Acoustic Evaluation of the Ten Houses in the Austin Oaks Project

Elmer L. Hixson

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By

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I. Introduction

Ten single family dwellings were constructed in Austin, Texas under the sponsorship of the U. S. Department of Housing and Urban Development. In the search for adequate housing within the financial reach of low income families, HUD selected houses using widely different building materials and construction practices. The University of Texas was asked to provide engineering, architectural, sociological and psychological evaluations of the houses as family dwellings. The tests reported here are part of the engineering evaluation but also bear on the sociological and psychological factors.

Acoustic evaluations appropriate to the single-story dwellings already constructed are carefully specified in "American Society for Testing Materials, Tentative Recommended Practice for the Measurement of Airborne Sound Insulation in Buildings", (ASTM Designation: E336-67T). Three types of tests are recommended. The Field Transmission Loss is an engineering evaluation of the acoustic noise isolation properties of a wall panel as constructed in the building. This test is useful in comparing the interior wall materials and construction methods. The second test, Noise Isolation, provides a measure of isolation between rooms under normal conditions when the sound can travel all possible paths. These are through walls, heating and air conditioning ducts and return paths, doors, windows, ceilings, floors, etc. The third test, Insertion Loss, is a measure of the effectiveness of the exterior walls and roofs in blocking outside noises from getting in the house.

The Field Transmission Loss is clearly an engineering evaluation while the other two factors bear on the "livability" of a house. The Noise Isolation provides a measure of the privacy of the occupants of a room and the protection from unwanted noise from the rest of the house. The Insertion Loss is a measure of the isolation from disturbing outside noises.

II. Test Procedures

Field Transmission Loss - In order that the tests might be valid and uniform so that comparisons can be made to tests on other partitions, the ASTM document cited above requires that the following conditions must be met:

a) The test partition should be approximately 8' x 9' or larger to be independent of edge effects.

b) The test signal is to be random noise and measurements are to be made in 1/3 octave bands with center frequencies from 100 Hz to 5 KHz.

c) The source room and receiving room (separated by the partition under test) must have reverberant sound fields. To insure this condition there must be at least 10 modes excited and the average absorption coefficient be less than 0.25 in the frequency band of interest. (The minimum room volume for each 1/3 octave band is given in the ASTM specification). In addition the measuring microphone must be no closer than 1/3 wavelength to any wall.

d) To prove that the sound measured in the receiving room is passing through the test wall and not arriving by flanking paths, the wall must be acoustically shielded and the sound pressure level in the receiving room must drop at least 3dB.

In each of the houses, an interior partition was chosen that was unincumbered by closets, shelves or other attachments. In all cases the size was sufficient to satisfy condition (a). Condition (b) limits the lowest frequency for these tests. This is the case since the low frequency 1/3 octave bands have the lowest band width which will support the least number of modes. In several of the houses the rooms were so small that testing could not be done down to 100 Hz as required.

To satisfy the conditions of (d), an attempt was first made to eliminate flanking paths. Duct registers, windows and doors adjacent to the test partition were blocked with fiberglass batting. Then after the transmission loss test, the wall was blocked on the receiving side by a portable sound blocking partition. This consisted of large sheets of 3/4" plywood with 1" thick fiberglass board on one side. These were placed with the fiberglass toward the test wall, fitted and sealed with masking tape. In several cases flanking paths predominated at the extremes of the frequency range. In one case, the wall was so effective that flanking paths could not be eliminated and transmission loss could not be measured.

Field transmission loss is calculated from measured sound pressures as follows:

$$\text{F.T.L. (dB)} = \overline{L_1} - \overline{L_2} + 10 \log S - 10 \log A_2$$

where $\overline{L_1}$ is the average sound pressure level in the source room and $\overline{L_2}$ is the average sound pressure level in the receiving room where both are in dB relative to 0.0002 μbar. The area of the test partition in square feet is S and A_2 is the total receiving room absorption in Sabines. The absorption in third octave bands spaced one octave apart was determined from reverberation time measurements. This was sufficient since A_2 did not vary greatly with frequency. (Reverberation time, T, is the time in seconds for the reverberant sound field in the room to drop 60 dB after the noise source is turned off). Then:

$$A_2 = 55.2\ V/c\ T$$

and can be expressed in dB as

$$A(\text{dB}) = 10 \log A_2$$

where V is room volume in cubic feet and c is sound speed in feet per second. Since c depends on air temperature and water vapor content, wet and dry bulb temperature measurements were taken.

