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Acoustical Evaluation of a Single Family Attached Wood-Frame Modular Housing System Constructed on an Operation Breakthrough Prototype Site

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

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Acoustical Evaluation of a Single Family Attached Wood-Frame Modular Housing System Constructed On An Operation BREAKTHROUGH Prototype Site

by

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ABSTRACT

The acoustical performance of a single family attached wood-frame modular housing system was tested on an Operation BREAKTHROUGH prototype site.

Test results are given concerning the noise isolation of intra-dwelling walls and floor-ceilings, as well as the noise levels within living units.

Key Words: Acoustics; field impact insulation class; noise criterion curve; noise isolation class; Operation BREAKTHROUGH

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1. INTRODUCTION

Drawings and specifications for the housing systems being demonstrated as a part of Operation BREAKTHROUGH were reviewed in order to determine the acoustical performance of the dwelling units. Any potential deficiencies in acoustic performance were noted such that appropriate action could be taken prior to manufacture and site installation of the housing units.

Poor workmanship, however, can negate even the best planned acoustical improvement. The many unknowns associated with workmanship, possible damage to the housing modules during shipment, assembly of the housing modules on the building site, and even the modular concept of construction typical of many of the Operation BREAKTHROUGH housing systems, emphasized the importance of performance testing.

More builders than ever before are now at least aware that acoustic quality in buildings is becoming an essential consumer requirement. A great deal of information can ultimately be drawn from the acoustical performance testing of Operation BREAKTHROUGH housing.

2. OBJECTIVE

The objective of this work was to obtain information regarding interior noise levels and the intra-dwelling noise isolation provided by this prototype housing system constructed within the Operation BREAKTHROUGH Program on one of the prototype sites, and to provide this information as a data base for possible comparison with the acoustical performance of conventional housing.

3. TEST PROCEDURE

All tests were performed in accordance with the methods outlined in the appropriate standards. The pertinent tests include:

Appendix A1 of ASTM E 336-71, "Recommended Practice for the Measurement of Airborne Sound Insulation in Buildings."

ASTM E 413-70T, "Tentative Classification for Determination of Sound Transmission Class." (This test method is used for the determination of Noise Isolation Class.)

ASTM RM 14-4, 1971, "Proposed Tapping Machine Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies."

ASTM C 423-66, "Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms," Section 9.1, for measurement of decay rate procedure.

ANSI S1.2-1962, "ANSI Standard Method for the Physical Measurement of Sound."

All measurements were carried out using the NBS Mobile Acoustical Laboratory[1/]. A complete list of the equipment utilized for these measurements is given in Table 1.

Airborne noise reductions were measured using 1/3-octave bands of pink random noise[2/] to excite the speaker systems. A multiplex system which scanned the outputs of the microphones was used for simultaneous spatial averaging in both the source and receiving rooms. The output of the multiplexer was passed through a 1/3-octave band-pass filter set and then to the measuring system.

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(1) Winzer, George E., National Bureau of Standards Mobile Acoustical Laboratory, Sound and Vibration, May 1970.

(2) Pink random noise is a quantity (e.g., sound pressure) whose amplitude probability is a normal (Gaussian) distribution curve and whose frequency spectrum slopes at minus 3 dB per octave.

A total of six microphones, in a modified spherical array as shown in Figure 1, was used in all rooms.

Temporal averages of sound pressure levels were obtained using a true root-mean-square voltmeter in order to obtain less statistical error in sound pressure levels than can be obtained with the graphic level recorder recommended in ASTM E 336-71. A differential amplifier was used with two true r.m.s. voltmeters to obtain the differences in the r.m.s. sound pressure levels of the random noise between the source and the receiving room. Airborne noise reduction determination averaging times of 100 seconds for tests at frequencies from 125 through 400 Hz and 30 seconds for tests at frequencies from 500 through 4000 Hz were used in order to achieve a statistical error (due to temporal averaging) of less than $\pm$ 0.4 dB (at a confidence level of 95 percent).

The uncertainty in measured sound pressure levels, due to random and systematic uncertainties associated with the over-all data acquisition system, is estimated (95 percent confidence level) to be less than $\pm$ 1 dB for relative sound pressure levels (measured to determine airborne noise reductions) over a range of band-center frequencies from 100 to 4000 Hz. ASTM E 336-71 specifies that for suitable accuracy in determining the average sound pressure levels in the source and receiving rooms the rooms shall be large enough that there are at least 10 normal modes per measurement bandwidth. The lower limit of frequency for which this would occur using 1/3-octave bands was: 225 Hz for the bathroom and 155 Hz for the bedroom.

For the airborne noise reduction measurements, as well as for impact sound transmission measurements, the background noise in the receiving room was at least 10 dB below the transmitted signal. The equivalent sound absorption of the receiving rooms was determined by the reverberation decay method described in ASTM C 423-66.

For the measurement of impact sound transmission through the floor-ceiling assembly, the same modified spherical array, multiplex system and true root-mean-square voltmeter were used. The output of the voltmeter was recorded with a graphic level recorder. The positions for the tapping machine are shown in Figure 1. The tapping machine was positioned according to those positions suggested by ASTM RM 14-4, 1971, where space permitted.

