

# Airport Noise Insulation of Homes Surrounding Stapleton International Airport

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The Stapleton Noise Insulation Program (SNIP) was initiated by the city and county of Denver, Colorado, to provide aircraft noise insulation modifications to owner-occupied homes within the 70- $L_{dn}$  (equivalent day-night sound level) contour and to schools and churches within the 65- $L_{dn}$  contour of Stapleton International Airport. SNIP is not a part of an FAA Part 150 study, and such a study has not been completed on this airport. The project area includes approximately 3,936 homes, 22 churches, and 8 schools. The primary data base for homes in the study area was acquired from assessor's records. A data base program was used to sort and arrange the homes into distinct categories from which representative samples were selected for a detailed engineering survey—a total of 52 homes. Twenty-six of these homes were selected and used for preconstruction sound insulation testing, and 24 were used for preconstruction air infiltration testing. Because the construction funds available for this program limited expenditures to \$7,500.00 per home, recommended sound insulation modifications developed from results of the detailed engineering survey were given priority to achieve the maximum sound insulation for the least cost. Two sample homes were completed as a part of the design phase. Before-and-after A-weighted acoustical tests show a 9- to 17-dB improvement in exterior-to-interior noise reduction as a result of SNIP modifications.

In 1986, the city and county of Denver agreed to a \$27 million program to insulate homes around the existing Stapleton International Airport. This program preceded the May 17, 1988, vote by Adams County in favor of allowing Denver to annex property for the construction of a new international airport.

Denver residents had known that a major new airport was imminent because of growing air traffic and the physical constraints of the Stapleton site (originally established in 1928). But because new airports take time to plan and build, Stapleton needed to expand in the interim to keep up with traffic growth until the new airport could be opened in the mid-1990s.

Airport operations affect three counties—Denver, Arapahoe, and Adams. Denver and Adams Counties are affected the most heavily. In order to expand the airport by adding a new runway, Denver entered into an Intergovernmental Agreement (1) with the commissioners of adjoining Adams County. This agreement conditionally approved expansion of Stapleton by adding a new east-west runway located partially on the Rocky Mountain Arsenal northeast of the existing airport. Remedial measures addressing the noise issue required as

a condition for the Intergovernmental Agreement were a noise-monitoring system and a noise-insulation program. Stapleton had already enjoined a penalty system for noncompliance with its noise cap regulations. However, the monitoring system provided for the identification of individual noise events that were not in compliance with the noise cap regulations.

## SCOPE

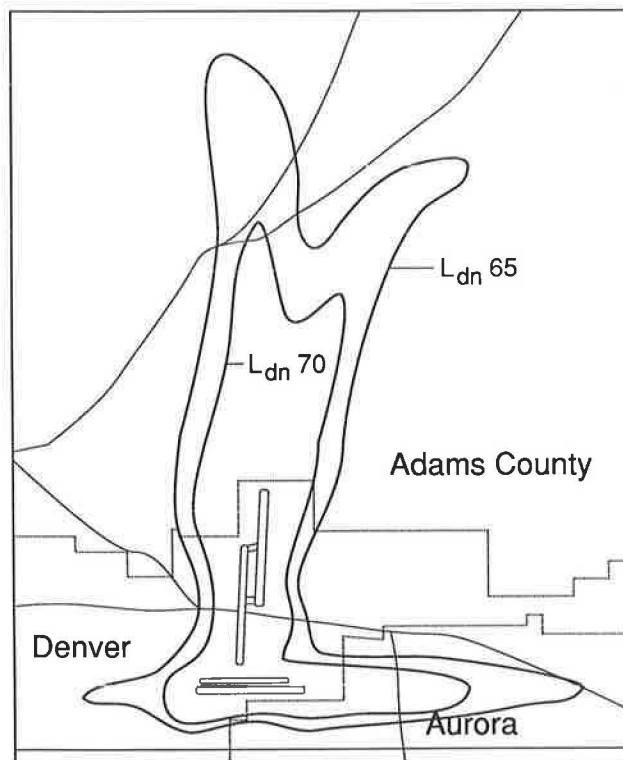
The Stapleton Noise Insulation Program (SNIP) created by the Denver-Adams County Intergovernmental Agreement (1) is a municipal project with specific monetary commitments. SNIP is not an FAA Part 150 study (2) and no such study has been completed on this airport. The program allows reimbursement of up to \$4.00 per ft<sup>2</sup> for churches and schools and up to \$7,500.00 for each owner-occupied home. The monetary limits were negotiated amounts based on the estimated value of the aviation easement required from each participating homeowner. A monetary maximum went against conventional FAA program wisdom, but it does present an interesting challenge for the engineering team comprising David L. Adams Associates, Inc., acoustical consulting engineers; W. C. Muchow & Partners, Inc., architects; System Engineering Corporation, mechanical engineers; and Roos Szymskie, Inc., electrical engineers.

The homes designated as eligible by the Intergovernmental Agreement are those located within the 70- $L_{dn}$  (equivalent day-night sound level) contour. A noise measurement verification program is not included in the scope of this project. In heavily developed areas where the contour intersects a block, the  $L_{dn}$  contours have been expanded to include whole blocks. The requirement of owner occupancy was implemented to prevent real estate speculation in an already crisis-stricken market. Figure 1 shows the basic areas affected.

The other major constraint that required the most creativity from the engineering team was the predetermined installation format. Before the request for proposal was even released, the Stapleton administration had determined that local existing rehabilitation agencies such as the Denver Urban Renewal Authority and Aurora Community Service would handle all contracting. Their responsibilities included contact with the homeowners, inspection of the homes, preparation of bid packages, bidding, and construction administration.

