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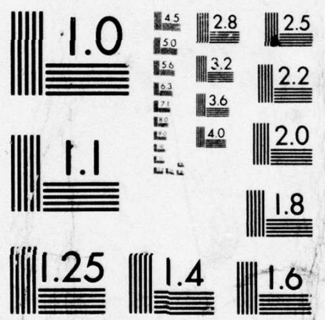
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Report No. FAA-RD-76-155

FEASIBILITY STUDY OF NOISE-LEVEL REDUCTIONS FOR COMPUTER DISPLAY CHANNEL EQUIPMENT USING UNDERFLOOR ENVIRONMENT AIR COOLING

John B. Garry

November 1976

FINAL REPORT

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16. Abstract

A Rocky Mountain Region Employee Suggestion, No. 9-73-4-ZDV-AF, recommended the removal of equipment cooling fans and the use of existing room air-conditioning for a noise-level reduction and as the equipment cooling medium. The underfloor cooling air was directed into the cabinets through the area occupied by the fans. The removal of the fans would result in a noise-level reduction within the room. This report evaluates feasibility studies of noise-level reduction through recovery conducted at the Boston Air Route Traffic Control Center (ARTCC). Results showed that it is possible to reduce noise levels and, in most equipment critical electronic locations, provide a reduction in operating temperature as a result of the flow of the colder underfloor air through the Computer Display Channel (CDC) equipment.

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METRIC CONVERSION FACTORS

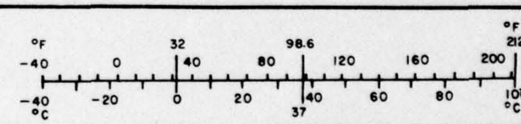
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Acknowledgment is made to the following personnel for their excellent contributions to the project effort: Mr. Robert Warley, electronics technician, ANA-140; Mr. Richard Marek, program manager, ARD-160; Mr. Irving Taylor, ANA-510, for his expeditious delivery and installation of all sheet metal work; Mr. Edward LaDrew and Mr. Joseph Bruckler for their efforts in the preparation and accomplishments using oxy-acetylene torch cutting procedures; Mr. Bill Liu, Raytheon, Inc., for his unselfish assistance in establishing the thermal requirements required for the project; Messrs. Dave Dardi and Vincent Lanzilla, ANA-439, and Richard Allard, AFS-815, for their assistance during the "mid-shift" operation hours that were assigned for the modification of the equipment.

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INTRODUCTION

PURPOSE.

The purpose of this project is to determine the noise-level reductions that can be expected by removing the cooling fans from the computer display channel (CDC) equipment cabinets. The air-conditioning presently used to cool the equipment room is directed from beneath the raised floor into the cabinets and used as a cooling medium to replace the fans. The methods used to direct the colder air into the cabinets are also evaluated, as are the expected temperature results compared to fan cooling.

BACKGROUND.

An employee suggestion (No. 9-73-4-ZDV-AF) from the Rocky Mountain Region, dated March 25, 1974, recommended the removal of the CDC cooling fans and the use of underfloor air-conditioning, ducted from floor-located cool-air vents into the cabinets through external hoods and deflectors, to reduce noise below hazardous levels in the CDC room by eliminating many noisy fans.

A noise-level survey was conducted at the Salt Lake City and Denver Air Route Traffic Control Centers (ARTCC's) by the Industrial Hygiene Section, AAC-162, and a similar survey was made at the Boston ARTCC by ANA-140. Both surveys showed the noise level over an 8-hour period to be well below the Occupational Safety and Health Administration's hazardous level of 90 decibels (dB). The noise level was high enough, however, to make normal speech and telephone usage very difficult.

ARD-160 and ANA-140, with assistance from the Raytheon Company, conducted a temperature survey on the CDC equipment to determine the effect of using the underfloor air-conditioning instead of individual-unit cooling fans to cool the equipment. The results of the study warranted the issuance of National Airspace System (NAS) Configuration Control No. T3450, which authorized the modification of three CDC cabinets at the Boston ARTCC for direct internal introduction of underfloor air into the cabinets.

DESCRIPTION OF EQUIPMENT.

The CDC equipment, manufactured by Raytheon, Inc., as installed in the Boston ARTCC, consists of the following:

- 6 - Display Generators (DG)
- 5 - Refresh Memory Imput/Output Controls (RMIOC)
- 5 - Buffer Memories (BM)
- 1 - Input/Output Control (IOC)
- 1 - High-speed Filter (HSF)
- 1 - Expanded Refresh Control (ERC)
- 1 - Central Processor (CP)
- 1 - Configuration Control Monitor (CCM)
- 2 - Radar Keyboard Multipliers (RKM)

All cabinets rest on a 3/8-inch-thick Masonite® panel which serves as an electrostatic isolator. The masonite separates the metal cabinet base from the indoor/outdoor rubber-backed carpeting which is glued to the 24-inch-square metal floor panels that support the equipment. The panels, used at the Boston ARTCC, are fabricated from 1/8-inch-thick, Z-shaped metal ribs, which are crossed into a square pattern and then spot welded to the steel floor plate. These panels serve as a false floor 16 inches above the real floor. The space between the false and real floor serves as a conduit for cable and wire runs and air-conditioning. As presently configured, ambient room air enters the cabinet cooling fan inlet through perforated covers. Behind each cover is a filter which is positioned in front of the cooling fans. The fan-discharged air enters into a plenum area and is then ducted into specific electronic areas of the cabinet through openings designed to control both volume and velocity.