Measurements of noise levels of certain mechanical equipment were carried out for comparison with the Noise Criterion (NC) contours[3/]. An octave band-pass filter set and graphic level recorder were used for these measurements. The background noise in the receiving room was at least 10 dB below the sound pressure level of the equipment being measured.

During the field measurements the temperature was nominally 66°F and the relative humidity 41%.

(3) Schultz, T. J., "Noise Criterion Curves for use with the USASI Preferred Frequencies," J. Acoust. Soc. Am. 43, 637-638 (1968)

4. DESCRIPTION OF HOUSING SYSTEM

The housing system which was tested was classified as a single family attached housing system. It consisted of a two story building made up of first and second floor modules. The floor plan of the living unit tested, which was an end unit, is shown in Figure 1. Adjacent units contained different floor plans.

The three modules comprising this living unit contained respectively:

(1) a dining area, two bedrooms, and a bathroom

(2) a living room, kitchen, mechanical room, and stairway

(3) two bedrooms and a bathroom.

The living units were unfurnished except for floor coverings and kitchen equipment.

The first floor modules were placed over a full basement.

A cross-section of the floor-ceiling assembly is shown in Figure 2. The floor ceiling assembly consisted of 2 x 8 (nominal) wood joists located 16 inches on center with a 5/8-inch plywood subfloor. The ceiling joists were spaced 3-1/2 inches from the bottom of the floor joist and consisted of 2 x 6 (nominal) wood studs located 16 inches on center with 1/2-inch gypsum drywall on the room side.

The intradwelling walls within a module were of conventional construction built of 2 x 4 (nominal) wood studs located 16 inches on center with 1/2-inch gypsum drywall on each side. Interior doors were of a hollow core wood construction and were undercut approximately 3/4 inch.

The gas fueled, warm air circulation HVAC system was located on the first floor in the area between the living room and kitchen as shown in

Figure 1. The single cold air return register, which was located near the floor, controls the flow of return air to the HVAC unit through a short duct run of approximately 12 inches.

5. TEST RESULTS

5.1 Noise Isolation of Intra-Dwelling Walls

Each measured noise reduction was normalized to a reference receiving room absorption, A_o, of 10 m^2 (100 ft^2) according to the following equation:

$$NR_n = NR - (10 \log_{10} \frac{A}{A_o})$$

where NR_n = Normalized noise reduction

NR = Noise reduction before normalization

A = Total sound absorption of the receiving space.

The results of measurements of the normalized noise reduction between the bathroom and the horizontally adjacent back bedroom are shown in Figure 3. The three-segmented solid line represents the Noise Isolation Class (NIC) contour fitted to these data according to the specified procedure in ASTM E 413-70T. The dotted line points to the normalized NIC value. The normalized NIC value obtained is also given in Table 2.

5.2 Noise Isolation of Intra-Dwelling Floor-Ceiling

The results of measurements of the normalized noise reduction between kitchen and vertically adjacent back bedroom are shown in Figure 4. The impact noise isolation was measured between two second floor rooms and the kitchen; (a) a carpeted back bedroom and (b) a bathroom with vinyl-covered floor. The impact sound pressure levels were normalized according to the procedure stated in ASTM 14-4, 1971. The normalized impact sound pressure levels vs. frequency are shown in Figures 5 and 6 for these two cases. These figures also include the Impact Insulation Class (IIC) contour fitted to these data according to the specified procedure in ASTM RM 14-4, 1971. The normalized NIC value and IIC values obtained are given in Table 2.

5.3 Noise Levels Within Living Unit

The noise levels in both the living room and kitchen with the heating system in operation are given in Figures 7 and 8, along with the Noise Criterion contours (NC).

6. OBSERVATIONS

During the tests of the housing unit two conditions were observed which affected its acoustical quality:

(1) Due to the proximity of the HVAC system installation normal conversation was difficult in the living room when the system fan was in operation.

(2) Some of the walls in the second floor module did not quite meet the ceiling, leaving gaps of 1/8- to 1/4-inch which could be possible "flanking-paths" for sound.

Table 1

Instrumentation*

1. Brüel & Kjaer 1402 Random Noise Generator
2. (3) Brüel & Kjaer Models 1612, 5004 Band-Pass Filter Sets
3. JBL Speaker Systems
4. (2) Brüel & Kjaer 2606 Measuring Amplifier
5. (2) Brüel & Kjaer 215 RMS Converter & Log Amplifier
6. (2) Brüel & Kjaer 221 Microphone Energizer - Multiplexer
7. Brüel & Kjaer 2305 Graphic Level Recorder
8. (12) Brüel & Kjaer 4132 Condensor Microphones
9. (12) Brüel & Kjaer 2619 FET Preamplifier
10. (2) Brüel & Kjaer 4220 Pistonphone
11. Brüel & Kjaer 3204 Tapping Machine
12. NBS Differential Amplifier
13. NBS Reverberation Time Measuring System
14. HP 5325 A Counter

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* Commercial instruments are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.