Field transmission loss data are presented later in the test result section.

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Regions where flanking paths existed are indicated on the curves. Values of A(dB) are plotted at the frequency of the 1/3 octave band in which they were measured. Since values of A(dB) were not determined in every band the values plotted cannot be connected with a graph. In addition a Field Sound Transmission Class (FSTC) rating is determined for each partition. This is done by fitting a profile to the Field Transmission Loss plot. This profile is flat from 1.5 KHz up, increases at 6dB per octave from 350 Hz to 1.5 KHz and has a slope of +10 dB per octave below 350 Hz. The profile is fitted to the F. T. L. curve from below and placed where it just touches some point on the curve. Then the FSTC is read from the flat portion. This rating has been determined as a good measure of a partition's effectiveness in blocking noise that is most annoying to people.

Noise Isolation - This factor was measured by producing broad band noise in a room then measuring the noise in octave bands in the source room and a receiving room. Only one microphone position was used in each room. Noise Isolation is then the difference in sound pressure level in dB between the two rooms. Regardless of room size, data were taken in octave bands centered at 63 Hz to 8KHz.

In each house, the living-dining area was used as source room. In normal living this would be expected to be the noisy area of the house. Each of the other rooms was successively used as receiving room.

For realistic results, the house and furniture were kept in normal condition. No sound paths were blocked but all doors were closed.

Insertion Loss

This quantity is defined as the ratio in dB of the sound pressure level from an external source that is measured in the houses to the sound pressure level measured at the same place with the house not there. Since it was not possible to remove the houses, another procedure was used. A loudspeaker producing broad band noise was placed outside 50' from a microphone in the center of the test room. Sound pressure level was measured in octave bands with center frequencies from 63 Hz to 8KHz. Then the source was moved away from the house and the microphone placed 50' from it to simulate the no house conditions. Precautions were taken to keep the same path direction to minimize wind effects and to stay away from other houses to prevent reflected paths. Sound pressure levels were again measured with the same electrical drive to the loudspeaker. The two sets of data were than used to calculate Insertion Loss.

Only one room in each house was used in the test. This was usually a bedroom, being one of most concern to outside noise, and there was usually a window in the exterior wall facing the sound source. Thus, the exterior wall material and construction was not evaluated but the combination of wall-window-roof effectiveness in blocking outside noises was measured.

III. Measurement Equipment

The equipment used in all the tests are shown in block diagram form in figure 1. It is shown in the configuration used for Field Transmission Loss measurement. Since the 1612 filter could be operated as a 1/3 octave and full octave filter set, all the tests could be performed with the equipment as shown.

The electrical noise source used in the tests provided a noise spectrum that decreased with frequency so that the energy in proportional band filters such as the octave filter set would be constant. This is called "Pink Noise" because of higher amplitudes at the low frequency end.

The noise signal was then passed through an octave filter set. With the combination of the "pink noise" and octave band widths, the best utilization of the power capabilities of the amplifier and loudspeakers could be made. The amplifier had two channels with 30 watts per channel to two wide range loudspeakers. With this system, sound levels of approximately 90 dB re 0.0002 μ bar in most octave bands in the rooms could be obtained.

Sound pressure levels were determined by the use of a ½" capacitor microphone whose calibration was checked before each test with a piston phone. The sound level meter provided power for the microphone pre-amplifier, further amplified the signal and provided a direct reading of sound pressure level. The sound level meter provided an output to the 1/3 octave filter and power for the octave filter.

The third octave filter could be automatically stepped from one band to the next by the level recorder. The filtered signal, after being amplified, was fed to the level recorder. This instrument detected the signal and plotted it logaritmically. Then as the chart ran at constant speed the filter was stepped, spending about 5 seconds at each third octave. When the 1612 filter was switched to octave band widths about 15 seconds was spent in each. The octave filter determining the transmitted noise spectrum was manually switched in synchronism with the third octave filter.

