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:

- <u>Project Initiation.</u> 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.

- <u>Contractor Selection/Bid Process.</u> 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;

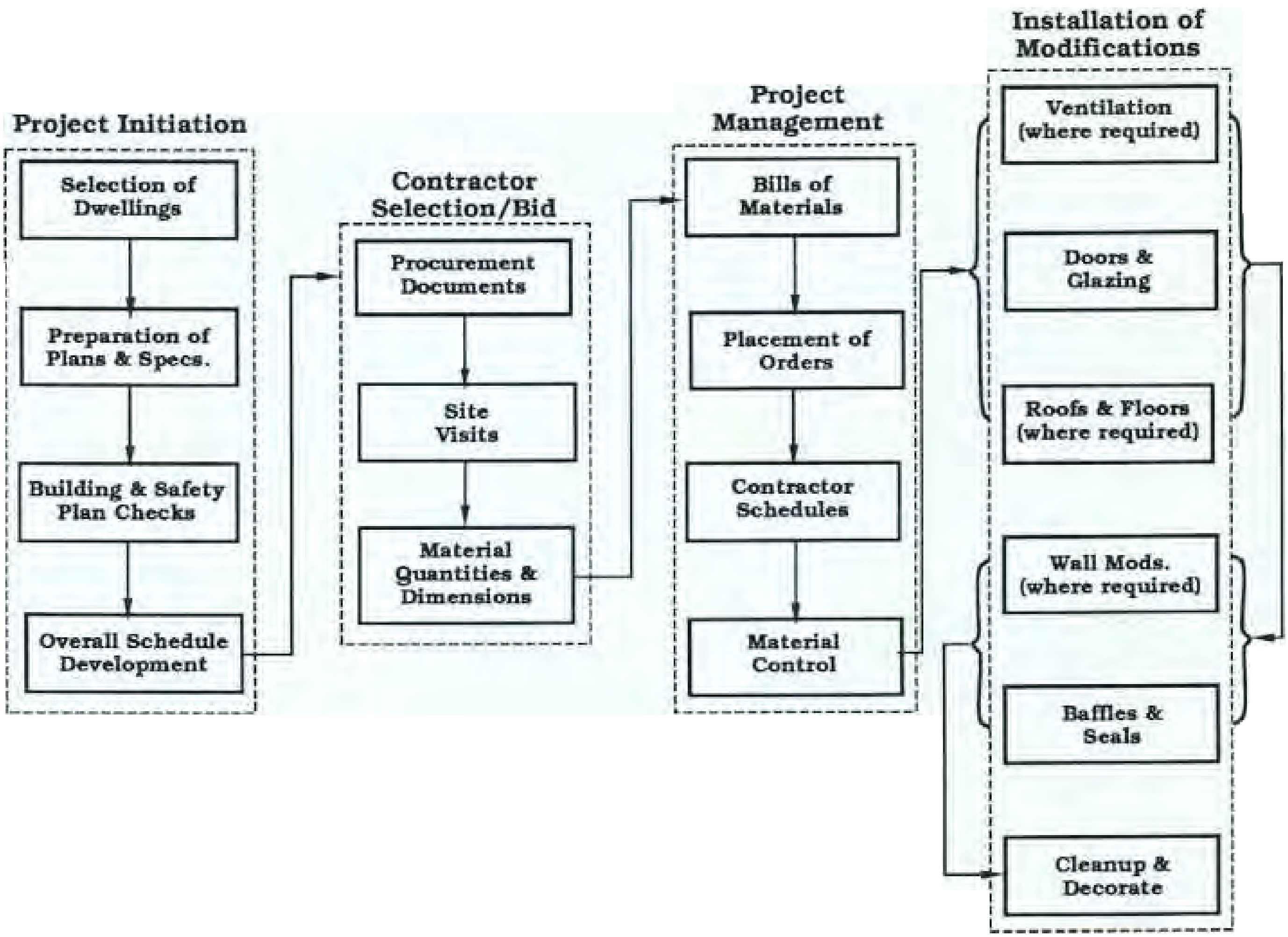


Figure 3-1. Project Implementation Flowchart.

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	✓	✓	|||
"	"	"	"	"	"	—	✓	卌 卌 |||
1S	BS	VA	AL	CR	1K	✓	✓	卌 卌 |
1S	SD	VA	WD	BA	1K	✓	✓	|||
1S	SD	VA	CA	CR	1K	✓	—	卌
"	"	"	"	"	"	✓	✓	卌 卌
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.