Table 2

The measured noise isolation characteristics of the housing system

Partition	Source Room Unit	Receive Room Unit	Normalized NIC	Normalized IIC (Mean)
Intra-dwelling Wall	Bathroom 09-SFA/03-16	Bedroom (Back) 09-SFA/03-16	30	--
Intra-dwelling Floor/Ceiling	Kitchen 09-SFA/03-16	Bedroom (Back) 09-SFA/03-16	29	--
Intra-dwelling Floor/Ceiling	Bedroom (Back) 09-SFA/03-16	Kitchen 09-SFA/03-16	--	61
Intra-dwelling Floor/Ceiling	Bathroom 09-SFA/03-16	Kitchen 09-SFA/03-16	--	33

Equipment	Receive Room Unit	NC
Heater on	Living Room 09-SFA/03-16	<60
Heater on	Kitchen 09-SFA/03-16	<55

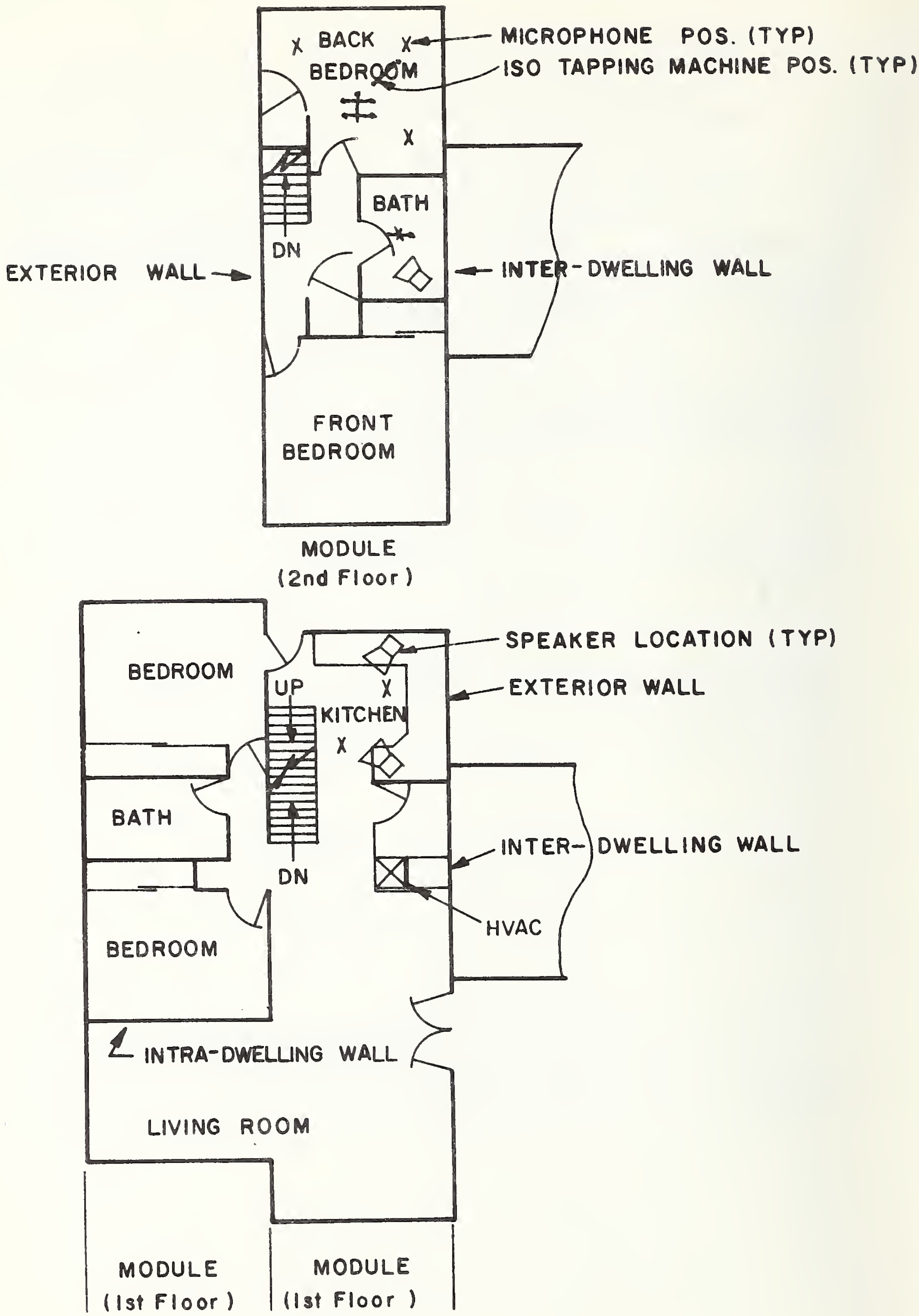

Figure 1. Floor plans of housing system showing microphone, speaker, and tapping machine positions tested.