Since the level recorder had a writing speed faster than 600 dB per second it was used for reverberation time measurements. With the noise on, the chart drive was run at high speed, then the noise turned off. From the slope of the decay curve which was linear because of the log plot, the reverberation time was determined.

With the equipment described, the three kinds of measurements could be rapidly made.

IV. Test Results

The figure labeled House No. 1 shows the house plan and indicates the wall tested and detail of the wall construction. Other information about the house construction is given.

The Field Transmission Loss curve for the wall tested in House No. 1 follows. The template used to determine FSTC is shown dotted and values of absorption, A, are plotted. Regions where flanking paths nullified the data are indicated.

The FTL curve slope is typical of the walls in the rest of the houses and walls in general. Mass effects control the characteristics above about

300 Hz. The slope is about 20 dB per decade. The wall stiffness may resonate with the mass to produce a dip such as at 300 Hz and result in a rise in FTL at low frequencies. Another effect often occurs that is indicated by this curve. Building partitions readily support flexural waves that can be excited by sound incident at some oblique angle. The peaks and dips at 0.63, 1.0 and 1.6 kHz are typical of these effects.

It can be seen that the dip at 1.0 kHz determines the FSTC which is 27. A value of about 40 is necessary to provide reasonably good noise isolation between rooms. For values below 20 ordinary conversation could probably be understood in the adjacent room.

The noise isolation curves for house No. 1 might be expected from the placement of rooms shown on the floor plan. The bath and bedroom No. 5 are equidistant from the source in the kitchen-living room area. However, the door to the bath is nearer the source giving a lower noise isolation. Taking an average for the curves above 250 Hz the bath is 22 dB, bedroom No. 5, 30 dB and the other bedrooms about 34 dB. Although the wall FSTC is not good, because of the separation, four of the bedrooms are fairly well isolated from the noisy area.

The insertion loss for House No. 1 in bedroom No. 1 is poorer than the wall FSTC would predict. This results from the windows providing a flanking path. This was typical of all the houses with a window facing the sound source.

The three sets of curves for each house are not included here but the general characteristics are summarized in Table 1. This table is followed by a floor plan and wall detail of the houses.

In general the mass of the wall controlled the FSTC with some exceptions. House No. 6 had very light weight walls and poor FSTC. Houses 1, 3, 4, 5 and 10 had light weight walls and FSTC about 27. Houses 2, 8 and 9 had medium weight walls but only No. 8, the most conventional partition, was adequate. No. 2 was limited by transverse wave effects. No. 7 had massive walls but it was completely negated by flanking paths.

Insertion loss was poor in all but one case because of windows facing outside sources. In No. 2, however, heavy sliding doors faced outward instead of windows and insertion loss was significantly higher.

Conclusions

The construction practices used in these low cost houses resulted in light weight and flexable walls which provide poor acoustic isolation. However, it should be noted that acoustic considerations were not design considerations in planning the houses. In many cases small changes could have improved the acoustic characteristics considerably.

It is felt that acoustic noise isolation should be a strong consideration in low cost housing design since it bears greatly on the "livability" of a house. Good noise isolation insures the privacy of the members of the household, provides conditions for children to get adequate sleep and reduces the irritation of long noise exposure.

House No.	Wall Weight lb/ft^2	FSTC	Noise Isolation Bath dB	Noise Isolation Bedroom dB	Insertion Loss dB
1	2.9	27	22	34	20
2	7.5	25	20	27	30
3	2.8	32	22	30	23
4	2.8	24	20	24	27
5	2.8	25	22	25	15
6	1.25	19	18	27	17
7	96	28	16	24	20
8	5.2	38	16	23	18
9	9.0	32	16	20	25
10	1.4	31	15	15	22