The process was complicated because lengthy negotiations with the installing agencies were not completed until 6 months to 1 year after the engineering team finished the study and

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**FIGURE 1** SNIP study area. The program includes owner-occupied homes within the 70- $L_{dn}$  contour and schools and churches within the 65- $L_{dn}$  contour.

design phases. The engineering team did not know exactly who would be doing the installation or what their capabilities would be. The time allotted for the engineering study was 6 months. The time allotted for the completion of the entire project was a maximum of 3 years.

## RESEARCH PROCEDURE

The only material available with which to start the project was a map of the area showing the noise contours superimposed. The administrators had not gathered records or lists of the homes involved.

Research commenced with a search of all assessor's records for homes located within the contour area. Obtained from the assessor's records were owners' names and addresses, house addresses, house sizes, dates of construction, and basic construction types. Although the assessor's records were set up to record extensive information, their formats varied widely from one assessor to another, making the information unreliable. However, using a data base system, the engineering team was able to sort, categorize, and group the homes by basic construction type, size, age, and type of heating and ventilating system. The data base was also used for mass mailings that later proved to be very helpful.

The initial study of assessor's records established the following basic information about homes located in the study area:

1. There are 3,936 dwellings in the study area that could potentially be owner occupied—632 in Denver and 3,304 in Aurora or Adams County.

2. Most homes were built between 1949 and 1963, as shown in Figure 2. The peak year for construction was around 1952. The construction dates ranged from the 1880s to 1983.

3. At least 65 percent of the houses are of wood frame construction with forced air heating and ventilating systems, as shown in Figure 3.

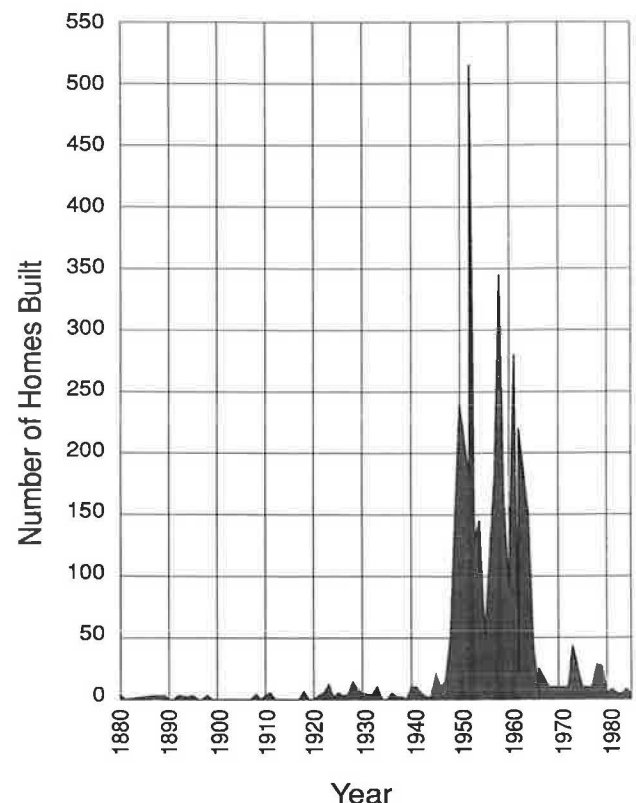
4. Approximately 80 percent of all houses are single-story structures.

5. The average house size is approximately 1,000 ft<sup>2</sup>.

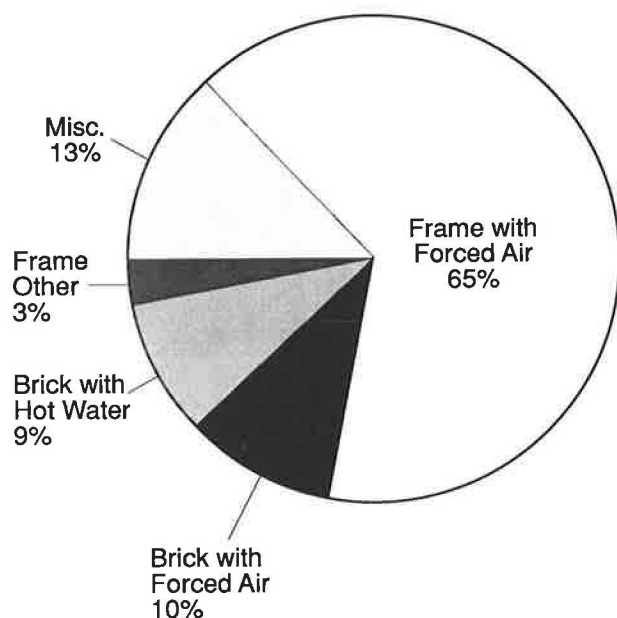
From the basic information obtained from the assessor's records, a selection of homes was made including all categories of construction, heating systems, age, and location. A detailed engineering survey was initiated to cover at least 2 percent of the study population. It was the intent of the detailed engineering survey to document the conditions in the various home types in order to have a broad base of data from which to develop solutions.

Residents were contacted by mail soliciting voluntary participation in the engineering survey. A total of 52 homes were finally surveyed. The survey team consisted of architects, mechanical engineers, and electrical engineers and was headed by the acoustical engineering team. Tasks for survey responsibilities were divided among the team members so that everyone would complete field documentation in approximately 1 hr. A designated spokesperson was appointed to answer homeowner questions.

From the detailed engineering survey, information was compiled regarding types, locations, and frequency of exterior shell penetrations; wall construction; window construction;



**FIGURE 2** Number of homes built per year within the study area.



**FIGURE 3** Distribution of basic construction and heating types in the study area.

room layouts and sizes; type and condition of heating and cooling systems; and electrical service capacity. Photographic records were used extensively and were later very valuable in developing details.