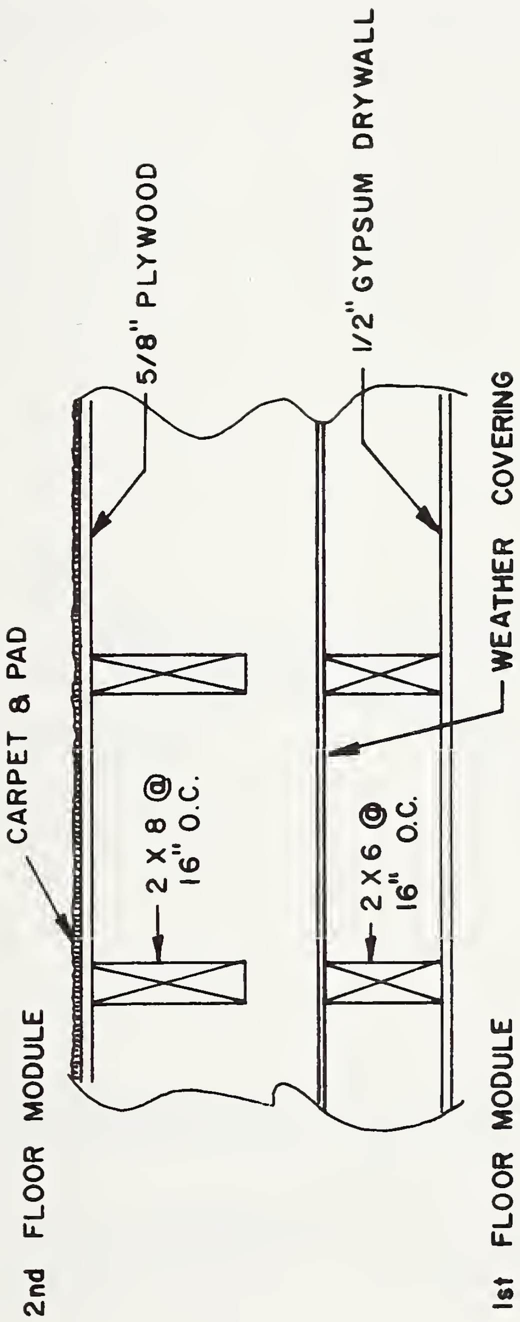

Figure 2. Cross section of floor-ceiling assembly.

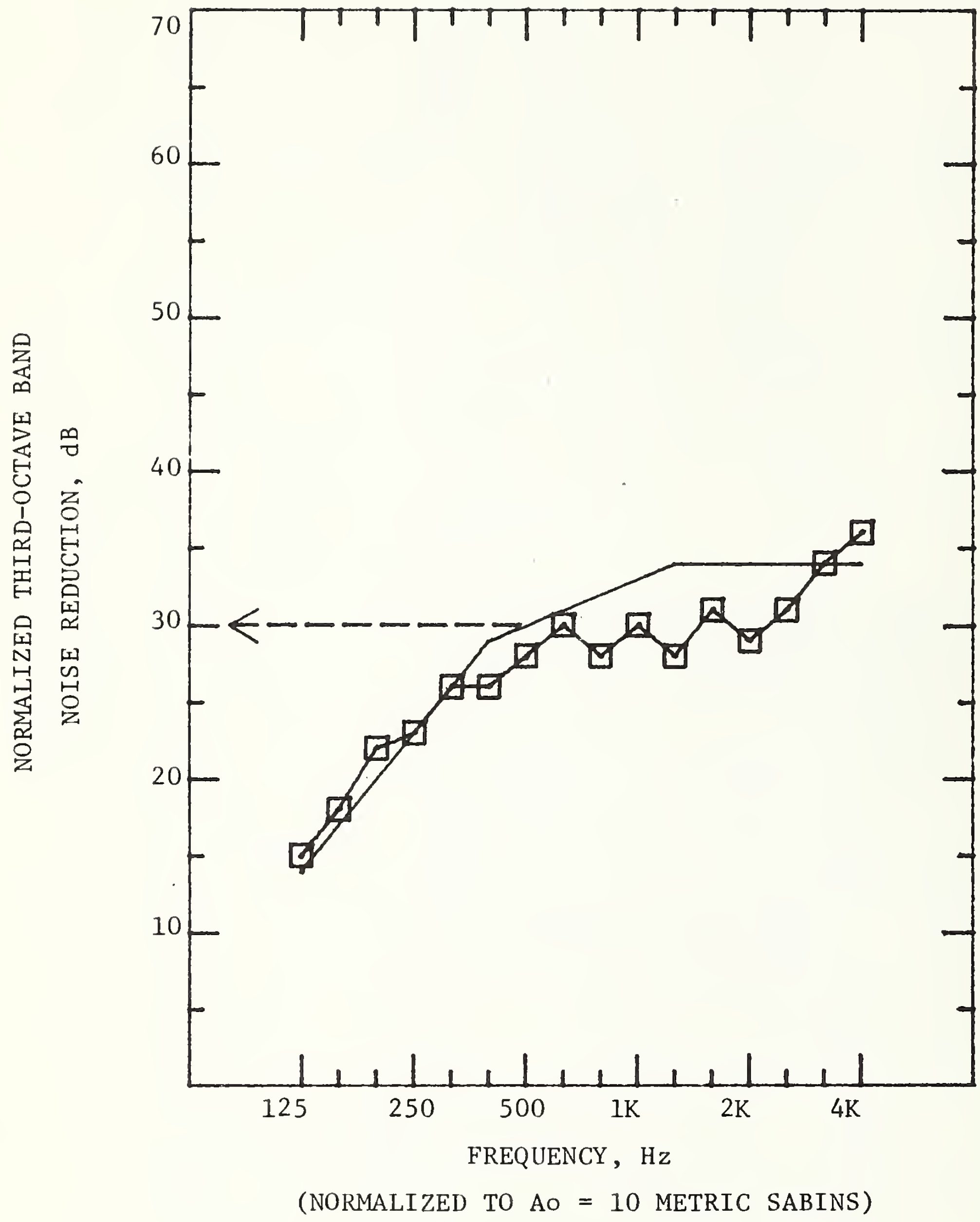

Figure 3. Normalized 1/3-Octave Band Noise Reduction Between a Bathroom and a Back Bedroom Separated by an Intra-Dwelling Wall. Unit 09-SFA/03-16 (NIC - 30).