DISCUSSION

GENERAL.

Noise-level surveys, feasibility studies, and experimental methods for equipment modification were conducted by ANA-140 with the assistance of ARD-160, ANE-439, FS-815, ANA-410, ANA-533F, and Raytheon, Inc.

NOISE-LEVEL STUDIES.

Noise-level measurements were taken by AAC-162 in the CDC rooms at the Salt Lake City and Denver ARTCC's, at the eight locations shown in figure 1. Noise-level measurements were also taken at the Boston CDC room by ANA-140 at the 12 locations shown in figure 2. The equipment used by AAC-162 was a Bruel & Kjaer (B&K) sound-level meter, type 2204, and a filter set, type 1613. Also used for the surveys was a NAGRA IVD tape recorder. The tape recordings were played back on an Ampex recorder, model AG-500, using a B&K band-pass filter set, type 1612, and a B&K graphic level recorder, type 2305. During the ANA-140 survey, the equipment used was a General Radio sound-level meter, model 1551-C, and a General Radio analyzer, model 1554. This equipment was used for a 1/3 octave band frequency versus sound pressure level data as compared to the full octave band frequency versus sound pressure level data recorded by AAC-162. During the modification procedure study period, ANA-140 used a General Radio (GR) sound-level meter and analyzer, model 1933. This equipment allows for full octave band frequency analysis of sound levels.

For comparison purposes, and to show the effects of noise levels on communication, speech interference levels (SIL's) were calculated for each survey. SIL is the arithmetic average of the sound pressure levels (SPL) at the 500-, 1000-, and 2000-hertz (Hz) frequencies. Figures 3 and 4 show the relationship between SIL and speech difficulty for both face-to-face and telephone communication.

The following tabulation shows the comparison of the SIL's for the Denver and Salt Lake City CDC rooms, with all equipment operational.

Denver		Salt Lake City	
Position	SIL	Position	SIL
1	65.3	1	66.3
2	64.7	2	66.0
3	66.0	4	68.0
4	67.7	5	68.7
6	67.0	6	67.0

A special survey was conducted at the Boston ARTCC to show the difference in noise level in the CDC room with just the CDC equipment operational and with only the environmental equipment (EDPAC) operational. The following data, collected with the GR 1933 sound-level meter (SLM), show the SIL that may be expected in the CDC room where the CDC equipment is not being fan cooled.

Position	CDC Fans ON/EDPAC OFF	CDC Fans OFF/EDPAC ON
3	60.7	52.0
5	66.7	59.7
6	64.7	61.3
7	66.3	55.0
8	68.7	57.0
9	67.0	59.3
10	69.6	51.7

The SPL versus full-octave frequency for the above data is shown in figures 5 through 11.

UNDERFLOOR COOLING STUDIES.

As a result of the noise-level surveys, it was decided to conduct feasibility studies at the Boston ARTCC to determine the best method for introducing underfloor cooling air into the CDC cabinets. Also to be examined was the effect of this type of cooling on the internal temperatures within the cabinets. Critical locations within the cabinets were selected by the Raytheon Company for the placement of copper-constantan thermocouples (T/C's). These temperatures were then recorded on a 24-channel Westronics chart recorder. The first cabinet surveyed was the display generator (DG). The temperatures using fan cooling were recorded, and then after removing the fans and using underfloor cooling air, the temperatures were recorded again. Table 1 and figure 12 show the temperature, and table 2 describes the T/C location for the DG cabinet. Table 3 shows the T/C locations for the RMIOC, and figure 13 shows the temperature recorded.

TABLE 1. DISPLAY GENERATOR CABINET TEMPERATURES

Thermocouple Number	Fan-Cooled (° F)	Underfloor-Cooled (°F)
1	92	90
2	112	106
3	110	110
4	127	116
5	128	125
6	125	120
7	142	118
8	78	72
9	88	75
10	85	78
11	108	105
12	82	75

The data are plotted and shown in figure 12. The T/C locations for the DG are shown in table 2.