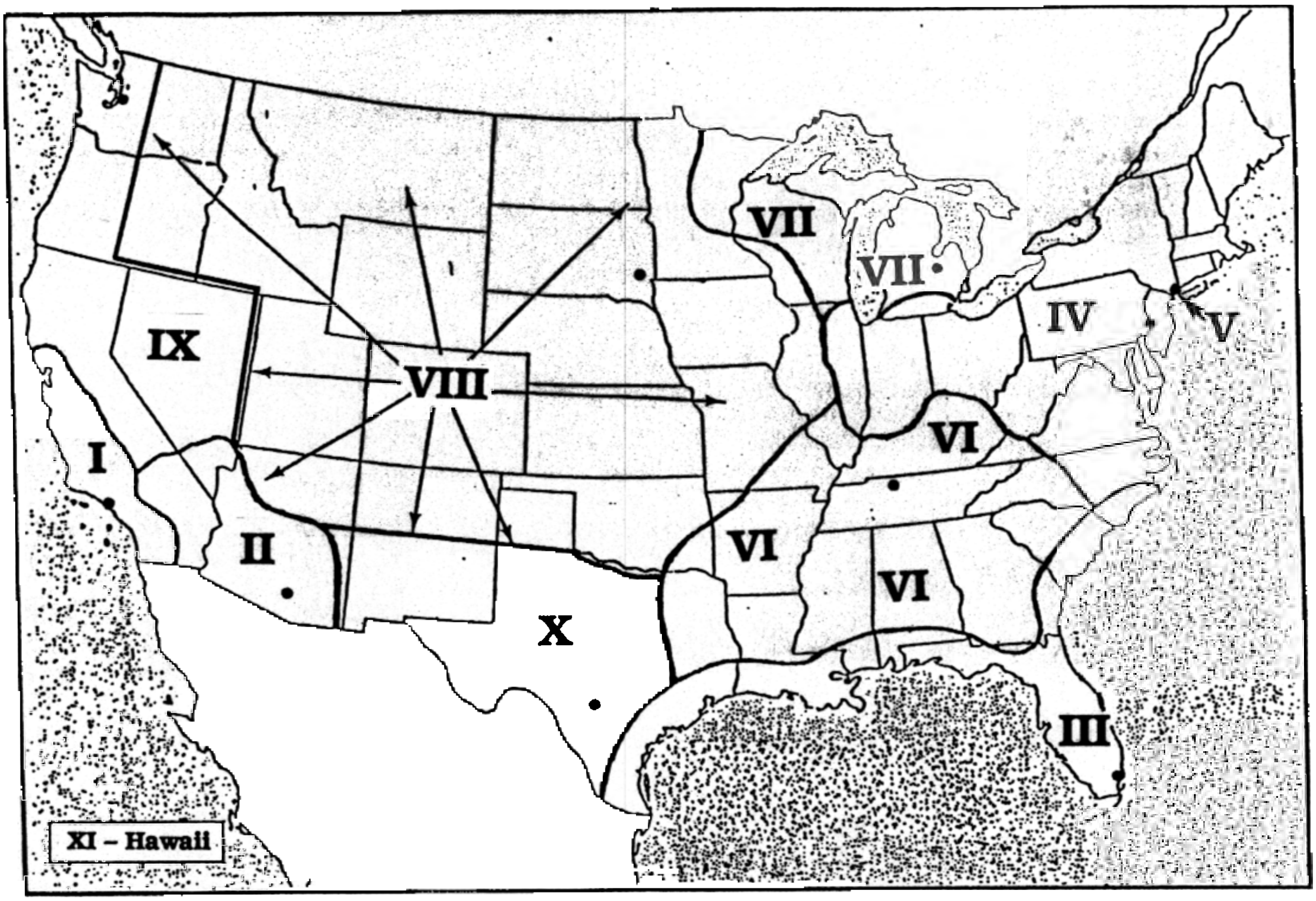
Region IV: Eastern Seaboard and inland to Central Illinois, except for New York City (see Region V). The climate is quite cold for half the year and insulation properties are important. Brick and various types of siding are common, often in combination. This area typically has more storm doors and windows 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.



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

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:	10	--	--	50	70	--	5	--	30	--	--
Gas	90	80	--	50	20	25	95	100	40	95	--
Electricity	--	20	100	--	10	75	--	--	30	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 not 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

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.

<u>Testing Methods</u>

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

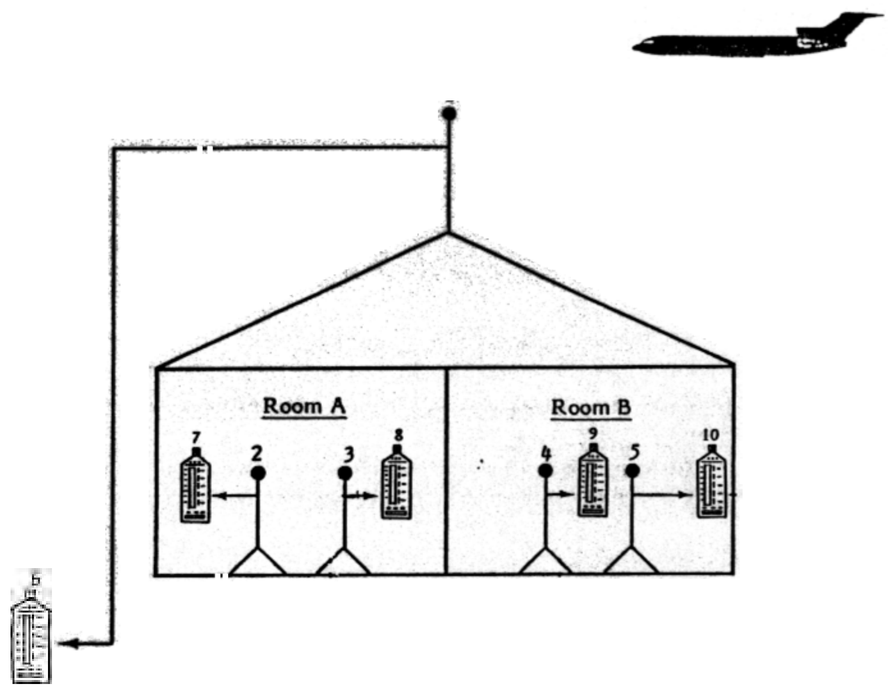
Placement of Microphones

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



Figur **3-4**. Schemati)f Sound Meas 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.