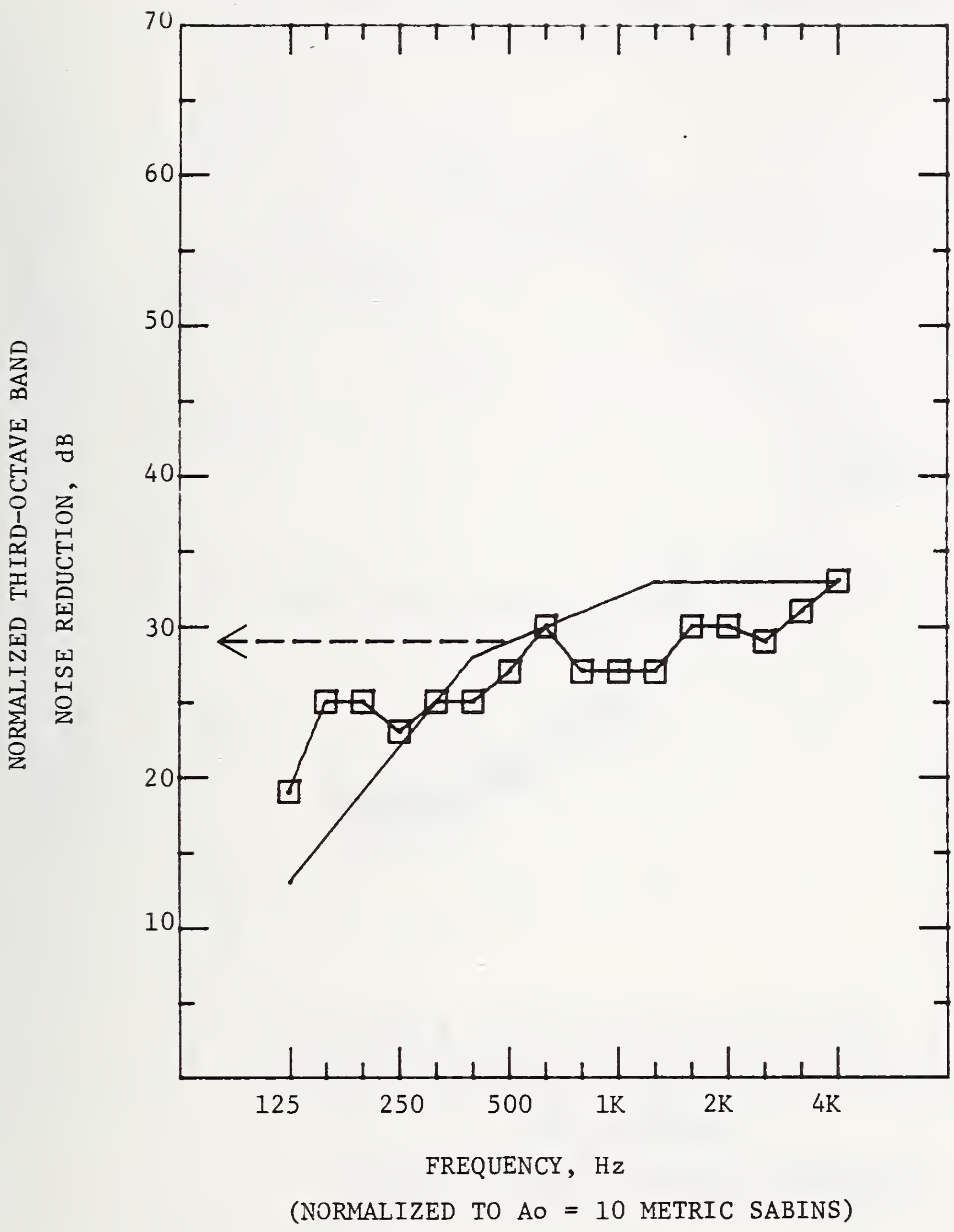

Figure 4. Normalized 1/3-Octave Band Noise Reduction Between a Kitchen and a Back Bedroom Separated by an Intra-Dwelling Floor-Ceiling Assembly. Unit 09-SFA/03-16 (NIC - 29).