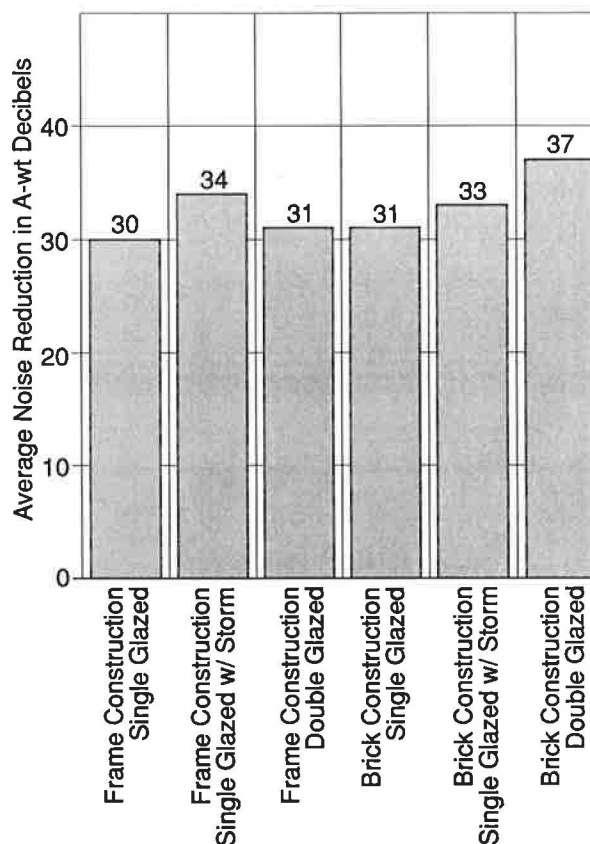
Objective testing of the noise insulation capability of the exterior shell was completed on 26 residences. Average noise reductions in A-weighted decibels for the residences tested, grouped by construction, are shown in Figure 4. These tests were conducted using ASTM Standard E966-84 (3). There was typically a 7-dB spread between test results on houses within a given category. The widest deviations occurred on the homes with brick constructions, single-glazed windows, and aftermarket storm windows. The wide variety of storm window styles is the most likely source of this variation.

Infiltration testing was completed on the same 26 homes using the standard blower door method. The homes were tested to determine the amount of air leakage that a home experiences before any modifications made for sound insulation. The range of the results compiled is shown in Figure 5. To establish the effectiveness of the retrofit measures, all 26 homes will be retested after modifications are completed.

One of the primary reasons for including infiltration testing is the current high level of concern over radon gas levels in the Rocky Mountain region. Recent U.S. Environmental Protection Agency studies have shown Colorado to have higher than normal levels of radon gas. The public is generally very concerned about indoor air pollution and radon gas. Advanced documentation on air infiltration was acquired so that the program's impact on indoor air quality could be documented and homeowners' concerns could be addressed.

## METHODS OF ANALYSIS

The goal of the analysis was to determine the most cost-effective methods of improving each home's exterior-to-



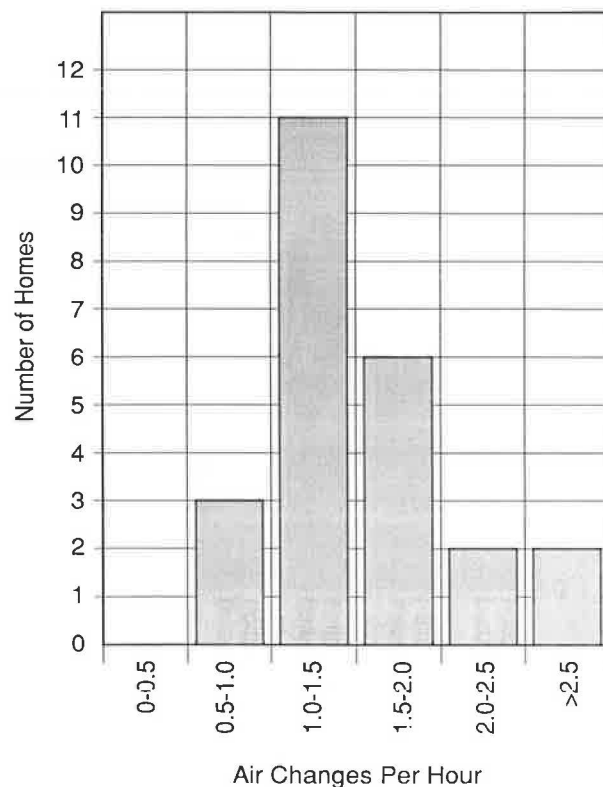
**FIGURE 4** Results of preliminary acoustical testing showing average noise reduction (in A-weighted decibels) by composite exterior construction.

interior sound insulation. The results of the field surveys were used as the data base, and the tested houses were used to verify the calculation methods.

The basic calculation method used to establish the acoustical effectiveness of various treatments was the external wall noise reduction method developed by Wyle Laboratories under contract to the U.S. Department of Housing and Urban Development (4). This method was later expanded to also address highway and aircraft noise under contracts to the FAA and the FHWA (5). Although there is still considerable controversy regarding this method, it had the largest existing data base on external wall constructions at the time of its compilation.

Calculations were made on a living room area and the worst case bedroom for each home. A computer program developed for the calculations incorporated a data base of exterior construction elements such as walls, windows, and roofs. A base-case calculation was completed along with a series of upgrades. As shown in Figure 6, major sound paths are well established from previous research and the engineering team's initial calculations. The following detailed priority list for the purpose of improving sound insulation was established from the detailed series of calculations:

1. Control direct penetrations into living areas such as mail slots, dryer vents, and exhaust fans.
2. Baffle penetrations into plenum areas such as attic vents directly adjacent to living areas not separated by a double-sided wall in the upper levels of the house.



