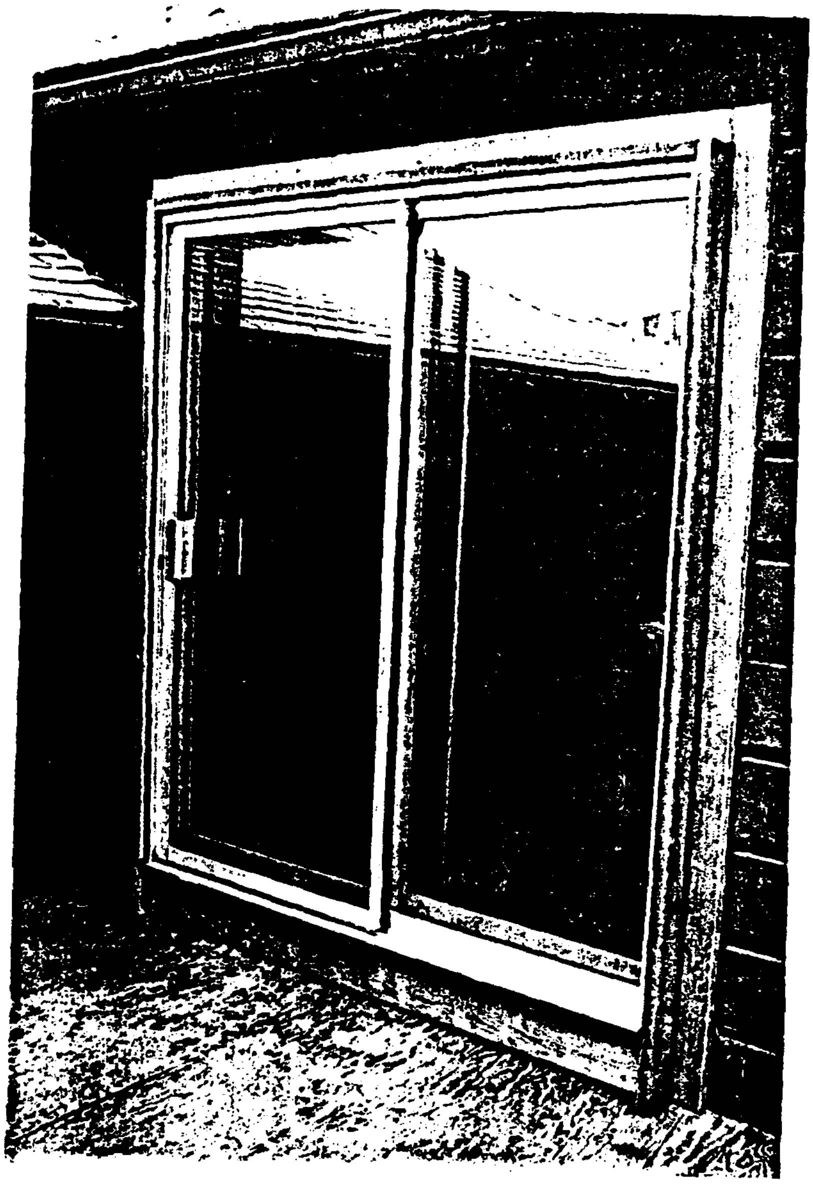


Figure 3-9. Exterior-Mounted Secondary Sliding Glass Door.

Table 3-9

Summary of Methods for Improving Door Sound Insulation

1. Increase the weight of the door. This results in higher transmission loss characteristics. 2. Use solid-core wood doors or hollow-core metal doors filled with fibrous fill. Special acoustical wood and metal doors are available which can be specified for optimum results. 3. Fill hollow metal door frames with fiberglass or use solid wood door frames. Caulk around door frames at the wall. 4. Door frames and hardware should be reinforced to handle the extra weight of acoustical doors. Use ball-bearing hinges and long screws for attachment to framing members. 5. Provide full seals and weatherstripping at the perimeter of the door jamb and head to minimize perimeter air infiltration. 6. Provide a drop seal at the door bottom which makes full contact with a raised threshold. The drop seal should be adjustable to compensate for misalignment of the door. 7. Vision lites should have similar transmission loss characteristics to the door. Use two layers of 1/4-inch laminated glass separated by an airspace. Provide full seals and gasketing at the window perimeter. 8. Add a second sliding glass door in parallel with the existing sliding glass door. Position the new sliding glass door so it is a minimum of 2 inches from the existing sliding glass door.

barrier. Blown-in cellulose is not recommended since it compacts over time, reducing its effectiveness.

The absorption of a material should not be confused with transmission loss (TL) or noise reduction (NR). The NR depends on several factors, including the transmission loss or sound-insulating properties of the construction, the size of the attic, the wall areas, and the absorption in the attic. There is no direct relationship between a material's absorptive properties and the overall TL or NR, unless all other parameters are known.

A simple method for determining the proper thickness of sound-absorbent materials is to use the concept of the material's thermal rating (R-value). This R-rating is a commonly used and well-known rating for building products. The R-values, thickness, and acoustical absorption coefficients for several common fiberglass batt dimensions are given in Table 3-10. The higher the sound absorption coefficient, the better the absorption performance of the material. The value of the acoustical absorption coefficient at 125 Hz depends on the thickness of the material. For noise sources with a significant low-frequency component, such as aircraft flyovers, the thickness is the most important parameter. Thicker materials provide better low-frequency sound absorption.

As the table shows, R-30 provides significantly better low-frequency absorption than R-19. The difference in sound insulation between the two, however, will be negligible. For most applications, the R-19 material can be considered a practical lower limit for noise control when used in attics. Obviously, for thermal insulation purposes more material may be used, to the benefit of the noise control effort. Note that this table only applies to fiberglass batts. For other acoustically absorptive materials, such as blown-in fiberglass and blown-in mineral fiber, different thicknesses will give these R-values. Table 3-11 compares the thickness and R-value of several different materials.

Sound Barriers

The third noise control measure involves the application of a single layer of sound barrier material. Gypsumboard may be hung just under the interior finish ceiling to improve the transmission loss characteristics in most roof structures. Gypsumboard or plywood may be added to the attic rafters or in cases where the roofing material is lightweight or deteriorated. This additional layer adds mass to the ceiling, providing approximately 3 dB improvement in the STC rating of the original roof. If the barrier is mounted on resilient channels, it will give more than 3 dB improvement. The gypsumboard should be 5/8-inch fire-code product, since it is heavier than the standard. Also, putting absorption between the added layer and the ceiling and in the attic space reduces the reverberant sound level. In homes with an exposed beam ceiling it may be necessary to provide a standard finish ceiling.

If the attic contains dormer-style bedrooms, they can be insulated with barrier materials applied to the walls and ceiling and sound absorption installed in the rafters.

All barrier treatments should be cut to fit tightly against the perimeter of the roof or ceiling. Acoustical caulking around the edges helps eliminate flanking.

Treatments for Non-Attic Roofs

Roofs without attics, whether flat or pitched, light or heavy joist, are treated in one of two ways. They can be modified inside, at the finish ceiling, or outside, by supplementing the existing roofing material. The choice of methods depends on:

- Noise exposure;
- Existing noise reduction;
- Additional noise reduction required;
- Strength of the existing structure.

Both treatments are discussed below. Open-beam ceilings are addressed separately under that heading.

Interior Treatment: Attach a sound barrier to the interior finish ceiling. The barrier can be a single layer of 5/8-inch fire-code-rated gypsumboard, or gypsumboard combined with sound-deadening board. Screws hold the barrier in place and all edges must be well sealed. The barrier adds mass to the ceiling and can improve the noise reduction by 3 dB. In high-noise zones this may not be sufficient and the next method may be necessary.

Exterior Treatment: For greater sound insulation, remove the roofing material, add either 1/2-inch layer of plywood sheathing or $3^1/_2$-inch rigid insulation assembly covered with the plywood. Then new roofing is applied to the top surface.

Table 3-10

R-Value, Thickness, and
Sound Absorption Coefficients
for Fiberglass Batts

R-Value	Thickness, Inches	Sound Absorption Coefficient, Hz				
		125	250	500	1000	2000
R-11	3.5	0.34	0.85	0.99	0.99	0.95
R-19	6	0.64	0.99	0.99	0.99	0.99
R-30	9	0.80	0.99	0.99	0.99	0.99

Table 3-11

Material Thickness and R-Value
for Common Insulating Materials

Material	Thickness, Inches		
	R-11	R-19	R-30
Roll or Batt Fiberglass (Vapor Barrier on one side	3.5	6	9
Blown-In Fiberglass	5	8	13
Blown-In Mineral Fiber	4	6.5	11

The primary question with this treatment is whether or not the existing roof structure is strong enough to support the extra weight of the roof improvement. Figure 3-10 shows this treatment for a flat roof. For maximum sound insulation, both methods can be employed together.

Treatments for Open-Beam Ceilings

Open-beam ceilings present insulation problems for two reasons: The roof system itself tends to be lighter than conventional schemes simply because of the absence of the sheathing layer on the interior face. The exception to this, of course, is the decorative exposed-beam ceiling attached to a conventional ceiling for aesthetics. The second part of the problem stems from homeowner reluctance to accept the simplest and most cost-effective treatment – enclosing the beams in a conventional finish ceiling. Residents usually want to preserve the appearance of their open-beam ceilings. Keeping this is mind, there are three ways to improve the noise reduction of open-beam ceilings:

Enclosure: Enclose the beams with a layer of gypsumboard or similar barrier material and install fiberglass batts or other absorbent material between the now-covered beams (often unacceptable to homeowner).

Partial Enclosure: Install absorbent material between the beams and cover with barrier panels fitted between the exposed beams. The total thickness of the additional material is kept to about one-half to two-thirds of the exposed beam depth. This avoids covering the beams over completely but does make the exposed part shallower. Partial enclosure affords some noise protection but has proven to be time consuming and expensive.

Exterior Roof Modification: As discussed for non-attic roofs, scrape off the existing roof covering, add a $3^1/_2$-inch rigid insulation assembly applied to the roof surface, sheath with a layer of 1/2-inch plywood, and cover with a new roof surface. This provides very good noise reduction improvement, but can only be used after checking the structural integrity of the roof to ensure it will support the additional load.

Whole-House Attic Fans

Dwellings which have a whole-house attic exhaust fan at the interior finish ceiling should be modified. This is because the fan, whether operating or turned off with the dampers closed, provides little noise attenuation. The simplest modification consists of removing the fan and repairing the hole to match the rest of the ceiling. It is generally not feasible to install mufflers to limit the noise passing from the attic space to the interior of the home.

Table 3–12 gives a summary of the requirements for attic and ceiling modifications used for improving dwelling sound insulation.

3.5.2.4 Interior Wall Modifications for Sound Insulation

Determining a Need for Wall Modifications

Depending on the dwelling's exterior construction and materials, it may be necessary to modify the inner face of the outside walls. Homes in regions where there is a wide variation in insulation properties need to be examined on a case-by-case basis. There are, however, some rules-of-thumb which hold for most neighborhoods.

Generally, dwellings which are of vinyl, aluminum, or wood siding exterior construction require modification in the highest noise impact zones. Dwellings which use brick veneer, stucco, concrete masonry block, and other cementitious materials typically do not. In some cases, a dwelling with stucco exterior, lacking adequate thermal insulation in the stud cavity, may need interior wall treatment if it is located in a very high noise zone (DNL in excess of 75 dB). Also, it is quite common for builders to combine siding with other exterior construction materials such as brick or stucco. For the purposes of this guide, the siding and siding-combination constructions are taken to have approximately the same sound insulation performance. Only those walls with little or no shielding effects need to be modified.

Options Overview

The modifications are directed at:

- increasing the mass of the wall,
- adding mass and resiliency to the wall, or

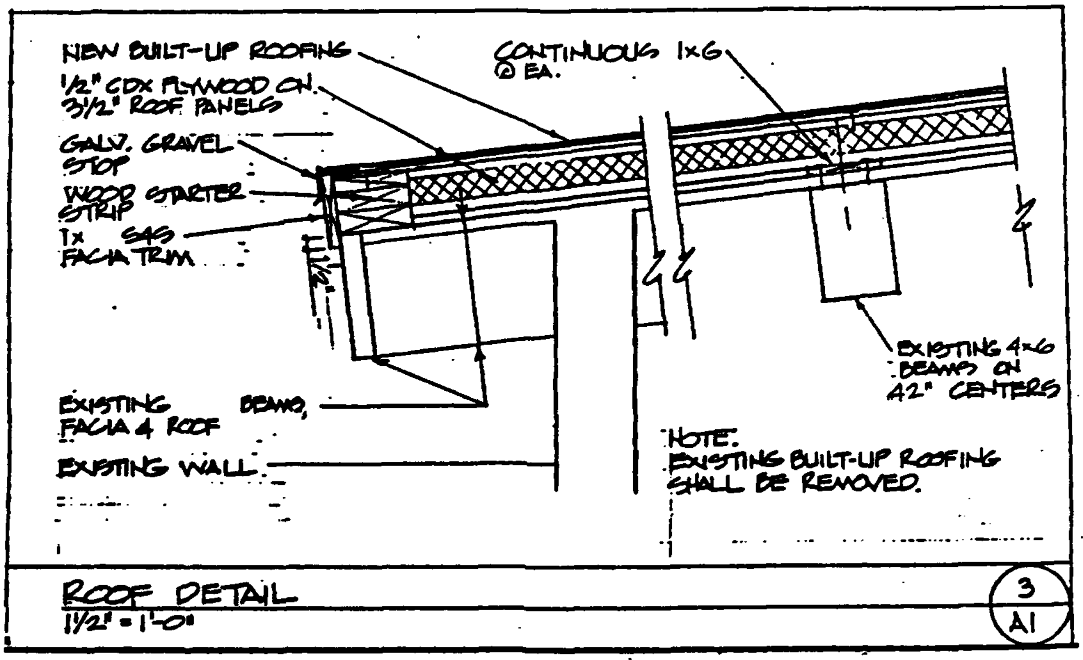


Figure 3-10. Exterior Roof Improvement.

Table 3-12

Summary of Methods for Improving Attic and Ceiling Sound Insulation

1. Install baffles on attic vents where practical.
2. Add acoustically absorptive material to a thickness equal to R-19 to the attic space to reduce reverberant sound level buildup. Apply material evenly throughout the attic space, taking care to keep it away from eave vents and openings.
3. Add one layer of 5/8-inch fire-code gypsumboard to the interior finish ceiling for dormer, non-attic, lightweight, or deteriorated roofs.
4. For greater noise control in attics add 5/8-inch plywood or gypsumboard to the rafters or add plywood flooring to the joists. Use absorptive material equivalent to R-19 between the rafters or joists.
5. Cover exposed beam ceilings with interior finish ceilings or partial enclosures.
6. For higher noise insulation on non-attic roofs: strip off existing exterior surface, add 3.5-inch rigid insulation assembly, 1/2-inch plywood sheathing, and new roofing material.
7. Remove whole-house attic exhaust fans and repair the interior ceiling to match the existing conditions.

• decoupling the wall from the supporting structure.

Both the second and third methods combine sound and vibration transmission loss in the composite wall structure. Figure 3-11 shows the features of the modifications.

Specific Modifications

The simplest modification is to attach a single layer of 5/8-inch gypsumboard with screws to the interior finish wall. This modification increases the mass of the wall assembly, resulting in approximately a 3 dB increase in the STC rating of the existing wall. Fire-code gypsumboard, which is heavier than standard, should be used for all these modifications.

A variation of the first modification consists of a layer of 1/2-inch sound-deadening board (a compressed paper slurry product) attached to the wall. Then a layer of gypsumboard is adhesively attached on top of it. This modification provides both mass and resiliency to the interior finish wall. The mass is provided by both the sound-deadening board and the gypsumboard. The resiliency is provided by the adhesive application. Screws produce a more rigid attachment, resulting in less sound insulation than provided by the adhesive attachment. The existing wall assembly STC rating can be improved by 6 dB when the adhesive attachment modification is used.

A second method of increasing the mass and resiliency of the wall is to attach the gypsumboard to the existing interior surface with 1-inch, resilient, vibration-isolation channels. This will provide a noise reduction improvement of about 8 dB to a typical wood frame structure.

Providing a separately furred-out wall from the interior finish wall is the third modification which can be used. A layer of 5/8-inch gypsumboard is attached with screws to 3 $^{5}/_{8}$-inch metal studs and runners. The runners and studs are positioned no less than 1 inch from the existing finish wall, resulting in a 5-inch-deep free-standing wall. Unfaced fiberglass batts are placed between the studs in the wall cavity. This modification provides acoustical decoupling and separation between the exterior wall and the interior of the room, resulting in approximately 12 dB increase in the STC rating of the existing wall.

The first and second modifications - the panels adhesively mounted or attached with resilient channels - have one advantage in common: They add less than two inches to the wall thickness, thereby avoiding the noticeable encroachment into the room area that the third method causes. However, the furred-out wall scheme is much more effective at reducing the noise problem.

Miscellaneous Considerations

When planning for wall modifications, it will be necessary to pull forward and reinstall electrical outlets or switches. The furred-out wall modification will also require pulling back the carpeting and reinstalling it so that the new wall meets the finished floor. In dwellings where baseboard heating systems are used, the wall modification can be extended to the top of the heating fixture since it may be difficult to relocate the fixture.

After completion of the wall modifications, it will be necessary to paint the entire room so all of the walls and ceiling have a uniform appearance. Due to mismatching of paint lots, it is not feasible to paint only the wall which is modified.

Modifying interior walls is very intrusive on the homeowner compared to other noise control treatments. The task requires repeated visits to the dwelling to install channels or studs, apply the boarding, apply finish plaster, and redecorate and clean up the room. This process can require up to a week and a half of inconvenience to the residents.

It should be noted that wall modifications are generally infeasible in kitchens due to the presence of cabinets, plumbing fixtures, and wall tile. A summary of the requirements for wall modifications used for improving dwelling sound insulation is given in Table 3-13.

3.5.2.5 <u>Exterior Wall Construction Improvements</u>

Options Overview

If interior sound level goals can not be attained using the methods outlined in other parts of Section 3.5.2, it is possible to modify the dwelling exterior. This usually costs more than other treatments and is normally only chosen for noise impact of 75 dB or more. Figures 3-12, 3-13, and 3-14 schematically illustrate six possible modifications for the exterior wall construction. These modifications include:

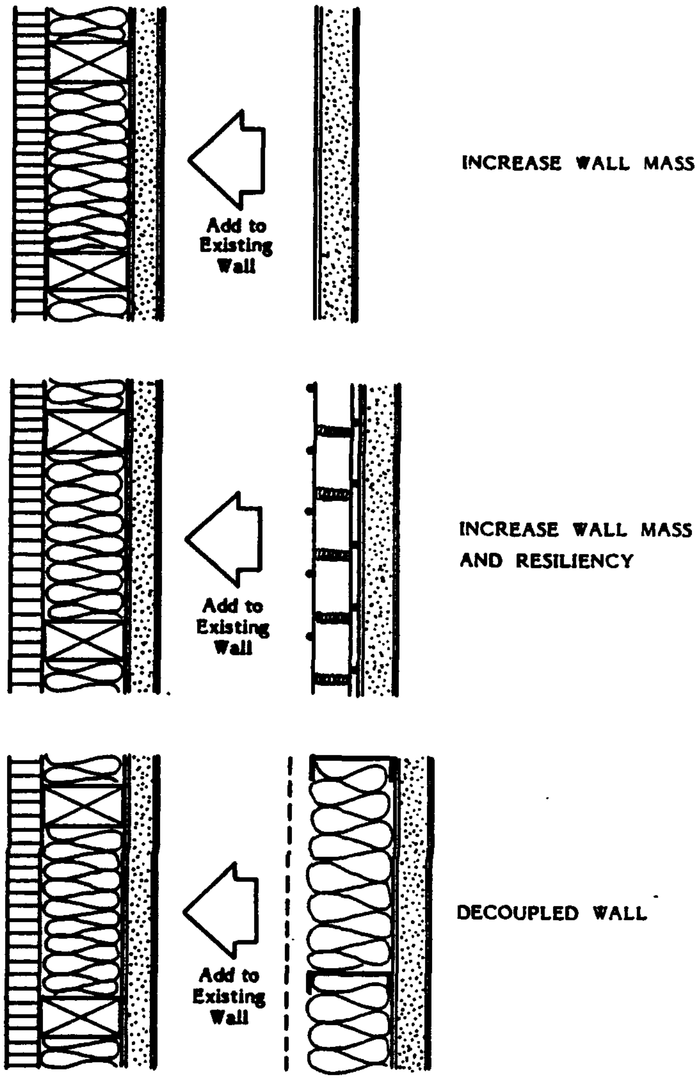


Figure 3-11. Types of Wall Modifications.

Table 3-13

Summary of Methods for Improving Interior Wall Sound Insulation

1. Use heavy gypsumboard such as fire-rated products in 5/8-inch thickness. Adding one layer of 5/8-inch gypsumboard increases the wall STC rating by 3 dB.
2. Use a discontinuous construction between the existing wall and the new wall finish. This can be achieved by adhesive attachment of gypsumboard and sound-deadening board to the existing wall or by furring out a separate wall. Increases of 6 dB and 12 dB, respectively, to the STC rating are achieved.
3. Use light-gauge metal channel studs (25-gauge or lighter) because they are less stiff than wood or load-bearing metal studs. The use of wide (3.5-inch) metal channel studs will increase the transmission loss at low frequencies.
4. Use 3-inch-thick sound-absorbing blankets in the wall cavity. Install blankets tightly between studs using friction fit or with fasteners to the studs to prevent sagging.
5. Cut new gypsumboard so that it fits tightly against walls, floor, and ceiling.
6. Apply acoustical caulking around perimeter of new gypsumboard and around all electrical outlets and switches to eliminate sound flanking.

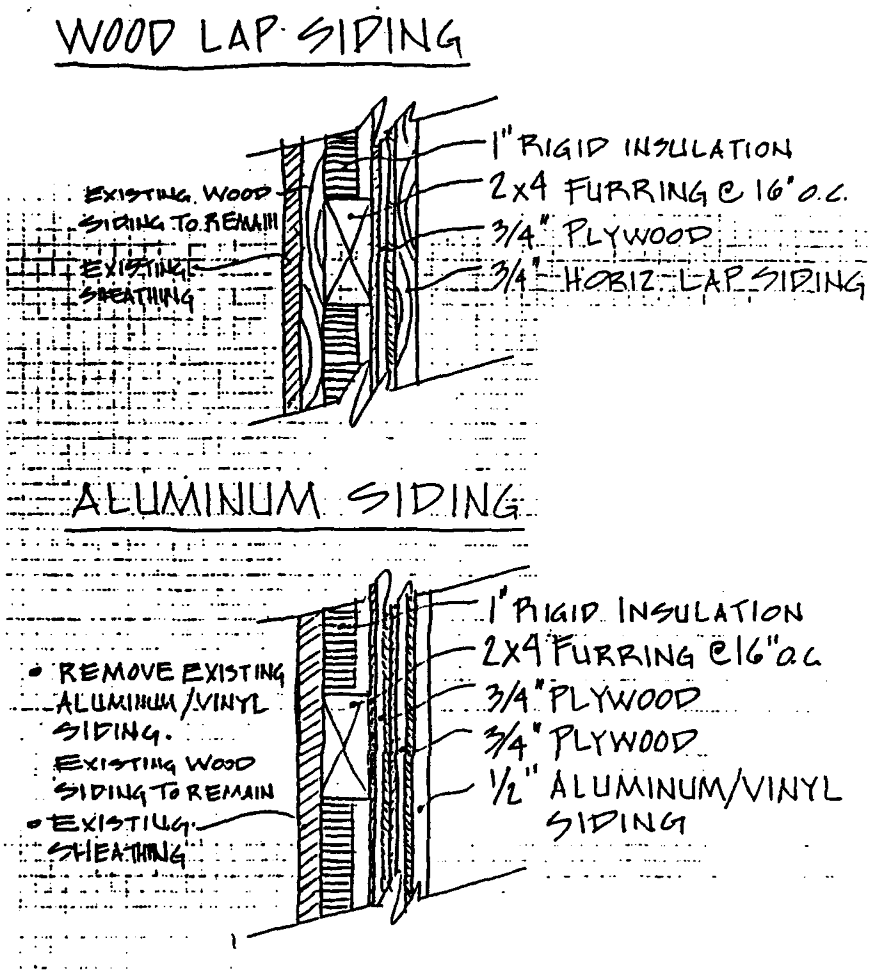


Figure 3-12. Schematic Exterior Wall Modifications.

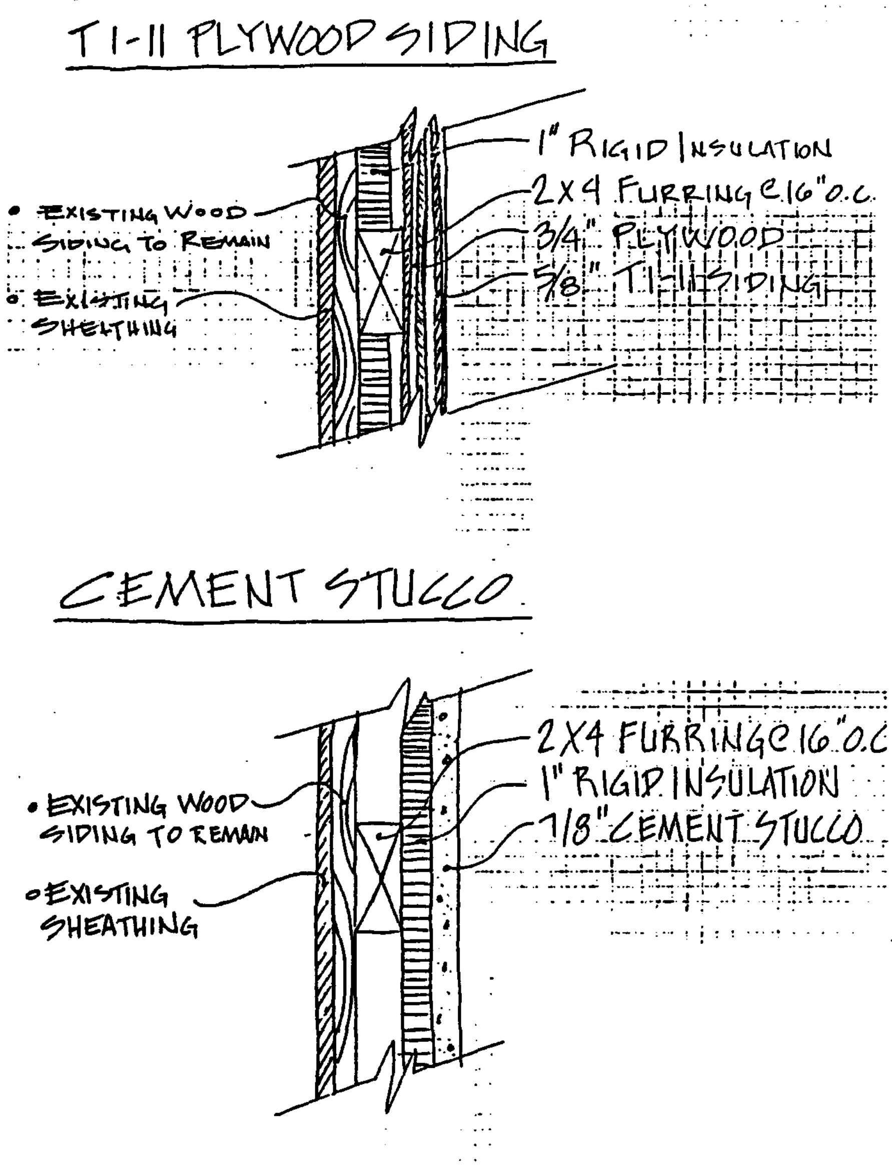


Figure 3-13. Schematic Exterior Wall Modifications.

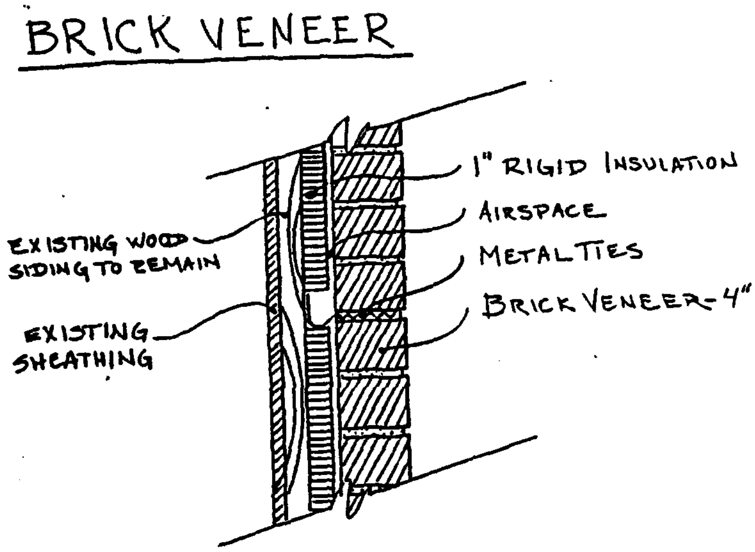


Figure 3-14(a). Schematic Exterior Wall Modifications.

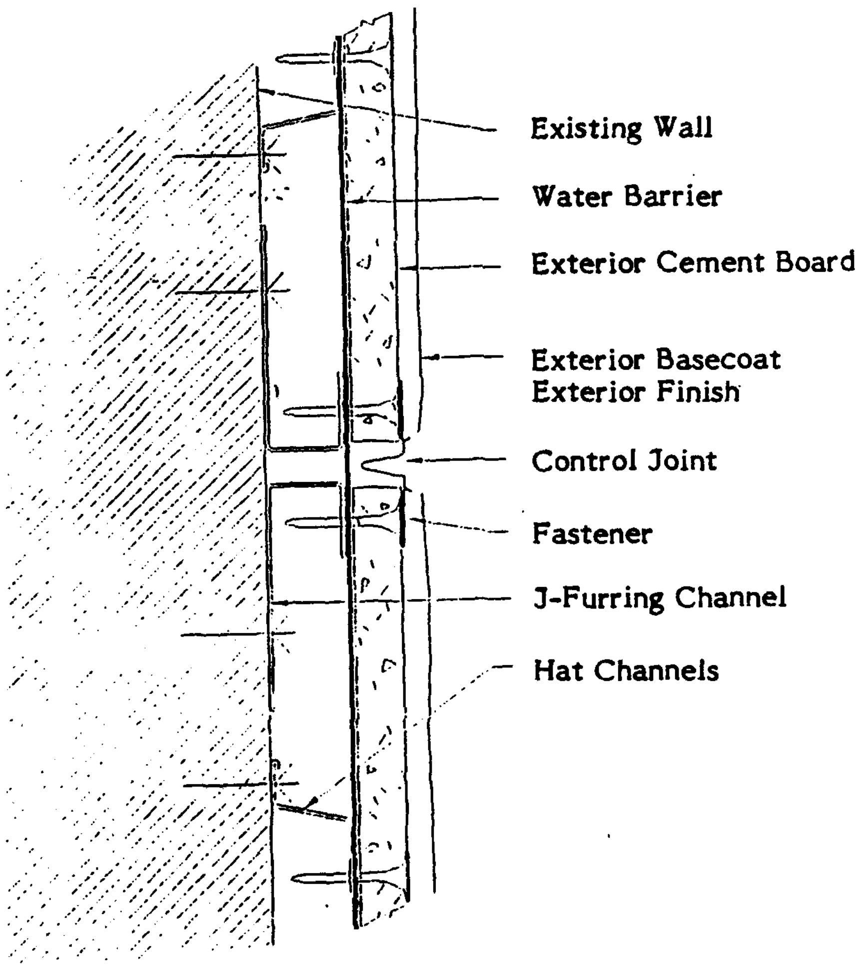


Figure 3-14(b). Schematic Furred Cement Board.