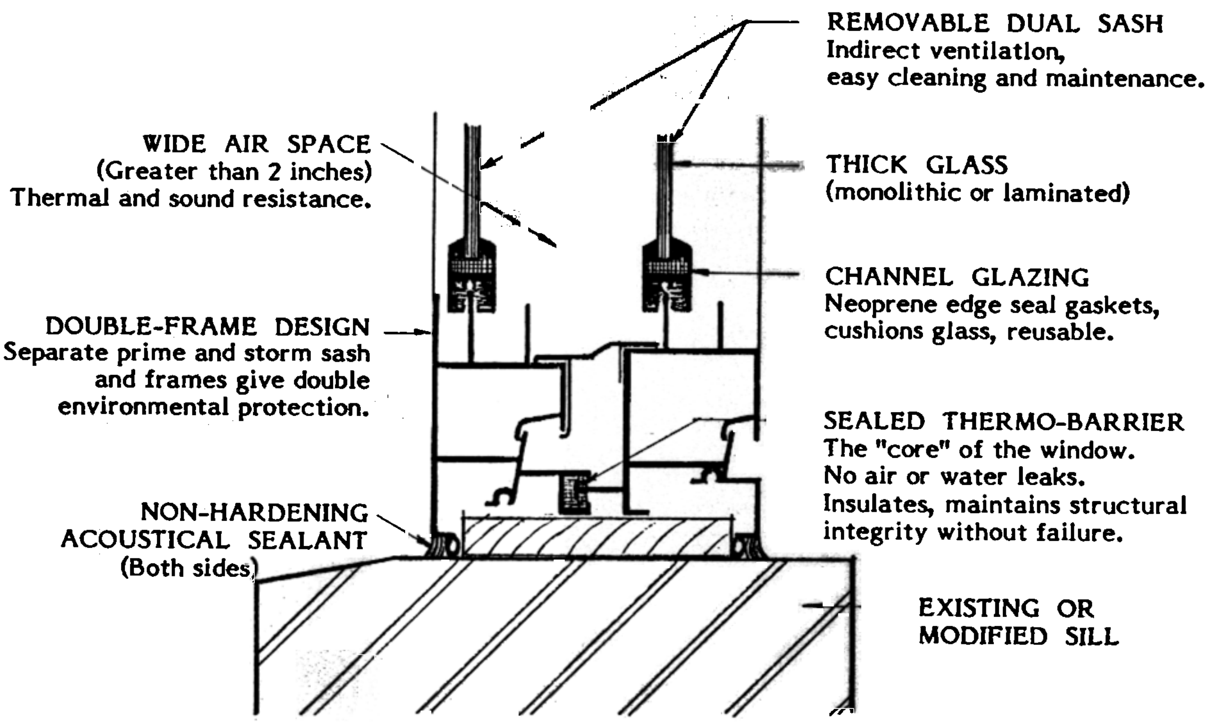

Figure 3-5. Construction Features of Acoustical Window.

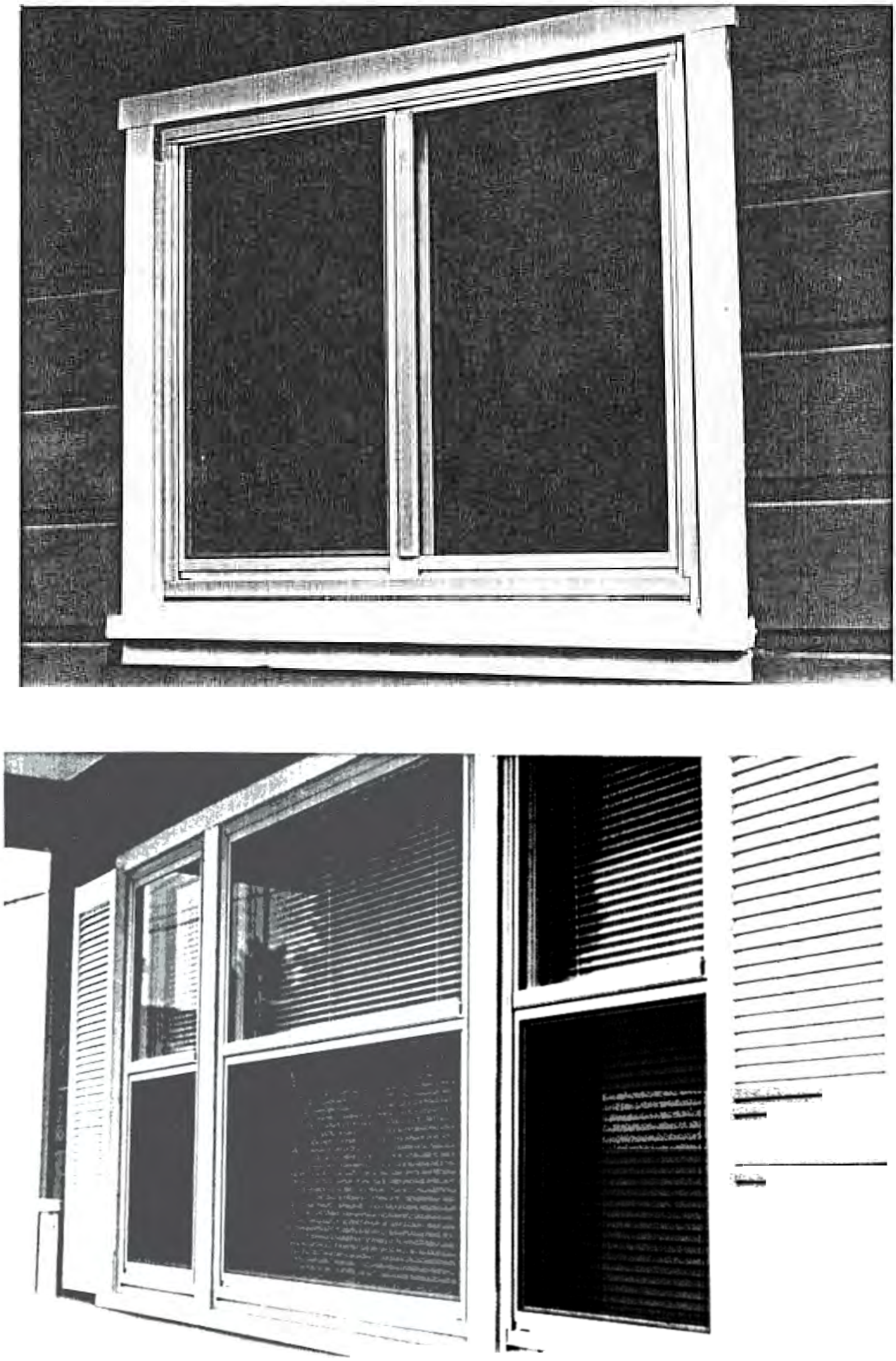

Figure 3-6. Typical Acoustical Windos in Place.