**FIGURE 5** Results of preliminary air infiltration testing showing distribution of homes having various levels of air infiltration.

3. Introduce sufficient fresh air ventilation so that windows can remain closed on the large number of temperate days characteristic of the Colorado climate.

4. Add sound insulation in attics that are not insulated or are poorly insulated.

5. Upgrade sound insulation of the window units in bedroom and living areas.

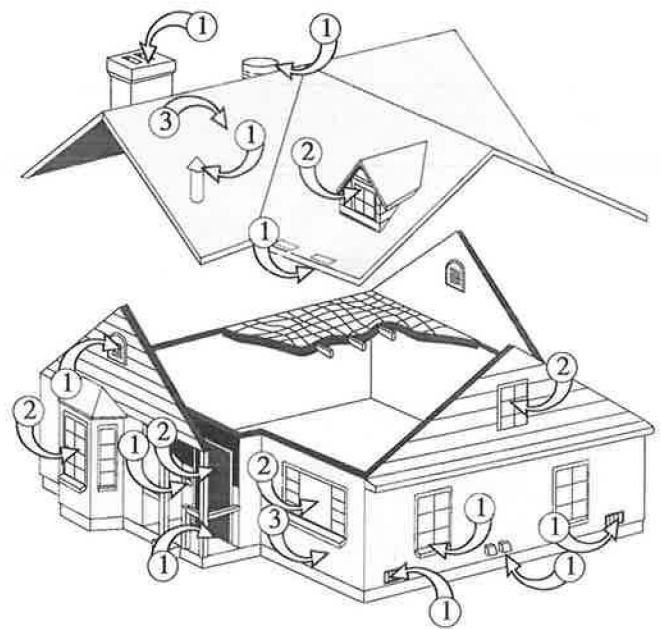
6. Reduce sound and air infiltration of both standard and sliding glass doors.

7. Upgrade large building surfaces when the existing walls cannot perform as well as upgraded windows and doors.

8. Baffle penetrations into plenum areas such as crawl space vents directly adjacent to living areas not separated by a double-sided wall in the lowest levels of the house.

9. Add air conditioning or a specially designed evaporative cooling system, as money allows.

The priority item generating the most controversy is the preference given to small building elements such as windows and doors over large building elements such as the roof. The justification for this decision is best explained by a short series of illustrations. Figure 7 shows the effectiveness of typical wall constructions without any penetrations. Figure 8 shows the effectiveness of each of these walls when an average single-glazed window is placed in the wall. The poor sound insulation of the window quickly becomes the determining factor in the overall sound insulation. Figure 9 shows improvements in sound insulation gained through acoustical upgrades to the window system.



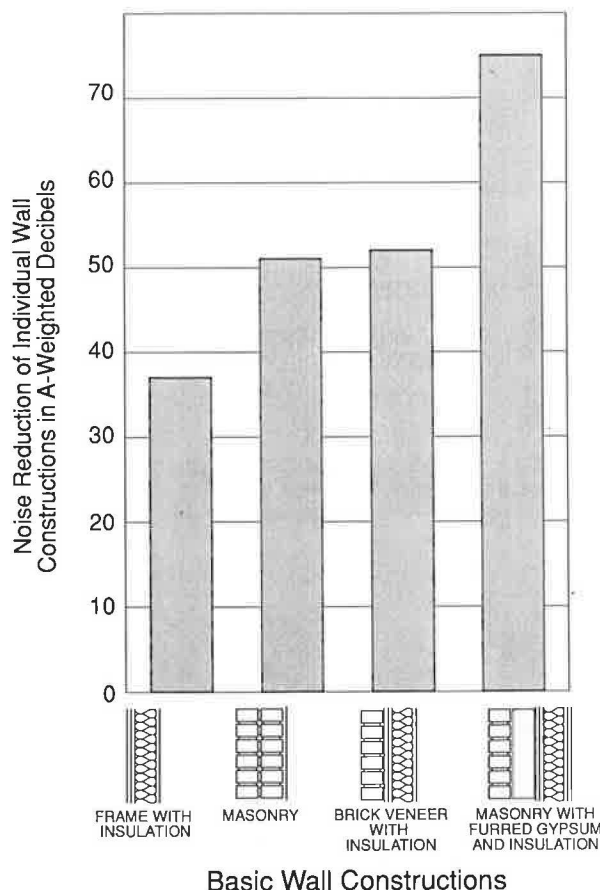
**FIGURE 6** Major sound paths into typical residential construction: 1, air infiltration; 2, small building elements; 3, major building elements.

Extensive cost estimating has been done on all basic remedial constructions. The results of these cost estimates refined the priorities of some measures. Other measures had to be modified or eliminated altogether to comply with stringent local building codes. Such code limitations, for example, eliminated any modifications to existing flues or chimneys.

## PROGRAM DESIGN FOR THE INSTALLING AGENCIES

Ideally, in such a program, the experienced engineering team could enter the individual homes, rapidly make an assessment, input the necessary information into a computer program, and directly generate the necessary drawings and specifications for each home in the program. The intentional separation of the engineering team from the decision-making process in the installing portion of the program forced a reconsideration of how to best convey the necessary information to the installing agencies. Although installing agency personnel are experienced in housing rehabilitation procedures, they can be expected to have no acoustical background and very little heating, ventilating, and air-conditioning experience. Neither of the installing agencies had any computer system or computer experience. The engineering team's responsibility was to devise a manual system to guide the installing agency personnel through the inspection, decision-making, and construction document process. The bidding and construction management processes were planned to be handled in a conventional manner.