- Adding furred-out wood lap siding;
- Removing aluminum or vinyl siding and replacing as furred-out construction;
- Adding furred-out plywood siding;
- Applying layer of furred-out cement stucco;
- Applying layer of 4-inch brick veneer;
- Applying layer of furred-out cement board.

Appropriate Use of Options

Experience from residential sound insulation programs shows that masonry or heavy stucco exterior constructions do not require the extensive interior wall modifications which are usually required for lightweight frame construction dwellings. Thus the brick and stucco modifications in Figures 3–13 and 3–14 could be expected to provide greater additional sound insulation to the existing lightweight frame construction than the wood framing designs shown in Figures 3–12 and 3–13. In general, only the unshielded sides of the dwelling need to be treated externally, though other sides may be modified to maintain uniform appearance.

Upgrading Insulation

Existing lightweight construction usually consists of studs between an interior layer of gypsumboard and an exterior layer of wood or aluminum siding, brick, or light stucco veneer. In some areas of the country, notably Hawaii, the interior layer is sometimes eliminated, leaving a very light single leaf construction. Thermal insulation is often packed into the wall air cavity, but not always, and it may be inadequate for sound reduction requirements. Adding 3-inch sound-absorbing blankets in the wall cavity can significantly improve the sound attenuation. These should be installed tightly between studs, with fasteners if necessary, to prevent sagging.

Advantages/Disadvantages

An advantage to modifying the exterior of the dwelling is that the amount of interior wall modification can be reduced. This may be preferable, for example, to the separately furred-out interior wall if that is recommended to meet the noise reduction criteria. The interior modification could be downgraded to gypsumboard, or gypsumboard and sound-deadening board, applied directly to the walls. In previous sound insulation programs, homeowners tended to resist accepting the interior furred-out wall modification because of the loss of floor space. Improving the external wall also minimizes the inconvenience to the homeowner since it eliminates the need for up to a week and a half of interior construction.

A disadvantage to modifying the exterior of the dwelling is that the square-foot cost can be considerably higher than the interior wall modifications. Additionally, the entire outside of the dwelling may have to be covered in order to maintain a uniform appearance.

3.5.2.6 <u>Floor Modifications</u>

Options Overview

Depending on the geographic region, dwellings will have one of these four types of floor systems at the ground level:

- Concrete slab
- Crawlspace
- Basement
- Pilings

Since noise control measures are concerned with the external building envelope, floors between stories in a home are not addressed, except in the discussion of attics in Section 3.5.2.3.

There are three stages of floor modifications for sound insulation:

- Sealing or baffling any openings;
- Installing insulation between the floor joists;
- Attaching a barrier panel to the floor joists.

Concrete slabs require no treatment. Crawlspaces, basements, and pilings will be discussed in that order below.

Crawlspaces

Most parts of the country have some dwellings with wood plank and beam construction over a vented crawlspace. The simplest way to improve these systems is to install noise control louvers to the underfloor vents as shown in Figures 3–15 and 3–16. These provide a noticeable quieting in the rest of the house. For stronger treatment, it is possible to install thermal insulation between the joists but this option is not usually exercised for crawlspaces. Batts need to be fixed in place and protected from moisture. This requires labor and extra materials, making this approach less cost effective than installing acoustic louvers to the vents. In some cases, however, if the vents are of

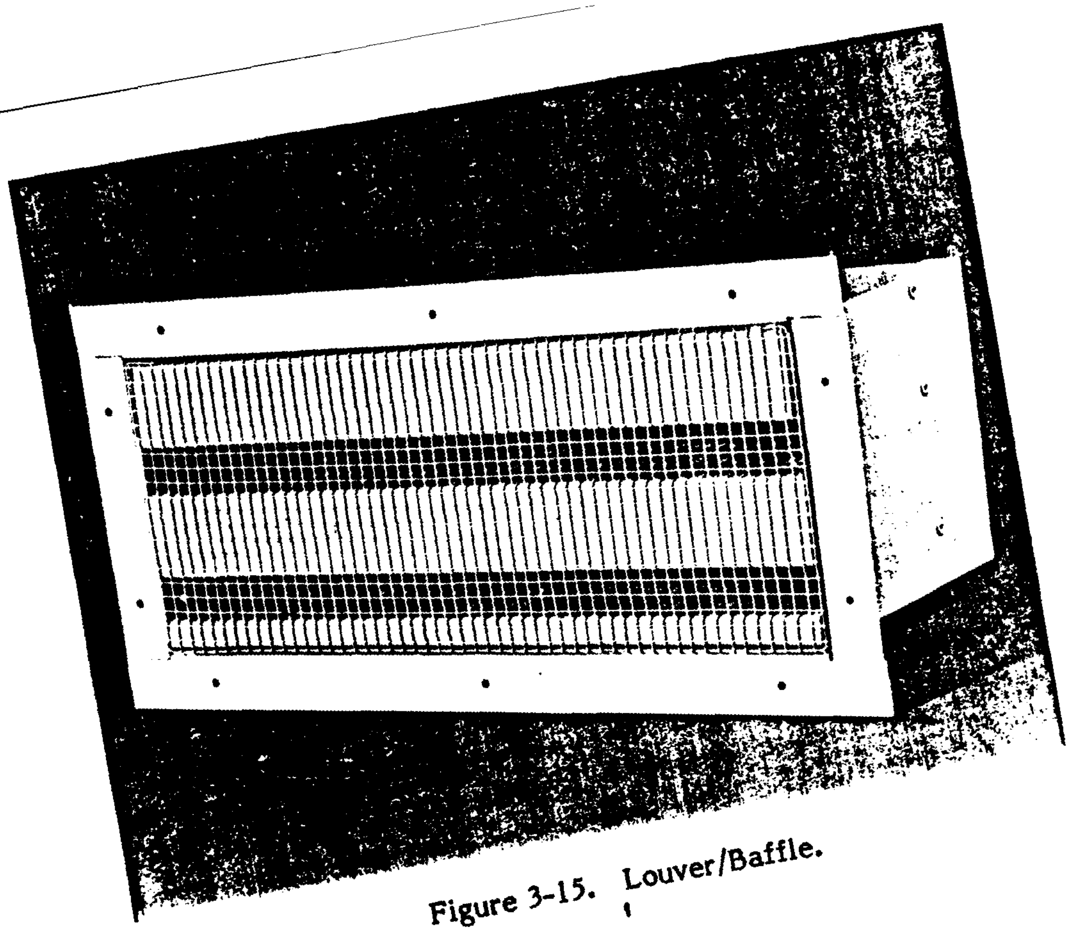


Figure 3-15. Louver/Baffle.

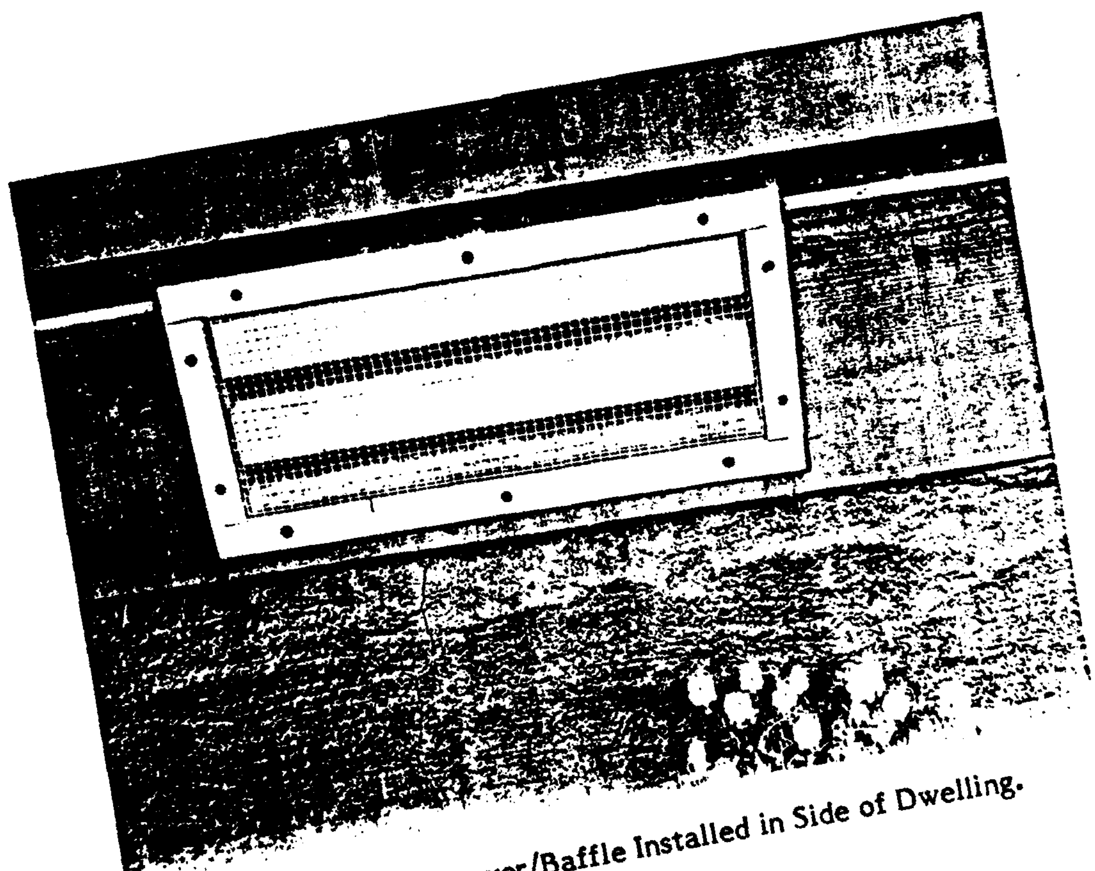


Figure 3-16. Louver/Baffle Installed in Side of Dwelling.

varying sizes or if pipes, cables, or other items obstruct access it may be necessary to modify the underside of the floor.

Basements

Basements can be modified with a combination of methods discussed in other sections of this report. The first phase of noise reduction should replace weatherstripping and seal up possible flanking paths around windows and doors. Storm windows and doors can be added for further protection. Thermal insulation can be installed between the joists to absorb sound reverberating in the basement. This option may be necessary if part of the basement consists of a garage with a garage-door facing the flight path. As a last resort, a gypsumboard or plywood barrier can be hung under the floor with insulation in the cavity, similar to the treatment discussed for interior ceilings in Section 3.5.2.3.

Pilings or Columns

In coastal and flood-prone areas, homes are frequently built on columns or pilings. These vary in height from less than a foot to as much as one whole story. In some cases the pilings raise the dwelling off a concrete pad which is then used for parking or storage. This can be a significant source of noise intrusion, depending on the construction of the floor – whether it is concrete slab or wood planking on beams. Most cases where the pilings support a concrete slab which forms the house floor will not need further sound insulation underneath. If the floor is constructed of wood it may be necessary to install thermal insulation between the beams and to attach a layer of exterior sheathing under the floor. If the house is not raised too high above grade level, it is also possible to enclose the under-house space and vent it, converting it to a crawlspace.

3.5.3 Building Components and Techniques for New Construction

Most of the methods discussed in Section 3.5.2 are directly applicable to new construction and the text and figures should be studied for guidance. To avoid costly remodeling work in new construction, the designer should evaluate the acoustic performance of standard construction materials and techniques before using them in a neighborhood exposed to DNL 65 dB or greater.

As a starting point, the developer should consider the suggested practices given in Table 3-14.

3.5.4 Miscellaneous Features

3.5.4.1 Ventilation Requirements in Dwellings

In order to maintain the noise reduction benefits of improving windows and doors and sealing leakage paths, it is important to keep these openings closed. While an acoustically well-insulated home can provide 30 dB of noise reduction, this figure drops to 15 dB if the windows and doors are kept open. However, since this eliminates a source of natural ventilation, any home insulation project must address the means for replenishing and circulating the air inside. This section and the two which follow discuss heating, ventilation, and air-conditioning (HVAC) systems for dwellings. These systems do not directly affect the sound insulation performance, but they enable residents to keep the windows and doors shut year-round and benefit from the sound insulation modifications. The extent of modifications required will depend on the existing HVAC system in the home and on applicable building codes.

These points will be discussed in greater detail in the next section on basic ventilation systems. Simple and reasonably priced systems are available to meet these general requirements for airflow and noise control. Most are readily installed and, beyond the recommendations of the next section, the specific details are best left to the General Contractor. Issues relating to bathroom, kitchen, and fireplace ventilation will be addressed specifically in Section 3.5.4.3.

Ventilation Specifications

Building ventilation serves to bring fresh air into the dwelling and clear the air of contaminants such as carbon monoxide, smoke, dust, formaldehyde, radon, cooking and heating by-products, and others. Toward this end the ventilation system should provide one to two changes of the air in any habitable room per hour. In kitchens and bathrooms this air exchange should be increased to five air changes per hour. Between 10 to 20 percent of this air volume should be supplied from fresh outside air. Specific values are set by local building authorities.

Table 3-14

Suggested Guidelines for Design of New Construction

1. Do not build homes where DNL is 75 dB or greater.
2. Orient homes on the lot so noise-sensitive areas, such as TV rooms and bedrooms, are shielded from the flight track.
3. Use more massive external cladding, such as brick or other masonry, in place of siding wherever practical.
4. Where siding is used, or the noise exposure is high, use sound-deadening board, multi-layer gypsumboard, or a furred-out interior wall construction as discussed in Section 3.5.2.4.
5. Use heavy roofing materials, preferably with an attic rather than single-joist construction. Use R-19 or better insulating batts in the attic and R-11 to R-15 insulating batts in the walls. Use open-beam ceilings with extreme caution.
6. Use acoustical windows of an appropriate STC rating, properly installed.
7. Avoid large picture windows and sliding glass doors on sides of the dwelling which face the flight track.
8. Use solid-core doors with storm doors or, preferably, specialty acoustical doors.
9. Give careful attention to weatherstripping and seals.
10. Eliminate unnecessary openings such as through-the-wall air conditioners, vents, chimneys, skylights, and whole-house attic fans. Baffle or shield those that are used.
11. Provide a forced-air HVAC system with fresh air replenishment as described in Section 3.5.3.2.

Most building codes state similar requirements: The Building Officials and Code Administrators International (BOCA) mechanical code specifies 10 cubic feet per minute per residential room, which for an average sized room is slightly less than one air change per hour. The American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAE), Standard No. 62, "Standards for Natural and Mechanical Ventilation," recommends 7 to 10 cubic feet per minute air replenishment per human occupant (the minimum allowable is 5 cfm). Using the ASHRAE "default" guide of five occupants in a 1,000-square-foot living area, and assuming one-fifth (20 percent) of the airflow is replenishment from fresh air, this agrees with a requirement of two air changes per hour. Two changes per hour and one-fifth fresh air is also the standard stated in the Uniform Building Code (UBC), Chapter 12, Requirements for Group R Occupancies, Section 1205, "Light, Ventilation and Sanitation," which is used throughout California.

Air Circulation

Whether the air needs to be heated, cooled, dehumidified, or simply circulated and replenished depends on the local climate and the season. Refreshing the air supply and moving it around is important for health and comfort no matter what the outside temperature. When residents do not want heating or cooling, the system should allow for circulation/ventilation alone. This setting must still provide fresh-air replenishment. The ventilation fan should provide at least two fan speeds, with the lower speed satisfying the minimum airflow requirements. This ensures that the system can meet peak circulation needs.

Noise and Vibration Control

It is important to limit the amount of noise the HVAC system generates and the noise it carries in from the outside. Taking the steps outlined below will help to minimize the noise from fans, airflow, equipment vibration and aircraft noise sources:

- Provide vibration isolation mounting for all equipment and locate it so that the structureborne sound and vibration are kept to a minimum.

- Use ducting materials appropriate to the location to minimize either the sound picked up or the sound transmitted through the system. Flexible ductwork should be used throughout except in attics and crawlspaces where heavier sheetmetal ducts will provide better sound insulation.

- The sound level in each room due to the system's operation at the lowest fan speed should not exceed 35 dB(C)* at a distance of 3 feet from the air supply or return diffusers.

- All open air paths between the outside and the inside of the dwelling should be eliminated. The noise reduction through the system from the exterior to the interior of each room should be at least 30 dB for noise in the 250 Hz octave band. This ensures that the ventilation system is not inadvertently permitting the passage of aircraft noise, which has a strong low-frequency component.

3.5.4.2 Basic Ventilation Systems

Depending on the geographic region, any of the following basic system types may be encountered:

Existing Mild Climate Systems:

1. No household ventilation system other than open windows and doors and vents/fans for the kitchen and bathroom.
2. Ducted air system without heating or cooling, or separate from the heating and/or cooling.

Existing Moderate to Cool Climate Systems:

3. Hot water or electric heating delivered through baseboard units.
4. Central forced hot air heating delivered by a fan system through attached ductwork.
5. Central forced hot air heating and cooling delivered by a fan system through attached ductwork.
6. Gravity heating hot air convection system without a fan.

Systems 1 and 2 may be supplemented by space heaters or wood, coal, or kerosene stoves. Systems 1 through 4 may be supplemented by window air conditioners or room dehumidifiers.

* C-weighting is a system similar to A-weighting except that the measured levels are not adjusted up or down in the frequency range from about 30 Hz to 8000 Hz. It is used rather than A-weighting which would give a reduced measurement of the low-frequency fan noise.

Recommended Ventilation Systems

This guide will focus on two types of systems: type 2 with optional cooling or dehumidifying and type 5 upgraded to provide supplemental fresh air. A brief discussion on how to modify the other system types so that they conform to one or the other of these is included. These two systems represent the most effective designs for the mild climate (system type 2 with options) and the moderate to cool climates (upgraded system type 5) which typify most of the country.

Recommended Mild Climate System

For mild climates the simplest acceptable system is a ducted air system consisting of a few standard, readily available components. Table 3-15 provides a summary description of this ventilation scheme, except the heating coils will be unnecessary and the cooling coils and condenser optional. The cooling and/or dehumidifying elements, if chosen, would use the same ductwork as the rest of the system. Proper attention should be given to noise control concerns, as outlined in Table 3-16.

Figure 3-17, which displays the entire HVAC system, shows how these basic functional elements fit together. The ducted ventilation system is simply a version of this without the heating coils, and possibly eliminating the cooling and condenser units as well. The heating and cooling units would be replaced in the figure with a straight section of flexible duct.

System type 1 will require the installation of the entire ventilation package from fan and ductwork to plenums, including auxiliary ductwork from the return air plenum to the exterior to supply 10 to 20 percent fresh air.

System type 2 will only require providing the make-up fresh air duct system since the fan and ductwork supplying the rooms is already in place.

Recommended Moderate to Cool Climate System

For moderate to cool climates where heating is required, the existing system should be upgraded to one capable of providing forced hot air heating, cooling, and supplemental fresh air ventilation delivered through ductwork. Again, Table 3-15 summarizes the basic system components and Figure 3-17 illustrates the system.

Of systems typical for moderate and cool climates, system type 3 requires the most changes to upgrade it to the forced-air HVAC configuration. Generally, this requires providing a fan, ductwork, furnace, cooling coils, and condensing unit. A heat pump can be provided in place of the fan, furnace, and cooling coils. Ductwork installed in the dwelling will deliver the conditioned air to the rooms. A supplemental duct is routed between the return-air plenum and the exterior to provide 10 to 20 percent make-up fresh air to the system. The original heating system can be wired with the new controls so that it operates as a backup. Many homeowners request this because they prefer the older radiant heating to the new forced-air systems.

System type 4 requires providing cooling coils to the existing furnace and fan system and a installing a condensing unit. Depending on the size or condition of the existing furnace, it may be necessary to replace the furnace to accommodate the new cooling coils. The make-up fresh air duct, as described above, must also be installed.

System type 5 only requires providing the make-up fresh air duct system since the system is complete with respect to providing conditioned air.

The gravity heating system, type 6, would require modifications to provide a fan, furnace, cooling coils, and condensing unit. The existing gravity furnace should be removed and the new equipment connected to the existing ductwork. The make-up fresh air duct and upgraded electric panel would also be required.

General Considerations

A number of considerations apply regardless of the specific system used: The controls should provide for running the fan by itself without the use of the heating or cooling elements. The fresh air duct should have a variable damper so the duct can be closed off if desired.

Whenever the contractor makes modifications to the ventilation system it is important to ensure that the electric service panel can supply the increased electricity demand of air-conditioning equipment, if installed. The existing electric service may need to be upgraded.

Open air paths between the exterior and the interior should be eliminated. Typical paths include unit air conditioners in windows or walls,

Table 3-15

Components of Ducted Air Heating, Cooling, and Ventilation System

1. Circulation fan capable of supplying the required air volume exchange through the ducting in each room.
2. For climates where heating is necessary, forced hot air heating, cooling, and ventilation capabilities through appropriate heating and cooling coils and condenser unit.
3. Fresh air inlet located on the shaded side of the dwelling provided that side is not exposed directly to the flight path. It should also be adjacent to a return air plenum to facilitate mixing the fresh air with the recirculated air.
4. Supply and return air diffusers in each room to circulate the air. The supply air diffusers should be adjustable to allow redirection or shut-off of the airflow. In systems without a furnace, the return plenum should be located near the ceiling to encourage recirculation of rising warm air. Furnaces have return-air plenums as part of the system.
5. Flexible ducting connecting the fan air supply vents and the return plenum to each room and to the exterior. Sheetmetal ducting should be used to provide superior sound insulation in attics and crawlspaces.
6. Control switch with on/off and at least two fan speeds, the lower of which provides the minimum required air circulation. The switch should permit air to be circulated without activating the heating or cooling elements. Existing radiant heat can be used as a "backup" system.

Table 3-16

Recommendations for Noise and Vibration Control in Residential HVAC Systems

1. Mount the motor/fan at grade level on factory-supplied vibration isolators to minimize vibration transmitted to the house.
2. If fans or other pieces of equipment are located in the attic, use mounting bases and vibration isolators to reduce structureborne noise and vibration transmission. Due to local building code restrictions it may not be possible in some areas to locate mechanical equipment for heating or cooling in the attic.
3. Install flexible duct connectors to limit vibration transmitted to the ductwork or the dwelling structure.
4. Use of standard sheetmetal ductwork in attics and crawlspaces. Ductwork is exposed to higher levels of aircraft noise in these spaces. Do not use flexible ductwork in attic spaces since it does not have as good sound-insulating properties as standard sheetmetal.
5. Supply grilles in the rooms should be of the opposed-blade type and be designed for low noise.
6. A duct sound trap (muffler) should be installed just inside the fresh-air inlet opening. The sound trap will reduce any aircraft noise that passes through this opening and will eliminate the possibility of aircraft noise being transmitted via the duct path.

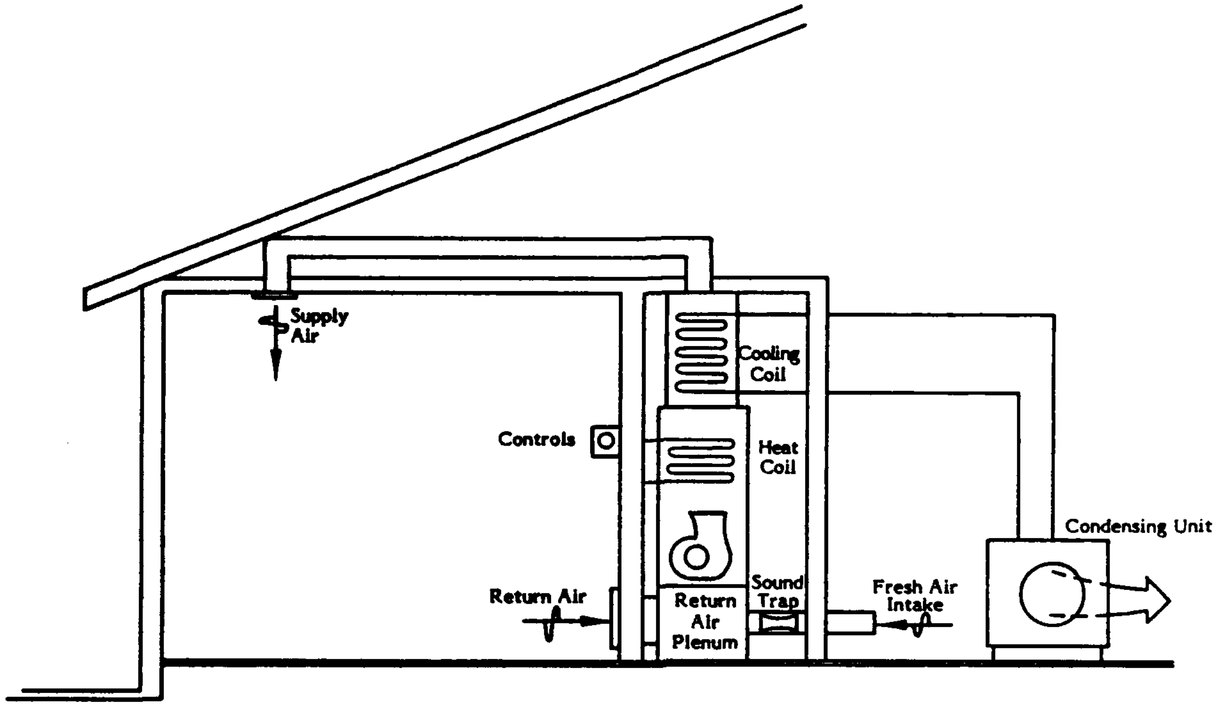


Figure 3-17. Modified System Functions.

whole-house exhaust fans, and wall-mounted exhaust fans. Wall-mounted fans can have a baffle box installed, as shown in Figure 3-18, to limit the transmission of aircraft noise to the dwelling interior. All other air conditioners, fans, and ventilators should be removed and the surfaces repaired to match the existing conditions.

Table 3-16 summarizes the measures recommended to reduce noise and vibration in the dwelling ventilation system.

3.5.4.3 Bathrooms, Kitchens, and Fireplaces

Kitchen and bathrooms ventilation should not be connected to the air circulation system that serves the rest of the house. Most kitchens and bathrooms already have fans installed for ventilation purposes. If there is none, or if it is inadequate to provide five air changes per hour, an appropriate ventilator should be installed as needed.

Bathrooms

Bathrooms are not normally modified since they are not considered noise-sensitive rooms. If necessary, however, bathroom ventilators can be "muffled" with the insertion of a section of noise control flexible tubing so that there is no direct, unobstructed path from the exterior to the interior. This is illustrated in Figure 3-19. For wall-mounted ventilators, a "cross-talk" silencer, shown in Figure 3-18, may be used instead.

Kitchens

Kitchen ventilation fans can be modified in the same manner as bathroom fans, except for range cover exhaust hood. The exhaust hood never gets modified because doing so encourages the accumulation of grease or soot films in the vent and creates a serious fire hazard. Also, fiberglass must never be used in the ventilation ducts due to the fire hazard.

Fireplaces

Frequently, homes with fireplaces will require some type of modification. This is especially true if the outside noise exposure is high, or the fireplace is in a room used for watching TV. The treatment package consists of two parts: First, glass doors are mounted at the front of the fireplace. Second, a standard chimney-top damper is installed. The glass doors by themselves provide a noticeable improvement and these two treatments, in combination, have proven to be very effective at reducing noise entering on this path.

3.5.5 Manufactured Homes

Popularity

Manufactured homes are quite common in most areas of the country. There are two primary reasons for their popularity. They generally have a lower purchase price than similar conventional homes (though they are not much less expensive per square foot once their size is taken into account) and they can be bought and built more quickly than conventional housing. Local zoning ordinances restrict them in many areas but, as their appearance and structure conforms more to that of conventional homes, restrictions may be loosened and they may become more prevalent.

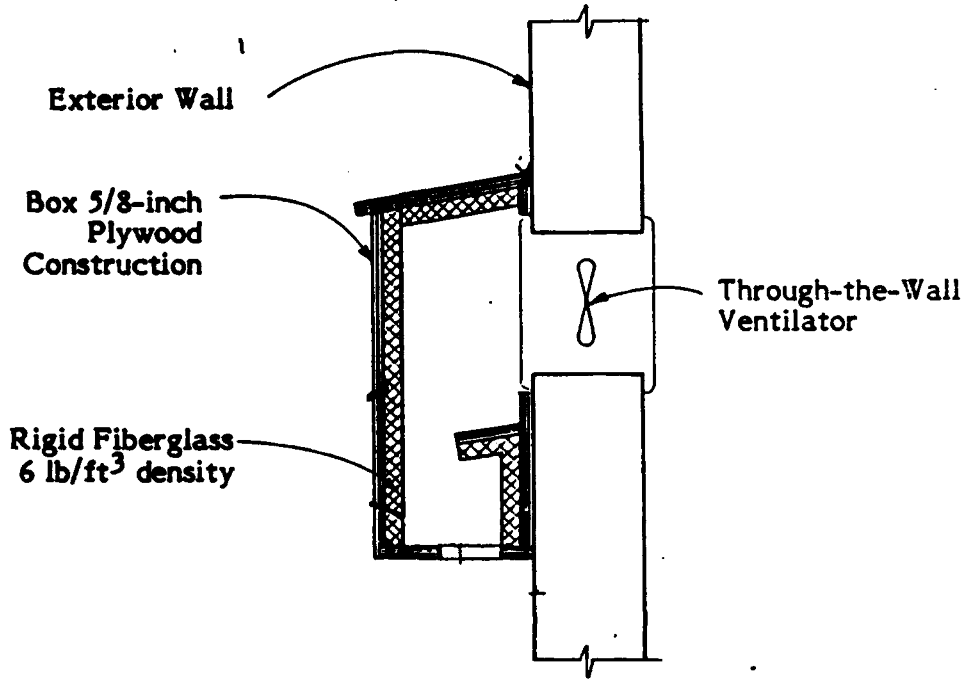
HUD Construction Standards

Since 1976 the manufactured housing industry has been closely regulated by the federal government. Factory-built homes must meet HUD standards for construction quality, energy efficiency, ventilation, and fire protection. These standards are expressed in HUD's "Mobile Home Construction and Safety Standards", published in 1975 and in force for models built since in 1976. Subsequent regulations and interpretations update this set of codes. The latest update was published in April 1988.

Comparison to Conventional Housing

Factory-built dwellings are available incorporating many of the features that buyers want in conventional homes. Wall constructions are similar to those found in site-built houses, including the exterior siding and interior finishes used. Manufacturers offer optional upgrades in thermal insulation, doors, and windows. Over the past several years the stereotyped picture of the metal-skin mobile home has been replaced by modular designs that are sometimes difficult to distinguish from what the industry calls "stick-built" dwellings.

Unfortunately, with respect to acoustical performance, there are still some significant differences, particularly in roof construction, air infiltration rates, and noise reduction of standard windows and doors. Recent improvements in



NOTE: Size Box as Required for Vent Opening.

Figure 3-18. Baffle Box for Through-Wall Ventilator.