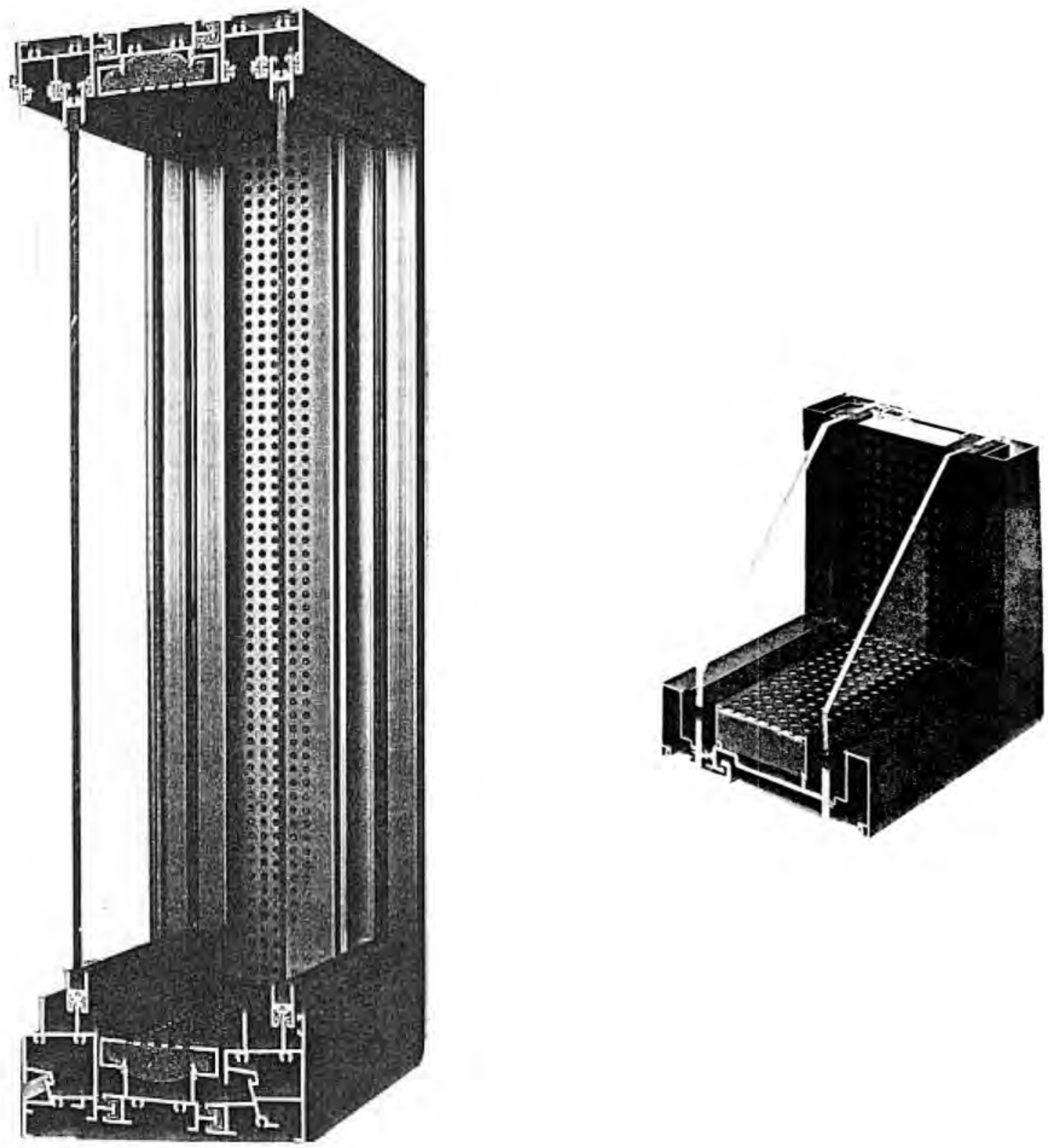

Figure 3-7. Examples of Double-Glazed Window Constructions. (DeVac: #653, STC 44; and #720, STC 48)

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

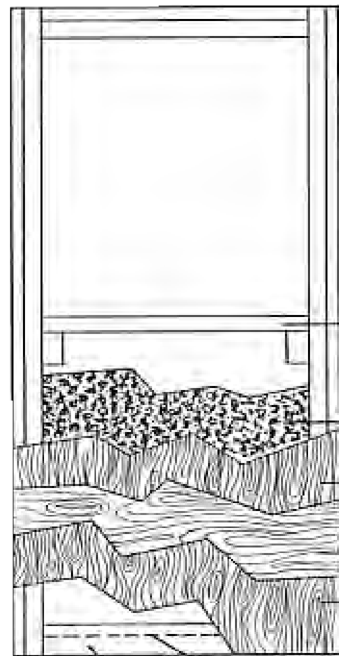

Figure 3-8. Wood Acoustical Door Construction.