The system that the engineering team devised is contained in the SNIP Installing Agency Manual (unpublished). Figure 10 shows the section-by-section breakout of the manual with a brief description of its contents. Not included in this figure are the lists of homes by jurisdiction. The lists are



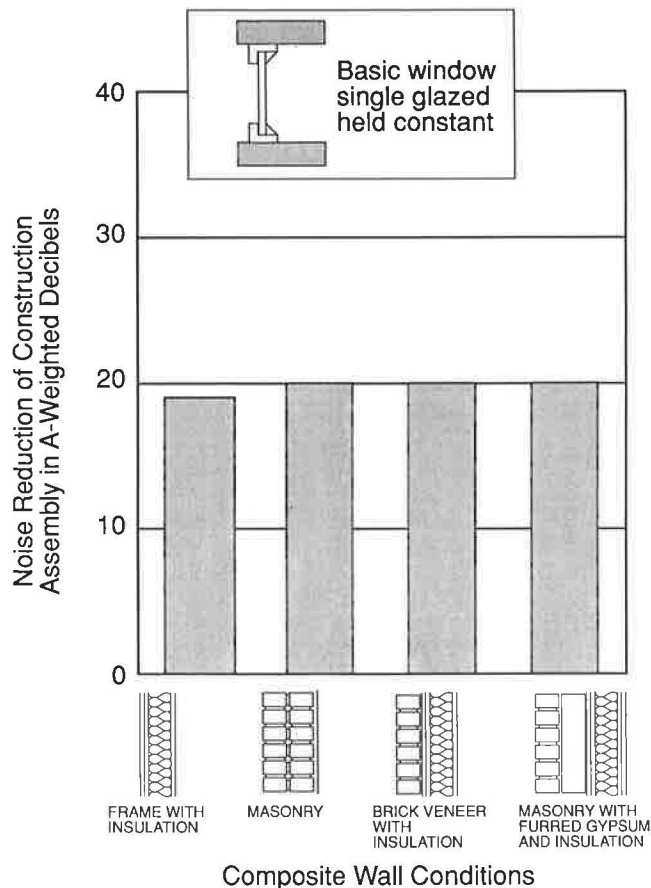
**FIGURE 7** Comparison of noise reductions (in A-weighted decibels) of three common exterior wall constructions found in the field and one common modification used in the sound and energy insulation program.

ordered to directly correspond to utility billing lists. In this manner, they allow for a preliminary determination of whether or not a home is owner occupied.

The checklist system is designed to aid the inspector in recording information crucial to evaluating such items as the condition of a window or door. Even though there are many parallels, a window acceptable for energy efficiency is not necessarily acceptable for acoustical insulation. A small sample of a checklist is shown in Figure 11.

The corresponding decision tree is shown in Figure 12. The decision tree sections pose the questions necessary to evaluate the existing construction conditions. Though most of the decision trees are much more complex than the one shown here, they all direct the inspector to a reference in the priority blocks, applicable details, and appropriate specification sections to be included. The specification references are intended as guides and are not intended to be limiting.

Through use of the priority block system, the inspector is given direction not only to the relative importance of any item to the overall sound insulation but also to the cost-estimating procedure shown in Figure 13. The cost estimate for each item is included as a part of the priority block along with a description of the required action. The series of 11 priority blocks covering all actions allows for a running subtotal of



**FIGURE 8** Comparison of composite noise reductions (in A-weighted decibels) of the same wall constructions as shown in Figure 7 with a standard single-glazed window installed in the wall.

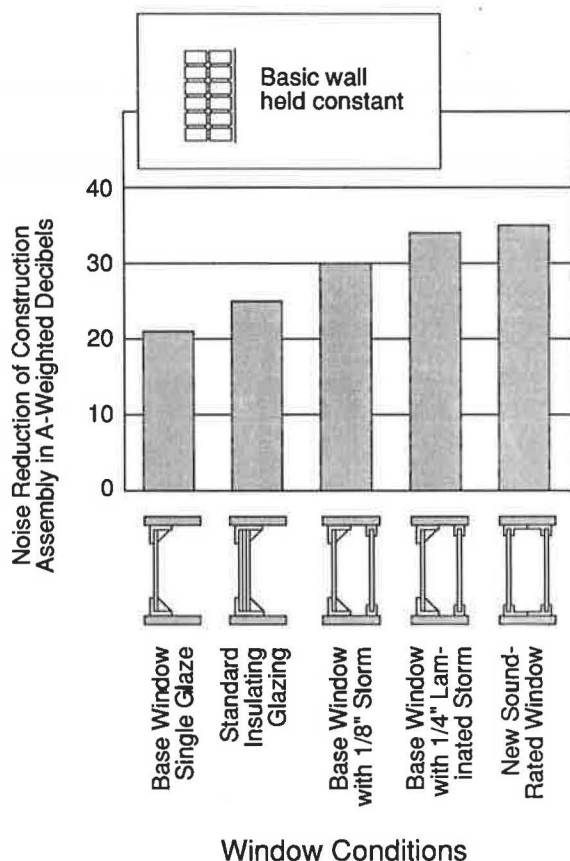
ordered measures. These measures are also ordered by the room involved and that room's location within the home. By developing a list of items the estimated total cost of which is between 120 and 150 percent of the allotted \$7,500.00, the installing agencies can prepare a package of details and specifications for competitive bid.

The program was designed to group 20 homes together in each bid package. The group of 20 homes was selected as being a cost-effective package for smaller contractors. To minimize disruption for the homeowner, the contractors are allowed only 1 week in each home.