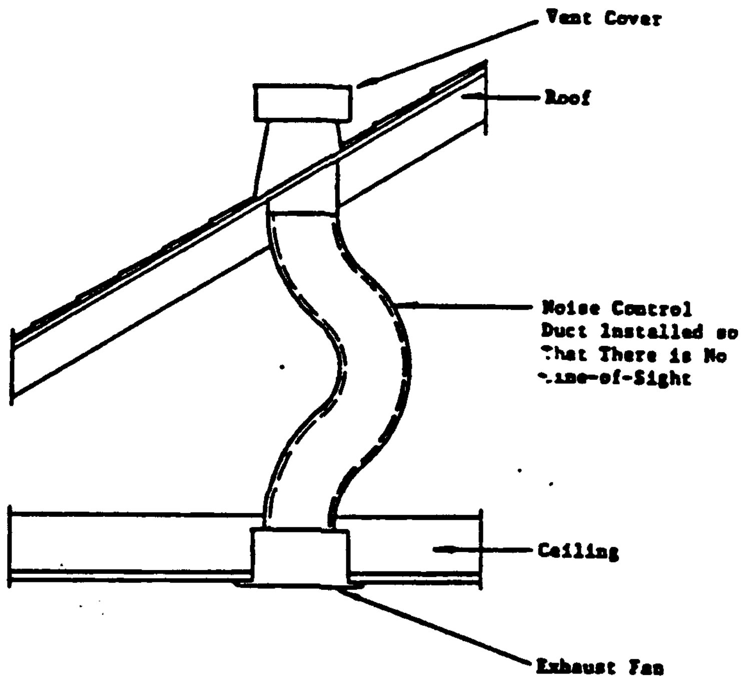


Figure 3-19. Bathroom/Kitchen Ventilator Modification.

construction materials and methods enhance the noise reduction somewhat but there are still many older homes in use with very poor sound insulation. The next section, Construction and Noise Reduction Properties, discusses typical factory-built construction elements and methods. The following section, Improving the Sound Insulation, describes the limited number of options available and their appropriate use. This information is provided primarily for residents and local officials. FAA guidelines generally do not provide for financial assistance to sound insulate manufactured homes because satisfactory results cannot be achieved at reasonable cost.

3.5.5.1 Existing Construction and Noise Reduction Properties

Variation in Construction

Since the introduction of federal standards for manufactured home construction there has been a trend toward more standardized materials and methods. Still, there are many older mobile homes in use and there are many different styles and customizing options available in newer units. Because of this diversity, it is difficult to detail any set of building elements that typifies factory-built homes. The sound-insulating performance can vary significantly depending on the age, model type, and general condition of the home. Manufactured homes tend to have certain features in common, however, which influence their noise reduction performance.

Roofs

From an acoustic point of view, one of the most significant features of factory-built housing is the consistent use of much lighter roofing than is normally found in other dwellings. Since the roof is fully exposed to aircraft noise, this presents serious problems. Many homeowners modify their roofs for thermal insulation, or to eliminate the annoying rattle associated with metal roofs. These measures, however, do not significantly improve the noise reduction. Figure 3-20 illustrates a typical factory-built roof construction.

As the figure shows, the roof pitch is lower than conventional roofs, leaving less space for insulating material and a smaller buffer zone for trapping and absorbing noise. The ceiling insulation rating varies depending on the age of the home and the options the owner chose when purchasing it. Prior to the HUD standards in 1976 there were widely varying state regulations in place. Homes built before 1976 normally used R-7 insulation. Since the 1976 standards, homes must have at least R-11 rated thermal insulation and R-19 is most common.

While many roofs are metal covered, models using asphalt or fiberglass shingles are available. One advantage of newer factory-built homes is the use of a large single piece of gypsumboard for the finish ceiling, eliminating joint leaks. However, a 1979 HUD study, PDR-636, "Thermal Envelope Systems Test Report", found significant air infiltration around the ceiling perimeter where it meets the walls. Part of the reason for seam infiltration is uneven settling of the home on its supports. This is especially true of double- and triple-wide models. The ceiling seams between the modular units separate if the home is not level.

Walls

The wall construction varies considerably depending on the age and model of the home. Figure 3-21 shows schematically two common assemblies. Early models employed a sheetmetal skin with attached structural members. The air cavity often had a layer of styrofoam insulation inside. A sheet of thin (5/32 inch) hardboard luan paneling was stapled on as the interior finish. Recent housing surveys found many older mobile homes of this type still in use, though they are slowly being replaced by more modern designs.

Newer models feature wood, vinyl, or aluminum siding mounted to 2x4-inch studs, as in conventional construction. Sometimes the siding is attached to the studs with a layer of thermal sheathing between. Most often, it is mounted directly, without an intermediate layer. Wall cavity insulation is usually R-7 batts or blown-in, though higher grades are available and more common in the north. In addition, many models in the north have 2x6-inch sidewall studs. The interior finish is likely to be gypsumboard.

In 1985 a HUD study of formaldehyde out-gassing from particleboard and decorative paneling prompted regulations governing allowable formaldehyde levels. These standards drove the industry away from the use of the thinner paneling toward gypsumboard. Actually, consumer demand had already encouraged a shift toward using drywall in the early 1980s. The formaldehyde problem, however, eliminated heavy reliance on particleboard, hardboard luan, and urea products. A 1988 study performed by the Manufactured

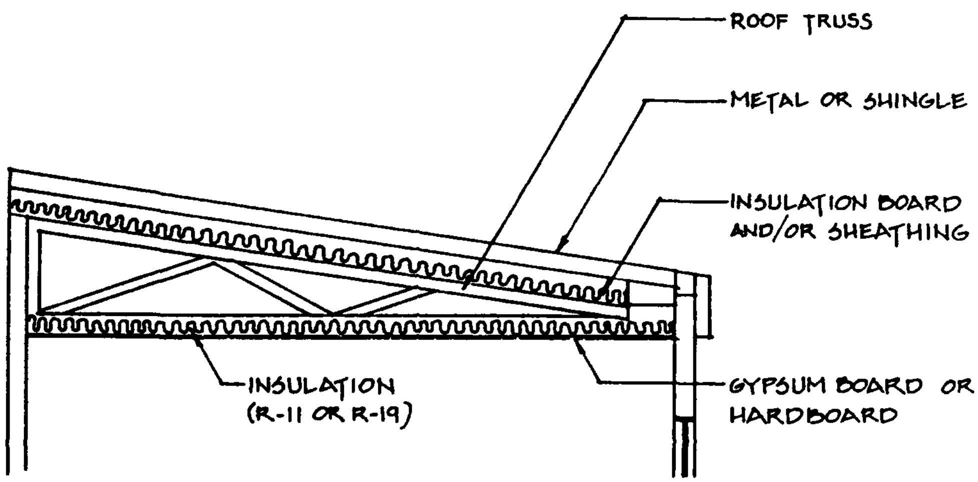
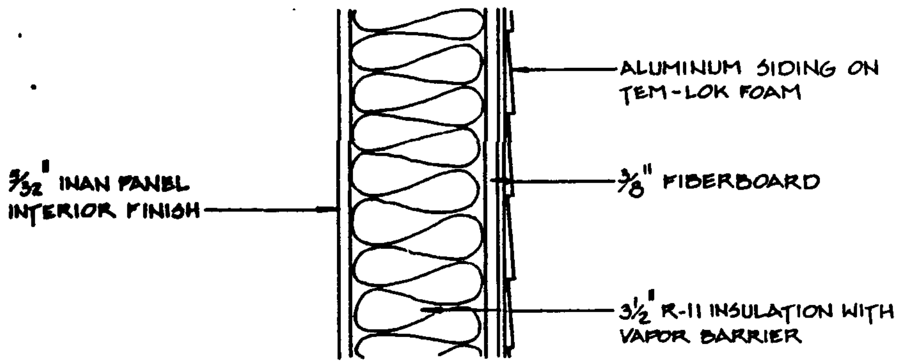
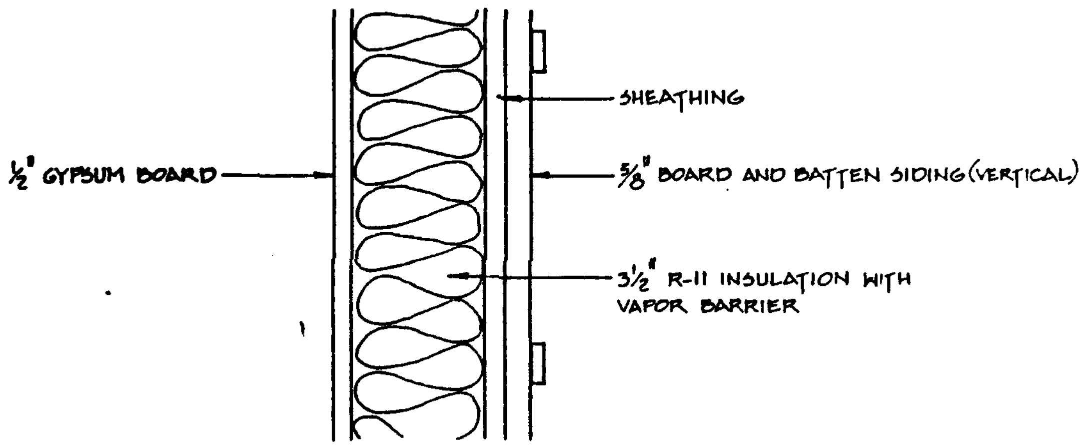


Figure 3-20. Roof Construction of a Manufactured Unit; One-Half of a Double-Wide Dwelling.



(a) Typical Pre-1985 Mobile Home.



(b) Typical Current Manufactured Home.

Figure 3-21. Typical Manufactured Home Wall Constructions.

Housing Institute showed that 95 to 98 percent of current factory-built homes use gypsumboard walls and ceilings. Gypsumboard is heavier and provides better acoustic insulation than earlier materials. It also has superior flame-retardant properties, provides added stability and is easier to decorate.

Some factory-built homes have vented air cavities in the wall construction. These vents at the bottom of the wall provide a ready path for noise transmission into the dwelling. Fortunately, this construction scheme does not seem very common. Another, more common, path for air and sound infiltration is the gap left open at the wall bottom where the corrugated siding does not seal completely with the deck. The 1979 HUD study on thermal envelope performance, mentioned above, found air infiltration to be a problem at most joining points and openings in the mobile home walls.

Floors

The design of manufactured dwelling floors has been governed by loading requirements peculiar to a house which may travel 800 miles before resting on its foundation. There are actually two types of manufactured homes in use; true modular units which are transported on a truck and lifted into place by a crane, and mobile modular units which are built with removable hitch, axles, and wheels. Most older models are of this second kind.

Two basic under-floor structural support systems are available in manufactured homes. One uses a wood deck supported by a steel underframe. The alternative, which is gaining popularity, is a unified floor system based on a strong wood beam truss. Both will typically use a plywood floor over insulating material, covered with carpeting or multi-purpose tile. Hardboard sheathing normally seals the underside. Unfortunately, air-conditioning, plumbing, and other improvements can only be installed through the floor and this often degrades the sub-floor noise attenuation by leaving openings there.

Windows and Doors

The windows in manufactured homes are almost always insufficient for good sound attenuation. They are normally single-pane assemblies, though double and triple glazed systems are available. As Section 3.5.2.1 explained, multiple glazing in thermal windows is rarely effective for cutting down noise since the panes are too close together. Poor quality control of weatherstripping and caulking will aggravate the sound transmission problems. Storm windows, which come as standard equipment on homes in cold winter climate areas, will improve the noise reduction somewhat but are mounted too close to provide optimum relief.

Doors on manufactured homes are typically comprised of either a steel exterior with a foam insulation core or sheetmetal with a corrugated honeycomb cardboard core. The steel doors with the foam core seem to provide better sound attenuation and, if not standard, are available as factory-installed options or as home improvements.

Sliding glass doors are constructed similarly to those found in conventional homes, though they are often smaller. Most use aluminum frames, but wood is also popular. They have the same problems as sliding glass doors in site-built homes, generally being weaker sound insulators than the surrounding wall.

Homes built prior to 1985 may have significant problems with air leakage around doors and windows. Since that date, standards issued by the American Architectural Manufacturers Association (AAMA) have specified compliance with leakage limits based on ASTM testing methods. The applicable standards are: for doors, AAMA 1702.2-1985; for windows and sliding glass doors, 1701.2-1985; and for egress windows, 1704-1985. Recent Manufactured Housing Institute tests indicate significant improvements in leakage problems with conformance to these standards.

Assembly Methods and Quality Control

In the factory, the walls, floor, and roof are built as units and joined with metal straps and fasteners to form the house. Ideally, this method should provide a good seal. And one of the selling points of these homes is the assurance that closer supervision in a factory environment gives better quality control. Unfortunately, this is not always the case. The 1979 HUD thermal envelope tests on two standard, new, mobile homes documented significant air infiltration at the wall edges, door edges, vents, windows, and under the floor. They found improperly installed weatherstripping. In general, the testing team concluded that the lack of appropriate quality control during construction significantly increased the air infiltration of the dwelling.

Since these tests were performed there have been revisions of some standards, leakage limits have been imposed, and consumers have been demanding higher quality. Manufacturers have responded to these pressures and corrected some of the problems cited. Homes built prior to the mid-1980s, however, still suffer from these weaknesses.

Ventilation

One advantage of factory-built houses is the fact that most use ducted ventilation systems. A ducted air system is a prerequisite for proper climate control and air circulation since the windows and doors must be kept closed for sound insulation. In general, HUD requires the same ventilation and light specifications for manufactured homes as other codes require for conventional housing. These requirements include:

- One air change per half hour (or two per hour);
- A 20 percent, or one-fifth, mix of fresh air;
- Glazed openings for natural light in each room with an area equal to 8 percent of the floor area;
- Kitchens may have artificial light.

Manufactured homes vary as much as conventional homes in the type of ventilation systems currently in use. The fresh-air make-up is more common in forced-air systems or as an intake to the furnace when that is in operation. A Commerce Department study of typical constructions found that 50 percent of all manufactured homes nationally have air-conditioning. The percentage in any specific geographical area ranges from 80 percent in the south to about 40 percent in the north. Optional use of the fan without heating or cooling, an important facility when the windows and doors must be closed year-round, is not normally provided.

Measured Noise Reduction Values

Recent exterior and interior noise measurements of a typical mobile home and modular factory-built home near Seattle indicate that the "as is" noise reduction levels are slightly lower the average of homes tested in that Seattle study. Table 3-17 shows the noise reduction values for the major habitable rooms of these homes along with the project average.

3.5.5.2 <u>Improving the Sound Insulation</u>

Due to the lighter construction of many manufactured homes, the sound insulation options are usually limited to window and door replacement and some minimal wall modifications. When a homeowner buys a manufactured home they are provided with a consumer handbook. This handbook gives valuable information regarding the maintenance and repair of their home. It usually describes window attachment schemes, siding type and attachment, ventilation duct networks, and other topics useful in sound insulation. Copies are almost always available from the manufacturer.

Roofs

The walls and ceiling/roof assembly are comparatively weak, structurally, and so are not as readily altered as in conventional dwellings. During a sound insulation project near Seattle, roof modifications were recommended for a mobile home and a modular prefabricated home but could not be installed. In both cases, the walls would not support the increased weight of the improved roof. As a result, the dwellings could not be brought to a condition which satisfied the noise reduction requirements.

If there is ready access to the attic space, the attic insulation can be improved. The primary interest here is to provide material to absorb sound reverberating in the space, not to block it. In most cases R-19 is sufficient, though some benefit is gained by upgrading as far as R-30. The peak height is generally no greater than 35 inches, which, along with weight limits, prevents more effective treatments. Most double- and triple-wide homes allow access to the attic space, as do homes with active attic ventilation systems. Attics are not usually accessible in single-wide homes.

If there is a skylight in place, it should be removed and the roof repaired to match the existing condition.

Walls

Greater sound attenuation through the walls is achieved by adding mass to either the outside or the inside. On many mobile homes, particularly those with aluminum or wood siding, the exterior panels are removable for maintenance and repair. This makes it very easy to take down the panels, mount a layer of sheathing or sound-deadening

Table 3-17

Noise Reduction Improvements in Major Habitable Rooms

Room Category	Mobile Home[1]			Pre-Fabricated Home[2]			Study Average[3]		
	Before	After	Improv't	Before	After	Improv't	Before	After	Improv't
Living Room	26.9	29.5	2.6	28.9	28.1	-0.8	27.7	32.3	4.6
Kitchen	27.2	32.5	5.3	26.2	26.3	0.1	27.3	32.9	5.6
Bedroom 1	34.0	35.2	1.2	27.9	31.6	3.7	30.2	34.5	4.3
Bedroom 2	27.3	29.1	1.8	32.1	32.3	0.2	--	--	--

1 Mobile Home modifications consisted of installing STC 45 dB windows on all exposed facades, STC 35 main door, and secondary sliding glass door. Gypsumboard was added to the unshielded living room and bedroom #1 walls.

2 Pre-Fabricated Home modifications included adding gypsumboard to walls in living room and bedroom #1, installing STC 35 windows and STC 40 door in kitchen, adding STC 35 or secondary STC 30 windows in other rooms.

3 Modification in study included those discussed above plus other wall and roof improvements.

board, and then replace the siding. This is probably the preferred treatment in the majority of cases since it avoids inconveniencing the homeowner and taking away any of the interior floor space.

Where this is infeasible – for homes with vinyl siding which is not easily removed, for example – similar results can be attained by treating the dwelling interior. This is accomplished by removing the interior finish paneling, attaching an extra layer of gypsumboard or sound-deadening board to the studs, and reattaching the interior finish material. In either case, the walls should be examined to ensure they will support the weight of the additional material.

Windows and Doors

Acoustic windows and doors have been installed successfully in manufactured homes. Because the walls and roof are so light, it is usually necessary to specify the highest possible STC-rated products in order to appreciably reduce the interior noise level. In most cases the windows can be replaced from the outside. Secondary windows, mounted at least 2 inches away from the primary windows, have also been used with good results. The acoustic performance of sliding glass doors can be improved by building a secondary sliding glass door, mounted on 2x4 studs, at least 2 inches outside the primary door. Storm windows are frequently used on factory-built homes as well. They should be installed with caution on emergency egress windows since they make escape during a fire more difficult.

Air Infiltration

There are a number of steps to be taken to correct air infiltration problems. A close inspection of the external envelope, including the underside, should reveal any gaps or openings to be sealed. This is often a problem around plumbing and appliance access sites and around improperly installed vents. The vents themselves can be baffled using the techniques described in Section 3.5.4.

Older homes may need considerable attention to gaps and leaks around windows, doors, and seams. Newer models, subject to the AAMA leakage standards, are less likely to have problems here. Weatherstripping should be repaired or replaced, as needed. Multiple-module homes should be checked for separation at the seams resulting from uneven settling of the units. The home should be leveled if necessary and the seams repaired and sealed.

Ventilation

The ideal ventilation system, as described in Section 3.5.4, provides air replenishment and circulation, with heating or cooling as needed, through a system of ducts. The measures required to bring the existing system into conformance with this will depend on the type of system in place.

Most manufactured homes feature environmental systems supplied by a few large companies. These companies usually offer packages to upgrade to their systems which satisfy almost all these requirements. The only feature which is not always available is the option to run the fan with replenished air when the heating and air-conditioning are not operating. Refer to Section 3.5.4 for a more complete treatment of ventilation.

Noise Reduction Improvements

If all these measures are used together, a noise reduction of from 1 to 5 dB can be expected. This is considerably lower than the improvements attained when roof modifications and more effective wall modifications are possible.

Table 3-18 presents a summary of modifications for improving the noise reduction of manufactured homes.

Table 3-18

Summary of Methods for Improving Noise Reduction in Manufactured Homes

<u>Roofs:</u>

1. Upgrade attic insulation to R-19, or better, where feasible.
2. Remove skylight and repair roof to existing condition.

<u>Walls:</u>

3. Add mass under exterior siding, or under interior decorative finish surface, by mounting sheathing, gypsumboard, or sound-deadening board.

<u>Windows and Doors:</u>

4. Mount secondary windows and sliding glass doors at least 2 inches away from existing elements on the dwelling exterior.
5. Replace existing windows and doors with highest STC rated products available.

<u>Air Infiltration Paths:</u>

6. Seal gaps and openings in external envelope.
7. Baffle vents.
8. Repair or replace weatherstripping.
9. Check and repair seals between modular units in double and triple-wide homes. Re-level home if necessary to prevent recurring problem.

<u>Ventilation:</u>

10. Upgrade existing system, as necessary, to provide air replenishment, circulation, heating and/or cooling to enable homeowner to keep windows and doors closed year-round.

3.6 Cost Estimation

This section discusses the process of choosing between various noise reduction options. It includes sample improvement packages and costs per square foot for insulating 26 dwelling types. In addition to the costs given for the modifications packages, cost multipliers are given for different regions of the country, and for new versus remodeled construction. A detailed example shows how to use the modifications and cost factors to develop rough cost estimates for home sound insulation construction.

3.6.1 Estimating Insulation Required

Design Criteria

In order to meet the noise reduction goals, a package of modifications is designed for each eligible house. The goals are defined using predicted DNL noise exposure and the recommended noise reduction for that exposure zone. An SEL criteria may also be used to supplement the DNL guided NLR. There are two ways to determine the existing sound insulation condition of the house. One is by taking field measurements in the house, as described in Section 3.3. The other is by calculating the noise reduction for each room from the building component EWR or STC ratings. A computerized cost optimization program with a data base of EWR or STC ratings for typical construction elements and methods is a useful tool for such calculations. Which modifications will comprise the design package, of all the possible options, depends on which combination best meets certain requirements. The design must be:

- Capable of providing the necessary NLR improvement;
- Practical, installable in the particular house;
- Cost effective;
- Acoustically balanced;
- Aesthetically acceptable to the homeowner.

Example of Balancing the Design Criteria

These aims may conflict at times and must be balanced during the design phase of the project. To illustrate this process, consider the house belonging to a resident of Oak Harbor in Washington State. Her single-story house is very typical of homes across the country and is described by the floor plan in Figure 3-22. Assume that the back of this aluminum siding house is shielded from the flight track. It features a vented attic and sits on a crawlspace. The windows have 1/8-inch-thick single panes of glass and use aluminum frames. Her front door is the standard wooden hollow-core type.

The resident lives within the 65 to 70 dB DNL contour zone so, using Table 1-1, the noise reduction in all habitable rooms must be improved to 25 dB. Assume that field measurements show that the existing NLR in the living room is 18 dB. The living room faces the flight track and is not shielded in any way from the aircraft noise. Subtracting the existing NLR (18 dB) from the required NLR (25 dB) indicates that the sound insulation performance must be improved by 7 dB.

Example calculation:

Exterior Noise Level	= 70 dB
Required Noise Reduction	= 25 dB
Measured Existing Noise Reduction	= 18 dB
Required Improvement	= 7 dB

Each room in the home will be examined in this way to determine the necessary improvement in NLR. A design will be developed to modify the dwelling and install sound-insulating materials to meet the NLR goal. This can be achieved in a variety of ways, and the acoustic consultant preparing the design will consider all the requirements stated above.

Improving the windows and doors first usually nets the best results for the least cost. But optimizing the cost must be balanced against other considerations. Suppose the most cost-effective solution for the living room is to replace the front window and door with specialized acoustic ones and to mount a secondary window outside the window on the other side of the room. The homeowner will probably reject this configuration because she wants all the windows in her living room to look the same. Most design packages take the aesthetic acceptability into account and aim for a uniform appearance of all the windows in a room. This may also be extended to ensure that all windows on a given side of the house look alike.

Suppose that the designer recommends acoustic baffles for the attic vents. This is a useful modification in many homes. Unfortunately, most baffles are made in a rectangular shape and the attic may have triangular vents. If so, the selected

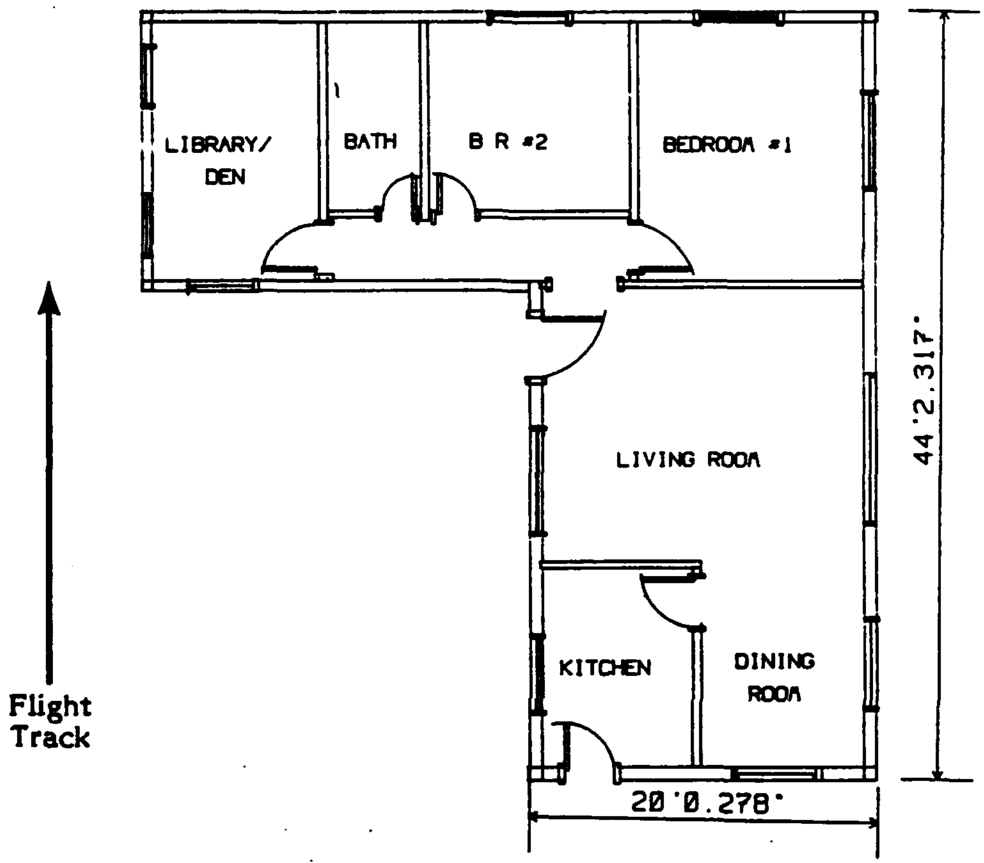


Figure 3-22. Sample Single-Story Dwelling.

option cannot be installed without modifying the wall to accommodate the different shape. It may be more practical to add insulating batts to the attic instead. Another option would be installing the baffles to the underfloor crawlspace vents which are already rectangular.

For a final example, if the resident lives in a higher noise zone she may need more sound insulation in her kitchen than even the very best acoustic windows and doors can provide. In any other room of her house the acoustic consultant could choose to add a layer of sound-deadening board and gypsum wallboard to the interior finish wall. But, because the kitchen walls have cabinets and tile on them, this normally effective option cannot be exercised. Here, the designer may have to improve the windows and the door, then go a step further and modify the ceiling to achieve the noise reduction goal.

This illustration demonstrates the complexity of deciding how to sound insulate a home and indicates some of the factors involved. Two houses may be very much alike and yet each will have unique features which require special treatment. While it is useful to discuss, in general terms, typical dwelling categories and classes of modifications, the actual site-specific design requires the services of an acoustics consultant or an acoustics-knowledgeable architect.

Modifying Categories of Dwellings

For rough costing purposes, however, it is valid to determine common dwelling categories and the types of modifications that can be expected, in general, to satisfy the noise reduction goals. Toward this end, 26 home types have been selected as representative of many houses across the country. Table 3-19 gives this list of homes. The choice ranges from siding to brick, stucco, concrete, and manufactured housing. Most of the homes on the list are single-story dwellings but two double-story houses and three multi-level townhomes have been included. The features identified for each home are those that have the greatest influence on noise reduction performance. The construction details are the same as those noted on the Housing Inventory Worksheet, Figure 3-2. For these purposes, all types of siding, including aluminum, wood, and vinyl, are treated the same.

A computerized sound insulation cost-optimization program has been used to examine each case for all four noise zones. Each house is treated room by room and a set of modifications is developed to meet the NLR goal. Other considerations entered into the design as well. For example, if one room needed attic insulation to improve the insulation performance, then all rooms get attic insulation. It is not practical to selectively insulate parts of the attic. The overall design of the other rooms is then rebalanced for the lowest cost required to meet the NLR target. A minimum NLR improvement of 5 dB was enforced to ensure that the homeowner would be able to perceive the NLR increase.

Modification Tables and Results

Table 3-20 defines the modification codes used in the computerized cost estimates. Then, Tables 3-21 through 3-46 outline a package of reasonable modifications which would satisfy the interior noise goals for DNL exposures of 65 dB, 70 dB, 75 dB, and 80 dB. Each table takes one of the 26 house types and lists the modifications suggested in each room to achieve the noise reduction goal.

The first column tells which room is being modified. Not all rooms need insulation improvements. In order for the modifications to be effective, all of the treatments listed for all rooms must be carried out. In the "Building Element" column appears "NR BEFORE", followed by individual building elements and "NR AFTER". "NR BEFORE" and "NR AFTER" give the computer predicted noise reductions of the room before and after the modifications are implemented. These values are based on EWR ratings for the building elements used.

The building elements listed are on the exterior wall only, plus the ceiling or roof and floor. Modifications to interior walls and doors do not improve the aircraft noise protection. Where there is more than one exterior wall or window, these will be numbered: Wall 1, Wall 2, Window 1, and Window 2, etc. To the right of the element name is the specific modification to be applied to it. These modifications are chosen depending on the noise exposure zone and the noise reduction goals given in Tables 1-1 and 1-2. The modifications become more extensive, and more costly, as the outside noise exposure increases.

If a block is empty, as many are for the 60-65 dB zone, then no modifications were required. The modification packages listed here are chosen from numerous optional combinations of materials and methods. Other choices might work as well. The final customized design should

Table 3-19

Table of Housing Configurations Used in EWR Cost Optimization Program

Ident.	Ext. Wall	Roof	Window	Foundation	Door
One-story Houses:					
A	Stucco	VA	AL; 1/8 oper.	Crawl	SC
B	"	SJL	1/8 dual pane	Slab	SC
C	Brick	VA	AL; 1/8 oper.	Slab	SC
D	"	VA	1/8 dual pane	Basement	SC
E	"	VA	1/8 dual pane	Slab	SC
F	"	SJL	1/8 dual pane	Crawl	SC
G	"	SJH	1/8 dual pane	Crawl	SC
H	"	VA	1/8 oper.	Crawl	SC
I	Siding	VA	1/8 dual pane	Basement	SC
J	"	VA	1/8 oper.	Crawl	SC
K	"	VA	1/8 oper.	Slab	SGD
L	"	ECL	Jalousie	Slab	SGD
M	"	VA	1/8 oper.	Slab	SC
N	"	SJL	1/8 dual pane	Slab	SC
O	"	SJL	1/8 oper. w/st.	Basement	SC
P	"	ECL	1/8 dual pane	Crawl	SC
Q	"	SJL	1/8 oper.	Slab	SGD
R	Block	VA	AL; 1/8 oper.	Slab	SC
S	Concrete	VA	1/8 dual pane	Crawl	SC
T	"	SJL	1/8 dual pane	Crawl	SC
Manufactured Home:					
U	Siding	VA	1/8 oper.	Crawl	HC
Two-story Townhouses:					
V	Siding	VA	1/8 dual pane	Basement	SGD
W	Brick	VA	"	"	SGD
End Unit Townhouse:					
X	Siding	VA	1/8 dual pane	Basement	SGD
Two-story Detached Dwelling:					
Y	Siding	VA	1/8 dual pane	Basement	SC
Z	Brick	VA	"	"	SC

Notes:
- Where there is a sliding glass door (SGD), the other exterior door is solid core (SC).
- One side of all dwellings is "shielded", usually the back side.