TABLE 2. THERMOCOUPLE LOCATION IN DISPLAY GENERATOR CABINET

Thermocouple	Location
1	VG-N2A2, air between cards A4 and A5 (front)
2	VG-N2A1, air between cards A4 and A5 (front)
3	VG-N1A2, air between cards A4 and A5 (front)
4	VG-N1A1, air between cards A4 and A5 (front)
5	VG-N2A3, air between cards A4 and A5 (right side)
6	VG-N1A3, air between cards A4 and A5 (left side)
7	Center top of power supply (under grate)
8	Under N2A8 I/O card basket bottom
9	Between A13 and A14 I/O cards, N2A8 basket (lower)
10	Between A3 and A4 I/O cards, N2A8 basket (lower)
11	Between A13 and A14 I/O cards, N1A8 basket (upper)
12	Between A3 and A4 I/O cards, N1A8 basket (upper)
13	Room ambient temperature

TABLE 3. THERMOCOUPLE LOCATIONS IN REFRESH MEMORY INPUT/OUTPUT CONTROL CABINET

Thermocouple	Location
1	Bottom of lower book N1A2, supply air plenum, front left side
2	Bottom of upper book N1A1, top of bottom book N1A2, front left side
3	Top of upper book N1A1, cabinet exhaust, fron left side
4	Bottom of lower book N2A2, supply air plenum, front right side
5	Bottom of upper book N2A1, top of bottom book N2A2, front right side
6	Top of upper book A1N2, cabinet exhaust, front right side
7	Top of power supply right rear, under I/O conn.
8	Top of power supply left rear, under I/O conn.
9	Bet. A2A2 and A2A3 I/O cards basket A7, rear
10	Bet. A1A5 and A1A6 I/O cards basket A4, rear
11	Bet. A1A5 and A1A6 I/O cards basket A3, rear
12	Cabinet air intake, bottom rear

CABINET MODIFICATION METHODS.

The last part of this project effort complies with that part of the NAS configuration control decision (CCD) technical order (3540) which establishes the procedures and equipment required for the removal of the cabinet base material to allow underfloor cooling of the CDC equipment at the Boston ARTCC.

The first-tried method was the modification of the DG cabinet using a Milwaukee Sawzall, No. 6512, power saw to remove the cabinet base material and to cut the appropriate opening in the floor panel directly beneath the cabinet opening. Prior to cutting the cabinet base,the Masonite isolator panel was removed by scoring with a knife and breaking off the isolator with a chisel. Modification of the rear of the DG cabinet and floor panel required over 7 hours. Although successfully accomplished by ANA-533F and ANE-439B personnel, this method was discarded due to the number of manhours required.

A second effort was attempted by ANE-439B personnel using a hydraulically powered punch and die set. The punch and die set was ineffective and caused buckling of the front fan mounting panel. As a result, this method was also rejected.

A third attempt was made by ANE-439B personnel using a circular saw and a friction blade. This method proved to be time consuming, as well as dangerous, and was also rejected.

A fourth method tried was the use of an oxy-acetylene torch, Victor model 1000. Using the cutting torch, the front base of the DG cabinet was modified by ANA-410 in 20 minutes. The Sawzall was used to cut the opening in the floor panel.

A fifth approach was made using an electric cutting torch, Plasma Arc PAC-20 model. The work was accomplished on the front and rear base of the IOC and RMIOC cabinets. However, due to the continuous loss of electric power through circuit breaker activation, and the high spark intensity caused by the high-velocity gas flows used for metal removal, this procedure was also rejected.

ANA-410 personnel returned to the Boston ARTCC and completed the modification of a second DG cabinet using an oxy-acetylene torch. The masonite isolator panel under the first modified cabinet was problematic. In order to remove just the area to be cut, the panel was scored from below and broken off using a chisel. During the modification of the second DG cabinet, the panel was cut quickly and neatly with an electric power panel saw, Kett, Inc., model KS-4AM. The average time required to complete the removal of a cabinet base was 20 minutes. During this operation the metal floor panel was modified using the oxy-acetylene torch as follows: after marking the area to be removed, which is the same area as the cabinet opening, the carpeting was cut with a knife and lifted back off the base plate. The plate opening was cut and the surrounding carpeting replaced. During the modification of this cabinet, a 16-millimeter (mm) color film was made showing the highlights of the reworking procedures.

PLENUM MODIFICATION.

The cabinets to be modified were instrumented with copper-constantan T/C's. The baseline-recorded temperature (fan cooled) of 148° F for location No. 7 was recorded. With underfloor cooling the temperature was reduced to 143° F. As a result of this small drop in temperature, it was decided to modify the the interior air plenum by adding a deflector to increase the baffle length from 1.84 inches to 5.0 inches. Further, the deflector decreased the air outlet area from 103 to 67 square inches. This reduction in area produced an increase in cooling air velocity. As a result of this modification, the DG power supply temperature was reduced from 143° to 118° F. There were no other internal plenum modifications required for the other cabinet types surveyed.

CABINET AIRFLOW MEASUREMENTS.

Upon completion of the cabinet modifications, air volumes were calculated for the front and rear sections of the DG and logic cabinets. The DG front section had a volume air flow of 1,450 cubic feet per minute (ft^3/min). The volume air flow of the rear section was 1,160 ft^3/min. In the logic cabinets, the front sections received 660 ft^3/min and the rear sections 1,108 ft^3/min per unit.

CONCLUSIONS

1. Removal of the CDC equipment cooling fans can reduce the speech interference levels 8 to 20 dB within the CDC room. This reduction allows normal voice usage for face-to-face communications at separation distances up to 8 feet. Reference figure 3 for position 10. Prior maximum separation for normal voice communication was less than 2 feet.