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** Mo   ed Secondary Sli**d**ing Glass Doo

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

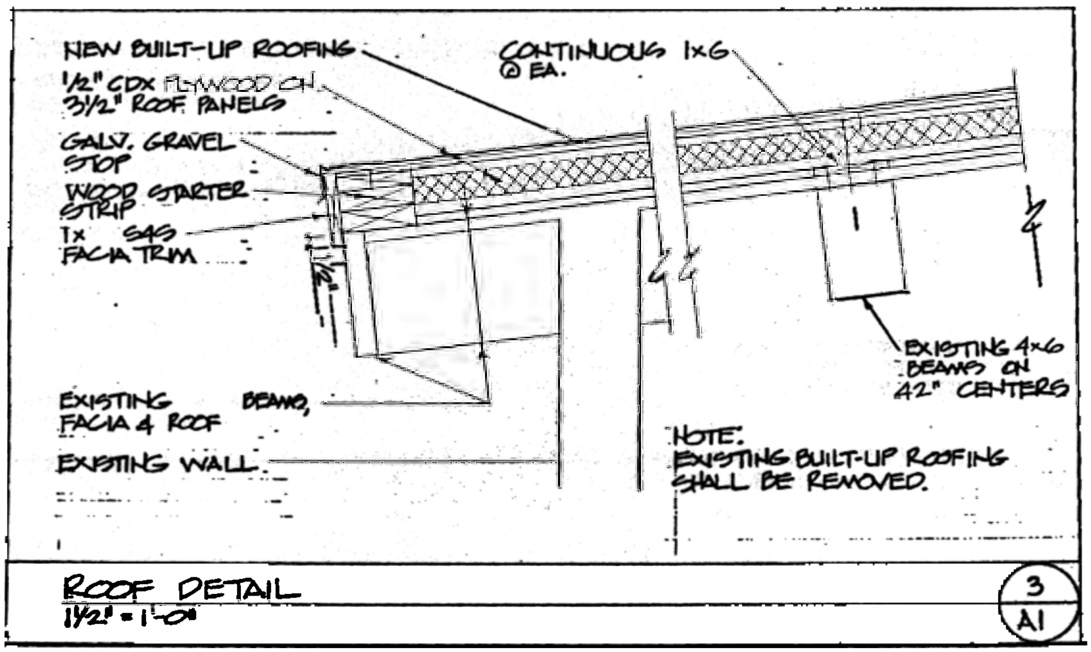

Figure 3-10. Exterior Roof Improvement.

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 Exterior Wall Construction Improvements

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:

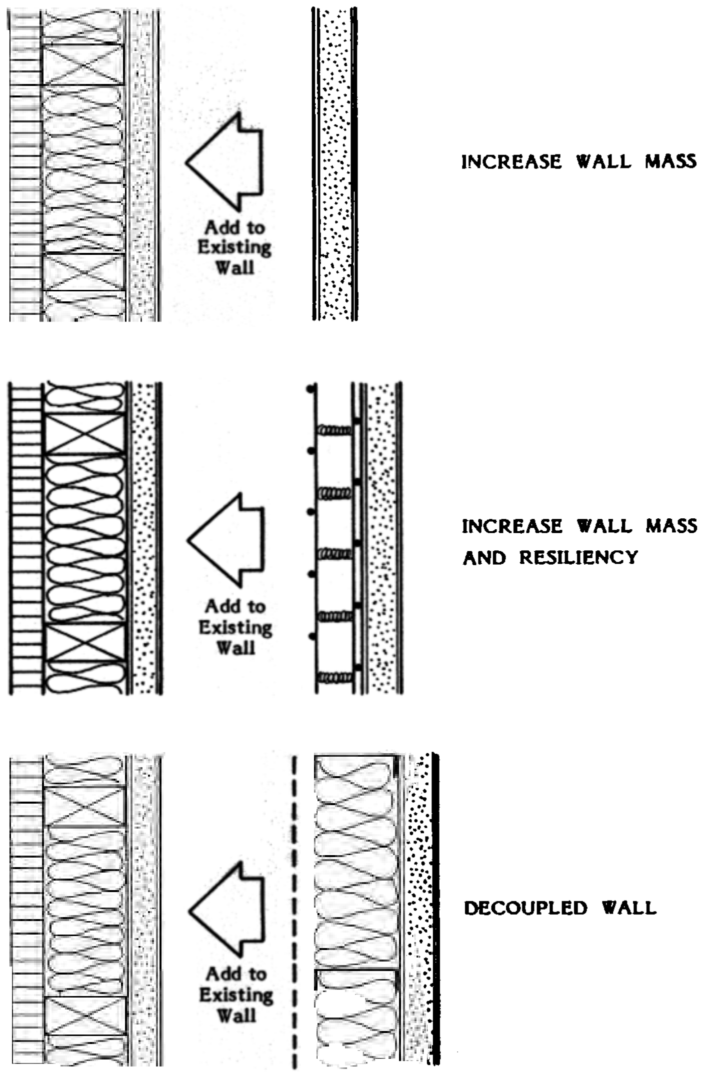

Figure 3-11. Types of Wall Modifications.

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.