Table 1

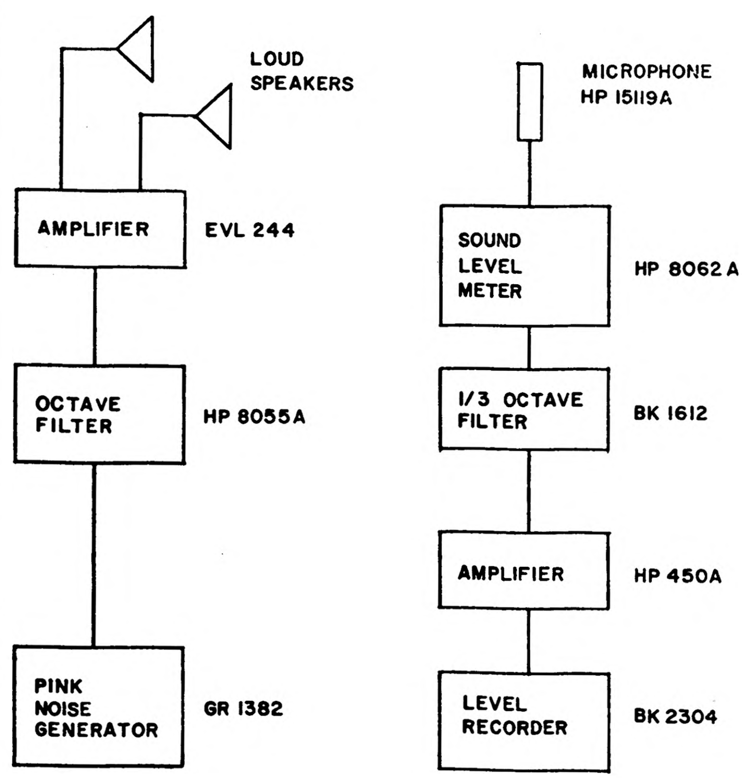
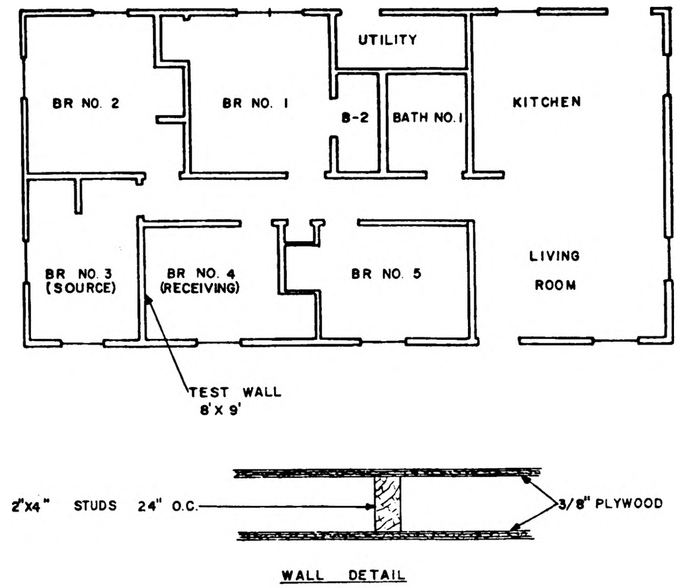
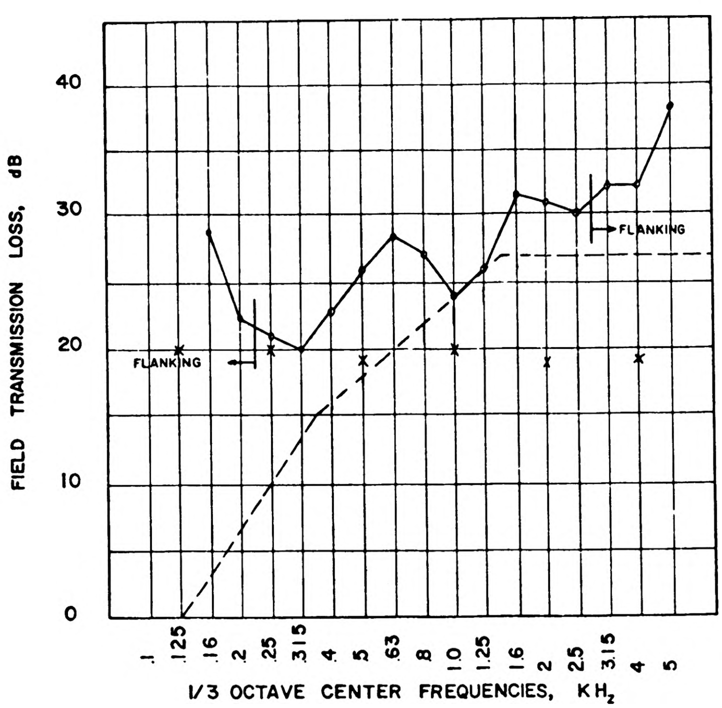