2. The use of underfloor environmental cooling air will effectively reduce the level of heat within the CDC cabinets.

3. The modifications required to achieve the above results may be best accomplished using an oxy-acetylene cutting torch. Use of the cutting torch is the least time-consuming method for the required modification.

4. The total number of cabinets that can be modified for underfloor cooling is restricted by the present total volume of environmental cooling air delivery. At the maximum delivery volume of 8,200 ft^3/min per EDPAC unit, the six installed units in a CDC room deliver 49,200 ft^3/min. The volume required to cool the six DG cabinets is 15,660 ft^3/min. Each logic cabinet requires 1,765 ft^3/min. Therefore, 49,200-15,660/1765=19, or only 19 logic cabinets can be effectively cooled.

5. When the EDPAC units are operating at maximum airflow output, the 25 CDC equipment cabinets will utilize all of the air delivered to the CDC room for cooling. As such, none of the EDPAC air would be available to maintain the room at the 72° F, 50-percent relative humidity condition as required by specifications.

RECOMMENDATIONS

From the conclusions, it is recommended that:

1. A study be conducted to investigate the results of total underfloor cooling air utilization for equipment cooling.

2. A study be conducted of the cost versus benefit derived from modifications of the CDC equipment in order to reduce the noise level in the CDC room.

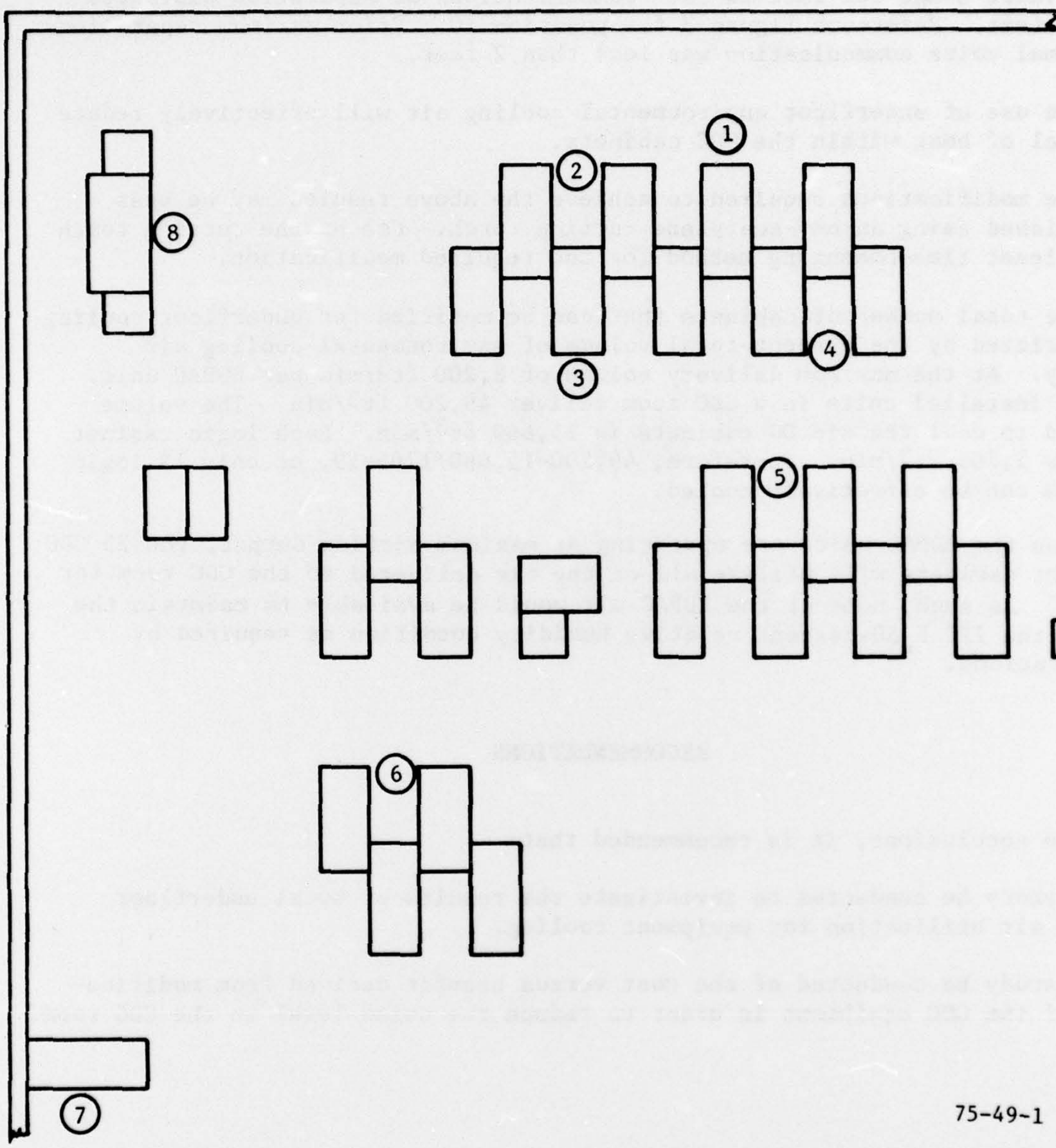


FIGURE 1. CDC NOISE MEASUREMENT LOCATIONS, DENVER AND SALT LAKE CITY ARTCC'S

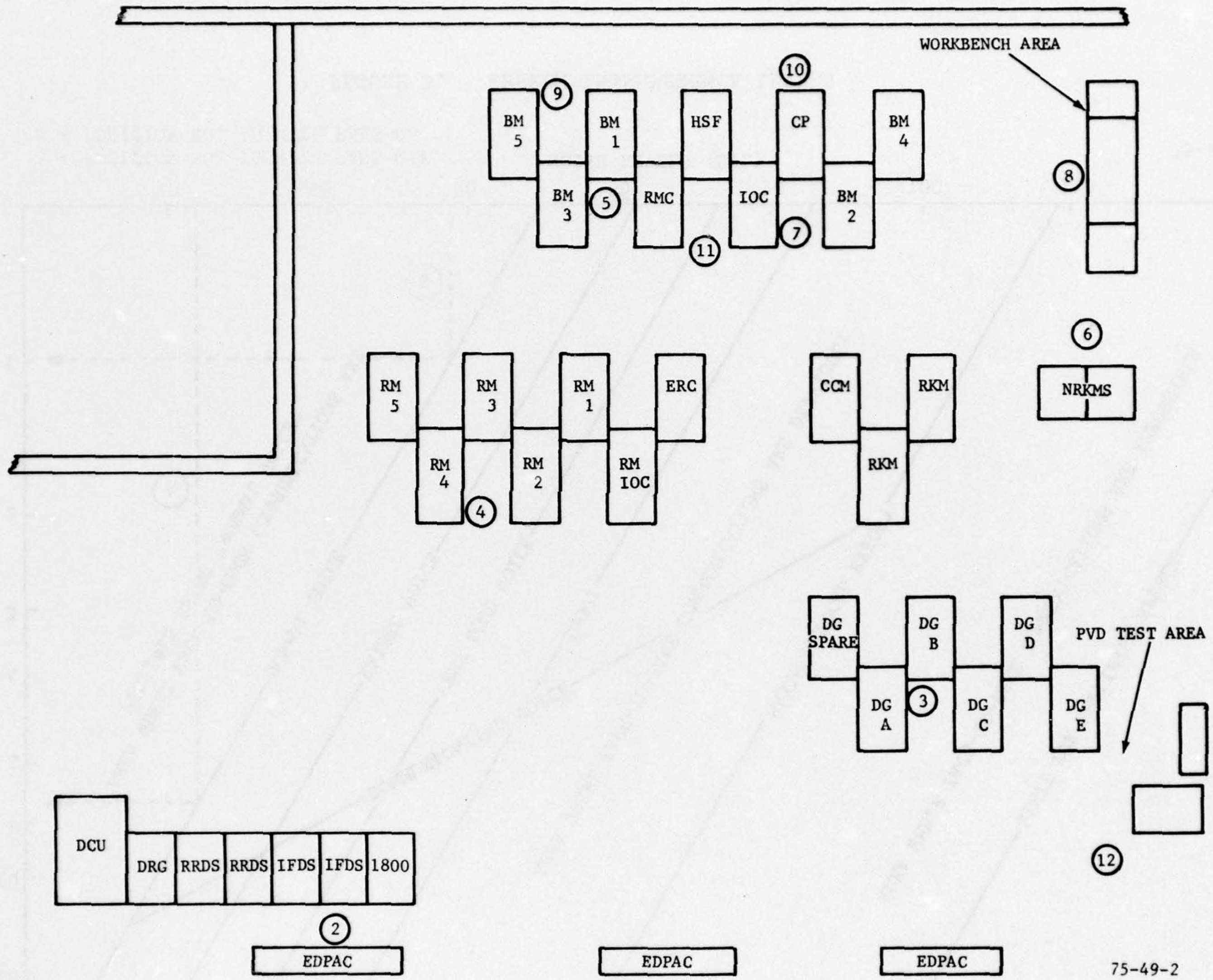
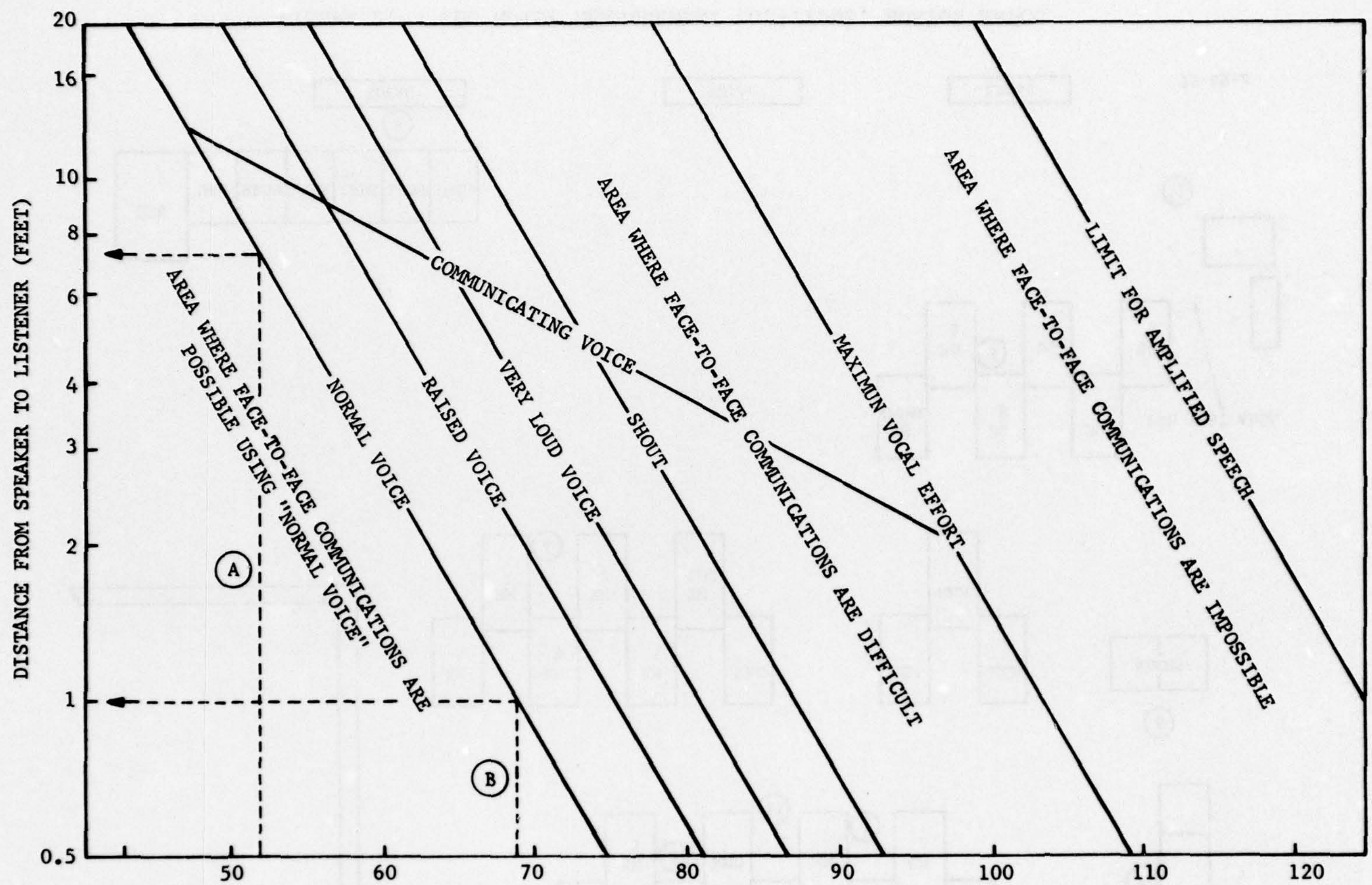