VA = Vented Attic
SJL = Single Joist, Light
ECL = Exposed Ceiling, Light

SC = Solid Core Door
HC = Hollow Core Door
SGD = Sliding Glass Door

Table 3-20

Housing Modification Description Codes

Door Modifications	Description
SC+SEald	Solid Core + Vinyl Bulb Seal
SC+WSTRP	Solid Core + Weatherstrip
SC+SE+ST	Solic Core + Vinyl Bulb Seal + Storm Door
SG+WSTRP	Sliding Glass + Weatherstrip
RSTC35	Door having an STC Rating of 35
RSTC40	Door having an STC Rating of 40
RSTC45	Door having an STC Rating of 45
HC+STORM	Hard Core + Storm Door
HC+WS+ST	Hard Core + Weatherstrip + Storm Door
Window Modifications	**Description**
8p+STORM	1/8-inch Pane + Storm Window
8p+STC25	1/8-inch pane + Window having an STC Rating of 25
RSTC35	Window having an STC Rating of 35
RSTC40	Window having an STC Rating of 40
RSTC45	Window having an STC Rating of 45
Wall Modifications	**Description**
STUC+GYP	Stucco + 5/8-inch Gypsumboard
STUC+2GY	Stucco + 2 Layers Gypsumboard
STUC+MG	Stucco + Metal Stud + Gypsumboard
STUC+MGA	Stucco + Metal Stud + Gypsumboard + Absorption
WDGY+GYP	Wood/Gyp + 5/8-inch Gypsumboard
WDGY+2GY	Wood/Gyp + 2 Layers Gypsumboard
WDGY+RGA	Wood/Gyp + Resilient Chan. + Gypsumboard + Absorption
WDGY+MG	Wood/Gyp + Metal Stud + Gypsumboard
WDGY+MGA	Wood/Gyp + Metal Stud + Gypsumboard + Absorption
HBLK+GYP	Hollow Block + Gypsumboard
HBLK+2GY	Hollow Block + 2 Layers Gypsumboard
HBLK+RGA	Hollow Block + Resilient Chan. + Gypsumboard + Absorption
HBLK+MGA	Hollow Block + Metal Stud + Gypsumboard + Absorption
BRIK+GYP	4-inch Face Brick + Gypsumboard
BRIK+2GY	4-inch Face Brick + 2 Layers Gypsumboard
BRIK+MG	4-inch Face Brick + Metal Stud + Gypsumboard
BRIK+MGA	4-inch Face Brick + Metal Stud + Gypsumboard + Absorption
Roof Modifications	**Description**
VP+Absrp	Vented Pitched + Absorption
VP+Ab+GY	Vented Pitched + Absorption + Gypsumboard
SJL+GYP	Single Joist (Light) + Gypsumboard
SJL+A+RG	Single Joist (Light) + Resilient Chan. + Gypsumboard
ELt+GYP	Exposed Ceiling (Light Joist) + Gypsumboard
EL+Ab+GY	Exposed Ceiling (Light Joist) + Absorption + Gypsumboard
EL+Spc B	******** Needs Clarification ********
Floor Modifications	**Description**
FB+A+STd	Floorboard + Absorption + Storm Door (Basement)

Table 3-21
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type A

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *			RSTC35	RSTC45
	Wall 1				STUC+MGA
	Wall 2 *				STUC+MG
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.8	24.9	30.4	34.9
Dining Room	NR BEFORE	21.0	21.0	21.0	21.0
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC45	RSTC45
	Wall 1 *				STUC+2GY
	Wall 2				STUC+MGA
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	21.0	25.4	30.0	34.8
Kitchen	NR BEFORE	18.7	18.7	18.7	18.7
	Door 1	SC+SEald	SC+SEald	RSTC40	RSTC40
	Window 1	RSTC35	RSTC40	RSTC45	RSTC45
	Wall 1				
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	24.2	24.7	28.7	29.7
Bedroom #1	NR BEFORE	23.2	23.2	23.2	23.2
	Window 1 *		RSTC35	RSTC35	RSTC35
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *				STUC+GYp
	Wall 2				STUC+MGA
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	23.2	30.1	30.4	34.1
Bedroom #2	NR BEFORE	23.0	23.0	23.0	23.0
	Window 1		RSTC35	RSTC40	RSTC45
	Wall 1				STUC+GYp
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	23.0	30.2	31.0	34.0
Library/Den	NR BEFORE	19.5	19.5	19.5	19.5
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1			STUC+GYp	STUC+GYp
	Roof 1		VP+Absrp		VP+Absrp
	Floor 1				
	NR AFTER	19.5	26.7	30.5	31.5
Cost Per Dwelling Sq. Ft.	C/D. Sq.Ft.	$0.34	$6.40	$10.18	$15.65

* 5 dB shielding assumed.

Table 3-22
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type B

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.0	21.0	21.0	21.0
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC35	RSTC35	RSTC45
	Window 2 *		RSTC35	RSTC35	RSTC45
	Wall 1			STUC+GYP	STUC+RGA
	Wall 2 *				STUC+RGA
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.0	25.9	31.8	35.8
Dining Room	NR BEFORE	23.0	23.0	23.0	23.0
	Window 1 *		RSTC40	RSTC35	RSTC45
	Window 2		RSTC40	RSTC35	RSTC40
	Wall 1 *		STUC+GYp		STUC+2GY
	Wall 2				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.0	28.4	30.8	35.0
Kitchen	NR BEFORE	19.4	19.4	19.4	19.4
	Door 1		SC+SE+ST	RSTC40	RSTC40
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1				
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.4	24.8	30.0	30.0
Bedroom #1	NR BEFORE	24.6	24.6	24.6	24.6
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC35	RSTC35	RSTC40
	Wall 1 *				STUC+RGA
	Wall 2				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.6	28.1	31.7	35.3
Bedroom #2	NR BEFORE	24.5	24.5	24.5	24.5
	Window 1		RSTC35	RSTC35	RSTC40
	Wall 1				STUC+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.5	28.3	31.9	35.4
Library/Den	NR BEFORE	21.5	21.5	21.5	21.5
	Window 1		RSTC35	RSTC35	RSTC45
	Wall 1			STUC+GYp	STUC+RGA
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.5	26.4	30.1	35.0
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$7.29	$11.33	$17.46

* 5 dB shielding assumed.

Table 3-23
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type C

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		RSTC35	RSTC35	RSTC45
	Window 2 *			RSTC35	RSTC40
	Wall 1				BRIK+GYP
	Wall 2 *				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.0	30.3	35.3
Dining Room	NR BEFORE	21.3	21.3	21.3	21.3
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				
	Wall 2				BRIK+2GYP
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.3	25.9	30.7	36.1
Kitchen	NR BEFORE	19.0	19.0	19.0	19.0
	Door 1	SC+SE+ST	SC+SEald	RSTC35	RSTC40
	Window 1	8P+STorm	RSTC35	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.7	25.1	32.2	35.1
Bedroom #1	NR BEFORE	23.6	23.6	23.6	23.6
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC35	RSTC35	RSTC40
	Wall 1 *				
	Wall 2				BRIK+MGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.6	31.6	32.5	35.8
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.3	27.8	32.4	35.6
Library/ Den	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1		8P+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	24.6	29.4	35.9
Cost Per Dwelling Sq.Ft.	C/D. Sq. Ft.	$0.22	$4.45	$8.33	$12.11

* 5 dB shielding assumed.

Table 3-24
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type D

Room	Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.5	21.5	21.5	21.5
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC40
	Wall 1		BRIK+GYp		BRIK+MGA
	Wall 2 *				BRIK+RGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.5	26.9	32.0	34.6
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC40	RSTC45
	Window 2			RSTC40	RSTC45
	Wall 1 *				
	Wall 2				BRIK+MGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	33.8	36.1
Kitchen	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.6	31.9	34.4
Bedroom #1	NR BEFORE	26.2	26.2	26.2	26.2
	Window 1 *			8G+STC25	RSTC40
	Window 2			8G+STC25	RSTC45
	Wall 1 *				
	Wall 2				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	26.2	26.2	30.7	35.8
Bedroom #2	NR BEFORE	26.0	26.0	26.0	26.0
	Window 1			8G+STC25	RSTC40
	Wall 1				BRIK+MG
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	26.0	26.0	30.5	35.0
Library/Den	NR BEFORE	22.7	22.7	22.7	22.7
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	22.7	27.2	32.8	35.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$3.23	$8.97	$12.96

* 5 dB shielding assumed.

Table 3-25
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type E

Room	Element	Modifications by Noise Zone 60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.6	21.6	21.6	21.6
	Door 1		SC+SE+ST	RSTC35	RSTC35
	Window 1		8G+STC25	RSTC35	RSTC35
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYP		BRIK+2GYP
	Wall 2 *				BRIK+GYP
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	21.6	27.0	32.1	35.4
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	33.1	34.5
Kitchen	NR BEFORE	20.0	20.0	20.0	20.0
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STorm	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	20.0	25.2	27.3	35.8
Bedroom #1	NR BEFORE	26.3	26.3	26.3	26.3
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.3	26.3	33.9	35.6
Bedroom #2	NR BEFORE	26.1	26.1	26.1	26.1
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.1	26.1	34.0	35.7
Library/Den	NR BEFORE	22.8	22.8	22.8	22.8
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.8	27.3	32.2	36.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$3.96	$6.04	$13.15

* 5 dB shielding assumed.

Table 3-26
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type F

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC45
	Wall 1		BRIK+GYp		BRIK+MGA
	Wall 2 *		BRIK+GYp		BRIK+MGA
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	21.1	26.3	30.9	35.5
Dining Room	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+2GY		BRIK+2GY
	Wall 2		BRIK+GYP		BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	26.6	31.1	35.5
Kitchen	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SC+SE+ST	RSTC40	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	19.6	24.8	31.4	34.7
Bedroom #1	NR BEFORE	25.0	25.0	25.0	25.0
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	25.0	25.0	31.4	35.8
Bedroom #2	NR BEFORE	24.9	24.9	24.9	24.9
	Window 1			RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	24.9	24.9	31.6	35.9
Library/Den	NR BEFORE	22.1	22.1	22.1	22.1
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+2GY		BRIK+GYp
	Roof 1			SJL+GYp	SJL+A+RG
	Floor 1				
	NR AFTER	22.1	25.8	30.4	34.9
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$6.71	$9.69	$16.50

* 5 dB shielding assumed.

Table 3-27
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type G

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.4	21.4	21.4	21.4
	Door 1		SC+SE+ST	RSTC35	RSTC35
	Window 1		8G+STC25	RSTC40	RSTC40
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYP	BRIK+GYp	BRIK+2GY
	Wall 2 *				BRIK+2GY
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	21.4	26.3	30.8	34.6
Dining Room	NR BEFORE	23.8	23.8	23.8	23.8
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	23.8	27.7	31.1	35.0
Kitchen	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	19.8	25.5	29.9	35.8
Bedroom #1	NR BEFORE	25.7	25.7	25.7	25.7
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYP
	Wall 2				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	25.7	25.7	31.4	36.1
Bedroom #2	NR BEFORE	25.6	25.6	25.6	25.6
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYP
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	25.6	25.6	31.6	35.6
Library/Den	NR BEFORE	22.5	22.5	22.5	22.5
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1				SJH+A+RG
	Floor 1				
	NR AFTER	22.5	26.6	30.4	36.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$3.64	$8.05	$15.20

* 5 dB shielding assumed.

Table 3-28
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type H

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8P+STC25	RSTC35	RSTC45
	Window 2 *		8P+STC25	RSTC35	RSTC45
	Wall 1		BRIK+GYp	BRIK+GYp	BRIK+GYp
	Wall 2 *				BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.9	25.1	29.5	36.1
Dining Room	NR BEFORE	21.2	21.2	21.2	21.2
	Window 1 *		8P+STC25	RSTC40	RSTC45
	Window 2		8P+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+GYp	BRIK+GYp	BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	21.2	25.9	30.5	35.2
Kitchen	NR BEFORE	19.0	19.0	19.0	19.0
	Door 1		RSTC40	RSTC35	RSTC40
	Window 1		8P+STC25	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.0	26.8	29.5	35.2
Bedroom #1	NR BEFORE	23.5	23.5	23.5	23.5
	Window 1 *		8P+STC25	RSTC35	RSTC40
	Window 2		8P+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+GYp		BRIK+GYp
	Wall 2		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.5	27.9	31.3	35.9
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.3	27.7	31.2	35.9
Library/Den	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1		8P+STC25	RSTC40	RSTC45
	Wall 1		BRIK+GYp		
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.9	24.6	31.9	36.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$7.85	$8.59	$14.73

* 5 dB shielding assumed.

Table 3-29
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type I

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.0	21.0	21.0	21.0
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC45	RSTC45
	Window 2 *		RSTC40	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	21.0	26.0	30.2	35.7
Dining Room	NR BEFORE	22.4	22.4	22.4	22.4
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.4	28.1	30.3	35.2
Kitchen	NR BEFORE	18.9	18.9	18.9	18.9
	Door 1	RSTC35	RSTC35	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.4	24.5	24.7	25.0
Bedroom #1	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC40	RSTC45
	Window 2			RSTC45	RSTC45
	Wall 1 *				WDGY+2GY
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.1	24.1	30.2	35.3
Bedroom #2	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1			RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	24.1	24.1	29.8	37.0
Library/Den	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1		8G+STC25	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	24.1	29.9	34.7
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.02	$7.62	$13.40	$18.15

* 5 dB shielding assumed.

Table 3-30
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type J

Room	Building Element	Modification by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	17.9	17.9	17.9	17.9
	Door 1	HC+WS+ST	HC+WS+ST	RSTC35	RSTC40
	Window 1	8P+STC25	RSTC40	RSTC45	RSTC45
	Window 2 *	8P+STorm	RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.8	24.9	30.2	35.7
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	25.5	30.3	35.2
Kitchen	NR BEFORE	15.8	15.8	15.8	15.8
	Door 1	HC+WS+ST	RSTC35	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.7	24.5	24.7	25.0
Bedroom #1	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1 *		RSTC35	RSTC40	RSTC40
	Window 2		RSTC40	RSTC45	RSTC45
	Wall 1 *				WDGY+2GY
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	26.9	30.2	34.9
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC40	RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	27.4	29.8	37.0
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	RSTC40	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.4	26.7	29.9	34.7
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$3.34	$9.13	$13.40	$18.06

* 5 dB shielding assumed.

Table 3-31
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type K

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1 *		8P+STC25	RSTC45	RSTC45
	Window 2		8P+STC25	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2				WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	19.6	24.9	30.3	34.4
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+MGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	20.3	25.6	30.5	37.2
Kitchen	NR BEFORE	18.1	18.1	18.1	18.1
	Door 1	SC+SE+ST	RSTC35	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.2	24.6	24.8	25.0
Bedroom #1	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1 *		RSTC40	RSTC35	RSTC35
	Window 2		RSTC45	RSTC45	RSTC40
	Wall 1 *				WDGY+MG
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.3	27.3	30.1	34.5
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC35	RSTC45	RSTC40
	Wall 1			WDGY+GYp	WDGY+MG
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	22.2	26.8	30.0	34.7
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1	WDGY+2GY	WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Ab+GY
	Floor 1				
	NR AFTER	23.6	26.4	30.1	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$2.96	$8.97	$13.30	$17.79

* 5 dB shielding assumed.

Table 3-32
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type L

Room	Building Element	Modifications by Noise Zone			
		60–65 dB	66–70 dB	71–75 dB	76–80 dB
Living Room	NR BEFORE	16.2	16.2	16.2	16.2
	Door 1	SG+WStrp	SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1	RSTC35	RSTC45	RSTC45	RSTC45
	Window 2 *	RSTC30	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Wall 2 *			WDGY+RGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	23.2	25.8	29.9	33.6
Dining Room	NR BEFORE	16.5	16.5	16.5	16.5
	Window 1 *	RSTC30	RSTC35	RSTC40	RSTC45
	Window 2	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.5	25.3	30.5	36.0
Kitchen	NR BEFORE	15.7	15.7	15.7	15.7
	Door 1	SC+WStrp	RSTC40	RSTC40	RSTC40
	Window 1	RSTC40	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	20.4	23.4	24.3	25.0
Bedroom #1	NR BEFORE	17.9	17.9	17.9	17.9
	Window 1 *	RSTC30	RSTC30	RSTC40	RSTC40
	Window 2	RSTC35	RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.2	25.2	30.2	35.6
Bedroom #2	NR BEFORE	17.8	17.8	17.8	17.8
	Window 1	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MG
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	23.6	26.4	31.5	35.1
Library/Den	NR BEFORE	15.2	15.2	15.2	15.2
	Window 1	RSTC30	RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+MG	WDGY+MGA
	Roof 1	ELt+GYp	ELt+GYp	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	20.6	25.7	29.5	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$7.39	$10.27	$18.15	$22.77

* 5 dB shielding assumed.

Table 3-33
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type M

Room	Build' Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	19.5	19.5	19.5	19.5
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		RSTC40	RSTC45	RSTC45
	Window 2 *			RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2 *				WDGY+MG
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.5	25.0	30.4	35.2
Dining Room	NR BEFORE	20.3	20.3	20.3	20.3
	Window 1 *		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1 *				WDGY+RGA
	Wall 2			WDGY+MGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	20.3	25.6	30.5	35.0
Kitchen	NR BEFORE	18.1	18.1	18.1	18.1
	Door 1	RSTC35	RSTC40	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC40	RSTC45	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	23.0	24.7	24.8	25.0
Bedroom #1	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1 *		RSTC35	RSTC35	RSTC40
	Window 2		RSTC40	RSTC45	RSTC45
	Wall 1 *				WDGY+MG
	Wall 2			WDGY+RGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.3	27.0	30.1	35.6
Bedroom #2	NR BEFORE	22.2	22.2	22.2	22.2
	Window 1		RSTC35	RSTC45	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.2	26.8	30.0	36.7
Library/Den	NR BEFORE	18.5	18.5	18.5	18.5
	Window 1	RSTC40	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	23.5	24.9	30.1	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.72	$8.02	$13.24	$17.00

* 5 dB shielding assumed.

Table 3-34
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type N

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	20.6	20.6	20.6	20.6
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2 *		RSTC35	RSTC35	RSTC45
	Wall 1			WDGY+GYp	WDGY+MG
	Wall 2 *			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.6	26.3	30.7	35.0
Dining Room	NR BEFORE	21.9	21.9	21.9	21.9
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC40	RSTC40	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.9	26.9	29.5	35.2
Kitchen	NR BEFORE	18.6	18.6	18.6	18.6
	Door 1		RSTC40	RSTC40	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	18.6	25.0	25.0	25.0
Bedroom #1	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *		WDGY+GYp	WDGY+GYp	WDGY+MG
	Wall 2			WDGY+GYp	WDGY+MG
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	28.0	30.1	35.0
Bedroom #2	NR BEFORE	23.4	23.4	23.4	23.4
	Window 1		RSTC40	RSTC40	RSTC40
	Wall 1		WDGY+GYp	WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.4	30.5	30.5	36.1
Library/Den	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1		RSTC35	RSTC40	RSTC45
	Wall 1		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.0	26.1	30.6	35.5
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	\$0.00	\$12.01	\$15.45	\$18.34

* 5 dB shielding assumed.

Table 3-35
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type O

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	20.6	20.6	20.6	20.6
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+MGA	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	20.6	26.2	30.1	34.9
Dining Room	NR BEFORE	21.9	21.9	21.9	21.9
	Window 1 *		RSTC40	RSTC40	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2		WDGY+2GY	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	21.9	28.3	30.3	35.4
Kitchen	NR BEFORE	18.6	18.6	18.6	18.6
	Door 1	RSTC35	RSTC40	RSTC40	RSTC40
	Window 1	RSTC45	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.7	24.4	23.9	24.9
Bedroom #1	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		RSTC45	RSTC35	RSTC45
	Window 2		RSTC45	RSTC45	RSTC45
	Wall 1 *		WDGY+GYp	WDGY+GYp	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.3	28.6	30.2	35.4
Bedroom #2	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		RSTC45	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	23.3	28.9	30.3	36.0
Library/Den	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1		RSTC40	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1		SJL+GYp	SJL+GYp	SJL+A+RG
	Floor 1				FB+A+STd
	NR AFTER	20.0	25.5	31.1	34.1
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.10	$13.45	$16.28	$20.34

* 5 dB shielding assumed.

Table 3-36
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type P

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	18.4	18.4	18.4	18.4
	Door 1	SC+SE+ST	RSTC35	RSTC40	RSTC40
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2 *	8G+STC25	WDGY+GYp	RSTC40	RSTC45
	Wall 1				WDGY+MG
	Wall 2 *				WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.8	26.0	29.6	34.8
DiningRoom	NR BEFORE	19.4	19.4	19.4	19.4
	Window 1 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2	8G+STC25	RSTC35	RSTC45	RSTC40
	Wall 1 *		WDGY+GYp	WDGY+RGA	WDGY+MGA
	Wall 2			WDGY+2GY	WDGY+MGA
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	24.4	26.1	29.7	35.5
Kitchen	NR BEFORE	17.2	17.2	17.2	17.2
	Door 1	SC+SE+ST	RSTC40	RSTC40	RSTC40
	Window 1	8G+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.3	24.3	24.3	25.0
Bedroom #1	NR BEFORE	19.9	19.9	19.9	19.9
	Window 1 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1 *			WDGY+RGA	WDGY+MG
	Wall 2			WDGY+2GY	WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	25.4	26.3	29.8	34.7
Bedroom #2	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1			WDGY+RGA	WDGY+MG
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	25.6	26.6	30.5	35.0
Library/Den	NR BEFORE	18.1	18.1	18.1	18.1
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+MGA	WDGY+MGA
	Roof 1	EL+Ab+GY	EL+Ab+GY	EL+Ab+GY	EL+Spc B
	Floor 1				
	NR AFTER	22.1	25.3	30.9	35.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$6.74	$11.34	$18.04	$22.80

* 5 dB shielding assumed.

Table 3-37
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type Q

Room	Building Element	Modifications by Noise Zone			
		60 - 65 dB	66 - 70 dB	71 - 75 dB	76 - 80 dB
Living Room	NR BEFORE	19.3	19.3	19.3	19.3
	Door 1		SG+WStrp	SG+WS+SG	SG+WS+SG
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2 *		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+GYp	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.3	25.5	30.3	33.3
Dining Room	NR BEFORE	20.0	20.0	20.0	20.0
	Window 1 *		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	20.0	25.7	29.5	35.5
Kitchen	NR BEFORE	17.9	17.9	17.9	17.9
	Door 1	RSTC40	RSTC40	RSTC40	RSTC40
	Window 1	8P+STC25	RSTC45	RSTC45	RSTC45
	Wall 1				
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.5	24.9	24.9	24.9
Bedroom #1	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1 *		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1 *			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.7	26.8	30.3	35.9
Bedroom #2	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1		RSTC35	RSTC40	RSTC40
	Wall 1			WDGY+GYp	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.7	27.0	30.0	34.7
Library/Den	NR BEFORE	18.3	18.3	18.3	18.3
	Window 1	8P+STC25	RSTC35	RSTC45	RSTC45
	Wall 1	WDGY+2GY	WDGY+GYp	WDGY+RGA	WDGY+MGA
	Roof 1		SJL+A+RG	SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.9	25.1	30.6	34.2
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$3.08	$7.63	$16.50	$18.37

* 5 dB shielding assumed.

Table 3-38
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type R

Room	Building Element	Modifications by Noise Zone			
		60 - 65 dB	66 - 70 dB	71 - 75 dB	76 - 80 dB
Living Room	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SEald	RSTC35	RSTC40
	Window 1		RSTC40	RSTC40	RSTC45
	Window 2 *			RSTC35	RSTC40
	Wall 1				HBLK+MGA
	Wall 2 *				HBLK+GYp
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.9	24.9	31.9	35.2
Dining Room	NR BEFORE	21.2	21.2	21.2	21.2
	Window 1 *		8P+STC25	RSTC35	RSTC45
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				HBLK+GYp
	Wall 2				HBLK+RGA
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	21.2	25.8	30.2	36.4
Kitchen	NR BEFORE	18.9	18.9	18.9	18.9
	Door 1	SC+SE+ST	SC+SE+ST	RSTC35	RSTC40
	Window 1	8P+STC25	8P+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	24.5	24.5	31.2	33.3
Bedroom #1	NR BEFORE	23.5	23.5	23.5	23.5
	Window 1 *		8P+STC25	RSTC35	RSTC35
	Window 2		8P+STC25	RSTC35	RSTC45
	Wall 1 *				HBLK+GYp
	Wall 2				HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.5	27.8	31.9	35.1
Bedroom #2	NR BEFORE	23.2	23.2	23.2	23.2
	Window 1		8P+STC25	RSTC35	RSTC40
	Wall 1		HBLK+RGA		HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	23.2	27.8	31.9	35.4
Library/Den	NR BEFORE	19.8	19.8	19.8	19.8
	Window 1		8P+STC25	RSTC40	RSTC45
	Wall 1				HBLK+2GY
	Roof 1			VP+Absrp	VP+Absrp
	Floor 1				
	NR AFTER	19.8	24.4	31.6	35.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.38	$4.66	$8.94	$15.51

* 5 dB shielding assumed.

Table 3-39
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type S

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	21.5	21.5	21.5	21.5
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC40
	Window 2 *		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+2GY
	Wall 2 *		BRIK+GYp		BRIK+2GY
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	21.5	26.9	29.5	35.1
Dining Room	NR BEFORE	24.1	24.1	24.1	24.1
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.1	24.1	32.7	36.0
Kitchen	NR BEFORE	19.9	19.9	19.9	19.9
	Door 1		SC+SE+ST	RSTC35	RSTC40
	Window 1		8G+STorm	RSTC35	RSTC45
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	19.9	25.1	31.1	35.1
Bedroom #1	NR BEFORE	26.2	26.2	26.2	26.2
	Window 1 *			RSTC35	RSTC35
	Window 2			RSTC35	RSTC35
	Wall 1 *				BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.2	26.2	33.4	34.9
Bedroom #2	NR BEFORE	26.0	26.0	26.0	26.0
	Window 1			RSTC35	RSTC35
	Wall 1				BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	26.0	26.0	33.5	35.0
Library/Den	NR BEFORE	22.7	22.7	22.7	22.7
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+GYp		BRIK+GYp
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	22.7	27.2	31.9	35.3
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$4.37	$7.33	$14.08

* 5 dB shielding assumed.

Table 3-40
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
One-Story House: Type T

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		RSTC35	RSTC35	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC45
	Window 2 *		8G+STC25	RSTC35	RSTC45
	Wall 1				BRIK+2GY
	Wall 2 *				BRIK+2GY
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	21.1	26.3	32.4	35.5
Dining Room	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1 *		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STC25	RSTC35	RSTC40
	Wall 1 *		BRIK+RGA		BRIK+2GY
	Wall 2		BRIK+RGA		BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	23.3	26.6	33.5	35.5
Kitchen	NR BEFORE	19.6	19.6	19.6	19.6
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC40	RSTC45
	Wall 1				
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	19.6	24.8	27.6	34.7
Bedroom #1	NR BEFORE	25.0	25.0	25.0	25.0
	Window 1 *			RSTC35	RSTC40
	Window 2			RSTC35	RSTC40
	Wall 1 *				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	25.0	25.0	34.4	35.8
Bedroom #2	NR BEFORE	24.9	24.9	24.9	24.9
	Window 1			RSTC35	RSTC40
	Wall 1				BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	24.9	24.9	34.5	35.9
Library/Den	NR BEFORE	22.1	22.1	22.1	22.1
	Window 1		8G+STC25	RSTC35	RSTC40
	Wall 1		BRIK+MGA		BRIK+GYp
	Roof 1			SJL+A+RG	SJL+A+RG
	Floor 1				
	NR AFTER	22.1	25.8	32.5	34.9
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$6.33	$9.32	$16.33

* 5 dB shielding assumed.

Table 3-41
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Manufactured Home: Type U

Room	Building Element	Modifications by Noise Zone			
		MH L65	MH L70	MH L75	MH L80
Living Room	NR BEFORE	18.3	18.3	18.3	18.3
	Door 1	HC+WS+ST	HC+WS+ST	HC+WS+ST	HC+WS+ST
	Window 1	8G+STC25	RSTC35	RSTC45	RSTC45
	Window 2 *	8G+STC25	RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+2GY	WDGY+2GY	WDGY+2GY
	Wall 2 *		WDGY+2GY	WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	23.2	25.3	25.7	25.8
Kitchen	NR BEFORE	23.3	23.3	23.3	23.3
	Window 1		RSTC45	RSTC45	RSTC45
	Window 2 *		RSTC45	RSTC45	RSTC45
	Wall 1				
	Wall 2 *				
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	23.3	27.4	27.7	27.7
Bedroom #1	NR BEFORE	19.8	19.8	19.8	19.8
	Door 1		HC+WS+ST	HC+WS+ST	HC+WS+ST
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 2		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 3 *			WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	19.8	25.4	27.8	27.8
Bedroom #2	NR BEFORE	21.7	21.7	21.7	21.7
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC45
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+2GY
	Wall 2			WDGY+2GY	WDGY+2GY
	Wall 3 *			WDGY+2GY	WDGY+2GY
	Roof 1		VP+Absrp	VP+Absrp	VP+Absrp
	Floor 1			FV+Baf+A	FV+Baf+A
	NR AFTER	21.7	25.4	30.4	30.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$1.38	$11.11	$18.79	$18.79

* 5 dB shielding assumed.

Table 3-42
Noise Reduction, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type V

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE Door 1 * Window 1 * Wall 1 * Roof 1 Floor 1 NR AFTER	25.5 25.5	25.5 25.5	25.5 SC+SE+MT RSTC35 30.2	25.5 RSTC40 RSTC45 WDGY+RGA 35.8
Dining Room	NR BEFORE Window 1 Wall 1 Roof 1 Floor 1 NR AFTER	24.4 24.4	24.4 24.4	24.4 RSTC40 WDGY+GYp 31.6	24.4 RSTC45 WDGY+RGA 35.1
Kitchen	NR BEFORE Door 1 Window 1 Wall 1 Roof 1 Floor 1 NR AFTER	19.8 SG+WS+SG 8G+STorm 19.8	19.8 SG+WS+SG 8G+STorm 26.0	19.8 SG+WS+SG RSTC45 - 29.2	19.8 SG+WS+SG RSTC45 29.2
Bedroom #1	NR BEFORE Window 1 Wall 1 Roof 1 Floor 1 NR AFTER	25.0 25.0	25.0 25.0	25.0 RSTC35 WDGY+GY 30.4	25.0 RSTC45 WDGY+MGA 35.3
Bedroom #2	NR BEFORE Window 1 * Wall 1 * Roof 1 Floor 1 NR AFTER	28.8 28.8	28.8 28.8	28.8 28.8	28.8 RSTC45 WDGY+2GY 34.7
Bedroom #3	NR BEFORE Window 1 * Wall 1 * Roof 1 Floor 1 NR AFTER	28.3 28.3	28.3 28.3	28.3 8G+STC25 30.4	28.3 RSTC45 WDGY+RGA 35.1
Basement	NR BEFORE Window 1 * Window 2 * Wall 1 * Roof 1 Floor 1 NR AFTER	32.7 32.7	32.7 32.7	32.7 32.7	32.7 RSTC35 RSTC35 43.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.50	$2.95	$6.40

* 5 dB shielding assumed.