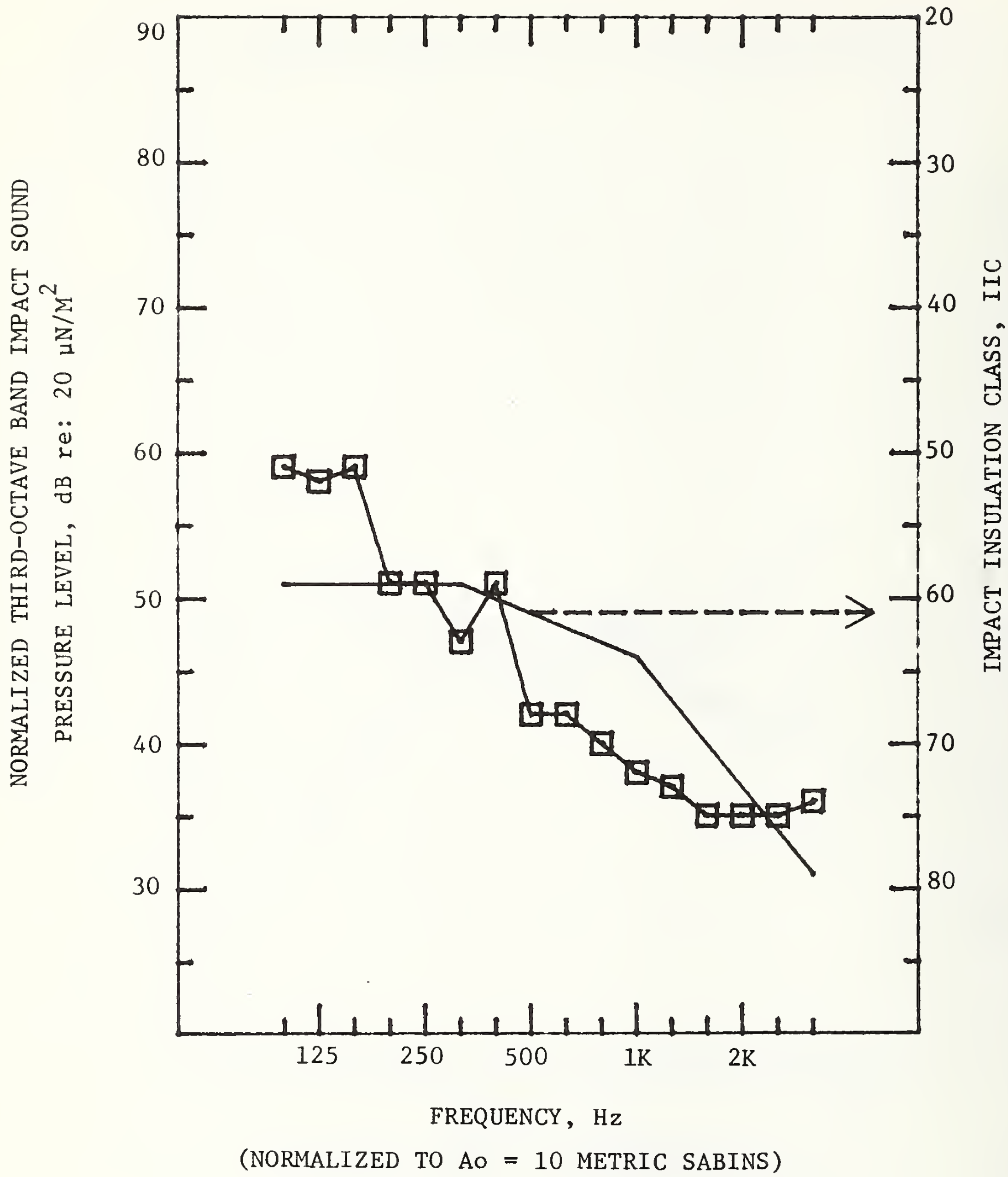

Figure 5. Normalized 1/3-Octave Band Impact Sound Pressure Level Between a Back Bedroom and Kitchen Separated by an Intra-Dwelling Floor-Ceiling Assembly. Unit 09-SFA/03-16 (IIC - 59).