FIGURE 1 MEASUREMENT EQUIPMENT



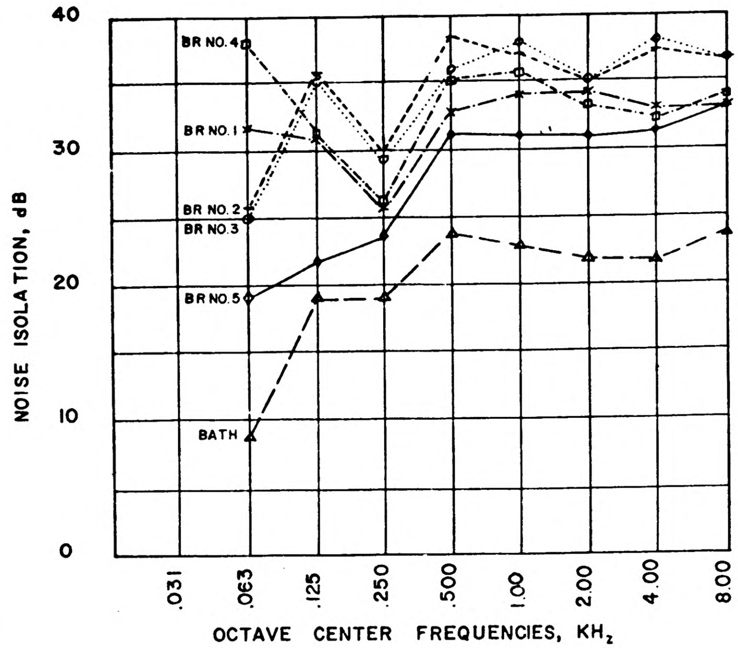
WALLS	PLYWOOD "STRESSED SKIN SANDWICH PANELS" WITH FIBERGLASS INSULATION STUDS AT WINDOWS AND DOORS, WT. 2.9 LBS/FT^2
CEILING	"STRESSED SKIN SANDWICH PANELS"
FLOOR	"STRESSED SKIN" 5/8 PLYWOOD ON 2"X 4", 16" O.C. SEAMLESS VINYL ACRYLIC COVERING
RECEIVING ROOM	8' X 9', α = 0.213