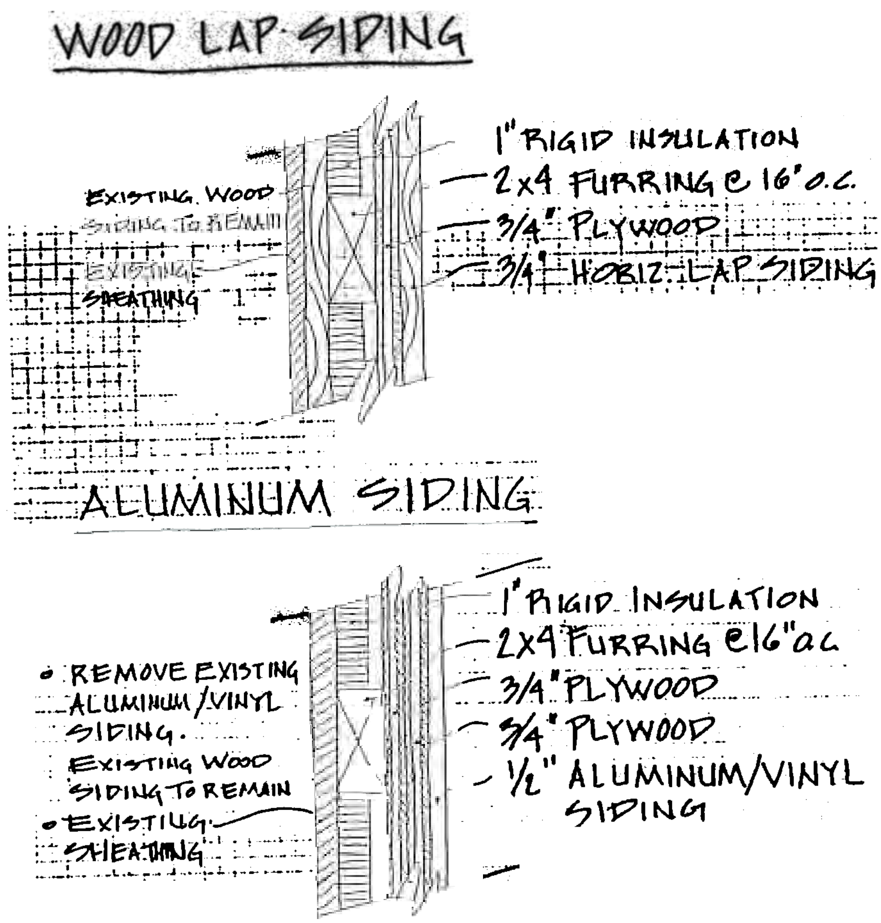

Figure 3-12. Schematic Exterior Wall Modifications.

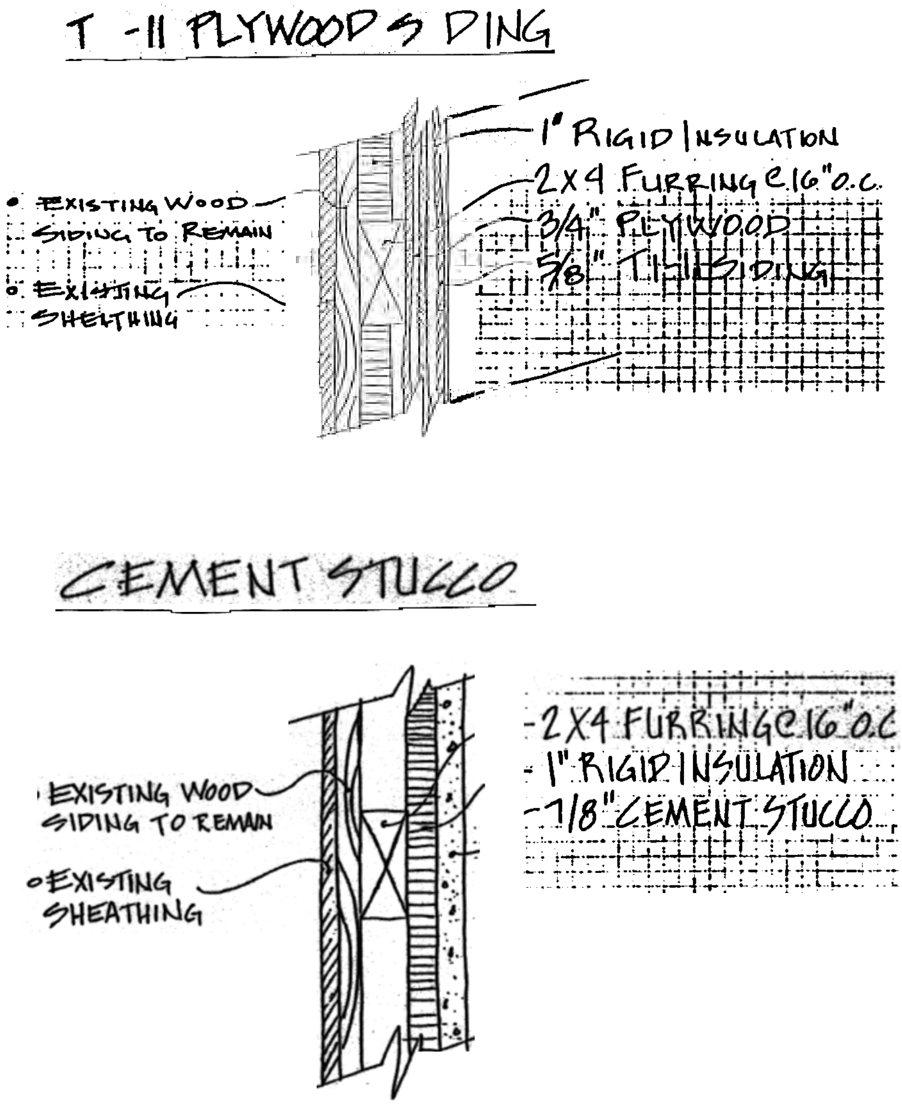

Figure 3-13. Schematic Exterior Wall Modifications.