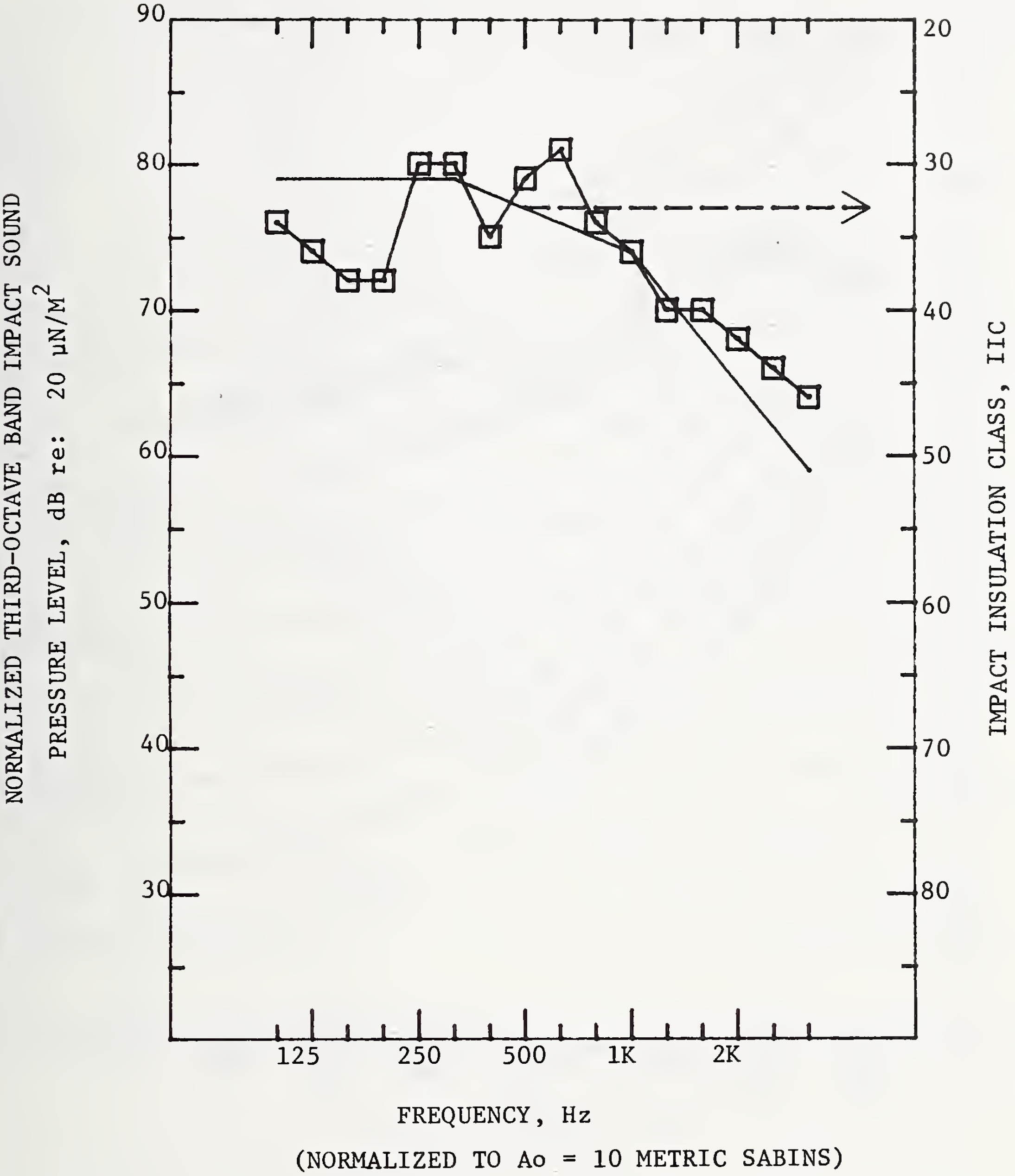

Figure 6. Normalized 1/3-Octave Band Impact Sound Pressure Level Between a Bathroom and a Kitchen Separated by an Intra-Dwelling Floor-Ceiling Assembly. Unit 09-SFA/03-16 (IIC - 33).