FIGURE 2. CDC NOISE MEASUREMENT LOCATIONS, BOSTON ARTCC



A = POSITION NO. 10 WITH FANS OFF
B = POSITION NO. 10 WITH FANS ON

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FIGURE 3. SPEECH INTERFERENCE LEVELS

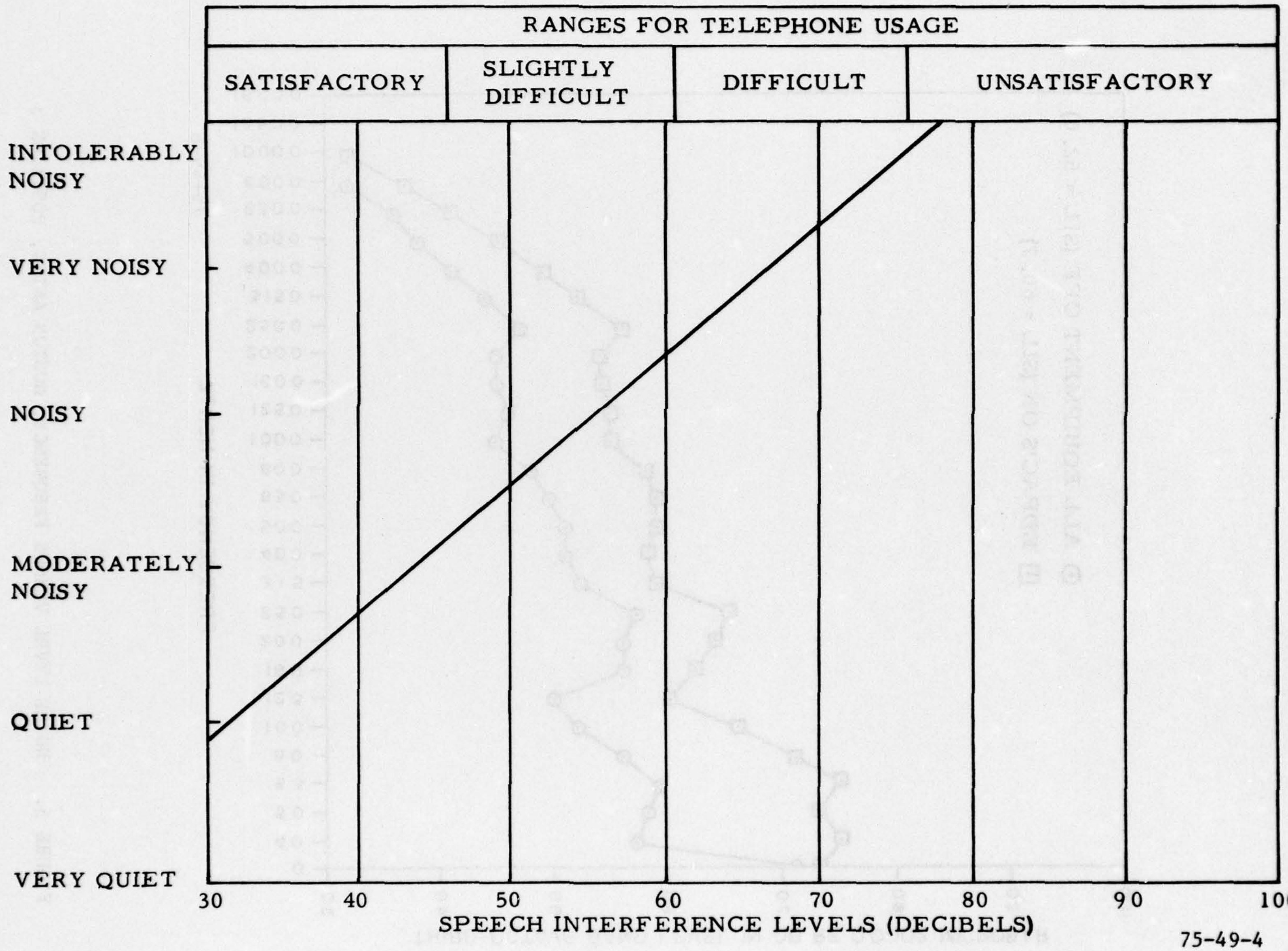