Table 3-43
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type W

Room	Building Element	Modifications by Noise Zone			
		60 - 65 dB	66 - 70 dB	71 - 75 dB	76 - 80 dB
Living Room	NR BEFORE	26.2	26.2	26.2	26.2
	Door 1 *			SC+SEald	RSTC35
	Window 1 *			RSTC35	RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	26.2	26.2	31.4	35.7
Dining Room	NR BEFORE	25.7	25.7	25.7	25.7
	Window 1			RSTC35	RSTC35
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	25.7	25.7	34.9	34.9
Kitchen	NR BEFORE	20.0	20.0	20.0	20.0
	Door 1	SG+WS+SG	SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1			RSTC35	RSTC45
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	20.0	24.9	31.1	32.2
Bedroom #1	NR BEFORE	26.7	26.7	26.7	26.7
	Window 1			RSTC35	RSTC40
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	26.7	26.7	34.1	35.1
Bedroom #2	NR BEFORE	30.1	30.1	30.1	30.1
	Window 1 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	30.1	30.1	30.1	35.3
Bedroom #3	NR BEFORE	29.7	29.7	29.7	29.7
	Window 1 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	29.7	29.7	29.7	35.2
Basement	NR BEFORE	32.7	32.7	32.7	32.7
	Window 1 *				RSTC35
	Window 2 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	32.7	32.7	32.7	43.4
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.41	$1.98	$3.85

* 5 dB shielding assumed.

Table 3-44
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Townhouse: Type X

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	24.5	24.5	24.5	24.5
	Door 1 *			RSTC35	RSTC40
	Window 1 *			RSTC35	RSTC40
	Window 2 *			RSTC35	RSTC40
	Wall 1 *				WDGY+RGA
	Wall 2 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.5	24.5	30.1	35.0
Dining Room	NR BEFORE	24.4	24.4	24.4	24.4
	Window 1			RSTC40	RSTC45
	Wall 1			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.4	24.4	31.6	35.1
Kitchen	NR BEFORE	19.2	19.2	19.2	19.2
	Door 1		SG+WS+SG	SG+WS+SG	SG+WS+SG
	Window 1		8G+STC25	RSTC45	RSTC45
	Wall 1				
	Wall 2				
	Roof 1				
	Floor 1				
	NR AFTER	19.2	24.4	25.5	25.5
Bedroom #1	NR BEFORE	22.0	22.0	22.0	22.0
	Window 1 *		8G+STC25	RSTC40	RSTC45
	Window 2 *		8G+STC25	RSTC40	RSTC45
	Wall 1 *		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Wall 2 *		WDGY+2GY	WDGY+2GY	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	22.0	26.9	30.3	34.7
Bedroom #2	NR BEFORE	25.9	25.9	25.9	25.9
	Window 1 *			RSTC35	RSTC45
	Window 2 *			RSTC35	RSTC45
	Wall 1 *			WDGY+GYp	WDGY+MGA
	Wall 2 *			WDGY+GYp	WDGY+MG
	Roof 1				
	Floor 1				
	NR AFTER	25.9	25.9	31.0	35.0
Bedroom #3	NR BEFORE	28.3	28.3	28.3	28.3
	Window 1 *			RSTC35	RSTC45
	Wall 1 *				WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	28.3	28.3	31.5	35.1
Basement	NR BEFORE	32.7	32.7	32.7	32.7
	Window 1 *				RSTC35
	Window 2 *				RSTC35
	Wall 1 *				
	Roof 1				
	Floor 1				
	NR AFTER	32.7	32.7	32.7	43.4
Cost/Dwell.Sq.Ft.	C/D. Sq.Ft.	$0.00	$1.96	$6.06	$9.14

* 5 dB shielding assumed.

Table 3-45
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Dwelling: Type Y

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Living Room	NR BEFORE	20.1	20.1	20.1	20.1
	Door 1		RSTC35	RSTC40	RSTC40
	Window 1		RSTC35	RSTC40	RSTC45
	Window 2		RSTC35	RSTC40	RSTC45
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+GYp	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	20.1	26.0	30.2	35.4
Dining Room	NR BEFORE	26.6	26.6	26.6	26.6
	Window 1 *			RSTC35	RSTC40
	Window 2 *			RSTC40	RSTC40
	Wall 1 *			WDGY+GYp	WDGY+RGA
	Wall 2 *			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	26.6	26.6	32.0	35.0
Kitchen	NR BEFORE	24.6	24.6	24.6	24.6
	Door 1 *			RSTC40	RSTC40
	Window 1 *			RSTC40	RSTC45
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	24.6	24.6	29.7	30.4
Family Room	NR BEFORE	24.8	24.8	24.8	24.8
	Window 1			RSTC35	RSTC45
	Wall 1			WDGY+GYp	WDGY+RGA
	Roof 1				
	Floor 1				
	NR AFTER	24.8	24.8	30.9	34.9
Bedroom #1	NR BEFORE	21.8	21.8	21.8	21.8
	Window 1		RSTC40	RSTC45	RSTC40
	Window 2		RSTC40	RSTC40	RSTC40
	Wall 1			WDGY+2GY	WDGY+MGA
	Wall 2			WDGY+2GY	WDGY+MGA
	Roof 1				
	Floor 1				
	NR AFTER	21.8	25.4	30.6	34.9
Bedroom #2	NR BEFORE	24.6	24.6	24.6	24.6
	Window 1			RSTC35	RSTC45
	Wall 1			WDGY+2GY	WDGY+MG
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	24.6	24.6	32.1	36.7

Table 3-45 (Continued)

Room	Building Element	Modifications by Noise Zone			
		60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Bedroom #3	NR BEFORE	22.3	22.3	22.3	22.3
	Window 1		RSTC35	RSTC45	RSTC45
	Window 2		RSTC35	RSTC45	RSTC40
	Wall 1		WDGY+GYp	WDGY+2GY	WDGY+MG
	Wall 2		WDGY+GYp	WDGY+GYp	WDGY+MGA
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	22.3	27.7	29.9	35.5
Bedroom #4	NR BEFORE	26.5	26.5	26.5	26.5
	Window 1 *			RSTC40	RSTC40
	Window 2 *			RSTC40	RSTC35
	Wall 1 *			WDGY+GYp	WDGY+RGA
	Wall 2 *				WDGY+2GY
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	26.5	26.5	30.7	35.2
Den	NR BEFORE	26.8	26.8	26.8	26.8
	Window 1 *			RSTC40	RSTC40
	Window 2 *			RSTC40	RSTC40
	Wall 1 *			WDGY+GYp	WDGY+2GY
	Wall 2 *			WDGY+GYp	WDGY+2GY
	Roof 1			VP+Absrp	VP+Ab+GY
	Floor 1				
	NR AFTER	26.8	26.8	32.8	35.6
Basement	NR BEFORE	34.6	34.6	34.6	34.6
	Window 1 *				
	Window 2 *				
	Wall 1				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	34.6	34.6	34.6	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$1.85	$6.52	$8.20

* 5 dB shielding assumed.

Table 3-46
Noise Reductions, Modifications, and Cost/Dwelling Sq.Ft.,
Two-Story Dwelling: Type Z

Room	Building Element	Modifications by Noise Zone			
		60-65 dB	66-70 dB	71-75 dB	76-80 dB
Living Room	NR BEFORE	21.1	21.1	21.1	21.1
	Door 1		SC+SE+ST	SC+SE+ST	RSTC40
	Window 1		8G+STC25	RSTC35	RSTC40
	Window 2		8G+STorm	RSTC40	RSTC40
	Wall 1			BRIK+GYp	BRIK+GYp
	Wall 2				BRIK+GYp
	Roof 1				
	Floor 1				
	NR AFTER	21.1	26.1	29.5	35.0
Dining Room	NR BEFORE	28.7	28.7	28.7	28.7
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	28.7	28.7	36.1	36.1
Kitchen	NR BEFORE	25.9	25.9	25.9	25.9
	Door 1 *			SC+SE+ST	RSTC35
	Window 1 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	25.9	25.9	32.5	35.6
Family Room	NR BEFORE	26.4	26.4	26.4	26.4
	Window 1			RSTC35	RSTC35
	Wall 1				
	Roof 1				
	Floor 1				
	NR AFTER	26.4	26.4	35.2	35.2
Bedroom #1	NR BEFORE	24.0	24.0	24.0	24.0
	Window 1			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1				BRIK+2GY
	Wall 2				BRIK+GYp
	Roof 1				
	Floor 1				
	NR AFTER	24.0	24.0	33.7	34.8
Bedroom #2	NR BEFORE	27.0	27.0	27.0	27.0
	Window 1			RSTC35	RSTC40
	Wall 1				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	27.0	27.0	34.2	37.6

Table 3-46 (Continued)

Room	Building Element	Modifications by Noise Zone 60 – 65 dB	66 – 70 dB	71 – 75 dB	76 – 80 dB
Bedroom #3	NR BEFORE	24.7	24.7	24.7	24.7
	Window 1			RSTC35	RSTC40
	Window 2			RSTC35	RSTC35
	Wall 1				
	Wall 2				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	24.7	24.7	33.2	35.6
Bedroom #4	NR BEFORE	28.4	28.4	28.4	28.4
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	28.4	28.4	34.7	36.8
Den	NR BEFORE	28.8	28.8	28.8	28.8
	Window 1 *			RSTC35	RSTC35
	Window 2 *			RSTC35	RSTC35
	Wall 1 *				
	Wall 2 *				
	Roof 1				VP+Absrp
	Floor 1				
	NR AFTER	28.8	28.8	34.8	36.9
Basement	NR BEFORE	34.6	34.6	34.6	34.6
	Window 1 *				
	Window 2 *				
	Wall 1				
	Wall 2 *				
	Roof 1				
	Floor 1				
	NR AFTER	34.6	34.6	34.6	34.6
Cost Per Dwelling Sq.Ft.	C/D. Sq.Ft.	$0.00	$0.30	$3.30	$4.52

* 5 dB shielding assumed.

take into account any information available about the specific dwelling being treated.

It was impossible to satisfy the noise goal for most of the dwelling categories in the 76–80 dB impact zone with the options provided in the computer model. More drastic measures could be used in actual circumstances. Only the modifications to house types C and H were completely successful in this zone. Many other homes, however, achieved the required sound insulation in all but one room, often the kitchen. For the remaining dwellings, no reasonable package of modifications could be identified. The measures given in the table represent an insufficient improvement in NLR. Of course, in an actual sound insulation project the measured exterior noise level would be used rather than the upper limit of 80 dB. If, for example, the actual outside noise level were 76 dB, the modifications would be more likely to provide adequate insulation. Many homes in the higher impact zones will not be modifiable in a cost-effective way.

3.6.2 Developing Cost Estimates From the Modifications Tables

Since the geographic region influences the types of houses usually built in a given community, Table 3–47 identifies the most common types found in each of the 11 regions shown in Figure 3–3. For any region, however, any of the 26 types may be encountered. The sound insulation methods used will be the same regardless of the locality. They depend only on noise exposure and existing NLR.

Most sound insulation costs depend on the overall size of the house. Wall, roof, attic, and floor treatment costs increase with larger dwellings. While the relationship is less obvious with windows, it still holds true: Larger houses feature more and bigger windows, so the modification or replacement cost goes up. The dwelling modifications suggested in Tables 3–21 to 3–46 give a cost per dwelling square foot for implementing the recommended construction features. This cost appears at the bottom of each column and can be multiplied by the living space of the home in square feet to get the overall cost. If the actual size is not known, Table 3–48 provides the average house size in each of the 11 geographic regions.

The values given are referenced to construction labor and materials rates for the Southern California area in 1987. Table 3–49 gives geographic cost multipliers for other regions of the country. By using these multiplication factors it is possible to estimate the cost of modifying a home in any region of the country. An example in the next section shows how to use these cost factors. All these costs are, of course, subject to inflation.

It is always more efficient, and cost effective, to build a house with the acoustic performance in mind from the start. The materials used to modify a dwelling may be the same as those used in building it to begin with. But remodeling involves demolition costs, cleanup costs, and other extra costs involved with working on a built, possibly aged, probably inhabited dwelling. An effort has been made to reflect the difference between the cost to remodel and the extra cost of using good acoustic principles in the initial design and construction. The following cost multiplier may be applied to the costs quoted in Tables 3–21 to 3–46. The new construction cost calculated using this factor will represent costs attributable to sound insulation which would be added to standard house construction costs. Each individual residence is unique, but this cost factor is useful for developing global cost estimates. To get the new construction cost, multiply the cost per square foot by:

New Construction Cost Factor: 0.70

Figures 3–23 and 3–24 provide worksheets for estimating dwelling modification costs. Figure 3–23 uses the total number of dwellings in a project, the types of dwellings expected, the percentage of each type, the house size, and the cost per square foot for each type, to develop an overall cost for that noise exposure zone. The process is described in the next section and can be repeated for each impact zone. Figure 3–24 allows a more detailed examination of a specific dwelling to develop a cost for it. This cost can then be used in Figure 3–23 to customize the cost estimate based on specific information about the houses involved.

Section 4 discusses program management and cost estimation. It includes a more comprehensive analysis of project costs including contractor markup, ventilation systems, contingency fees, etc. The modification costs presented here are part of the overall cost structure. For rough costing purposes, the following construction-related costs may be used. Not all

Table 3-47

Most Common Dwelling Types in Each Region

Region	I	II	III	IV	V	VI	VIII	VII	IX	X	XI
Dwelling Type*	A B J K M	C E B F U	M R C N U	O I T D F	O I F D N	D I F E J	I O S T M	O I D F N	J I O T D	K E J B D	L Q K N

* Ranked from most to least common.

Table 3-48

1987 Average Dwelling Size for New Construction

Region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Sq. Ft.	1,765	1,765	1,800	1,815	1,840	1,800	1,795	1,785	1,765	1,800	1,765

Table 3-49

Cost Multiplier for Each Region

Region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Cost Multiplier	1.03	0.86	0.77	0.88	1.07	0.78	0.87	0.84	0.94	0.79	1.04

SINGLE NOISE ZONE MODIFICATION COSTS WORKSHEET

Region	DNL Zone	House Type	No. of Units	Cost/ Dwelling Sq.Ft.	Size (Sq.Ft.)	Unit Cost	TOTAL COST
		A					
		B					
		C					
		D					
		E					
		F					
		G					
		H					
		I					
		J					
		K					
		L					
		M					
		N					
		O					
		P					
		Q					
		R					
		S					
		T					
		U					
		V					
		W					
		X					
		Y					
		Z					
						Zone Cost:	
						Geographic Cost Factor:	
						Adjusted Zone Cost:	

Figure 3-23. Single Noise Zone Modification Costs Worksheet.

INDIVIDUAL DWELLING MODIFICATION COST ESTIMATION WORKSHEET

Project: ______________________________

Dwelling Identification: ______________________________

ELEMENT	TYPE	NO.	UNIT COST	COST	
Sealing/ Caulking					Subtotal
Windows	Storm Secondary STC 35 STC 40 STC 45				Subtotal
Doors	Storm Secondary Acoustical Other				Subtotal
Attic/Ceiling	Absorption Barrier + Abs Other				Subtotal
Interior Wall	Gyp. panel Gyp. + SDB Furred-out Wall				Subtotal
Exterior Wall	Absorption Panel				Subtotal
Vent Baffles					Subtotal
Fireplace Treatment					Subtotal
Ventilation	Limited Moderate Extensive				Subtotal
				TOTAL	

Figure 3-24. Individual Dwelling Modification Cost Estimate Worksheet.

ventilation systems will need to be provided "from scratch". The figure shown here is the cost of a complete system including ductwork.

Contractor Profit and Overhead:	20% of total
Contingency Fee –	
New Construction	5% of total
Remodeled	20% of total
HVAC System, Complete:	$5,000

3.6.3 Cost Development Example

Before developing project costs, several parameters must be identified. They are:

1. Geographic Region (if needed to estimate the dwelling types involved – see Figure 3-3 and Table 3-3).
2. Noise exposure zone.
3. Number of dwellings of each type. (can use the percentage estimates based on which types are most common in each geographic region – see Table 3-3).
4. Cost per square foot to modify to house (Tables 3-21 to 3-46).
5. Size of house (can use average dwelling size based on geographic region if this is not known – see Table 3-48).

Figure 3-25 shows a worked-up example of a typical home sound insulation project. The project involves 50 homes divided among 5 house types in Region IV. The costs per dwelling square foot are taken from the 66-70 dB noise exposure column of Tables 3-24, 3-26, 3-29, 3-35, and 3-40. The average house size of 1,815 sq.ft. comes from Table 3-48. Multiplying the cost per dwelling square foot by the size of the house gives the unit dwelling cost for each house type. These costs are approximate and are rounded to the nearest ten dollars. Multiply this unit cost by the number of dwelling units of that type to get the total cost of modifying these residences. The dwelling type totals in the right-hand column are summed to estimate the cost of modifying all homes in the specified noise zone. Last, the geographic cost multiplier is used to get the equivalent cost in the given region.

SINGLE NOISE ZONE MODIFICATION COSTS WORKSHEET

Region	DNL Zone	House Type	No. of Units	Cost/ Dwelling Sq.Ft.	Size (Sq.Ft.)	Unit Cost	TOTAL COST
IV	66-70	A					
		B					
		C					
		D	5	3.23	1,815	$5,860	$29,300
		E					
		F	5	6.71	1,815	$12,180	$60,900
		G					
		H					
		I	10	7.62	1,815	$13,830	$138,300
		J					
		K					
		L					
		M					
		N					
		O	20	13.45	1,815	$24,410	$488,200
		P					
		Q					
		R					
		S					
		T	10	6.33	1,815	$11,490	$114,900
		U					
		V					
		W					
		X					
		Y					
		Z					
						Zone Cost:	$831,600
						Geographic Cost Factor:	0.88
						Adjusted Zone Cost:	$731,800

Figure 3-25. Example Cost Estimate.

4.0 PROJECT MANAGEMENT IMPLEMENTATION

4.1 Project Management

Project Scope

Many decisions concerning the management structure and task breakdown for a home insulation project depend on the scope of the project. A project to insulate a small number of homes could be managed by a small staff. Homeowners could deal directly with contractors and supervision could be provided by a local government or consulting agency. At the other end of the scale is the large project geared toward modifying several hundred homes per year for many years. This type of project usually requires a team of technical consultants, real estate experts, contracts specialists, and support staff. Among the factors to be considered in determining the scope of the project are:

- Number of impacted, eligible dwellings;
- Availability of funds and other resources;
- Completion of the overall project in a reasonable time span;
- Obtaining economies of scale in ordering materials;
- Having sufficiently large orders to command priority in obtaining specialized materials(i.e., acoustical windows);
- Having jobs large enough to attract competent construction contractors in what is, locally, a seller's market.

Using a Pilot Study

Ordinarily, large home sound insulation projects are conducted in phases with a pilot insulation project as Phase I. A pilot study consists of analyzing and modifying a limited number of representative homes before the entire community is treated. The pilot is, in effect, a complete version of the home insulation project from start to finish, but on a much smaller scale. This enables managers to develop and test implementation schemes and reliable cost estimates for the entire project by using results from actual installed modifications. The number of houses chosen for the pilot varies depending, again, on budgetary constraints. Twenty homes is a manageable number for a study and several airports have found that to be sufficient.

Management Structure

Although a wide variety of management structures is possible to implement such a program, they all fall into one of three general categories:

- The program can be managed entirely by the sponsoring agency, by organizing and staffing its own program office to carry out all the necessary functions (the "in-house" option);
- The program can be managed entirely by a single external entity, such as a consultant or some other governmental agency under contract to the sponsoring group, with that entity organizing and staffing its own local office to carry out the necessary functions (the "turnkey option");
- The program may be a mixture of these two extremes, with the sponsoring organization carrying out certain of the functions, and the external entity (or entities) carrying out the remaining functions (the "hybrid option"). In this case, the external entities could be the homeowners themselves.

With any of these options the sponsoring agency will be responsible for budgeting and any necessary legislative action. The agency will also be involved in setting design objectives, determining dwelling eligibility, selecting the dwellings, and negotiating with the homeowners. It is assumed the agency will want to audit the project, evaluate the results, and carry out public relations efforts. Beyond this minimal involvement, the choice of management options depends largely on staff availability and cost effectiveness.

The categories defined above are illustrated conceptually in Figure 4-1 along with a summary of the advantages and disadvantages of each option.

In-House Option

The "in-house" option provides the most direct control for the sponsoring agency. This structure, along with the "turnkey" structure, has the potential of being most efficient, since a single entity is in charge.

The "in-house" structure does, however, demand the most in terms of agency staff and support (e.g., office space, equipment, supplies, etc.). It may also be difficult to implement

"In-House" Option	"Hybrid" Option	"Turnkey" Option
Complete management by sponsor	Combined management between sponsor and one or more external entities, such as: • other agencies, • contractors, and • homeowners	Complete management by a single external entity such as: • another agency, or • a contractor
Advantages: - Most direct control. - Efficient management structure.	*Advantages:* - Reduces sponsor staff requirements.	*Advantages:* - Minimizes sponsor staff requirements. - Efficient management structure. - Insulates sponsor from specific decisions.
Disadvantages: - Most sponsor staff requirements. - May be difficult to fit into existing sponsor management. - May be difficult to obtain personnel and equipment within state system. - May be inefficient because of bureaucratic inertia within state system.	*Disadvantages:* - Less direct control. - Inefficient management structure. - Requires sponsor staff time in making many decisions. - If homeowners perform contracting functions, it will be impossible to realize economies of scale, obtain priority for materials, attract most competent remodeling firms, or obtain quality control.	*Disadvantages:* - Least direct control. - May be difficult to fund external entity. - Requires sponsor staff time in making some decisions. - May be inefficient if external entity is another bureaucratic agency.

Figure 4-1. Possible Management Structures for Sound Insulation Program Office.

within the existing management structure, since the required functions may be far removed from those the sponsoring agency is normally responsible for. There may be problems associated with hiring new staff, transferring them from other programs, and releasing them after the program is finished. If the sponsoring agency is a government organization, there may be inefficiencies in procurement methods and day-to-day operations due to governmental requirements.

Turnkey Option

The "turnkey" option causes the least impact on the sponsoring agency and offers similar or better efficiency. In addition, this structure insulates the sponsoring agency from responsibility for many of the house-specific decisions that must be made continually. If the external entity is a private contractor, there will be maximum flexibility in staffing and responding to changing program directions and levels. On the other hand, this option removes most of the day-to-day control from the sponsoring agency, which will be acting primarily in an oversight capacity.

Hybrid Option

The least efficient option appears to be the "hybrid" structure. This option reduces the involvement of the sponsoring agency but may introduce inefficiencies and complications in coordinating the effort. For small projects with limited funding, however, this may be justified and workable. If this option is chosen it will be crucial to outline carefully the respective areas of responsibility and to develop efficient day-to-day lines of communication. Ensuring quality control and proper supervision of the construction work, particularly the acoustically sensitive tasks, will be much more difficult if the project office is not involved on a daily basis.

This option provides the maximum flexibility in balancing responsibility by assigning to each group the tasks they do best.

General Considerations

Regardless of the management structure chosen, it is advisable to set up a system for procuring materials in large enough lots to take advantage of preferential pricing and delivery schedules. Also, if all the homes are contracted together it is easier to get competitive bids from larger, more competent remodeling and construction companies. Unfortunately, many home remodeling companies do not have sufficient capital to purchase materials to do a large number of houses at once. These conflicting needs will have to be balanced in the program structure.

The various tasks involved in a home insulation project are discussed in the next section, Program Planning. This section identifies the factors bearing on deciding how large the project should be and which homes should be included. The managing agency's staff requirements can be estimated based on information provided here for per-home manhours. The last section, Detailed Cost Estimates, shows how to develop project cost estimates using the worksheets provided in Appendix A.

4.1.1 Program Planning

Program Function

Conducting a residential sound insulation project requires carrying out the following functions:

1. Developing and successfully sponsoring the necessary legislative and budgetary authority to undertake the program.
2. Soliciting applicants for participation in the program.
3. Determining eligibility and setting design objectives for the dwellings to be modified.
4. Selecting and prioritizing the specific dwellings to be modified.
5. Establishing work plan schedules.
6. Developing the design of the acoustical modifications for each dwelling.
7. Negotiating with the owners and lien holders of these dwellings in order to proceed with the modifications. This may include obtaining appropriate avigation easements or similar legal assurances from the owners.
8. Defining the specific modifications for each dwelling, based on both acoustical design objectives and owner preferences, and preparing the bid package.
9. Holding pre-bid briefings for prospective contractors, and responding to questions during the bid process.
10. Selecting and negotiating with a general contractor or contractors for the actual modifications.
11. Reviewing the general contractor's shop drawings and materials lists.

12. Inspecting the acoustical materials prior to the modifications.
13. Inspecting work in progress to ensure proper quality control and workmanship.
14. Managing change orders and unforeseen deviations from the initial contracts which arise during the modifications.
15. Evaluating acoustical effectiveness of and owner satisfaction with the modifications after completion.
16. Managing and documenting the progress, including continual community relations, and auditing of the completed program.

Selecting and Prioritizing Eligible Homes

As discussed in Section 4.1, the scope of the project is one of the primary variables. Deciding how many and which homes to include depends on factors such as: How many homes are impacted by the aircraft noise now? In five years? How much money is available to modify homes?

Mapped noise exposure contours provide a starting point for estimating the number of eligible dwellings. AICUZ or airport contours for current operations should be examined and any projected changes in the number or type of flights over the next five years should be taken into account. Priority should be given to homes which are in the highest noise zones. In addition, some homes are exposed to more intrusive noise than others within the same noise zone. Homes impacted by the noise from departures and reverse engine thrust on landings experience more disturbing noise than homes exposed to simple landings and should be given preference.

During the construction phase of the project it is much more efficient to modify homes which are grouped together geographically. This minimizes the time the work crews have to waste traveling and transporting equipment and materials from one site to another. Another way to enhance procurement and construction efficiency is to treat groups of homes with similar modification requirements. Project managers may decide to provide sound-insulating materials exceeding those required to meet the design goals in a few homes if ordering extra products will gain better pricing or delivery times.

Staffing Requirements and Program Growth

Staffing requirements depend on the scope of the project and the management structure chosen. While it is not possible to predict how many manhours any given project entails, some of the tasks consistently require more work than others regardless of the number of homes being modified. The following discussion provides information on the relative labor requirements of each of the functions outlined at the beginning of this section.

Most programs, whether large or small, start out treating a limited number of homes. Pilot studies of about 20 homes are typical of many recent residential insulation efforts. Then, if the ultimate goal involves a large number of homes, the project will build up to treating several hundred homes every year. The following discussion assumes a project treating 200 to 500 homes per year. Table 4-1 provides manhour projections broken down by task. The information presented here is based on actual experience conducting home insulation projects.

The team for the project in Table 4-1 is comprised of two senior technical staff members, seven junior technical people, six real estate specialists, and four secretary/typists. For projects of much smaller scope the division of labor will change considerably, but the relative number of hours devoted to each function should be about the same. For example, the acoustics consultant or architect will spend most of their time developing the acoustical design package and reviewing the working drawings the contractor submits. Similarly, obtaining easements will require a significant effort on the part of a real estate specialist and the support staff.

Task Emphasis

Several of the tasks in Table 4-1 should be emphasized, since their importance might not be recognized immediately. Selecting and prioritizing applicants, developing acoustical designs, obtaining easements, and preparing bid packages are all critical elements of the program. However, maintaining quality control by reviewing working drawings, inspecting materials and work in progress, and carrying out spot acoustical measurements are equally important tasks. Interviewing each homeowner after he or she has lived with the modifications for a while enables management to monitor the continuing success of the program.

It will not take very many negative reports of poor quality or inadequate noise reduction before the credibility of the whole program is questioned. Thus it is vital that extra effort be expended to maintain quality control. It is also important that

Table 4-1

Annual Manpower Estimates for
Residential Sound Insulation Program Office

TASK	HOURS PER HOME			
	Sr. Tech.	Jr. Tech.	Real Spec.	Sec/Typ.
Solicit Applicants				1.0
Determine Eligibility		0.50	0.50	0.50
Select & Prioritize				
Schedule Work Flow				
Inspect Homes		4.00		0.25
Develop Acoustical Designs	2.00	6.00		2.00
Obtain Easements			20.0	5.00
Develop Bid Package	1.00	4.00		2.00
Conduct Pre-Bid Briefing				
Review Bids / Make Award				
Review Working Drawings	2.00	4.00		
Inspect Materials		1.00		
Inspect Work in Progress		1.00		0.25
Handle Change Orders	2.00	2.00		1.00
Sign Off / Spot Measurements	1.00	1.00		0.25
Documentation	2.00	2.00		2.00
Homeowner Interviews			1.00	0.50
Sponsor Meetings / Public Relat'ns				
General Management				

KEY:
Sr. Tech. – Senior Technical Person
Jr. Tech. – Junior Technical Person
Real Spec. – Reality Specialist
Sec/Typ. – Secretary or Typist

positive homeowner responses be made known to the general public and the legislature. This will ensure a steady supply of applicants and continued legislative support. Negative homeowner responses should be responded to and the problems corrected, where possible, so that they turn into positive responses.

4.1.2 Detailed Cost Estimating

Project costs can be broken down into several categories. There will be preliminary costs associated with defining the project, starting up, and preparing the necessary plans and specifications. During the dwelling modification phase, there will be a series of readily identifiable construction-related expenses. Administrative and program management costs will spread over the length of the project. Being able to predict costs helps the project sponsor to formulate the project and prepare preapplications for funds. Recent residential sound insulation projects provide information on construction-related costs. For rough costing purposes, the following guidelines may be useful:

Contractor Profit and Overhead	20%
Contingency Fee	
New Construction	5%
Remodeled	20%
HVAC System, Complete	$5,000

To facilitate identifying and estimating these costs, a set of five sample worksheets is provided in Appendix A. Their form and use is explained below.

- Preliminary Project Cost Estimates: Appendix worksheet A1 provides a framework for estimating project costs during the preapplication and project formulation stage. Principal factors include:

  - Number of eligible dwellings anticipated;
  - Noise reduction criteria to be used;
  - Noise exposure levels;
  - Dwelling categories identified;
  - Average cost of implementing an expected modifications package;
  - Additional cost factors.

  In the block for dwelling modification breakdown, each noise zone is treated separately, since homes with similar noise exposures normally receive a similar package of treatments. Within these basic groupings the homes are further broken down by dwelling category types such as: siding with vented attic, or brick with vented attic and basement, etc. The worksheet provided in Section 2.6, Cost Estimation, can be used to predict an average insulation package cost to use in this worksheet.

  Additional cost factors including design and development costs, contractor markup, noise measurement costs, avigation easement costs, and administrative costs are identified.

- Detailed Dwelling Unit Costs: Appendix worksheet A2 consists of a set of three worksheets to be used for preparing plans and specifications and for evaluating contractor bids. One of these worksheet sets is devoted to each individual dwelling in the project. The worksheet forms the basis for identifying costs for specific improvements to the house.

  Basic information about the dwelling such as the address, the exterior noise exposure level, and the dwelling description or category should be included. Then, for each room the following information is detailed:

  - Room type (living, dining, kitchen, bedroom, etc.);
  - Shielding of outside walls due to orientation with respect to the flight track;
  - Noise Level Reduction criteria used;
  - Additional noise reduction required over sound insulation provided by existing condition;
  - For each element type, the modifications and improvements along with their costs.

  Treatments covering the entire house, or not specifically identified with any one room, are listed below this with their associated costs. These items include attic, underfloor or other vent baffles, insulation, costs for upgrading the heating, ventilation, and air-conditioning system, electrical systems, and other miscellaneous costs.

  Sheet 2 provides additional space for specific room improvement notation and costs.

  A simple floor plan should be developed on Sheet 3 and should show:

  - Exterior cladding material;
  - Type of roof or attic structure;
  - Type of floor or foundation;
  - Number, use, and square footage of rooms;

- Number and type of windows and doors;
- Flight path orientation;
- Location of noise-sensitive rooms;
- Location of other noise-entry points (chimneys, vents, etc.);
- Existing insulation features;
- North arrow.