HOUSE NO. I

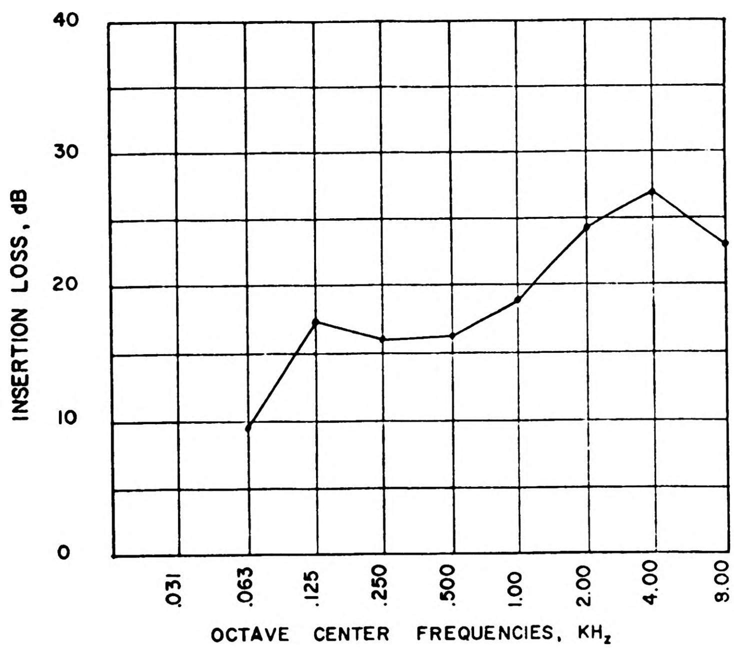


X- A(dB) FSTC = 27

FIELD TRANSMISSION LOSS, HOUSE NO. I



NOISE ISOLATION, HOUSE NO. I

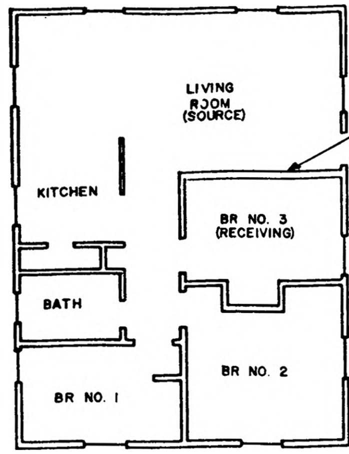


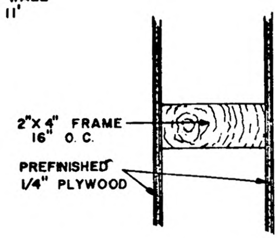
TEST ROOM- BEDROOM NO. I

INSERTION LOSS, HOUSE NO. I

House No.	Wall Weight lb/ft^2	FSTC	Noise Isolation Bath dB	Noise Isolation Bedroom dB	Insertion Loss dB
1	2.9	27	22	34	20
2	7.5	25	20	27	30
3	2.8	32	22	30	23
4	2.8	24	20	24	27
5	2.8	25	22	25	15
6	1.25	19	18	27	17
7	96	28	16	24	20
8	5.2	38	16	23	18
9	9.0	32	16	20	25
10	1.4	31	15	15	22

Table 1

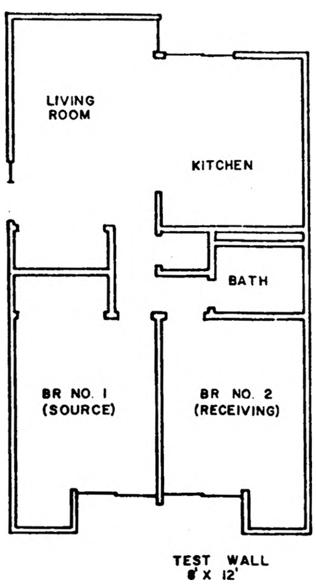


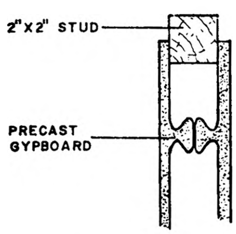


WALL DETAIL

WALLS	LAMINATED LOAD BEARING PANELS, 5/16" ALUMINUM CLAD PLYWOOD EXTERIOR, 1½" EXPANDED POLYSTYRNE CORE AND ¼" PREFINISHED PLYWOOD INTERIOR WT. 2.8 LBS/FT^2
CEILING	SUSPENDED ACOUSTICAL TILE WITH 3" FIBERGLASS INSOLATION
FLOORS	1⅛" PLYWOOD ON JOISTS
RECEIVING ROOM	8' X 12', α = 0.345

HOUSE NO. 3

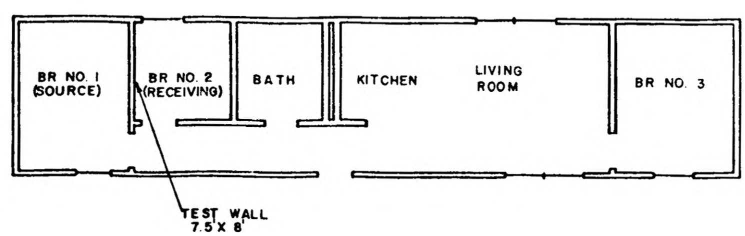


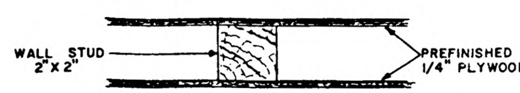


WALL DETAIL

WALLS	PREFABRICATED 4' X 8' PANELS WT. 7.5 LBS/FT^2
CEILING	PRECAST CONCRETE SLAB
FLOOR	CONCRETE SLAB, CARPETED
RECEIVING ROOM	10' X 16', α = 0.274