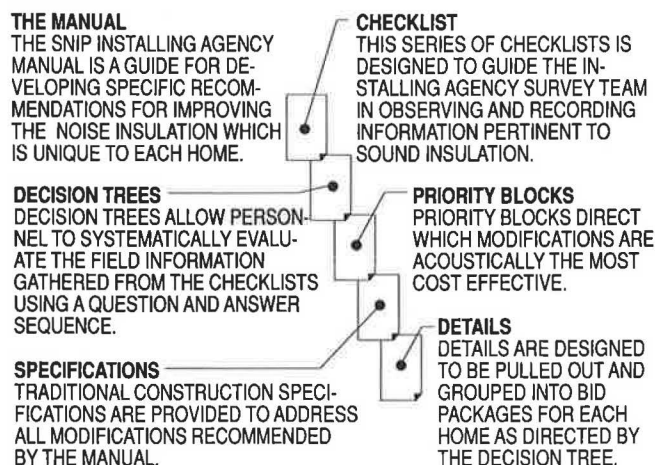
Two sample homes were completed to check the effectiveness of the proposed modifications. The sample homes also served as the background for the filming of two videotapes. One was for acquainting the contractors with acoustical construction practices; the other was for introducing the homeowners to the program and explaining the important features of the program.

To acquire acoustical windows having a consistent standard of acoustical performance, the windows were bulk bid so that all custom replacement windows will be supplied by a single manufacturer. This process, though laborious and controversial while in progress, is proving very beneficial from a cost standpoint and is maintaining a high level of quality control throughout the program. When storm windows are used instead





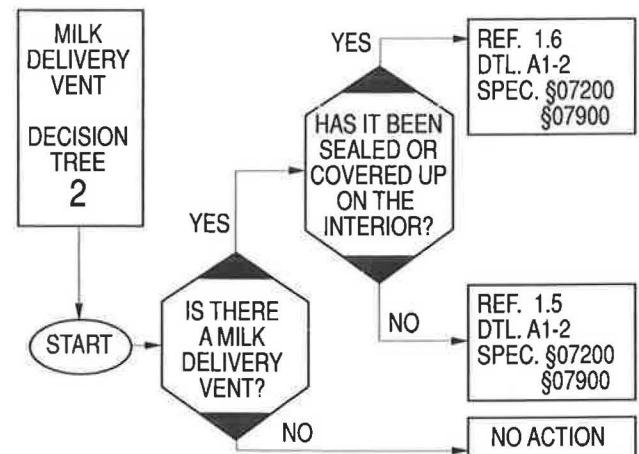
**FIGURE 9** Comparison of the effect on the noise reductions (in A-weighted decibels) when window upgrades are applied for the same basic wall construction.



**FIGURE 10** Organization of SNIP Installing Agency Manual.

Survey Checklist	
<b>MILK DELIVERY VENT</b>	
IS THERE A MILK DELIVERY VENT?	<input type="checkbox"/> YES <input type="checkbox"/> NO
HAS IT BEEN BLOCKED OR SEALED ON THE EXTERIOR?	<input type="checkbox"/> YES <input type="checkbox"/> NO
HAS IT BEEN BLOCKED OR SEALED ON THE INTERIOR?	<input type="checkbox"/> YES <input type="checkbox"/> NO
IS A DOOR MISSING?	<input type="checkbox"/> YES <input type="checkbox"/> NO
IF YES, CIRCLE WHICH IS MISSING: INTERIOR EXTERIOR	
COMMENTS: _____	

**FIGURE 11** Sample section of a survey checklist from the SNIP Installing Agency Manual.



**FIGURE 12** Sample section of a decision tree from the SNIP Installing Agency Manual.

REF.	CAT.	ACTION REQUIRED	ITEM COST	UNIT	AMOUNT	COST	SUB-TOTAL
PRIORITY BLOCK 1							
1.1	MAIL SLOT	NO ACTION REQUIRED.	\$0/EA				
1.2		SEAL EXISTING MAIL SLOT. INSTALL NEW MAILBOX.	\$78/EA				
1.3		REPLACE DOOR. INSTALL NEW MAILBOX.	\$45/EA				
1.4	MILK DELIV. VENT	SEAL EXISTING MAIL SLOT.	\$65/EA				
1.5		FILL VENT WITH INSULATION. PROVIDE SEALANT ON PERIMETER OF BOTH DOORS.	\$49/EA				
1.6		PROVIDE SEALANT ON PERIMETER OF BOTH SIDES.	\$45/EA				

**FIGURE 13** Sample section of a priority block from the SNIP Installing Agency Manual.

of replacement windows, there are several preapproved manufacturers, but the process allows continually evaluating new suppliers, if required. Currently, only two manufacturers have made the effort to apply for approval.

### SUMMARY

Results of the program are expected to vary with respect to the basic construction of each house. Tentatively, modifica-

tions are designed to achieve approximately 10 dB of additional sound reduction from exterior to interior of the homes.