- Construction Cost Summary: Construction costs for the project are conveniently summarized on worksheet A3. It provides space for noting costs associated with each dwelling category, by noise zone. The dwelling category can either be a specific dwelling type such as siding or brick, or it can be used for geographic groupings of homes, whichever is most appropriate. Costs used here are guided by the modification packages and estimates developed in the Detailed Dwelling Unit Costs worksheets. These costs are broken down into materials and labor per dwelling so that any overtime labor premium can be shown. These figures can be multiplied by the number of dwellings in the given category and zone. Since contingency multipliers may vary depending on the geographic distribution or the modification package, this is also identified for each housing category. Then the last column shows the cost for each category.

  Whole project costs for demolition, cleanup, equipment, inspections, insurance, permits, fees, and other miscellaneous costs, are itemized below the dwelling inventory.

- Non-Construction Costs: Worksheet A4 summarizes all non-construction costs which include all expenses not directly related to the installation of modifications in the dwellings. These costs will be important in determining funding for the project as a whole. All pre-implementation costs, design, planning and specification costs, noise measurement costs, bid preparations, review and supervision costs, and administrative costs should be listed here. Many of these can be defined in terms of a cost per dwelling so columns are included for this as well as the number of dwellings affected. For example: relocation expenses depend on the number of families to be relocated and all other dwellings may require avigation easement expenditures. Some expenses, however, do not lend themselves to this format so the cost per dwelling column can be ignored for them.

- Total Project Costs: This last worksheet summarizes the costs identified in the other worksheets and relies on them for input.

4.2 Plans and Specifications

Purpose and Use

Plans and specifications are used in three ways. They document the implementation plan and form part of the grant application package when FAA or other funds are being sought. At another stage in the project they form the basis for soliciting bids from contractors to perform the construction work. Finally, local Building Departments use these plans to issue construction permits.

Generalized Specifications and Custom Designs

For large projects with a limited number of identifiable house types, program managers may choose to use generalized modification specifications rather than having designs developed for each home individually. Such a set of generalized specifications typically outlines requirements for changes to windows, doors, walls, roofs, and other structural elements of a dwelling depending on the noise exposure zone. The specifications should allow for variations in the type of structure and the presence of shielding from the flight path. Table 4-2 gives an example of a summary table of generalized specifications used in southern California.

In order for generalized specifications to be valid and useful, the homes must be similar enough that the modifications package is appropriate for each case it is applied to. In neighborhoods where the homes differ in ways which are acoustically significant, it may not be possible to use this type of modification package. In that event, each home is analyzed individually and the dwelling modifications are custom designed. Some projects may use a combination of generalized specifications with exceptions for dwellings requiring specialized designs.

Preparation of Architectural Plans

Architectural plans, in the form of drawings and a thorough description of the existing conditions, are prepared for each dwelling. Figure 4-2 illustrates such a plan. These are used in the acoustical analysis of the sound insulation requirements for the dwelling. Later,

Table 4-2

Example Summary of Sound Insulation Applications1
Based on Generalized Specifications

Element	Noise Exposure Zone, DNL (dB)					
	Greater than 75		70-75		65-70	
	Directly Exposed	Shielded	Directly Exposed	Shielded	Directly Exposed	Shielded
Window[2] STC (dB)	40	40	45	35	35[3]	30[3]
Door STC (dB)	40	36	40	36	36[4]	30[4]
Wall Modifications	Yes	No	No	No	No	No
Attic Insulation	R-21	—	R-19	---	(R-19)[5]	---
Crawlspace Vent Baffles	Yes	Yes	Yes	No	No	No
Kitchen Vent Ducting[6]	Yes	Yes	Yes	Yes	Yes	Yes
Secondary Sliding Glass Doors[7]	Yes	Yes	Yes	No	Yes	No

NOTES:

1 These are for detached dwellings with a wood frame/exterior stucco wall structure.

2 Applicable only to openable windows. Different specifications apply to fixed pane (unopenable) windows.

3 The quoted STC ratings are for replacement windows if the existing windows are more than 10 years old. Otherwise, the specifications require a second (storm) window, with an STC of at least 25 dB, to be added.

4 If the existing door is solid core, an additional storm door should be added rather than replacing the existing door.

5 Attic insulation is not required for acoustical purposes but is added to improve thermal insulation of the dwelling.

6 Fiberglass may not be used in the kitchen vents due to the fire hazard.

7 Sliding glass doors, being of relatively large area, are usually the weakest sound insulation path in a dwelling. Addition of a secondary door will not necessarily meet sound insulation objectives, but is preferable to substituting an opaque door with fill-in of the surrounding wall.

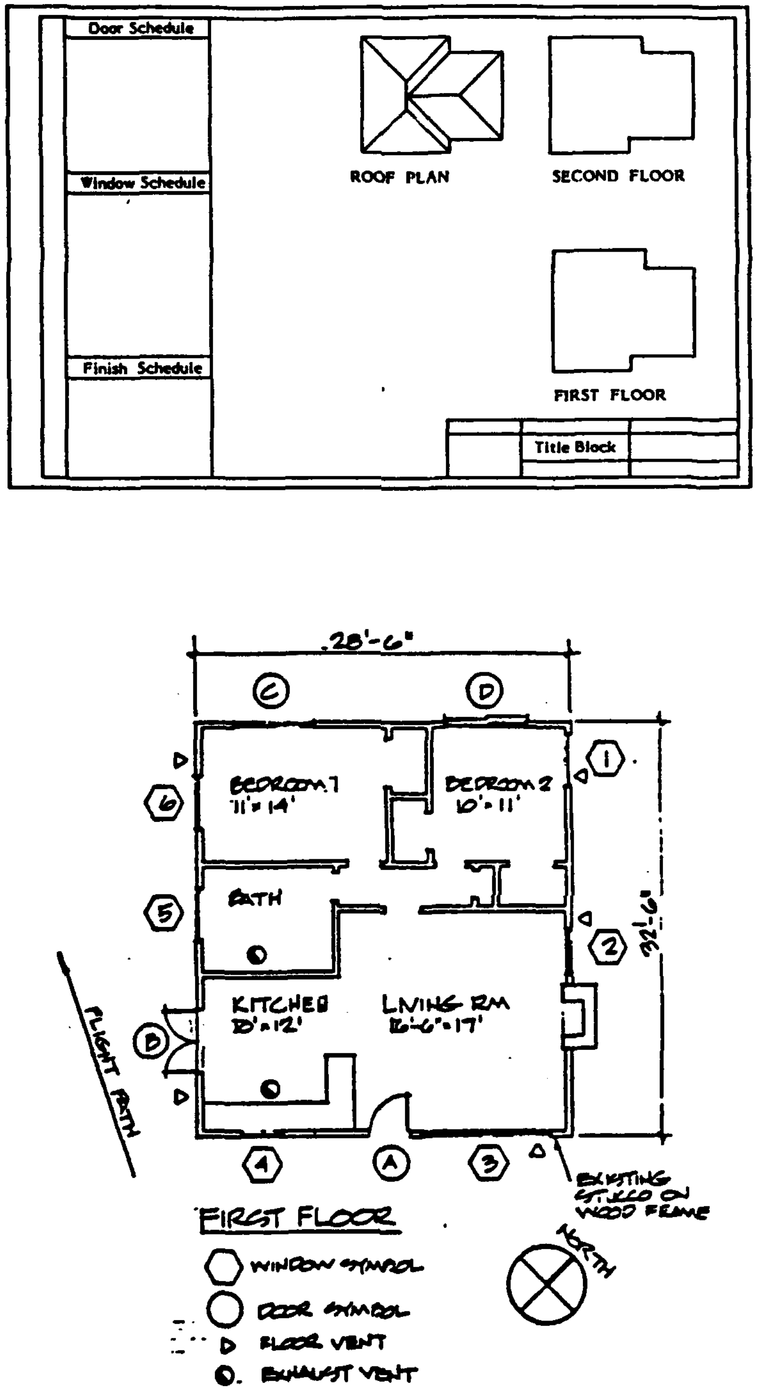


Figure 4-2. Architectural Plan Details.

they form the basis for specifying the dwelling modifications.

Floor plans are prepared in two stages. The first stage involves field-measuring each dwelling and gathering data which describes the existing physical features. Using this information, the floor plans, roof plans, window schedules, door schedules, and finish schedules are drawn. Later, the plans will be expanded to include the results of the Sound Insulation Specifications as well.

The specific items to be shown include:

1. Overall dimensions of each room except bathrooms, closets, and garage.
2. Overall dimensions of the dwelling.
3. Exterior materials and construction.
4. Swing of the exterior doors.
5. Arrangement of sash on horizontal sliding doors and windows.
6. Location of ventilating equipment (not grilles and registers).
7. Location of whole-house exhaust fans, wall-mount air conditioners, and kitchen exhaust vents.
8. Exterior elevations, on the window schedule, of each window type.
9. Location of underfloor vents (on the floor plan).
10. Location of attic vents (on roof plan).
11. Any other penetrations of the exterior envelope.
12. North arrow and orientation of aircraft flight path.
13. Schedules of existing doors, windows and rooms (Figure 4-3).

Definition of Sound Insulation Specifications

The specifications describe in detail the work, materials, and construction methods which the contractor(s) will use in modifying each home. Detailed window, door, and finish schedules, as shown in the example of Figure 4-3, will be completed to show the modifications for each element listed. Detail drawings of the installation of specialized acoustic products and modification techniques provide clear direction for implementing the insulation treatments.

Development of Implementation Plans and Schedules

Implementation schedules give more detailed information on the work to be performed on each dwelling in the program. The architectural plans and sound insulation specifications developed by the designer are normally included. The work requirements and material definitions are a part of these specifications. The shop drawings developed by the contractor are included in the project portfolio as well. They should also take into account the subdivision of work among the specialist subcontractors. The plans and specifications consist of:

- Plans
- Architectural schedules
- Specifications
- Shop drawings

The next two sections in this chapter discuss the last two topics in greater detail. Section 4.2.1 gives a detailed outline of the items to include in the statement of work requirements. Then, Section 4.2.2 tells how to develop the material definition specifications.

Submittal Review

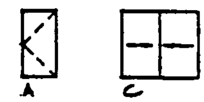
Because the construction work must meet rigid standards in order to be effective, it is important for the acoustical consultant or architect to review the contractor's shop drawing submittal carefully. This is especially true at the beginning of the project and when the contractor lacks experience with acoustical remodeling. Contractors frequently underestimate the amount of time it takes for their submittals to be reviewed and approved. It may be necessary to stress these points at the contractor briefings and to remind the contractor(s) of the submittal guidelines and deadlines.

4.2.1 Work Requirements

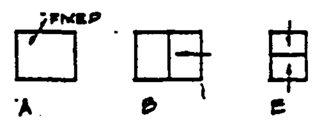
The work requirements consist of specific technical descriptions of the work to be performed and form part of the overall Plans and Specifications package. This section discusses the work descriptions along with specifications of the codes to be complied with and the documentation to be provided. Each major building trade is addressed as well as the principal structural or acoustic elements involved in the modifications.

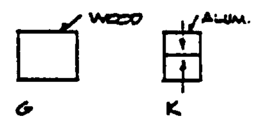
The subjects are presented in two parts: the General Specifications subsection identifies general requirements such as the scope of the work and required submittals. Then the Execution subsection outlines the topics which must be addressed in the technical directions for the work performance. The outline is presented here as a

DOOR SCHEDULE											
Existing								Modification			
	Size (N)			Type	Material			Modification Notes	Min. STC	New Type	Detail
	W.	H.	T.		Door	Frame	Glass				
A	48	80	1-3/4	HC	Wd	Wd	No	Replace Door	35	A	G, G 1-4
B	36	80	1-3/4	SC	"	"	Clr	Replace Seals			H, G 1-4
C	72	80	--	SG	Al	Al	"	None			
D	72	80	--	SG	"	"	"	Add Sec. SG Door	--	C	1



WINDOW SCHEDULE										
Existing							Modification			
	Size (N)		Type	Material		Glass Type	Modification Notes	Min. STC	New Type	Detail
	W.	H.		Sash	Frame					
1	48	60	A	Wd	Wd	DS	Replace Window	35	G	A
2	48	60	A	"	"	"	Replace Window	35	G	A
3	48	60	A	"	"	"	None			
4	36	80	B	"	"	"	None			
5	36	80	B	"	"	"	None			
6	42	72	E	"	"	3/16	Replace Window	40	K	A
7	48	60	A	"	"	DS	Replace Window	40	G	A
8	48	54	A	"	"	"	None			





FINISH SCHEDULE						
Existing					Modification	
Room	Floor	Walls	Ceiling	Ht.	Modification Notes	Detail
LR	Carp.	GB	SP	8	None	
Entry	Carp	GB	Open	--	None	
Fam	Carp/Ct	GB	SP	8	Furred Wall	E, C-1
Kit	Res	GB	Lum	7'-6"	None	
Dining	Carp	GB	SP	8	None	
BR1	Carp	GB	SP	8	None	
BR2	Carp	GB	SP	8	Add 1 layer GB	C, C-1

Figure 4-3. Door, Window, and Finish Schedules.

guide for developing work requirements for any home sound insulation project.

4.2.1.1 *Summary of the Work*

1.0 General
- 1.1 Project/Work Summary
  - A. Scope and goals of the work
  - B. Occupied condition of dwellings – The work will be completed on an occupied dwelling and consideration will be made of the necessity for cleanup and proper material and tool storage.
  - C. Addresses of the dwellings
  - D. Provisions and limitations of the Contract Documents
    1. Existing site conditions and restrictions
    2. Pre-purchase of materials and equipment, inclusion in Contract Sum.
- 1.2 Pre-Negotiated Orders – The project sponsor may choose to purchase certain specialty items, such as acoustical windows and doors, and provide them to the contractor for installation.
- 1.3 Performance Requirements for Completed Work

4.2.1.2 *Special Provisions*

1.0 General
- 1.1 General and Special Requirements – required by program sponsor or granting agency
- 1.2 Scope of the Work
  - A. Identifies the services, equipment, and materials to be provided, and refers to satisfactory compliance with the Drawings and Specifications.
  - B. Responsibilities of the General Contractor regarding any special provisions of the procurement or installation of any part of the work.
  - C. Schedule coordination responsibilities between concerned parties.
- 1.3 Specification Section Titles – Section titles and paragraphs not to be taken as correct or complete aggregation of materials and labor.
- 1.4 Water, Power, and Light Facilities – Identification of provider and declaration of provider's responsibilities.
- 1.5 Permits – Delegation of responsibility for permits, fees, etc.
- 1.6 Approval of Substitutes – The contractor must get prior approval from the sponsor or project manager before substituting for any specified or quoted item (especially important for specialty acoustic windows and doors).
- 1.7 Salvage – Identifies which party gets first right to claim.
- 1.8 Furnishing, Floor and Window Covering
  - A. Declaration of responsibility for protecting, moving, and replacing.
  - B. Handling of existing custom-made window coverings such as shutters, blinds, curtains, and draperies.
- 1.9 Off-Site Storage.

4.2.1.3 *Insulation*

1.0 General
- 1.1 Work Included – specifies labor, materials, equipment, and services to be provided.
- 1.2 Submittals – defines how contractor will document materials to be used, number of copies required, etc.
- 1.3 Quality Assurance
  - A. Identifies experience level required of insulation manufacturer (i.e., 3 years consecutive manufacturing experience).
  - B. Documentation required of R-value certification, including method used to determine R-value.

2.0 Execution
- 2.1 Installation – conformity with manufacturer's recommendations.
- 2.2 Cleanup – How often site must be cleaned, acceptable performance of cleanup, etc.

4.2.1.4 *Acoustical Caulking*

1.0 General
- 1.1 Work Included – requirement to furnish all labor, materials, equipment, and services necessary to install acoustical caulking as shown in the Drawings.
- 1.2 Submittals – number of sets of catalog

data and product samples to be provided to acoustical consultant or architect.

2.0 Execution
- 2.1 Installation
  - A. Conformity with manufacturer's instructions.
  - B. Caulking placement as shown in Drawings.
  - C. Sealant application specifics.
- 2.2 Warranty – terms and conditions of warranty.

4.2.1.5 *Steel Acoustical Doors*

1.0 General
- 1.1 Work Included – specifies the labor, materials, equipment, and services to be provided in compliance with the Specifications and work orders.
  - A. Doors and frames.
  - B. Finish hardware.
  - C. Acoustical seals, weatherstripping, and drop seals.
- 1.2 Responsibility of the Acoustical Door Manufacturer
  - A. General survey of site.
  - B. Field measurement services.
- 1.3 Shop Drawings – defines type and number of copies for documentation of materials, STC ratings, etc.
- 1.4 Quality Assurance
  - A. Experience of manufacturer
  - B. Compliance with specific ANSI or other standards.
  - C. Affidavit documentation of acoustical performance.
- 1.5 Sound Transmission Loss Test
  - A. Documentation requirements, standards citation.
  - B. Testing conditions.
  - C. Statute of limitations for using test results – Tests for specified items must apply to the exact item quoted and must have been performed within the past five years (for example).
  - D. List of approved acoustical testing laboratories.
  - E. Conditions for accepting reports from other laboratories.
  - F. Rejection of reports from unrecognized laboratories.

2.C Execution – defines acceptable standards for execution of each task identified.
- 2.1 Delivery and Storage
  - A. Provision of delivery and unloading.
  - B. Undamaged condition and protection during handling.
  - C. Inspection and repair.
  - D. Storage to prevent rust, warping, and other damage.
- 2.2 Inspection and Demolition
  - A. Inspection of existing condition.
  - B. Removal of existing doors and frames, salvage.
- 2.3 Installation
  - A. Compliance with shop drawings and manufacturer's specifications.
  - B. Alignment and anchoring.
  - C. Finish hardware.
  - D. Door and frame finish.
  - E. Threshold.
  - F. Acceptable paint products.
  - G. Final Adjustments.
- 2.4 Cleanup
- 2.5 Warranty

4.2.1.6 *Wood Acoustical Doors*

1.0 General
- 1.1 Work Included – specifies the labor, materials, equipment, and services to be provided in compliance with the Specifications and work orders.
  - A. Acoustical doors and frames.
  - B. Finish hardware.
  - C. Acoustical seals, weatherstripping, and drop seals.
- 1.2 Responsibility of the Acoustical Door Manufacturer
  - A. General survey of site.
  - B. Field measurement services.
- 1.3 Shop Drawings – defines type and number of copies for documentation of materials, installation, STC ratings, etc.
- 1.4 Quality Assurance
  - A. Experience of manufacturer.
  - B. Compliance with specific National Wood Window and Door Association or other standards.
  - C. Documentation requirements, Affidavit certification.
- 1.5 Sound Transmission Loss Test
  - A. Documentation requirements.
  - B. Testing conditions.
  - C. Statute of limitations for using test

results – Tests for specified items must apply to the exact item quoted and must have been performed within the past five years (for example).
D. List of approved acoustical testing laboratories.
E. Conditions for accepting reports from other laboratories.
F. Rejection of reports from unrecognized laboratories.

2.0 Execution – defines acceptable standards for execution of each task identified.
- 2.1 Delivery and Storage
  - A. Provision of delivery and unloading services.
  - B. Undamaged condition and protective packaging.
  - C. Inspection for damage and warping; repairs.
  - D. Storage to prevent damage and warping.
- 2.2 Inspection and Demolition
  - A. Inspection of existing condition.
  - B. Removal of existing doors and frames, salvage.
- 2.3 Installation
  - A. Compliance with shop drawings and manufacturer's specifications.
  - B. Re-use of existing subframe, molding, and trim.
  - C. Alignment and anchoring.
  - D. Latching and locking mechanisms.
  - E. Threshold
  - F. Finishing doors and frames
    1. Priming and final finish
    2. Application of sealer
  - G. Approved paint manufacturers
  - H. Finish carpentry standards
  - I. Final operating inspection and adjustments
- 2.4 Cleanup
- 2.5 Warranty

4.2.1.7 *Sliding Glass Doors*

1.0 General
- 1.1 Work Included – specifies the labor, materials, equipment, and services required to be provided.
  - A. Sliding glass doors
  - B. Acoustical seals, weatherstripping, and sealants
  - C. Door trim, molding, and casing materials
- 1.2 Submittals – defines the type of documentation required for the materials and installation methods.
- 1.3 Quality Assurance
  - A. Experience of the manufacturer
  - B. Affidavit certifying compliance with the specifications
  - C. Compliance with applicable AAMA performance and fabrication standards.
  - D. Compliance with applicable AAMA standards for air infiltration, water resistance, and load bearing.

2.0 Execution – specifies work performance requirements for all tasks involved in the work order.
- 2.1 Demolition
- 2.2 Installation
  - A. Compliance with shop drawings and manufacturer's instructions
  - B. Exterior sill and framing for secondary door
  - C. Caulking, fillers, and gaskets
  - D. Alignment, support, and anchoring
  - E. Gaps and voids
  - F. Exterior trim and molding
  - G. Interior trim, molding, and casing
  - H. Repair and patching of stucco, plaster, masonry, and drywall.
- 2.3 Cleanup
- 2.4 Warranty

4.2.1.8 *Aluminum Acoustical Windows*

1.0 General
- 1.1 Work Included
  - A. Field measurement services
  - B. Factory preglazed, assembled windows
  - C. Seals and weatherstripping
  - D. Storage and insurance
  - E. Inspection services
  - F. Repair and finish
  - G. Preparation of window schedule
- 1.2 Shop Drawings
  - A. Number of sets of shop drawings to be provided
  - B. Dimensioning of windows
- 1.3 Quality Assurance
  - A. Experience history of manufacturer
  - B. Affidavit certifying compliance with window construction standards
- 1.4 Sound Transmission Loss Tests
  - A. Documentation of test reports, testing methods used, and model

numbers of windows supplied.

- B. Conductance in accordance with appropriate standards
- C. Statute of limitations on STC rating tests for windows.
- D. List of recognized testing laboratories.
- E. Accreditation required of laboratories not on the list.
- F. Conditions for rejection of reports from unrecognized laboratories.

1.5 Miscellaneous Tests
- A. Documentation requirements (citing applicable standards)
  1. Water resistance tests
  2. Air infiltration tests
  3. Condensation resistance factor tests
  4. Overall heat transfer coefficient tests
  5. Forced-entry resistance performance tests
  6. Uniform load structural performance tests
- B. Model number verification for applicability of test results.

1.6 Field Performance Tests
- A. Specifications for number of rooms and dwellings to be tested, who should perform the tests, and conditions for accepting the test results.
- B. Repair and replacement agreements in the event of field test failure.
- C. Documentation requirements.

2.0 Execution

2.1 Responsibilities of the Acoustical Window Manufacturer
- A. Project survey of window types needed.
- B. Detailed survey of each residence for window dimensions.
- C. Documentation via window schedule.
- D. Allowable tolerance for window fit in wall openings.
- E. Storage.
- F. Liability and insurance.
- G. On-site inspections.
- H. Sash inspection and adjustment.
- I. Specialized field testing.

2.2 General Contractor's Responsibilities
- A. Demolition
- B. Window Installation
  1. Installation and match to existing conditions
  2. Liners, furring, blocking, and shimming.
  3. Back-sealing and fastening.
  4. Caulking.
- C. Repair and Finishes
  1. Treatment of voids
  2. Matching existing stucco
  3. Matching wood and aluminum siding
  4. Matching existing masonry.
  5. Caulking, insulation, molding, blocking, trim, and accessories to maintain visual continuity.
  6. Painting exterior.
  7. Adjoining surfaces
  8. Sound insulation performance of repairs and patching.
  9. Acoustical batt insulation.
  10. Acoustical caulking at frame perimeter.
  11. Finish of interior surfaces.
  12. Painting interior.

2.3 Cleanup

2.4 Warranties
- A. Installation Warranty
- B. General Contractor's Workmanship Warranty
- C. Product Warranty
- D. Supplementary Material Warranties - for materials not manufactured by the window manufacturer, such as sealants, etc.
- E. Owner's Responsibility

4.2.1.9 *Glazing*

1.0 General

1.1 Work Included - specifies the labor, materials, equipment, and services to be provided.

1.2 Submittals-type and number of copies of documentation

1.3 Quality Assurance
- A. Experience of company supplying laminated glass
- B. Affidavit certification from manufacturer that materials meet specification requirements.
- C. Compliance with applicable FGMA standards and other criteria.

1.4 Delivery, Storage, and Handling

2.0 Execution
- 2.1 Demolition – condition of exposed structural surfaces and adjacent wall surfaces.
- 2.2 New Laminated Glass
  - A. Framing, blocking, and attachment
    1. Protection from damage during handling and installation
    2. Avoiding impact, prohibition of use of pry bar.
  - B. Air infiltration limits for weatherstripping, sealants, and acoustical caulking.
    1. Application of sealant
    2. Elimination of sealant voids and surface bonding.
  - C. Matching existing interior trim.
- 2.3 Repair and Patching
- 2.4 Protection and Cleaning
  - A. Breakage protection and surface cleaning
  - B. Removal and replacement of broken glass.
  - C. Cleanliness of work area.
- 2.5 Warranty

4.2.1.10 *Gypsum Drywall*

1.0 General
- 1.1 Work Included
- 1.2 Submittals
  - A. Manufacturer's instructions to be provided to architect or engineer.
  - B. Product samples provided for approval
- 1.3 Quality Assurance
  - A. Manufacturer's experience
  - B. Fire-resistance rating compliance
  - C. Affidavit certification supplied by manufacturer regarding material compliance with specification requirements.
- 1.4 Delivery, Storage, and Handling
  - A. Packaging and labeling requirements
  - B. Storage and protection from exposure
  - C. Handling to prevent damage to edges, ends, and surfaces

2.0 Execution
- 2.1 Installation of Metal Studs
  - A. Dimensions, alignment, bracing, spacing, and plumb.
    1. Placement, fastening, reinforcement, and anchoring of studs used to frame openings.
    2. Horizontal intermediate bracing of studs.
    3. Installation, anchoring, and configuration of metal backing plates.
- 2.2 Sound Attenuation Blankets – fit and attachment requirements
- 2.3 Gypsum Wallboard Application and Finishing
  - A. ASTM standards to be met
  - B. Installation of imperfect, damaged, or damp boards prohibited
  - C. Positioning over supports, specified face out, abutment of edges, etc.
  - D. Attachment at openings and cutouts
  - E. Mounting of double layers
  - F. Sealing of perimeter and openings, treatment of expansion joints, sound flanking paths.
  - G. Fastener spacing.
  - H. Preparation for finishing and decoration
    1. Use of joint tape
    2. Use of joint compound
    3. Treatment of concealed drywall work
- 2.4 Cleanup
- 2.5 Warranty

4.2.1.11 *Painting*

1.0 General
- 1.1 Work Included
- 1.2 Submittals
- 1.3 Quality Assurance
- 1.4 Delivery, Storage, and Handling – packaging and labeling

2.0 Execution
- 2.1 Inspection
- 2.2 Surface Preparation
  - A. Cleaning and preparation procedures
  - B. Cleaning ferrous surfaces
  - C. Cleaning galvanized surfaces
  - D. Spackling and preparation of drywall
  - E. Filling cracks and preparing masonry walls
  - F. Miscellaneous surfaces
- 2.3 Application
  - A. Conformity with manufacturer's instructions.

B. Uniform coating of various surfaces.
C. Painting behind fixed and movable objects.
D. Painting inside ducts.
E. Painting back of access panels and hinged covers.
F. Finishing top, side, and bottom edges of doors.
G. Sanding
H. Surfaces which are shop-primed or touched up.
I. Matching existing color, texture and coverage.

2.4 Cleanup and Protection
A. Work areas
B. Window glass and other paint-spattered surfaces
C. Cleaning and repairing damaged work of other trades
D. Restoring painted surfaces damaged by other trades

2.5 Extra Stock
A. Volume to be provided
B. Labeling

2.6 Warranty

4.2.1.12 *Air Conditioning, Heating and Ventilation*

1.0 General

1.1 Work Included
A. Services, equipment and materials to be provided
1. Providing fresh air ventilation capability.
2. Installation of fan, ductwork, and fresh air ventilation capability.
3. Installation of central forced-air cooling.
4. Installation of central forced-air heating and cooling system
5. Responsibility for inspection and meeting HVAC goals.
B. Protection, replacement, and repair of adjacent areas.

1.2 Submittals
A. Number of copies and content of required documentation
B. Content of shop drawings
C. Required engineering calculations

1.3 Quality Assurance
A. Experience of HVAC system manufacturer
B. Requirements for Affidavit certifying compliance with specifications
C. Compliance with local building codes and energy conservation requirements.

2.0 Execution

2.1 General – meeting applicable codes and ordinances

2.2 Ductwork and Equipment
A. Construction and erection in accordance with drawings
1. Exterior condensing unit
2. Cooling, heating, and ventilation system equipment
3. Ductwork
4. Thermostat
5. Electrical work
6. Accessories (diffusers, vibration, and noise control elements, condenser pads, etc.)

2.3 Central HVAC Systems
A. Installation, location, and mounting
1. Ventilation in accordance with applicable local building codes
2. Modification of existing forced-air system
3. New exterior wall penetrations
4. Thermostat compliance with applicable local building codes
5. Mounting and location of exterior condenser unit or heat pump
6. Rain hood

2.4 Cleanup

2.5 Warranty

4.2.1.13 *Electrical*

1.0 General

1.1 Work Included
A. Services, equipment and materials to be provided
1. Connection and control of air-handling units
2. Supplementing the equipment provided by unit manufacturers
3. Installations and relocations required by drywall work
4. Low-voltage control wiring
5. Final test for operation
B. Protection and repair of adjacent surfaces and areas.
C. Compliance with local building codes.

2.0 Execution
  2.1 General – Verification and upgrade of system capability
  2.2 Wiring and Equipment
  2.3 Relocating Switches and Outlets
  2.4 Testing
  2.5 Cleanup
  2.6 Warranty

4.2.2 Materials Definition

Clear, comprehensive definitions of the materials used in the construction provide contractors with direction in how the work is to be performed. It enables them to respond more accurately to the bid request. The material definitions are also a valuable tool for the managers to use in evaluating contractor's bid proposals. They form an important part of the overall Plans and Specifications package.

The contractor should submit data for approval which substantiates the compliance of the proposed materials with the specifications and plans. Submittals normally include product catalog data, independent test laboratory reports, and other certified documentation.

Acoustically sensitive material, such as windows and doors, must be approved by the acoustical consultant before the order is placed with the manufacturer. The order, once approved, will be based on detailed architectural measurements from each dwelling. These items must be custom fit to be effective. In addition, they must be inspected for correspondence to the approved submittals as soon as they are delivered to the work site.

Sections 4.2.2.1 through 4.2.2.11 give an outline of the topics and details which must be addressed in defining the materials required to complete the work. Each of the major building elements and trades is presented with the products broken down into components. This outline is provided as a starting point and checklist for developing the materials definition part of the bid package.

4.2.2.1 *Insulation*

1.0 General
2.0 Insulation
  2.1 Type of materials to be used.
  2.2 Use of vapor barrier.
  2.3 Method to be used to achieve specified R-value (i.e., thickness).