HOUSE NO. 2

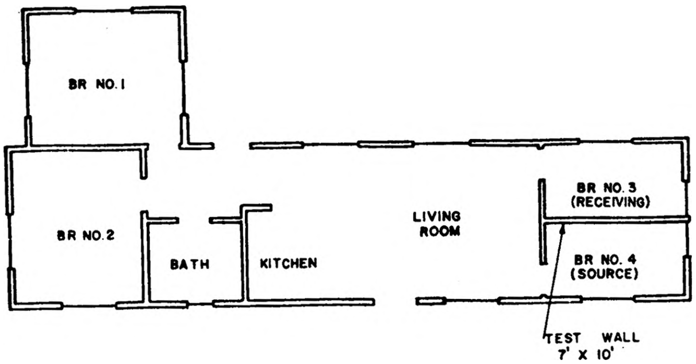


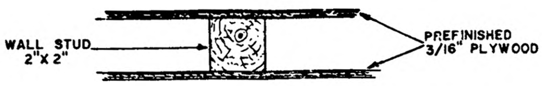


WALL DETAIL

WALLS	¼" PREFINISHED PLYWOOD ON 2" X 2" STUDS 16" O.C. WT. 2.8 LBS/FT^2
CEILING	⅜" GYPSUM BOARD
FLOORS	SHEET VINYL ON ⅝" PLYWOOD ON 2" X 6" JOIST 16" O.C.
RECEIVING ROOM	8' X 8', α = 0.143

HOUSE NO. 4

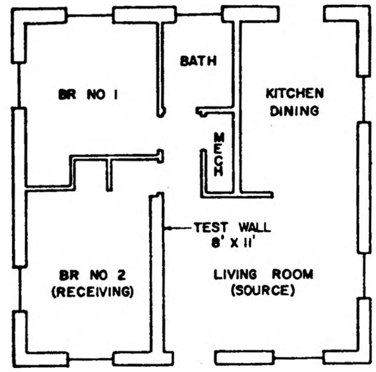


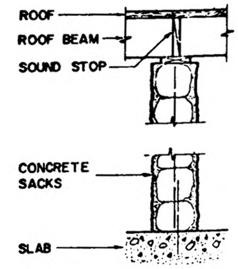


WALL DETAIL

WALLS	PREFINISHED PLYWOOD ON 2" X 2" STUDS 16" O.C. WT. 2.8 LBS/FT^2
CEILING	3/8" GYPSUM BOARD ON 2" X 4" JOIST 16" O.C.
FLOOR	VINYL ASBESTOS TILE ON 5/8" PLYWOOD ON 2" X 8" JOIST 20" O.C.
RECEIVING ROOM	6' X 10', α = 0.209

HOUSE NO. 5

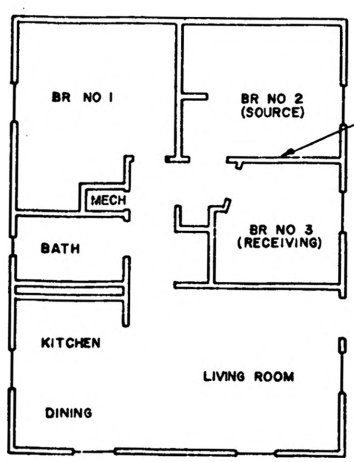


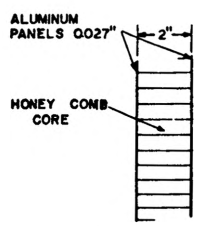


WALL DETAIL

EXTERIOR AND ONE INTERIOR WALL	CONCRETE SACK, GUNNITE SPRAYED FINISH WT. = 96 LBS/FT.^{2}
CEILING	OPEN BEAM - 4" X 6" AT 24" O/C W/ 5/8" PLYWOOD DECKING
FLOOR	VINYL ASBESTOS TILE ON CONCRETE SLAB
RECEIVING ROOM	8' X 9', α = 0.323