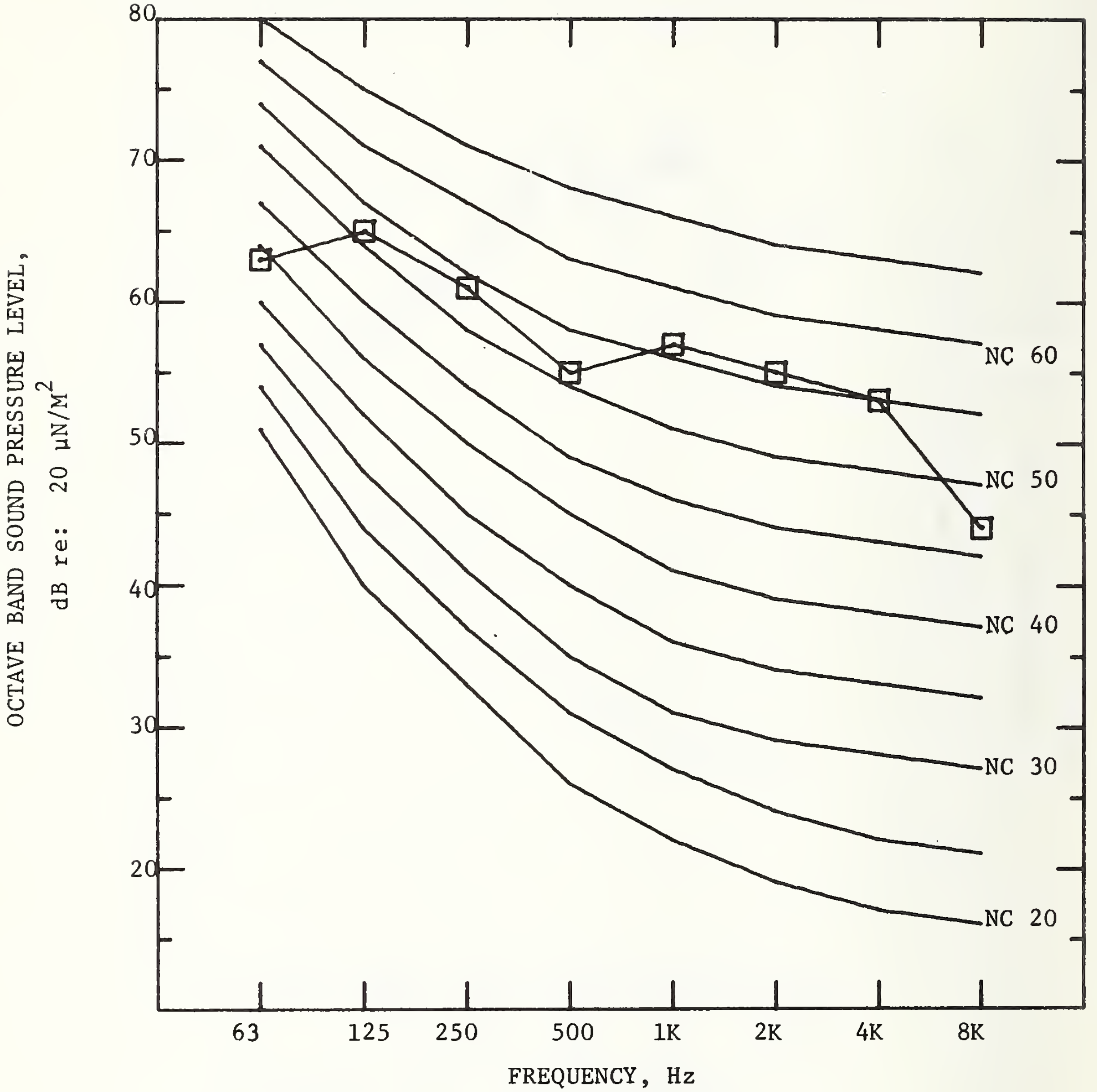

Figure 7. Octave Band Sound Pressure Level in the Living Room of Unit 09-SFA/03-16 with the Heating System Running. (< NC - 60).

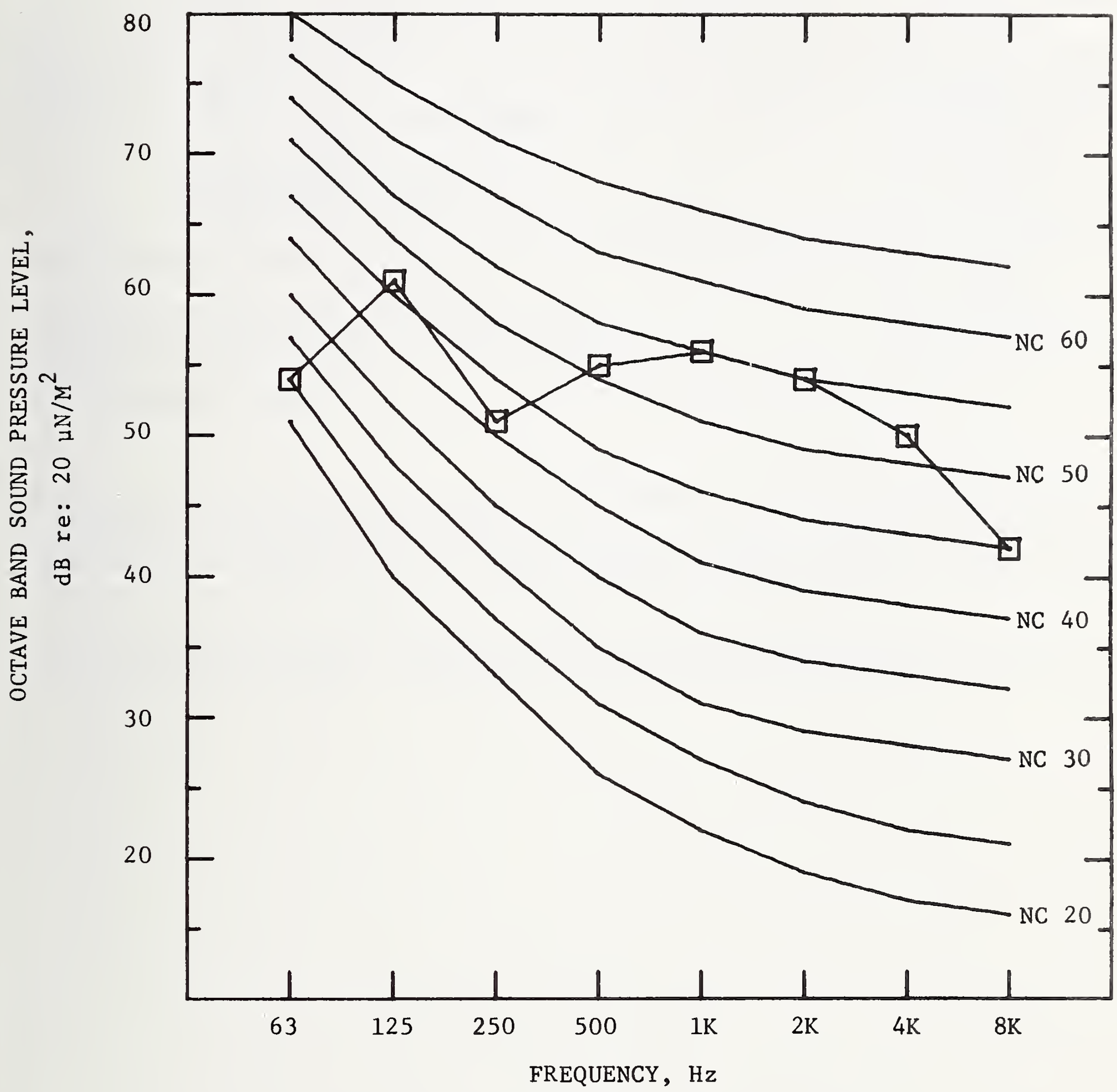

Figure 8. Octave Band Sound Pressure Level in the Kitchen of Unit 09-SFA/03-16 with the Heating System Running. (<NC - 55).

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

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17. KEY WORDS (Alphabetical order, separated by semicolons)

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