On the sample homes, before-and-after tests indicate improvements. The Aurora house, a frame house with aluminum siding over asbestos shingles, showed a 9-dB improvement. The Denver house, of solid masonry and brick construction, showed a 17-dB improvement. Floor plans of the Aurora and Denver homes with acoustical testing locations are shown in Figures 14 and 15, respectively. Results of the

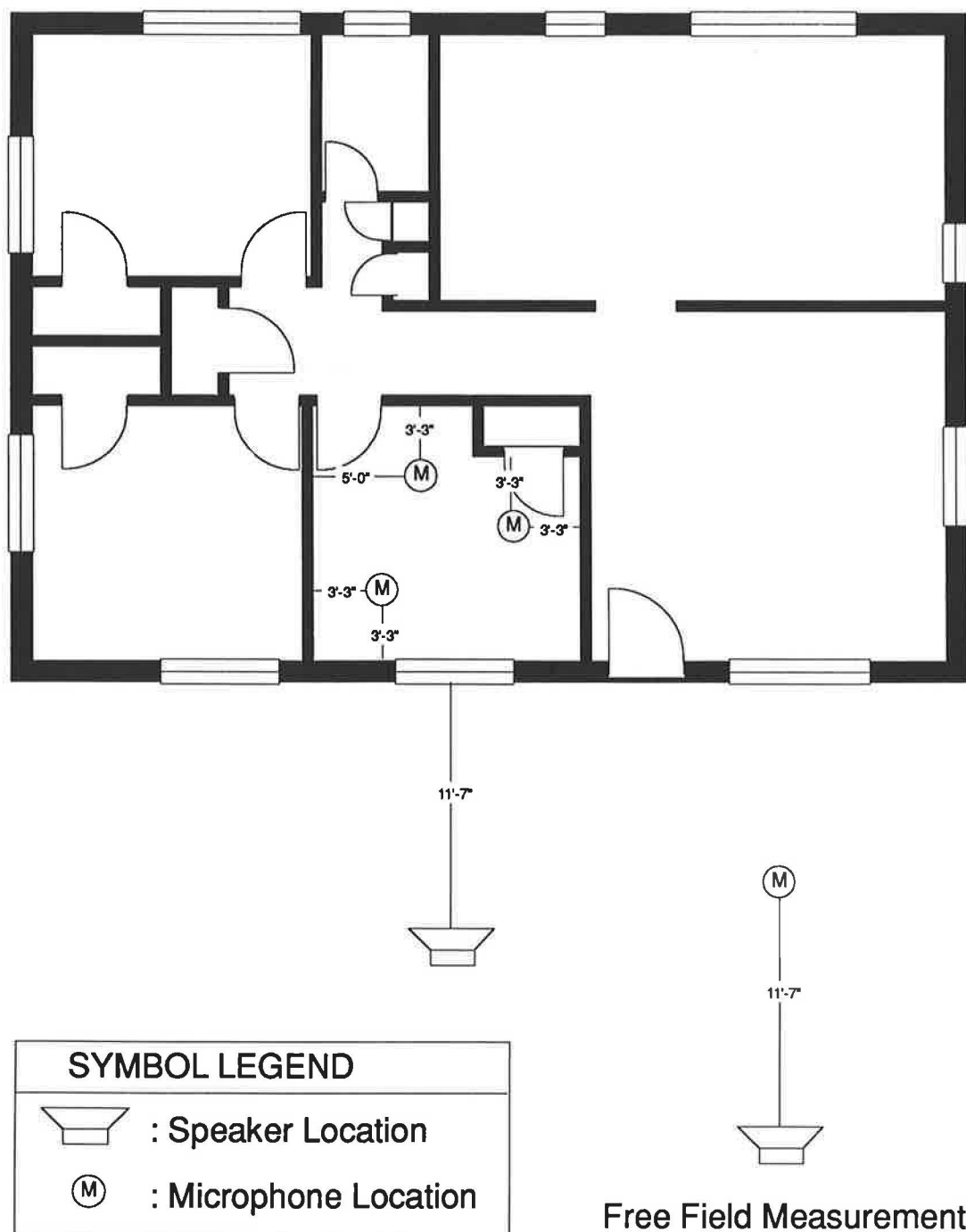
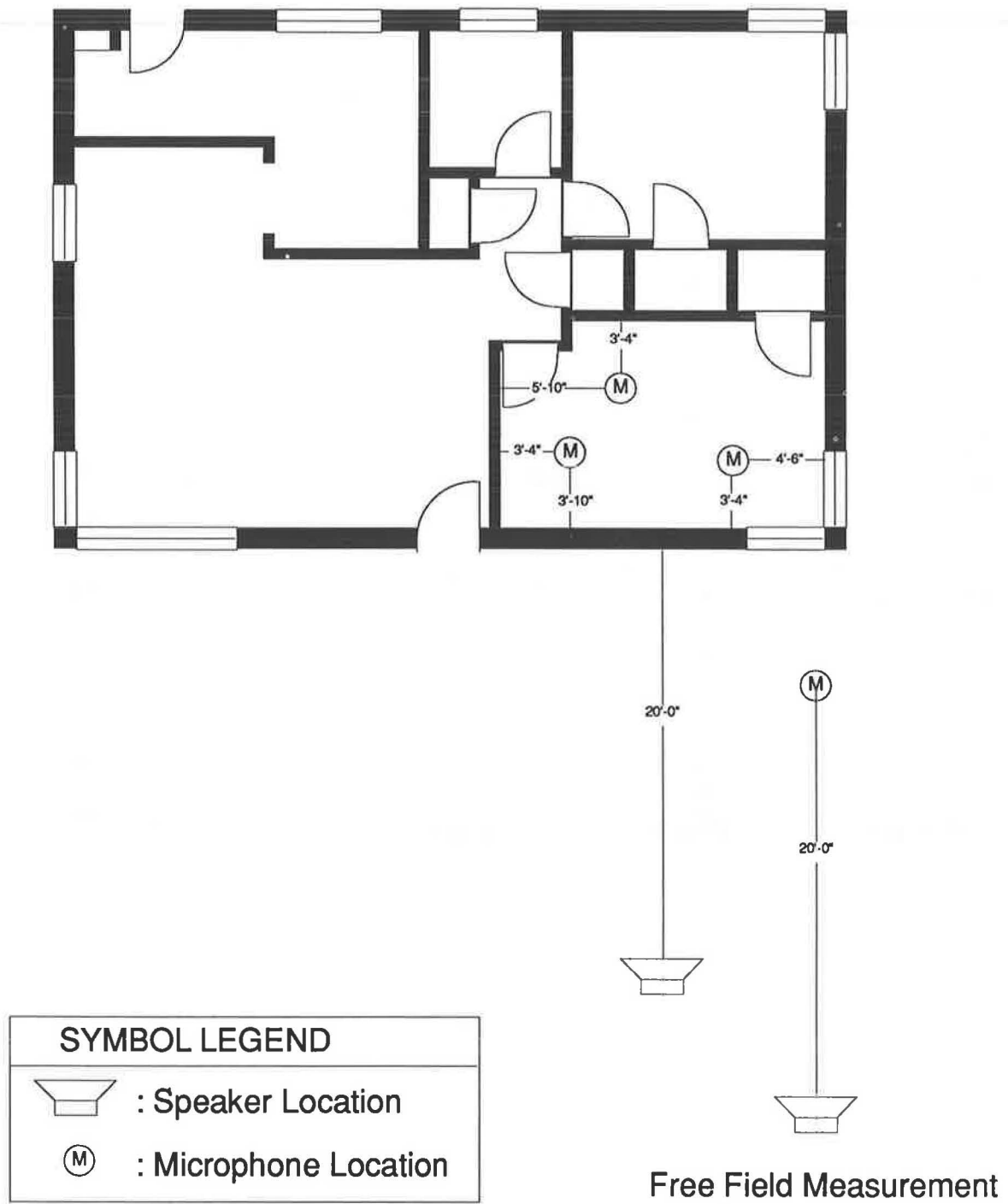