4.2.2.2 *Acoustical Caulking*

1.0 General
2.0 Products – specifies compound composition

4.2.2.3 *Steel Acoustical Doors*

1.0 General
2.0 Products – specifies acceptable ratings, dimensions, mounting, and other characteristics.
  2.1 Steel Acoustical Doors
    A. Composition and Construction
    B. Specification of exterior use
    C. STC rating required
  2.2 Steel Acoustical Door Frames
    A. Frame composition and construction
    B. Compatibility with field-installed seals
    C. Anchoring and clips
    D. Threshold
  2.3 Seals and Weatherstripping
    A. Type and performance of seals
    B. Type and performance of weatherstripping
  2.4 Finish Hardware – compatibility with door
  2.5 Vision Panels – construction and installation

4.2.2.4 *Wood Acoustical Doors*

1.0 General
2.0 Products – specifies acceptable ratings, dimensions, mounting and other characteristics.
  2.1 Wood Acoustical Doors
    A. Composition and construction
    B. Warranted for exterior use
    C. STC rating required of assembly
  2.2 Wood Acoustical Door Frames
    A. Composition and construction
    B. Compatibility with field-installed seals
    C. Anchoring and attachment
    D. Threshold
  2.3 Seals and Weatherstripping
    A. Field-installation seals and drop seal

B. Weatherstripping type and performance
2.4 Finish Hardware
2.5 Vision Panels

4.2.2.5 *Sliding Glass Doors*

1.0 General
2.0 Products – specifies the characteristics and performance standards with which the materials and workmanship must comply.
2.1 Sliding Glass Doors
A. Construction and configuration
1. Tracking, connections, and joints
2. Secondary door configuration
2.2 Lumber Trim
2.3 Compliance with specifications and standards
2.4 Hardware – closing and locking devices
2.5 Weatherstripping
A. Composition and configuration
B. Sliding weatherstripping for operable panels
C. Compliance with applicable AAMA standards
2.6 Glass and Glazing Materials – reference applicable standards
2.7 Finishes

4.2.2.6 *Aluminum Acoustical Windows*

1.0 General
2.0 Products
2.1 General Product Requirements
A. Configuration
B. Ease of cleaning and replacement.
C. Identification and STC labeling.
2.2 Product Material
A. Type of material to be used in framing and fixtures.
B. Screws and fasteners
C. Hardware for fabrication and installation
D. Weatherstripping
E. Sealant and gasket materials
F. Window screen mesh
G. Sealant performance
H. Lumber trim
2.3 Window Construction
A. Construction design facilitating replacement or repair
B. Joints, anchoring, and sealing
1. Frame sills – weep system, etc.
2. Locking mechanisms
3. Thermal barriers between frames
4. Fit within wall
C. Sash assemblies
1. Joints and anchoring
2. Sealing and securing of sash corners
3. Interlocking of interior and exterior sashes when closed
4. Removability for cleaning
5. Prohibition of metal-to-metal contact
D. Configuration and characteristics of frame connections, functions.
1. Thermal barrier
2. Air and water infiltration
3. Shielding thermal barrier from exposure
E. Glazing
1. Factory pre-glazing
2. Glazing channels
3. Tempering
F. Locking mechanisms for removable sashes
G. Insect screens
1. Dimensions and mesh
2. Removability
H. Finish coatings
2.4 Window Performance
A. Documentation of window style and STC ratings
B. Testing conditions
C. Compliance with appropriate standards (referencing standards where indicated)
1. Transmission Loss requirements for each one-third octave band
2. Water resistance penetration performance
3. Air infiltration performance
4. Condensation resistance factor
5. Overall heat transfer coefficient
6. Forced-entry resistance
7. Uniform load structural performance

4.2.2.7 *Glazing*

1.0 General
2.0 Products
2.1 Laminated Glass
A. Compliance with required thickness and STC ratings.
B. Color and construction
2.2 Glazing Sealant

4.2.2.8 *Gypsum Wallboard and Sound-Deadening Board*

1.0 General
2.0 Products
  2.1 Gypsum Wallboard – conformity to the Drawings and to ASTM or other standards.
  2.2 Sound-Deadening Board – required dimensions, thickness
  2.3 Metal Studs – gauge and configuration
  2.4 Trim Accessories – composition and configuration
  2.5 Joint Treatment Materials – conformity to ASTM or other standards, compliance with manufacturer's recommendations
    A. Joint tape
    B. Joint compound
  2.6 Miscellaneous Materials
    A. Auxiliary materials meeting manufacturer's recommendation
      1. Wallboard screws' compliance to applicable ASTM standards
      2. Concealed acoustical sealant composition and performance
      3. Exposed acoustical sealant composition and performance
      4. Sound-attenuation blankets specifications and density

4.2.2.9 *Painting*

1.0 General
2.0 Products
  2.1 Colors and Finishes
  2.2 Color Pigments
  2.3 Paint Coordination – compatibility with primer and other substrates.
  2.4 Materials
    A. Quality
      1. Substitution of products of equivalent quality
      2. Undercoat compatibility, use of thinners
    B. Paint products considered acceptable
      1. For exterior concrete, stucco, and masonry.
      2. For exterior concrete masonry units
      3. For exterior ferrous metals
      4. For exterior zinc-coated metals
      5. For interior drywall
      6. For interior galvanized ferrous metals.
      7. For interior zinc-coated metals.

4.2.2.10 *Air Conditioning, Heating, and Ventilation*

1.0 General
2.0 Products
  2.1 Oil-Fired Split System Gas Furnace
    A. List of acceptable manufacturers
    B. Mounting and installation
    C. Casing construction
    D. Compressors
    E. Coil construction
    F. Indoor air fan – type and drive
    G. Heat exchanger and burner construction and venting
    H. Cooling section controls and electric supply safety features
    I. Gas train heating controls
    J. Filters
    K. Thermostat and fan selection switch
    L. Functioning and control of components provided by thermostat
  2.2 Split System, Cooling
    A. Air-cooled condenser
    B. Condenser coil
    C. Condenser fan and motor
    D. Compressors
    E. Safety devices
    F. Casing
    G. Liquid line, suction line, and power supply
    H. Mounting
    I. Refrigerant piping
  2.3 Air-Handling Unit
    A. Type of air-handling unit required
    B. Cooling coil assembly
    C. Evaporator fan
    D. Casing
    E. Mounting and optional fan relocation
    F. Filters
    G. Thermostat
  2.4 Split System, Heat Pump
    A. List of approved manufacturers
    B. Assembly
    C. Condenser coil
    D. Condenser fan and motor
    E. Compressors
    F. Safety devices
    G. Casing
    H. Liquid line, suction line, and power line
    I. Mounting
    J. Refrigerant piping

- 2.5 Indoor Heat Pump Air-Handling Unit
  - A. Type of air-handling unit required
  - B. Cooling coil assembly
  - C. Evaporator
  - D. Casing
  - E. Mounting and optional fan relocation for vertical discharge
  - F. Heater electric service
  - G. Filters
  - H. Thermostat
  - I. Refrigerant piping
- 2.6 Ventilation System
  - A. List of approved manufacturers
  - B. Air-handling unit performance and vibration isolation
  - C. Duct connectors and vibration isolation
  - D. Appearance
  - E. Filters and grilles
  - F. Thermostat
  - G. Rain cap
- 2.7 Noise and Vibration Control
  - A. Mechanical equipment
  - B. Sound rating of exterior-located heat pumps and condensing units
  - C. Vibration isolation of fans and compressors
  - D. Flexible ductwork connections
  - E. Design of air grilles, diffusers, and registers
  - F. Noise levels for fans, ducts, and registers
  - G. Insertion loss around new penetrations of exterior walls
- 2.8 Sheetmetal ductwork
- 2.9 Flexible Ductwork
  - A. Fire hazard rating
  - B. Lengths supplied and galvanizing of ends
  - C. Insulation
  - D. Physical characteristics
    1. Temperature range
    2. Maximum working pressure
    3. Bursting pressure
    4. Maximum vacuum
    5. Crush to failure pressure
    6. Bending radius
- 2.10 Air Distribution System
  - A. List of approved manufacturers
  - B. Finish

4.2.2.11 *Electrical*

- 1.0 General
- 2.0 Products
  - 2.1 General
    - A. Compliance with codes
      1. NBFU
      2. NEMA
      3. NEPA
      4. U.L.
      5. ANSI
      6. All local governing codes

4.3 Advertising For Bids

After the plans and specifications are finished, contractors are invited to submit competitive bids for the work. The package of bid documents usually includes the Advertisement or Invitation to Bid, Instructions to Bidders, the bid form, other sample bidding and contract forms, and the proposed Contract Documents including any Addenda issued prior to receipt of bids. The Contract Documents proposed for the Work consist of the Conditions of the Contract (General, Supplementary, and other Conditions), the Drawings, the Specifications, and all Addenda issued prior to and all Modifications issued after execution of the Contract.

Bid responses in other home sound insulation projects have shown that most contractors who are suited to the type of work involved are not experienced with some of the specialized products and services required. They may underestimate or overestimate the detailed workmanship involved in installing acoustical windows and doors, for example. Also, few contractors are familiar with the stringent bid documentation requirements for a project operating under a federal grant. For these reasons, a pre-bid conference with potential contractors is strongly recommended. The briefing should cover the basic work requirements, material specifications, and contract compliance, and should include visits to the prospective dwellings. Naturally, all bidders should visit the sites as a group to minimize the intrusion on the homeowners.

4.4 Contractor Selection and Approval

Once bids have been received they must be analyzed carefully to ensure that the contractor has understood and responded to the project requirements and specifications. Experience shows that the number of bids received is often smaller than anticipated due to some aspects of the project such as purchasing large quantities of specialized products and construction time constraints.

For most home insulation projects a General Contractor will be chosen who will be responsible for obtaining and managing all of the subcontract trades involved. This simplifies organizing the construction phase and the coordination of the various tasks. If the project is too limited for a General Contractor, the organizing agency can execute contracts with the individual trade contractors. This second approach will require that the funding agency provide the necessary construction management so that scheduling and performance are closely supervised. The trades involved are:

1. Carpentry – Installs drywall, windows, wood doors, sliding glass doors, vent baffles, and wood trim. The carpenter usually installs the specialized acoustic windows and doors under the supervision of the manufacturer's local representative.
2. Electrical.
3. Insulation – Installs attic and underfloor insulation.
4. Air Conditioning and Ventilation
5. Fireplace Damper – This service can be provided by specialists in the trade.
6. Painting
7. Drapery and Window Coverings – Removes and reinstalls specialized window coverings.

Because most contractors have limited experience with sound insulation work they often include a high construction cost contingency on the actual work required. This is common practice in the construction trades and ensures that the contractor realizes an adequate profit for the work undertaken. Typically, cost contingencies and profit combined represent about 30 percent of the total cost.

Construction costs are also dependent on the level of construction activity in the community. A healthy market will always generate higher bids than if the market is depressed.

Another possible source of disagreement between predicted costs and bid proposals is the difference between standard cost estimate methods and estimates based on experience gained from previous dwelling insulation projects. Generally, most contractors use construction cost data tabulated in Means <u>Construction Costs</u> guidebook as the basis for their estimates. Data contained in these guidebooks are taken from actual construction projects and are broken down by work item and trade. Means guidebooks are a commonly accepted standard in the construction industry for determining project construction costs.

Means costs generally do not take into account the inherent inefficiencies (e.g., dealing with homeowners, cleaning up daily, missed appointments) of residential remodeling. There is also a considerable cost increase, roughly 10 percent, if the dwellings are spread apart and travel time between them is significant. It is more accurate to base cost estimates on modifications of Means estimates which are based on experience with residential sound insulation programs.

4.5 Scheduling

A proposed construction schedule should be organized to make sure the tasks of the various construction trades are coordinated to mesh efficiently. The schedule must show the expected delivery times of specialty items such as acoustic windows and doors. These items typically require long delivery times – up to four months. The project manager should review the schedule for compatibility with project objectives and for minimum inconvenience to the homeowners.

Timely submittals to local building authorities should be taken into consideration. Normally, the general contractor takes responsibility for submitting copies of the plans and specifications and securing the required building permits from the local building department.

Overall Project Schedule

There are a number of tasks to be scheduled (or considered) for the overall program. Table 4–3 lists them in a general chronological order. The entries are self-explanatory. Many of them will be performed concurrently. Figure 4–4 shows these same items in the form of a flowchart with some entries grouped together if they are likely to be performed within the same timeframe. The flowchart entries are abbreviated, but the item numbers correspond to the table entries for easy reference.

Several of the schedule items may not apply to all projects, depending on the specific project structure and funding. For example, not every dwelling insulation project will involve a pilot study. Similarly, the schedule entries for FAA funding applications stages can be ignored if FAA funds are not being used.

Table 4-3

Chronological List of Project Schedule Items

1. Initial conceptual planning
   - identify possible funding sources
   - estimate total number of eligible homes
   - get list of acoustical consultants, architects, and mechanical/electrical engineers
   - attend informational seminars
2. Pre-application to FAA
3. Conduct housing survey
4. Decide whether or not to do a pilot project
5. Design pilot, determine number of houses, funds available
6. Apply to FAA for project approval and funding.
7. Decide whether or not to use an outside consultants
8. Put out RFP for consultant services
9. Set up some sort of office and develop plans for office staff
10. Hire (or acquire) office staff and hire consultant(s).
11. Advertise program to the public
    - hold public meetings
    - get newspaper and TV coverage
12. Solicit participants (homeowners)
13. Review applicants for dwelling insulation
14. Select dwellings and alternates, and prioritize
15. Inspect homes to see if acceptable for pilot study
16. Perform noise measurements
17. Pre-modification survey
18. Determine sound insulation improvements required for each house.
19. Prepare plans and specifications for each house
20. Prepare work requirements and material definitions
21. Develop overall project schedule
22. Prepare bid package
23. Submit bid package to local building department for review and approval
24. Advertise for bids
25. Pre-bid briefings and site visits
26. Review bids and select winning contractor(s)
27. Give project construction seminar to winning contractor
28. Place order for specialized materials, if necessary
29. Inspect delivered materials before installation
30. Install modifications
31. Inspect work during construction
32. Post-modification final inspection
33. Post-modification sound measurements
34. Post-modification opinion survey
35. Assess program
36. Plan for continuing program, if appropriate

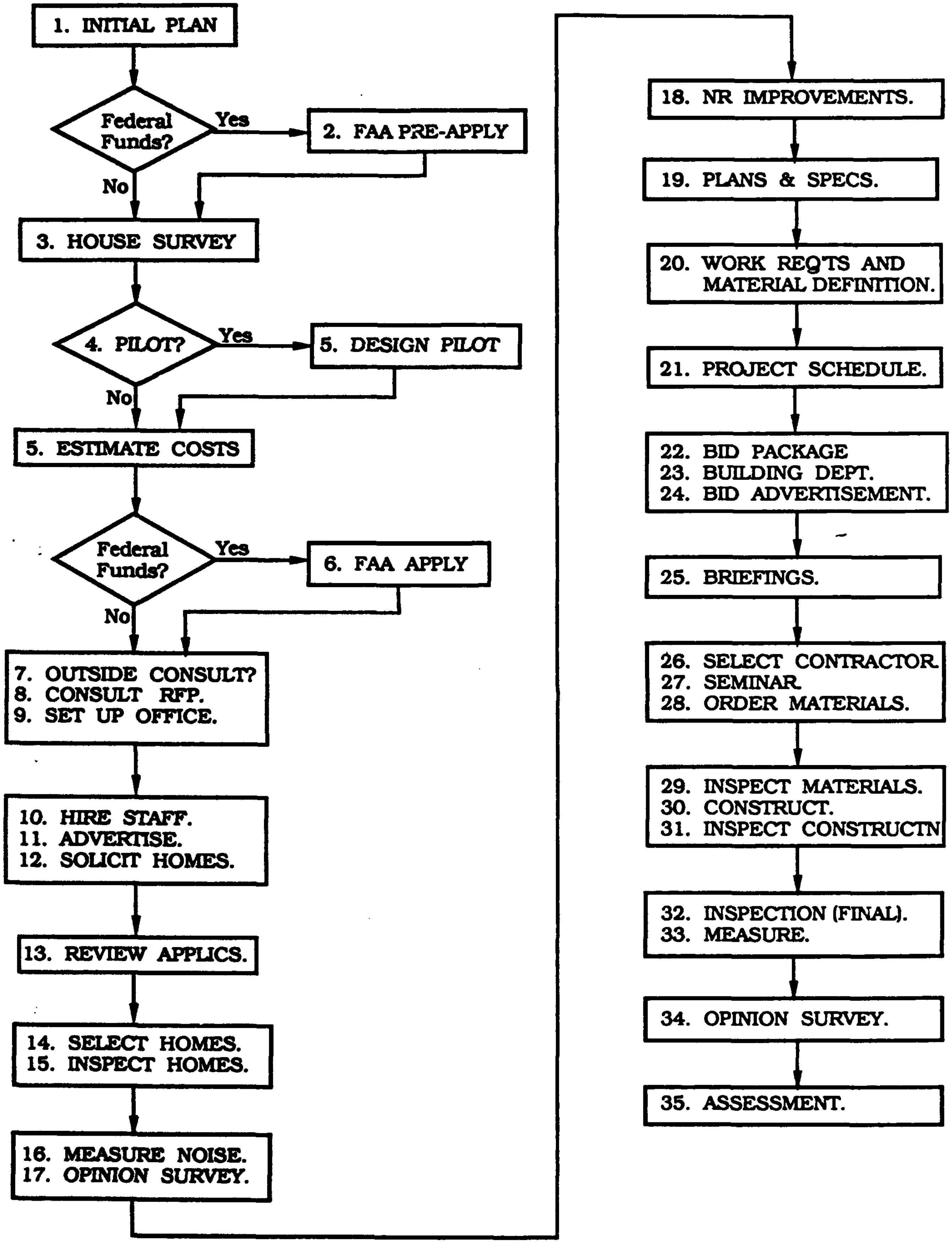


Figure 4-4. Program Schedule Flowchart.

Construction Schedule

The flowchart in Figure 4-5 shows the six basic stages of modifying a dwelling. These stages are:

- ordering, receiving and inspecting building elements;
- pre-demolition;
- demolition;
- construction;
- cleanup; and
- post-construction.

In order to minimize the length of time taken to finish the dwelling modifications, the work should not start until all the special-order items, such as acoustical windows and doors, are delivered, inspected, and approved. Past experience shows that, when construction commences on part of the work while waiting for these products, the project often gets interrupted and delayed for many weeks. This should be avoided whenever possible.

The coordinated work of a number of different building trades will be required to implement the full dwelling modifications package. These tasks need to be scheduled within the construction stage to facilitate efficient work performance. The treatments which might be required in the modification design include:

- HVAC
- attic/ceiling
- roof
- underfloor
- windows
- doors
- exterior walls
- interior walls

Of these construction tasks there are only two – HVAC and interior wall modifications – that should be given a particular place in the construction sequence. If the HVAC system modifications require changing or installing ductwork, this must be done before installing insulation or other attic treatments. It is best to schedule the HVAC work first in the construction schedule.

Conversely, the interior wall modifications should be scheduled last. This is because the window and door openings cannot be framed and trimmed until the new windows and doors are in place. The final window and door interior trim can be performed when the wall is finished.

Other than these considerations, the order of the remaining construction tasks can be left up to the general contractor or scheduled according to constraints that are specific to the project in question.

4.6 Construction Inspections

4.6.1 Work Supervision

Supervising the construction phase of the project is important to the accomplishment of the program goals. The supervisor should monitor the soundproofing efforts closely to ensure that the modifications are being done in accordance with the plans and specifications and also to minimize the intrusion on the homeowners. A technically knowledgeable project manager, the architect, or the acoustics consultant are the best choices for this assignment.

The success of the sound insulation project depends on the correct execution of the specified modifications. Acoustically superior products, such as specialized windows and doors, must be installed properly if their benefits are to be realized. The importance of this cannot be overstressed. Similarly, secondary wall and ceiling treatments need to be applied exactly as instructed with proper resilient mounting and edge sealing in order to be fully effective. Since many contractors have little or no experience with these items and methods, supervision of the work in progress ensures proper work performance and avoids unnecessary delays.

Cleaning up at the end of each day and minimizing the inconvenience to the residents should be given a high priority. If the work crews are unaccustomed to working in occupied houses it may be necessary for the supervisor to remind them of the importance of this. The supervisor should also deal with unforeseen conditions as soon as they are discovered. The project manager and general contractor should prenegotiate terms and conditions for handling the costs associated with unforeseen conditions requiring a change order to complete such work. As an example, wood framing around a window may be rotted and need replacement to support the weight of the new acoustic window. This would have probably been an unforeseen condition when the general

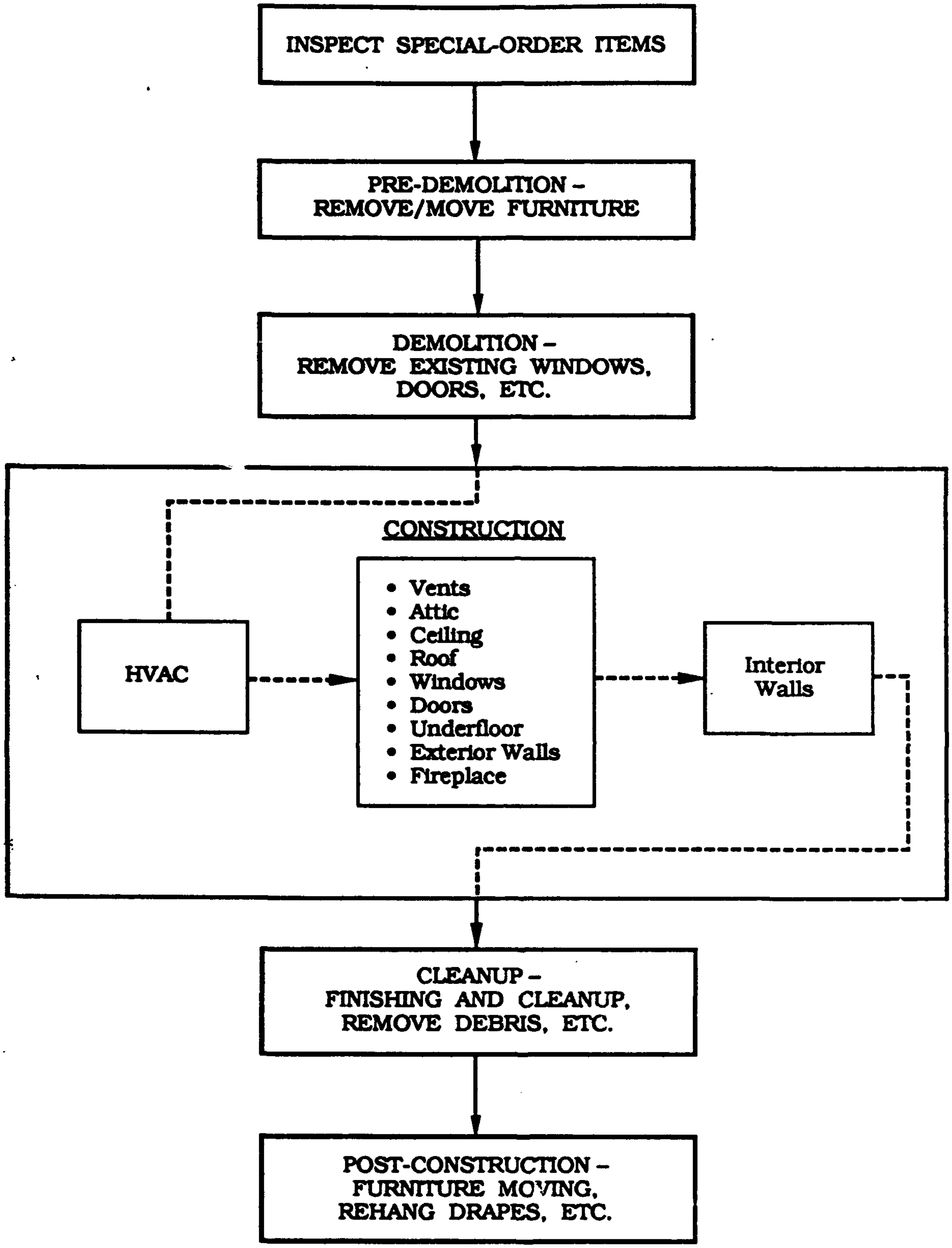


Figure 4-5. Construction Schedule Flowchart.

contractor prepared his bid. This will help shorten or eliminate delays that would further inconvenience homeowners and increase project costs as well.

4.6.2 Inspections

Inspection Tasks and Documentation

There are a number of inspection tasks for the project management to be concerned with. Inspections are needed prior to starting the construction phase, during construction, and after the modifications are completed. The contractor should be responsible for meeting local building code requirements and inspections are the responsibility of the local building department. Beyond this, regular field inspections and consistent documentation will ensure quality control and uncover problems as they develop. The tasks involved include the following:

- Review and process all submittals and shop drawings that are required by the Specifications.
- Inspect all materials before they are installed to ensure that they comply with approved submittals. This is particularly important for specialty products such as acoustical windows and doors.
- Inspect all work covered by shop drawings to ensure that it complies with approved shop drawings.
- Observe all work in progress to verify that it meets the requirements and intent of the Contract Documents.
- Issue a report to the General Contractor, in writing, of any part of the work in progress that does not conform to approved submittals, shop drawings, or Contract Documents.
- Prepare and issue to the General Contractor any clarification or interpretation of the Contract Documents.
- Consider and evaluate the Contractor's suggestions for modifications to the Contract Documents.
- Take photographs of the work in progress and the completed project.
- Review applications for payment to ensure that they agree with the work actually done and materials actually received.
- Prepare punch lists* at the appropriate time for each unit, distribute the lists to the General Contractor for execution, verify that punch list items are complete, and then certify the General Contractor's final invoice for payment.
- Visually inspect each unit before expiration of the guarantee/warranty period and issue a report describing all elements that are found to be in non-conformance, the reasons for their non-conformance, and a determination of the causes.

Obviously, conducting inspections is a significant part of the overall work effort. Such inspections are, however, vitally important to the success of the program and should not be neglected. A typical pilot study of up to 50 homes requires a staff of two or three knowledgeable persons just to conduct ongoing inspections.

Construction Phases

The field inspector should allocate time among the residences being modified according to the major phases of construction and material inspection, namely:

1. Inspection of Materials – before installation.
2. Pre-Demolition – Removal/moving of furniture, etc.
3. Demolition – Removal of existing windows, doors, etc., and enlargement or reduction of openings to accept new elements.
4. Construction – Installation of new elements.
5. Cleanup – Finishing and cleanup. Removal of debris,etc.
6. Post-Construction – Furniture moving, etc.
7. Final Inspection and Punch List

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* A Home Inspection Punch List is provided in Appendix C as an inspection aid. It consists of a detailed list of items to be checked concerning proper installation and operation of all modified items.

4.7 Post-Construction Noise Monitoring

After construction is completed, measuring the exterior and interior noise levels during aircraft flyovers will indicate the noise reduction improvement. All measurements should be conducted according to the methods described in Section 2.4. If noise measurements were performed prior to the modifications, the post-construction measurements should be conducted under the same conditions. Setup details which need to be duplicated include:

- The same houses should be remeasured.
- Weather conditions should be similar.
- The microphones should all be in the same places.
- There should be the same furniture in the room.
- All windows and doors should be tightly closed.
- Any noisy appliances such as refrigerators and ticking clocks, which were disabled, should be disabled again.
- A comparable number of flight events should be successfully recorded so there are similar number of samples in the average noise reduction calculation.
- Before and after measurements should compare takeoffs to takeoffs and landings to landings.

Post-modification measurements can indicate which rooms received the most improvement, which may point toward the effectiveness of specific modifications. Assess this cautiously, however, since the cause-and-effect relationship may not be a simple one.

4.8 Community Surveys

Soliciting the opinions of the residents who participate in the sound insulation project is a very effective means of assessing the success of the sound insulation efforts. A pre-modification survey shows the problems people have with noise in their homes and a post-modification survey indicates how well they feel their problems have been addressed. Sample survey questionnaires have been provided in Appendix F. Such surveys are easy to conduct and have proven worthwhile. The forms can be mailed to participants and the percentage of responses is generally high. Pre-modification opinions can be collected anytime before construction begins. Post-modification responses should be solicited about three months after the modifications are completed. One of the most important uses of such a survey is as a beneficial community relations tool for documenting the success of the program and encouraging other homeowners to participate.

REFERENCES

1. "Guidelines for Considering Noise in Land-Use Planning and Control", Federal Interagency Committee on Urban Noise, June 1980.

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3. Sharp, B.H., Kohli, V.K., and Stusnick, E., "A Study of Soundproofing Requirements for Residences Adjacent to Commercial Airports", Wyle Research Report WR 81-39, prepared for the U.S. Environmental Protection Agency, August 1981.

4. 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 Transportation Report FHWA-TS-77-220, prepared by Wyle Research, March 1978.

APPENDIX A1

Preliminary Project Cost Estimates

Preliminary Project Cost Estimates

Project: ____________________

Number of Dwellings: ____________________

Noise Reduction Criteria: ____________________

I. DWELLING MODIFICATIONS:

Noise Zone	Dwelling Category	Number Dwell	Avg Cost per Dwel	Cost
	1 2 3 4 5 6			
	1 2 3 4 5 6			
	1 2 3 4 5 6			
			SUBTOTAL:	

II.	Contractor Contingency Mark-up......................	
III.	Architectural/Engineering Design....................	
IV.	Preparation and Review of Plans & Specifications....	
V.	Noise Measurements (pre and post-modification)......	
VI.	Avigation Easement Costs............................	
VII.	Project Management Costs............................	
VIII.	Permits, Fees, Insurance, Bonds, etc................	
IX.	Miscellaneous Costs	
	TOTAL:	

APPENDIX A2

Detailed Dwelling Unit Costs

DETAILED DWELLING UNIT COSTS - Sheet 1

Project: ______________________________

Address: ______________________________

Exterior Noise Level: ______________________________

Square Foot Area: ______________________________

Description/Dwelling Type: ______________________________

I. LIST OF MODIFICATIONS:

Room Type	Shld	Criteria	Additn'l NR Req'd	Element	Description	Cost
Living Room				Windows Doors Walls Ceiling ________		
Dining Room				Windows Doors Walls Ceiling ________		
Kitchen				Windows Doors Ceiling ________		
Bedroom #1				Windows Walls Ceiling ________		
Bedroom #2				Windows Walls Ceiling ________		

SUBTOTAL:	
II. Baffles..............................	
III. HVAC..............................	
IV. Insulation..............................	
V. Electrical System..................	
VI. Contingency..........................	
VII. Permits, Fees, etc..................	
VIII. Miscellaneous..........................	
IX. Subtotal from additional sheets....	
TOTAL:	
COST PER SQUARE FOOT:	

DETAILED DWELLING UNIT COSTS - Sheet 2

Project: ______________________________

I. CONTINUED LIST OF MODIFICATIONS:

Room Type	Shld	Criteria	Additn'l NR Req'd	Element	Description	Cost

SUBTOTAL:

DETAILED DWELLING UNIT COSTS - Sheet 3

Project: ______________________________

I. FLOOR PLAN

II. Address ______________________________

III. Description: Type - ______________________________

Exterior Cladding - ______________________________

Roof - ______________________________

Foundation - ______________________________

Square Footage - ______________________________

APPENDIX A3

Construction Cost Summary

CONSTRUCTION COST SUMMARY

Project: ____

Noise Reduction Criteria: ____________________________

Contractor(s): ____

I. DWELLING INVENTORY:

Category	Noise Zone	Mat'ls per	Labor per	Labor Mult	Number Dwell	Conting Mult	Cost*
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

SUBTOTAL: ______

II. Demolition...................... ______
III. Clean-up...................... ______
IV. Equipment...................... ______
V. Inspections...................... ______
VI. Insurance...................... ______
VII. Permits, Fees, etc.............. ______
VIII. Miscellaneous Costs .... ______

TOTAL: ______

$$* \quad \text{Cost} = \left\{ \begin{pmatrix}\text{Mat'ls}\\ \text{per}\end{pmatrix} + \left[\begin{pmatrix}\text{Labor}\\ \text{per}\end{pmatrix} \times \begin{pmatrix}\text{Labor}\\ \text{Mult}\end{pmatrix} \right] \right\} \times \begin{pmatrix}\text{Number}\\ \text{Dwell}\end{pmatrix} \times \begin{pmatrix}\text{Contg}\\ \text{Mult}\end{pmatrix}$$

APPENDIX A4

Non-Construction Costs

NON-CONSTRUCTION COSTS

Project: ____________________

Number of Dwellings: ____________________

Noise Reduction Criteria: ____________________

Item	Cost per Dwell	Number Dwells	Cost
1. Modification Designs: 65-70 dB			
71-75 dB			
76+ dB			
2. Prepare & Review Plans & Specs			
3. Prepare Bid Documents			
4. Pre-bid Conference Costs			
5. Real Estate Consultant			
6. Architect/Engineer Consultant			
7. Noise Measurements			
8. Inspection Fees			
9. Relocation Expenses			
10. Administrative Expenses			
11. Avigation Easements			
12. Contingencies			
13. Insurance			
14. Bond Expenses			
15. Miscellaneous Expenses			
		TOTAL:	

APPENDIX A5

Total Project Costs

TOTAL PROJECT COSTS

Project: ______________________________

Number of Dwellings: ______________________________

Noise Reduction Criteria: ______________________________

I. Construction Costs	________
II. Non-Construction Costs	________
III. Miscellaneous	________
TOTAL:	________
COST PER DWELLING:	________

APPENDIX B

Bibliography

APPENDIX B

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APPENDIX C

Home Inspection Punch List

Home Inspection Punch List

HOMEOWNER: ______________________

ADDRESS: ______________________

INSPECTION DATE(S): INSPECTOR: ______________________

1. ________ 2. ________ 3. ________ DATE REQUESTED: ______________________

(NOTE TO INSPECTOR: Before starting punch list review, delete all items not applicable to this project by checking "N/A".)