HOUSE NO. 7

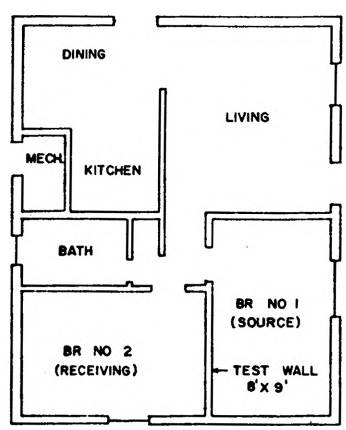


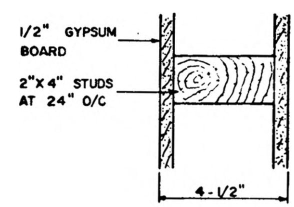


WALL DETAIL

WALLS AND CEILING	ALUMINUM SKIN HONEYCOMB CORE ROOF AND EXTERIOR WALLS - 3" INTERIOR WALLS - 2", WT. 1.25 LBS/FT^2
FLOOR	VINYL ASBESTOS TILE ON 3/4" PLYWOOD ON 2" X 6" JOIST 24" O.C.
RECEIVING ROOM	9' X 10', α = 0.311

HOUSE NO. 6

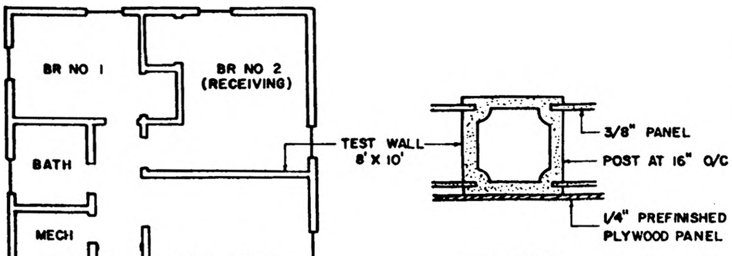




WALL DETAIL

WALLS	INTERIOR - GYPSUM BOARD ON STUDS, EXTERIOR - CONCRETE BLOCK WT. = 5.2 LBS./FT.^{2}
CEILING	1/2" GYPSUM BOARD ON 2" X 4" TRUSSES AT 24" O/C
FLOOR	ASPHALT TILE ON CONCRETE SLAB
RECEIVING ROOM	9' X 13', α = 0.202

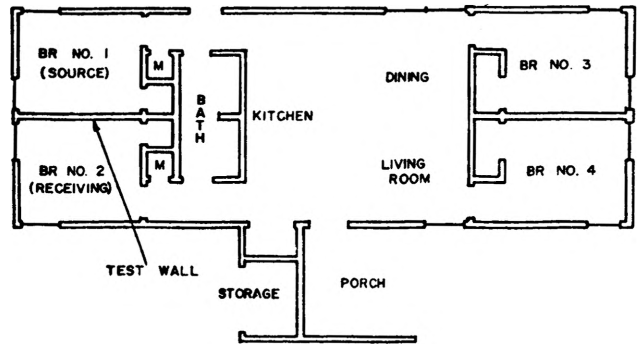
HOUSE NO. 8



WALL DETAIL

WALLS	POST AND PANEL SYSTEM ASBESTOS CEMENT EXTRUSIONS WT. = 9 LBS./FT.^{2}
CEILING	1/2" GYPSUM BOARD ON 2" X 4" TRUSSES AT 24" O/C
FLOOR	ASPHALT TILE ON CONCRETE SLAB
RECEIVING ROOM	10' X 10', $\alpha = 0.321$

HOUSE NO. 9



WALL DETAILS

WALLS	EXTERIOR 2" THICK CAST CONCRETE "PANEL LOCK" SYTEMS, INTERIOR VINYL COVERED CARDBOARD WT. 1.4 LBS./SQ.FT.
CEILING	1/2" GYPSUM BOARD ON 2"X4" JOIST 24" O.C.
FLOOR	CONCRETE SLAB
RECEIVING ROOM	7'X9', $\alpha = 0.372$

HOUSE NO. 10