FIGURE 14 Floor plan of the Aurora sample home indicating acoustical test locations.



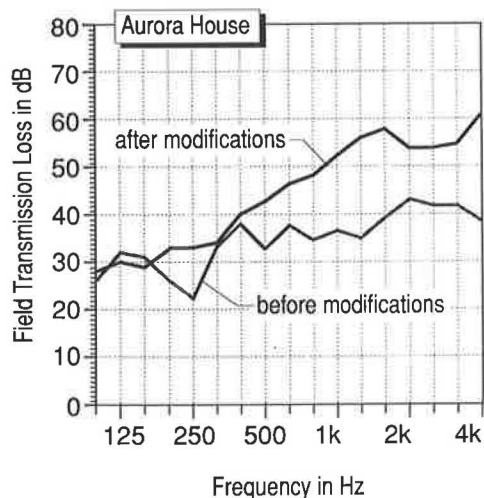
**FIGURE 15** Floor plan of the Denver sample home indicating acoustical test locations.



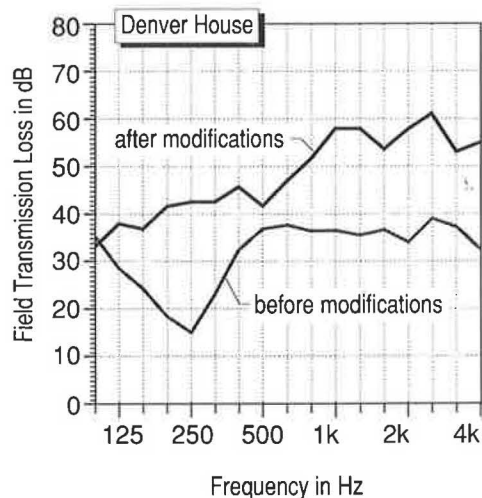
before-and-after tests are shown in Figures 16 and 17, respectively.

The construction portion of the program was delayed because of delays in contract negotiations between the city and county of Denver and the two designated installing agencies. The program is currently in the construction phase with 390 homes completed to date. Because of the widely scattered location of the originally tested homes, only four homes completed to date were part of the original testing program. Postconstruction test results on these homes show a 12- to 23-dB improvement over the preconstruction test results. To document performance, all previously tested homes are slated for acoustical and air infiltration tests after completion.

From the initial construction phases, several observations can be made regarding the effectiveness of the SNIP Installing Agency Manual design. Although the checklist and decision trees are valuable as an initial training tool, each agency has reduced the survey process to reflect the typical construction condition found in its areas. The checklist and decision trees are still used for assessing the action required on less fre-



**FIGURE 16** Before-and-after field transmission loss test results on a frame house with aluminum siding over asbestos shingles. Original steel casement windows are replaced with new dual-glazed sound-insulating windows.



**FIGURE 17** Before-and-after field transmission loss test results on a solid brick home. Original steel casement windows are replaced with new dual-glazed sound-insulating windows.

quently observed conditions. The priority list has become the core document used by both programs for selecting and bidding modifications.

## REFERENCES

1. *Denver-Adams Co. Intergovernmental Agreement*. 1988.
2. *Airport Noise Compatibility Planning*. Federal Aviation Regulations, Part 150 (14 CFR 150), FAA, U.S. Department of Transportation, Washington, D.C., 1989.
3. *Standard Guide for Field Measurement of Airborne Sound Insulation of Building Facade Elements*. ASTM Standard E966-84, ASTM, Philadelphia, Pa., 1988.
4. B. H. Sharp, B. A. Davy, and G. E. Mange. *The Assessment of Noise Attenuation Measures for External Noise*. Wyle Research Report WR 76-3, prepared for the U.S. Department of Housing and Urban Development, Arlington, Va., April 1976.
5. *Study of Soundproofing Public Buildings Near Airports*. Report FAA-AEQ-77-9, FAA, U.S. Department of Transportation, Washington, D.C., April 1977.

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