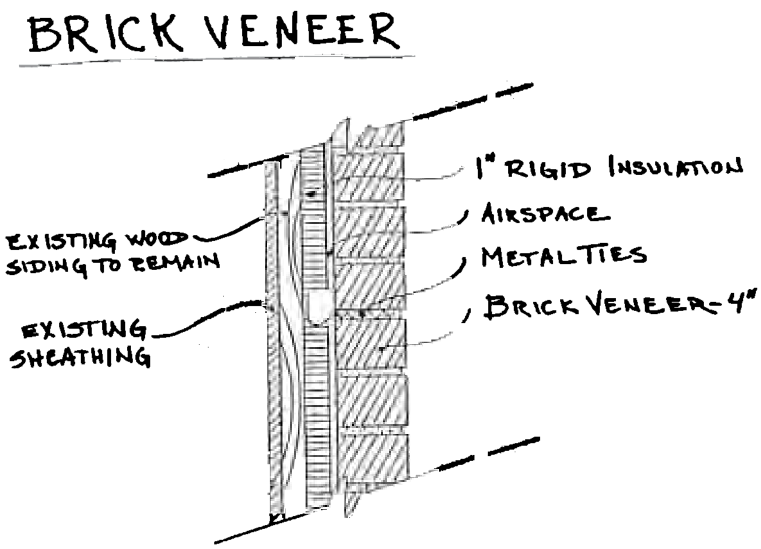

Figure 3-14(a). **Schematic Exterior Wall Modifications.**

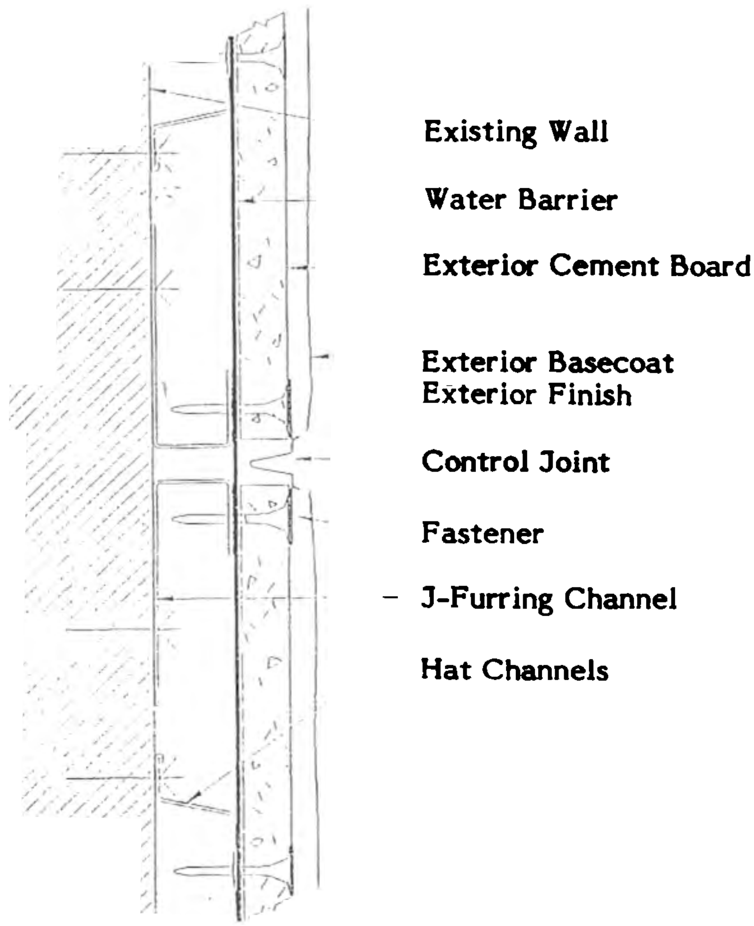

Figure 3-14(b). **Schematic Furred Cement Board.**

- 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 Floor Modifications

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

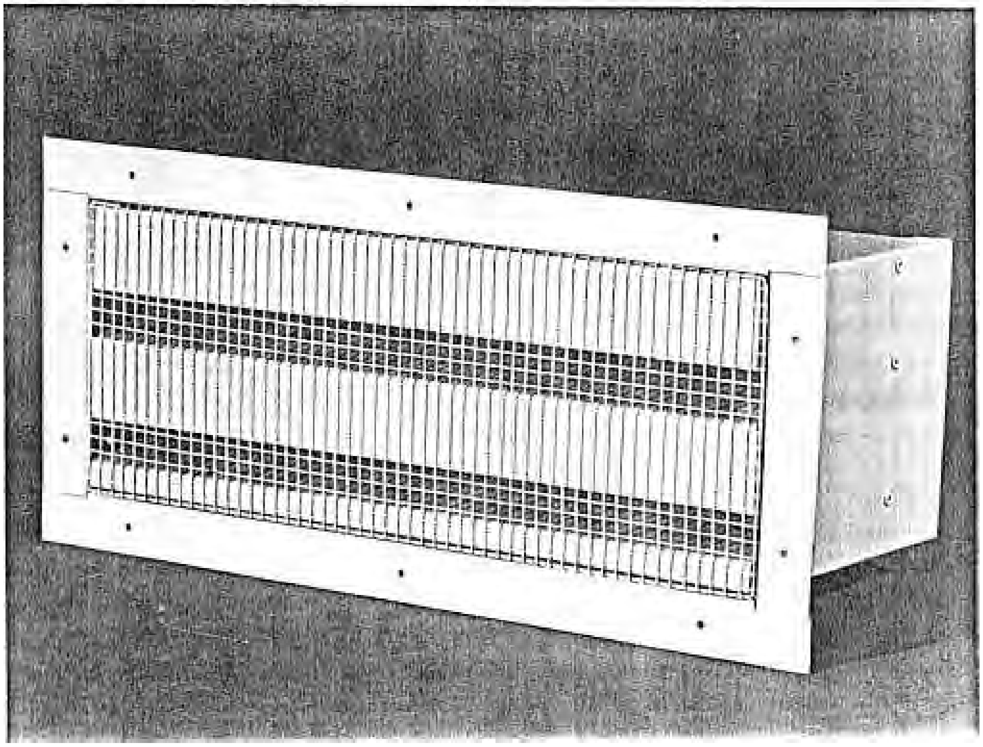