****

I. ACOUSTICAL WINDOWS

PART A

	YES	NO	N/A
1. Were all required primary acoustical windows installed?	___	___	___
2. How many? Primary ___STC 45 ___STC 40 ___STC 35 ___STC 30 ___Other			
3. Have STC test reports and rating from a recognized acoustical laboratory been provided for each window type?	___	___	___
4. Are units cleanly and properly installed?	___	___	___
5. Are all cracks and screw holes caulked?	___	___	___
6. Is overall caulking job a clean one?	___	___	___
7. Is the gap between the secondary and primary frame correct?	___	___	___
8. Are there weep holes at the bottom of the frame?	___	___	___
9. Are weep holes clear?	___	___	___
10. Do all units operate properly?	___	___	___
11. Do all locks and latches operate properly?	___	___	___
12. Is there proper clearance for operation of all units?	___	___	___
13. Is glazing correct for required STC rating, location, or application?	___	___	___
14. Is finish required color?	___	___	___
15. Is metal work clear of any defects?	___	___	___
16. Were all windows cleaned?	___	___	___
17. Where non-glass glazing is used, has Owner received cleaning instructions and information?	___	___	___
18. Have screens been provided where required?	___	___	___
19. Have sills been lowered or window openings enlarged where required?	___	___	___
20. Has all trim and sill work been replaced to match existing?	___	___	___

PART B

21. Other ____

____

Explain any "NO" answers above ____

____

____

____

____

****

II. DOORS

PART A — YES / NO / N/A

1. Were all required doors installed? ___ ___ ___
2. How many?
   ___STC( ) ___STC( ) ___STC( ) ___Storm ___Sliding Glass
3. Have STC test reports and rating from a recognized acoustical laboratory been provided for each door type? ___ ___ ___
4. Are units cleanly and properly installed with a good tight fit all around? ___ ___ ___
5. Have new doors been installed with all hinges, seals, gaskets, thresholds, weatherstripping, etc., required to achieve required STC rating and complete installation? ___ ___ ___
6. Do all doors operate properly? ___ ___ ___
7. Do all locks, deadbolts operate properly? ___ ___ ___
8. Is there proper clearance for operation of all doors and parts without binding or causing damage to adjacent surfaces? ___ ___ ___
9. Have door stops been installed where required? ___ ___ ___
10. Is glazing correct for required STC rating, location, or application? ___ ___ ___
11. Have existing doors been weatherstripped where required? ___ ___ ___
12. Were all doors cleaned? ___ ___ ___
13. Has all trim work been replaced to match existing? ___ ___ ___
14. Have new doors been weatherproofed and painted? ___ ___ ___
15. Are storm doors weathertight? ___ ___ ___
16. Has closer, safety chain, and locking latch been installed on storm doors? ___ ___ ___

PART B

17. Other ____
    ____

Explain any "NO" answers above ____
____
____

****

III. WALLS AND CEILINGS

PART A — YES / NO / N/A

1. Did Contractor request inspection of wall/ceiling components? ___ ___ ___
2. Was gypsum drywall installation acceptable? ___ ___ ___
3. Were all seams taped and wall perimeters caulked? ___ ___ ___
4. Is clearance between existing and new furred-out walls acceptable? ___ ___ ___
5. If not, were defects corrected and a second inspection completed and accepted? ___ ___ ___
6. Were all switches, outlets, grilles, vents, lights, etc., relocated with wall modification and are they operational? ___ ___ ___
7. Is gypsum drywall painting acceptable? ___ ___ ___
8. Was surface redecorated in a similar manner and style to previous surface? ___ ___ ___
9. Was all trim, siding, etc., replaced or installed to match previous or adjacent surfaces? ___ ___ ___

PART B

10. Other ____
    ____

Explain any "NO" answers above ____
____

****

IV. INSULATION

PART A

	YES	NO	N/A
1. Is all insulation required type, R-value, or thickness?			
- Attic	___	___	___
- Crawlspace	___	___	___
- Walls	___	___	___
- Airducts	___	___	___
2. Is insulation installed per manufacturer's recommendations?	___	___	___
3. For rolled insulation, is vapor barrier facing toward the heated living area?	___	___	___
4. Are all recessed heat-producing fixtures baffled and clear?	___	___	___
5. Are all soffit/eave vents baffled and clear? (2½ inches)	___	___	___
6. Are all chimneys/flues baffled and clear? (3 inches)	___	___	___
7. Are all ducts insulated properly?	___	___	___
8. Is ventilation in the attic adequate?	___	___	___
9. Is the access hatch framed properly and does it fit tightly in place?	___	___	___

PART B

10. Other ____

Explain any "NO" answers above ____

****

V. LOUVERS (ACOUSTICAL OR VENT)

PART A

	YES	NO	N/A
1. Do acoustic louvers meet minimum sound transmission loss requirements?	___	___	___
2. Have louvers been recessed into exterior wall or installed so as to avoid injury to persons or damage to the louver?	___	___	___
3. Is color correct?	___	___	___
4. Are all finishes undamaged?	___	___	___
5. Is required insect screening provided?	___	___	___
6. All joints filled tightly with sealants and fillers?	___	___	___

PART B

7. Other ____

Explain any "NO" answers above ____

****

VI. FIREPLACE/CHIMNEY MODIFICATIONS

PART A	YES	NO	N/A
1. Was manual operable damper modified or new installed?	___	___	___
2. Does damper close tightly against frame?	___	___	___

PART B

3. Other ____

____

Explain any "NO" answers above ____

____

____

****

VII. KITCHEN EXHAUST VENTILATION

PART A	YES	NO	N/A
1. Was noise control duct added to existing kitchen ceiling fan?	___	___	___
2. Was noise control baffle including insect screen added to existing kitchen wall.fan?	___	___	___
3. Does combustion air grille or duct draw true outside air?	___	___	___

PART B

4. Other ____

____

Explain any "NO" answers above ____

____

____

****

VIII. VENTILATION (NEW OR MODIFIED HVAC SYSTEM)

PART A	YES	NO	N/A
1. Have all permits been acquired and installation been approved by governing agencies?	___	___	___
2. Has equipment been installed properly, per approved shop or diagrammatic sketches?	___	___	___
3. Have all ducts been insulated and sound reduction elements been installed as required?	___	___	___
4. Has all patching of surfaces disturbed for installation of equipment been completed?	___	___	___
5. Has fresh-air intake and exhaust been provided?	___	___	___
6. Has damper been installed in fresh air duct intake and exhaust?	___	___	___
7. Are exterior condensing units level and mounted on concrete pads?	___	___	___
8. Has control system been modified to permit operation of fan system(s) independent of heating or cooling functions?	___	___	___
9. Have all the supply and return registers been installed in each room?	___	___	___
10. Has vibration isolation been installed where required?	___	___	___
11. Has perimeter of outside air intake and exhaust been caulked?	___	___	___
12. Has drainage been provided for cooling coil condensation?	___	___	___
13. Has system been tested and approved?	___	___	___
14. Is air flow evident at each supply and return register?	___	___	___
15. For gas-fired furnaces, has the bottom plenum been sealed to minimize combustion by products entering the dwelling? (Applicable only to some manufacturers' products.)	___	___	___

VIII. VENTILATION (Continued)

PART B

16. Other ____

____

Explain any "NO" answers above ____

____

____

____

****

IX. GENERAL

PART A

	YES	NO	N/A
1. Was the work area left clean and in good order?	___	___	___
2. Were demolition materials properly disposed?	___	___	___
3. Was work completed in a timely manner?	___	___	___
4. Was sponsor contacted to make progress inspections?	___	___	___
5. Has Owner been instructed on use of any new equipment or materials, e.g., HVAC system, thermostats, windows, doors, etc.?	___	___	___
6. Were all operation manuals and warranties left with the Owner?			
HVAC system	___	___	___
Windows	___	___	___
Doors	___	___	___
Other	___	___	___
______________________	___	___	___
______________________	___	___	___
______________________	___	___	___

PART B

COMMENTS: ____

____

____

****

Contractor must correct items listed in Part B of each item of work before requesting a second verification.

****

All discrepancies as indicated above have been corrected as of ______________________.
(date)

Contractor's Firm ____

Contractor's Representative's Signature ____

****

Discrepancies have been corrected and work is accepted by ______________________________

on this day ______________________. Please deliver completed copies of the following:

1. Subcontractor/Supplier Disclosure Form (Contractor).
2. Affidavit of Wages Paid (Contractor and Subcontractors).
3. Other ____.

APPENDIX D

Housing Survey Form (Windshield Survey)

HOUSING INVENTORY WORKSHEET

City:________________ Observer:________________ Date:____________

Community:________________ Ldn Zone: < 60 65 70 75 >

Street:________________ Side: N S E W

CATEGORY								COUNT
Type	Wall	Roof	Wndw	Floor	Size	Storms?	Chim?	

HOUSE TYPE:
- One Story: 1S
- Two Stories: 2S
- Three Stories: 3S
- Split Level: SL
- Duplex (or row end): DU
- Row, Townhouse: TH

WALL:
- Alum. or Wood Siding: SD
- Brick Veneer: BR
- Brick Veneer + Siding: BS
- Stucco: ST
- Block: BL
- Poured Concrete: CN

ROOF:
- Vented Attic: VA
- Single Joist, Light: SJL
- Single Joist, Heavy: SJH
- Exposed Ceiling, Light: ECL

WINDOW:
- Wood Frame: WD
- Alum. Frame: AL
- Jalousie: JA
- Casement: CA

FLOOR:
- Basement: BA
- Crawlspace: CR
- Concrete Slab: CO

SIZE:
- Small: 0K
- Medium: 1K
- Large: 2K

STORMS:
- All: ✓
- Some: S
- None: –

CHIMNEY:
- Yes: ✓
- No: –

APPENDIX E

Glossary

APPENDIX E

Glossary of Acoustical Terminology

Absorption Coefficient – The sound-absorbing ability of a material, defined as the ratio of the incident sound energy absorbed or otherwise not reflected by the material to the incident sound energy at the surface of the material. Unless otherwise specified, a diffuse sound field is assumed. Values of absorption coefficient are a function of the frequency of the incident sound. The values of sound absorption coefficients usually range from about 0.01 (for hard smooth surfaces) to about 1.0 (for thick absorptive fiberglass).

Acoustical Treatment – The application of design principles in architectural acoustics to reduce noise or vibration and to correct acoustical faults in spaces.

Acoustics – The science of sound, including the generation, transmission, and effects of sound waves, both audible and inaudible.

Aerodynamic Noise – Noise generated in moving air by turbulent flow conditions. Aerodynamic noise in a high-velocity HVAC system can be generated at abrupt turns, dampers, flow constrictions, and room diffusers.

Airborne Sound – Sound radiated initially into and transmitted through air rather than through solids or the structure of the building.

Ambient Noise Level – The level of noise that is all-encompassing within a given environment for which a single source cannot be determined. It is usually a composite of sounds from many and varied sources near to and far from the receiver.

American National Standards Institute (ANSI) – A voluntary federation of organizations concerned with developing standards covering a broad spectrum of topics.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE) – A professional organization which identifies and publishes specifications and standard practices relating to all aspects of heating, ventilation, refrigeration, and air conditioning.

American Society for Testing and Materials (ASTM) – An organization which develops and publishes recommended practices and standards for a broad range of testing and material properties issues.

Architectural Acoustics – The science of sound, including its production, transmission, control, and effects within buildings.

Arithmetic Average Sound Pressure Level – The sum of a series of sound pressure levels divided by the number of levels included in the sum.

Attenuation – The reduction of the energy or amplitude of a sound source.

A-Weighted Sound Level – A quantity, in decibels, read from a standard sound level meter with A-weighting circuitry. The A-weighting scale discriminates against the lower frequencies below 1000 hertz according to a relationship approximating the auditory sensitivity of the human ear. The A-weighted sound level is approximately related to the relative "noisiness" or "annoyance" of many common sounds.

Background Noise – Ambient noise from all sources unrelated to a particular sound that is the object of interest. Background noise may include airborne, structureborne, and instrument noise.

Balanced Design – A noise control design in which all important noise paths transmit the same amount of acoustic energy into the space, with the sum of these path contributions resulting in an acceptable noise level.

Building Officials and Code Administrators International, Inc. (BOCA) – A non-profit service organization which administers and enforces building design and construction codes in order to protect public safety, health, and welfare.

Coincidence – When the wavelength of the incidence sound wave projected onto a window, wall, door, or other architectural construction matches the bending wavelength of the partition or panel resulting in a decrease in the transmission loss at that frequency.

Composite Sound Transmission Loss – A measure of a complex built construction's assembly to reduce sound passing through it. A complex assembly contains two or more elements which exhibit different individual sound transmission loss properties. Expressed in decibels, it is 10 times the logarithm to the base 10 of the reciprocal of the sum of the sound transmission coefficients of the building elements. Unless otherwise specified, the sound fields on both sides of the complex built construction are assumed to be diffuse.

Critical Frequency – Lowest frequency where coincidence occurs. Critical frequency is raised for thinner and less stiff surfaces exposed to the sound field.

Dampen – To cause a loss or dissipation of the oscillatory or vibrational energy of an acoustical, electrical, or mechanical system.

Day-Night Average Sound Level (DNL or L_{dn}) – The day-night average sound level is a measure of the annual average noise environment over a 24-hour day. It is the 24-hour energy-averaged A-weighted sound level with a 10 dB penalty applied to the nighttime levels which occur between 10:00 p.m. to 7:00 a.m.

Decibel (dB) – The term used to identify 10 times the common logarithm of two like quantities proportional to power, such as sound power or sound pressure squared, commonly used to define the level produced by a sound source.

Design Criteria – Design goals used in acoustical and noise control design of buildings. Design criteria are usually stated as maximum allowable noise levels permitted inside buildings or as noise reduction values required for certain types of buildings or room occupancies.

Diffraction – Ability of a sound to bend or pass around a barrier or obstruction. Low-frequency sounds can diffract around obstacles more easily than high-frequency sounds because of their longer wavelength.

Diffuse Sound Field – A sound field due to the presence of many reflected waves in a room, arising from repeated reflections of sound from the various room surfaces in numerous directions, which results in constant sound level at different positions within the sound field.

Direct Sound – Sound which is transmitted from a source to a receiver in the shortest possible time relative to other sound paths with no reflections from room surfaces.

DNL – See Day-Night Average Sound Level.

Echo – Reflected sound which is loud enough and received long enough after the direct sound to be heard as a distinct entity from the source.

Energy-Averaged Sound Pressure Level – Ten times the common logarithm of the arithmetic average of the squared pressure ratios from which the individual levels were derived.

Environmental Noise – Unwanted sound from various outdoor sources which produce noise. Environmental noise sources include aircraft, cars, trucks, buses, railways, industrial plants, construction activities, etc.

Equivalent Sound Level (Leq) – The level of a constant sound which, in the given situation and time period, has the same average sound energy as does a time-varying sound. Specifically, equivalent sound level is the energy-averaged sound pressure level of the individual A-weighted sound pressure levels occurring during the time interval. The time interval over which the measurement is taken should always be specified.

Field Sound Transmission Class (FSTC) – A single-number rating derived from measured values of field transmission loss in accordance with ASTM Classification E413, "Determination of Sound Transmission Class". It provides an estimate of the performance of the built construction against sounds of speech, radio, television, etc.

Field Transmission Loss (FTL) – The radio, expressed on the decibel scale, of the airborne sound power incident on the built construction to the sound power transmitted by the built construction and radiated on the other side.

Flanking Transmission – Transmission of sound from the source to a receiver by a path other than that under consideration.

Free Sound Field – A sound field free from the effects of boundaries or in which the effects of boundaries are negligible over the frequency range of interest.

Frequency – The number of oscillations per second completed by a vibrating object.

Hertz – The unit used to designate frequency. Specifically, the number of cycles per second.

Impulse Noise – Noise of short duration (typically less than one second) with abrupt onset and rapid decay. Impulse noise is characteristically associated with such sources as explosions, impacts, discharge of firearms, sonic booms, etc.

International Electrotechnical Commission (IEC) – An organization comprised of national committees from member countries, concerned with standards for electrical technology.

International Organization for Standardization (ISO) – An organization which is responsible for developing worldwide technological standards, except for electrical technology (see IEC).

Loudness – The attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud. Loudness depends primarily upon the sound pressure of the source, but it also depends upon the frequency and wave form of the source.

Masking – The ability of one sound to inhibit the perception of another sound. Also, the use of an unobtrusive background noise to cover some other specific intruding sound.

Noise – Any sound which is undesirable because it interferes with speech and hearing, or is intense enough to damage hearing, or is otherwise annoying.

Noise Contours – Continuous lines of equal noise level usually drawn around a noise source. The lines are generally drawn in 5-decibel increments so that they resemble elevation contours found in topographic maps except that they represent contours of equal noise level. Noise contours are generally used in depicting the noise exposure around airports, highways, and industrial plants.

Noise Criterion (NC) Curves – Any of several versions (NC, NCA, PNC, RC) of criteria used for rating the acceptability of continuous indoor noise levels, such as produced by HVAC systems.

Noise Exposure – The cumulative acoustic stimulation reaching the ear of a person over a specified period of time (e.g., a work shift, a day, a working life, or a lifetime).

Noise Isolation Class (NIC) – A single-number rating derived from the measured values of noise reduction, as though they were values of transmission loss, in accordance with ASTM Classification E413, "Determination of Sound Transmission Class". It provides an evaluation of the sound isolation between two enclosed spaces that are acoustically connected by one or more paths.

Noise Reduction (NR) – The numerical difference, in decibels, of the average sound pressure levels in two adjacent areas or rooms. A measurement of noise reduction combines the effect of the transmission loss performance of the built construction separating the two areas or rooms, plus the effect of acoustic absorption present in the receiving room.

Noise Reduction Coefficient (NRC) – The arithmetic average of the sound absorption coefficients of a material at 250, 500, 1000, and 2000 Hz.

Normalized Level Difference – Difference in decibels between sound levels in rooms on opposite sides of a built construction which has been corrected for a standard amount of absorption representative of normal furnished conditions in the receiving room.

Octave – The interval between two sound frequencies having a ratio of 2.

Octave Band – A frequency range which is one octave wide. Standard octave bands are designed by their center frequency.

Octave Band Center Frequency – The geometric mean of the upper and lower frequencies of the octave. Standard octave band center frequencies in the audible range are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 hertz.

Pink Noise – Noise with a continuous frequency spectrum and with equal power per constant percentage bandwidth. For example, equal power in any one-third octave band.

Receiver – The listener or measuring microphone which detects the sound transmitted by the source.

Receiving Room – In architectural acoustical measurements, the room in which the sound transmitted from the source room is measured.

Reflected Sound – Reflected sound in a room is that sound which has undergone one or more reflections from room surfaces prior to arriving at the location of a receiver.

Resonance – The natural vibration of an area of material at a particular frequency as a result of excitation by a sound at that frequency.

Reverberant Sound Level – The level of the sum of all of the sound energy within the room which has undergone many reflections from the surfaces in the room.

Reverberation – The persistence of sound in an enclosed space, as a result of multiple reflections, after the sound source has stopped.

Reverberation Time – The time in seconds taken for the sound pressure level (or sound intensity) to decrease to one-millionth (60 dB) of its steady-state value when the source of sound is suddenly interrupted.

Shielding – The sound level reduction at various elevations of the building due to the relative orientation of the elevations to the sound source.

Society of Automotive Engineers (SAE) – Issues reports and standards concerning a wide range of topics on the design and operation of automobiles, engines, aircraft, spacecraft, and construction, and agricultural equipment.

Sound Absorption – The conversion of incident acoustic energy to heat or another form of energy within the structure of sound-absorbing materials.

Sound Exposure Level (SEL) – A time-integrated metric (i.e., continuously summed over a time period) which quantifies the total energy in the A-weighted sound level measured during a transient noise event. The time period for this measurement is generally taken to be that between the moments when the A-weighted sound level is 10 dB below the maximum (i.e., the 10-dB-down points).

Sound Insulation – Reducing the sound level inside a building through the installation of specific building construction materials, and component assemblies which provide increased noise reduction characteristics.

Sound Isolation – A quantity usually expressed in decibels which defines the amount of sound reduction between a sound source and a receiver; the reduction in level or intensity of unwanted noise through specific building component selection and construction techniques.

Sound Power Level – A measure in decibels of the rate at which sound energy radiates from a sound source. Specifically, it is the total energy per second produced by a sound source, and expressed in decibels, equal to 10 times the logarithm to the base 10 of the ratio of the power of a sound to the reference power of 10^{-12} watts.

Sound Pressure Level – A measure in decibels of the magnitude of the sound. Specifically, the sound pressure level of a sound, in decibels, is 10 times the logarithm to the base 10 of the ratio of the squared pressure of this sound to the squared reference pressure. The reference pressure is usually taken to be 20 micropascals.

Sound Transmission Class (STC) – A single-number rating derived from measured values of transmission loss, in accordance with ASTM Classification E413, "Determination of Sound Transmission Class". It provides an evaluation of the sound-isolating properties of built construction against sounds of speech, radio, television, etc.

Sound Transmission Coefficient – The fraction of the airborne sound power incident on the built construction to that transmitted by the built construction and radiated on the other side.

Sound Transmission Loss (TL) – A measure of a built construction's ability to reduce sound passing through it. Expressed in decibels, it is 10 times the logarithm to the base 10 of the reciprocal of the sound transmission coefficient of the building component. Unless otherwise specified, the sound fields on both sides of the built construction are assumed to be diffuse.

Source – The object which generates the sound.

Source Room – In architectural acoustical measurements, the room that contains the noise source or sources.

Spectral Characteristics – The frequency content of the noise produced by the source.

Structureborne Sound – Sound energy transmitted through a solid medium such as the building structure.

Thermal Insulation – A material or assembly of materials used primarily to provide resistance to heat flow.

TL – See Sound Transmission Loss.

Unified Building Code (UBC) – A comprehensive building code published by the International Conference of Building Officials covering the fire, life, and structural safety aspects of all buildings and related structures.

Unit – A precisely specified quantity in terms of which the magnitudes of other quantities of the same kind can be stated.

Vibration Isolation – A reduction, attained by the use of a resilient coupling, interposed between the vibrating source and the mounting structure.

Wavelength – The physical distance between identical points on successive waves.

Weighting – An additive (or subtractive) factor by which the sound pressure level at certain frequencies in an acoustic measurement is increased (or reduced) in order for that measurement to be more representative of certain simulated conditions.

White Noise – Noise with a continuous frequency spectrum and with equal power per unit bandwidth. For example, equal power in any band of 100 Hz width.

APPENDIX F

Homeowner Questionnaire

HOME SOUNDPROOFING PROJECT

Pre-Modification Survey

Address: ______________________________

Respondent's Name: ______________________________

Residential Status: (Check One) Homeowner _____ Renter _____
Family Member _____ Guest _____

Question No.

1. How many years have you lived at this address? ______ years

2. As of your last birthday, how old are you?

Less than 20 years old	____	40 to 50 years old	____
20 to 30 years old	____	50 to 60 years old	____
30 to 40 years old	____	More than 60 years old	____

3. How would you rate your health?

Very Good ____ Good ____ Fair ____ Poor ____ Very Poor ____

4. How much difficulty does aircraft noise cause you (inside your home) in terms of:

	Very Much	Much	Some	Very Little	None
Speech Communication (Conversation):	____	____	____	____	____
Sleep Onset (Falling Asleep):	____	____	____	____	____
Sleep Disturbance (Being Awakened):	____	____	____	____	____
Concentration (Reading, Studying, etc.):	____	____	____	____	____
Relaxation:	____	____	____	____	____
Listening to TV or Radio:	____	____	____	____	____
Telephone Use:	____	____	____	____	____
Other (Please specify):					
______________	____	____	____	____	____
______________	____	____	____	____	____

FOR OFFICE USE ONLY

Date Sent: ____________ **Date Returned:** __________ **Dwelling No.** _______

Question
No.

5. Have you considered moving from your home because of aircraft noise?

Yes _____ No _____

6. During the past five years, did you ever complain to BWI Airport or other officials about aircraft noise?

Yes _____ No _____

7. How would you rate the present thermal insulation of your home:

Very Good ____ Good ____ Fair ____ Not Good ____ Very Poor ____

Please add any comments, criticisms, or advice you may have regarding this and future similar sound insulation projects:

____

____

____

____

____

____

Thanks again. We will advise you of the statistical results of this opinion survey and of the acoustical results in your home.

WYLE LABORATORIES

HOME SOUNDPROOFING PROJECT

Post-Modification Survey

Address: ____

Respondent's Name: ____________________________________

Residential Status: (Check One) Homeowner ____ Renter ____ Family Member ____ Guest ____

Question No.

1. How many residents (including yourself) currently live at this address? ____

2. Of the current residents, how many are?

Less than 5 years old	____	31 to 40 years old	____
6 to 12 years old	____	41 to 50 years old	____
13 to 19 years old	____	51 to 60 years old	____
20 to 30 years old	____	Over 60 years old	____

3. How many years have you lived at this address? ____ years

4. As of your last birthday, how old are you?

Less than 20 years old	____	41 to 50 years old	____
20 to 30 years old	____	51 to 60 years old	____
31 to 40 years old	____	Over 60 years old	____

5. How would you rate your health?

   Very Good ____ Good ____ Fair ____ Poor ____ Very Poor ____

6. Since sound insulation was applied to your home, how would you describe the <u>changes</u> in the living environment (inside your home) in terms of:

	Much Improved	Improved	Slightly Improved	No Change	Worse
Speech Communication (Conversation):	____	____	____	____	____
Sleep Onset (Falling Asleep):	____	____	____	____	____
Sleep Disturbance (Being Awakened):	____	____	____	____	____
Concentration (Reading, Studying, etc.):	____	____	____	____	____
Relaxation:	____	____	____	____	____
Listening to TV or Radio:	____	____	____	____	____
Telephone Use:	____	____	____	____	____
Other (specify):					
________________	____	____	____	____	____
________________	____	____	____	____	____

FOR OFFICE USE ONLY

Date Interviewed: ________ **Dwelling No.** ______

Question
No.

7. For each major room in your home, how would you rate the aircraft noise intrusion?

	Much Improved	Improved	Slightly Improved	No Change	Worse
Living Room:	____	____	____	____	____
Kitchen:	____	____	____	____	____
Bedroom in which you sleep:	____	____	____	____	____
Bedrooms used by others in your household (e.g., children):	____	____	____	____	____
Bedrooms not commonly used (e.g., guest room):	____	____	____	____	____
Other (specify): ____________	____	____	____	____	____

8. In your opinion, how much has the overall sound insulation of your home been improved as a result of changes to the following:

	Much Improved	Improved	Slightly Improved	No Change	Don't Know
Ventilation System:	____	____	____	____	____
Doors:	____	____	____	____	____
Windows:	____	____	____	____	____
Attic Insulation:	____	____	____	____	____
Walls (if modified):	____	____	____	____	____
Underfloor Vent Baffles (if modified):	____	____	____	____	____
Chimney Damper (if modified):	____	____	____	____	____
Kitchen & Bathroom Vent Ducting (if modified):	____	____	____	____	____

9. How would you rate the overall exterior and interior appearance of your home following the application of sound insulation?

	Much Improved	Improved	Slightly Improved	No Change	Worse
General Exterior Appearance is:	____	____	____	____	____
General Interior Appearance is:	____	____	____	____	____

Question
No.

10. How would you rate the quality and appearance of each of the following specific changes to your home:

	Very Good	Good	Fair	Poor	Very Poor
Windows:	_____	_____	_____	_____	_____
Doors:	_____	_____	_____	_____	_____
Walls:	_____	_____	_____	_____	_____
Ventilation:	_____	_____	_____	_____	_____

11. Is the ventilation system installed as part of the sound insulation:

    Adequate: ____ Inadequate: ____ No Opinion: ____

    No Ventilation Installed: ____

12. How would you rate the present thermal insulation of your home:

    Very Good ____ Good ____ Fair ____ Poor ____ Very Poor ____

13. If the sound insulation for your home had been limited to only four (4) rooms, which rooms would you have chosen and in what order of priority (e.g., 1st priority, Child's Bedroom; 2nd priority, Family Room/Den; 3rd priority, Guest Room, etc.)

    1st Priority: ______________________________

    2nd Priority: ______________________________

    3rd Priority: ______________________________

    4th Priority: ______________________________

14. Do you think your home has increased in market value because of the sound insulation?

    Yes _____ No _____ Don't Know _____

15. Now that your home has been sound insulated, would you consider moving because of aircraft noise?

    Yes _____ No _____

16. In retrospect, was installing the sound insulation a good idea or not?

    Good Idea _____ Can't Tell Yet _____

    Not a Good Idea _____ No Opinion _____

Question
No.

17. If sound insulation was made available to other homeowners in your immediate neighborhood, would you recommend it to your neighbors?

Yes ____ No ____

16. With your knowledge, now, of the work involved in sound-insulating your home and of the long-term changes to your living environment, which of the following options would you recommend for other homes (or for your home if you could start again):

	More Sound Insulation	Less Sound Insulation	Same As Installed
Living Room	____	____	____
Kitchen	____	____	____
Bedroom (where you sleep)	____	____	____
Other Bedrooms (where others in your home sleep)	____	____	____
Other Rooms (Guest Room, Den, etc.)	____	____	____

APPENDIX G

Organizational Addresses

APPENDIX G

Organizational Addresses

Acoustical Society of America
335 East 45th Street
New York, NY 10017

American National Standards Institute
1430 Broadway
New York, NY 10018

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.
345 East 47th Street
New York, NY 10017

Building Officials and Code Administrators International, Inc.
17926 South Halstead Street
Homewood, IL 60430

International Conference of Building Officials
5360 South Workman Mill Road
Whittier, CA 90601

International Electrotechnical Commission
1-3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Noise Control Foundation
P.O. Box 3469
Poughkeepsie, NY 12603

Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096