Figure 3-   Louver/Baffl

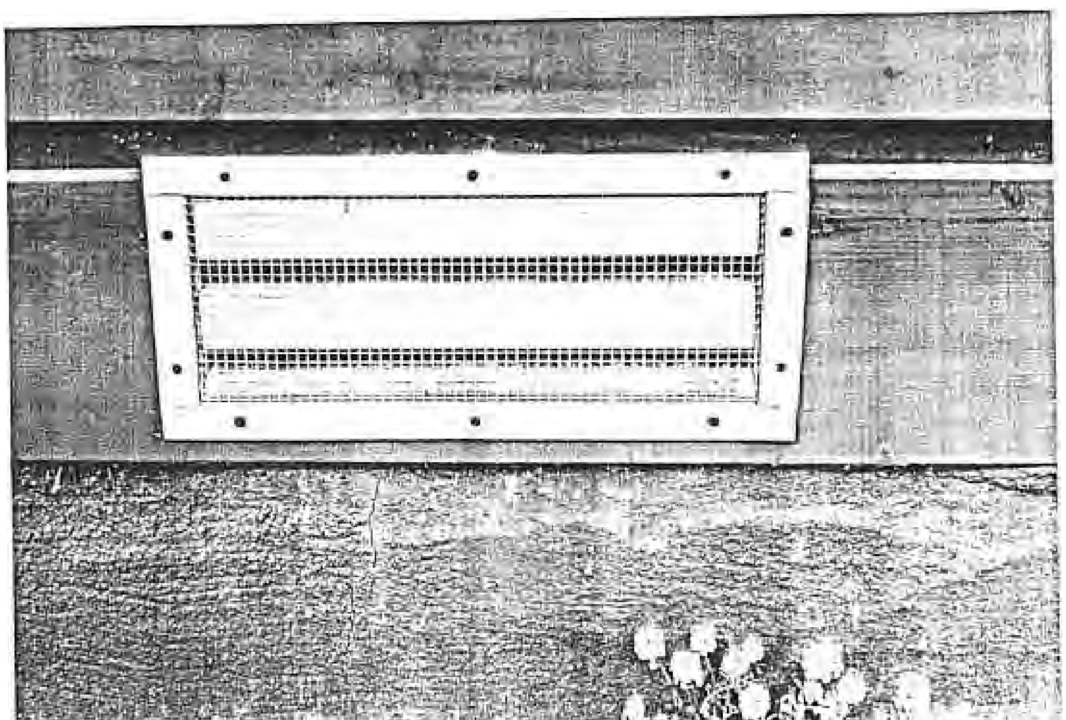

Figure 3-16.   Louver/Baffle Installed in Side of Dwelling.

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.

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* 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.

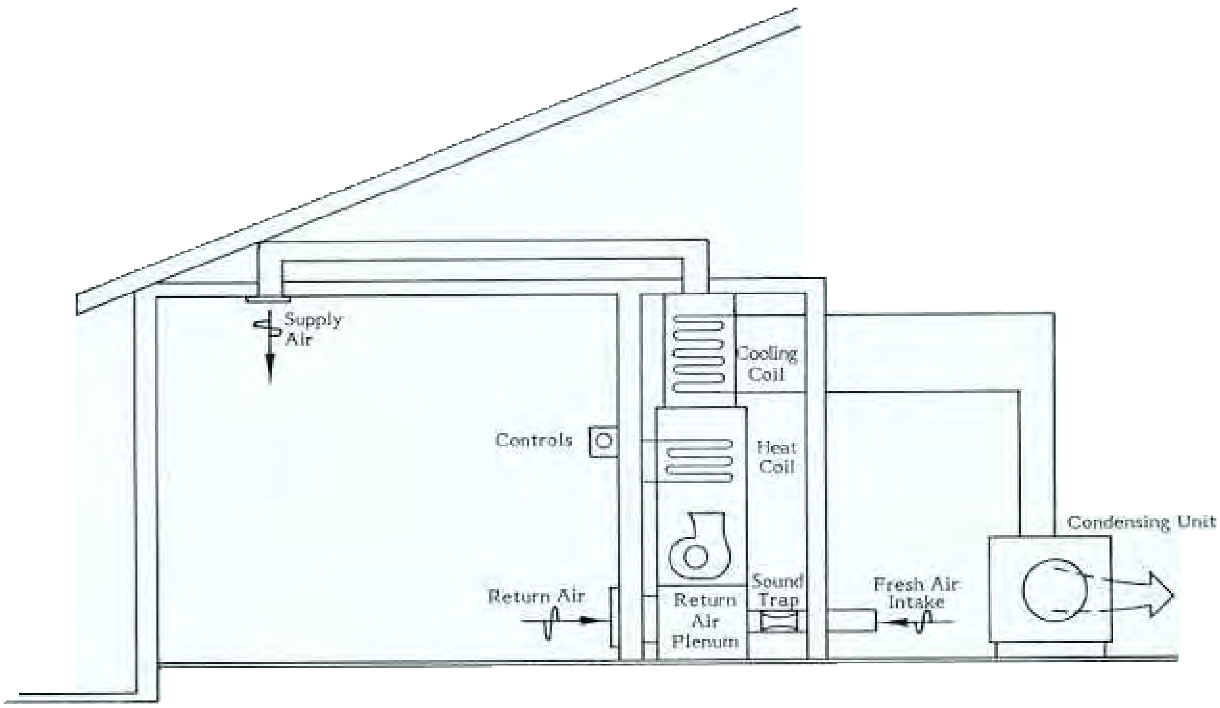

Figure 3-17. Modified System Functions.