FIGURE 4. SPEECH INTERFERENCE LEVELS FOR TELEPHONE COMMUNICATIONS

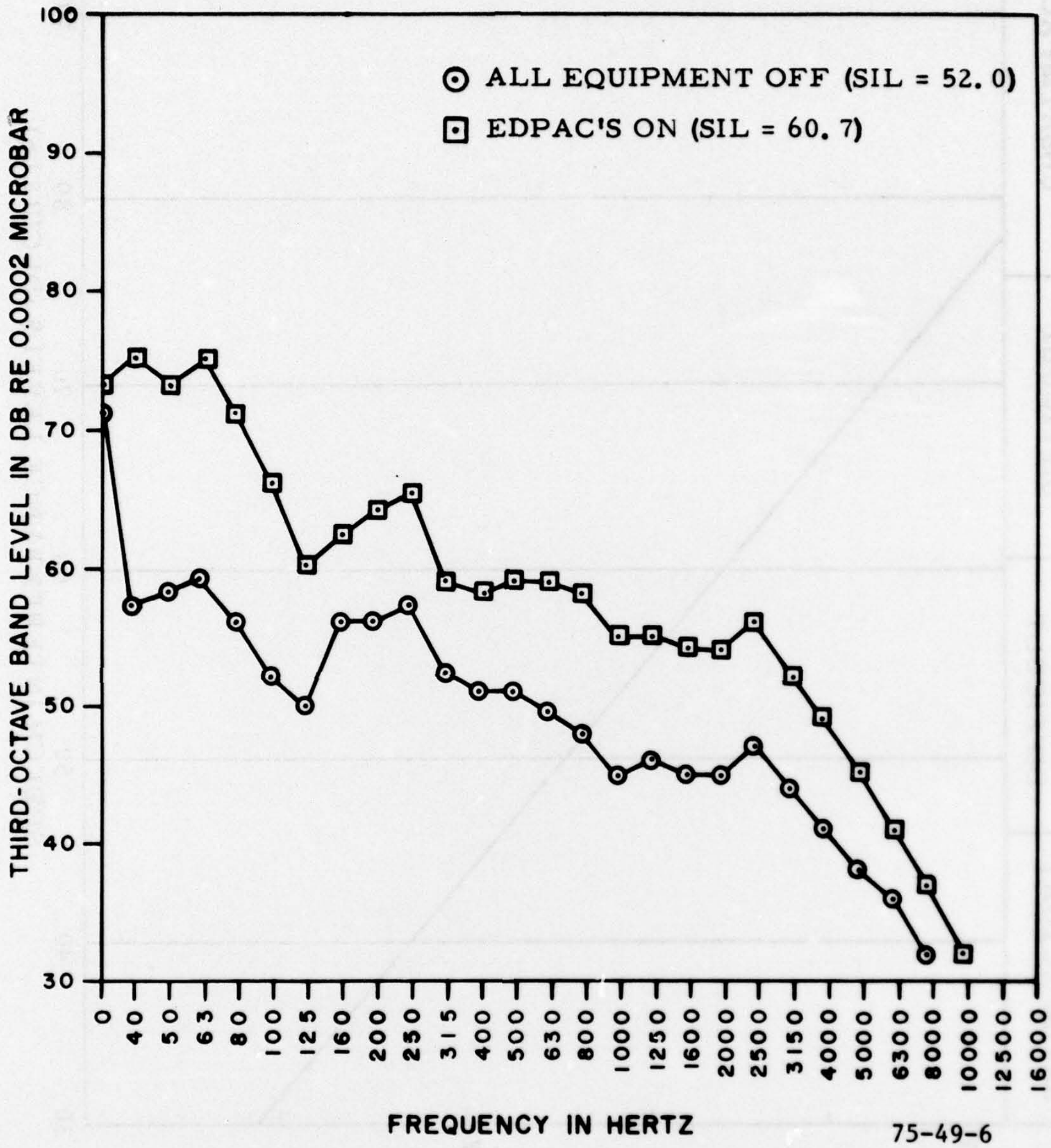

FIGURE 5. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 3

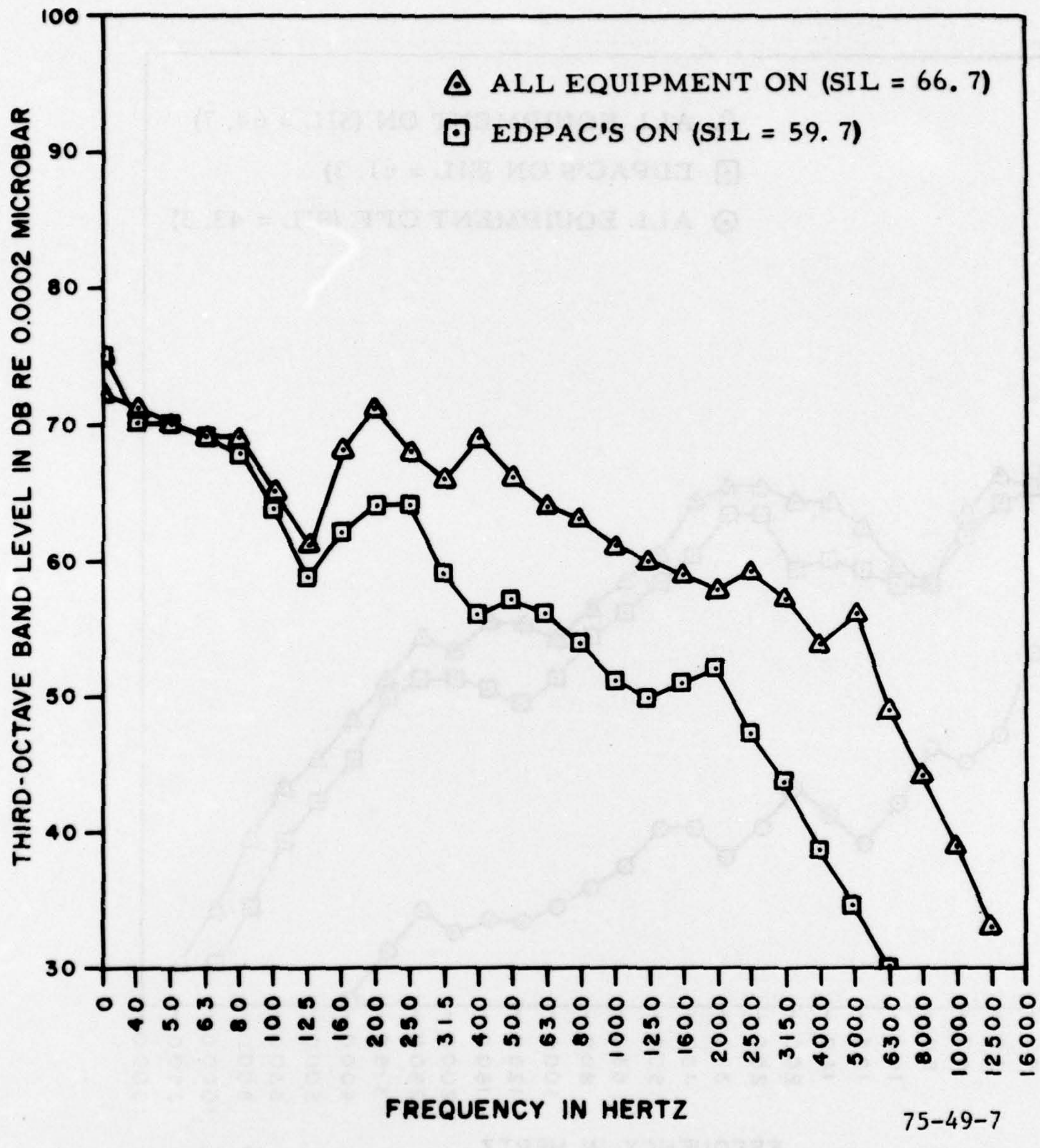

FIGURE 6. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 5

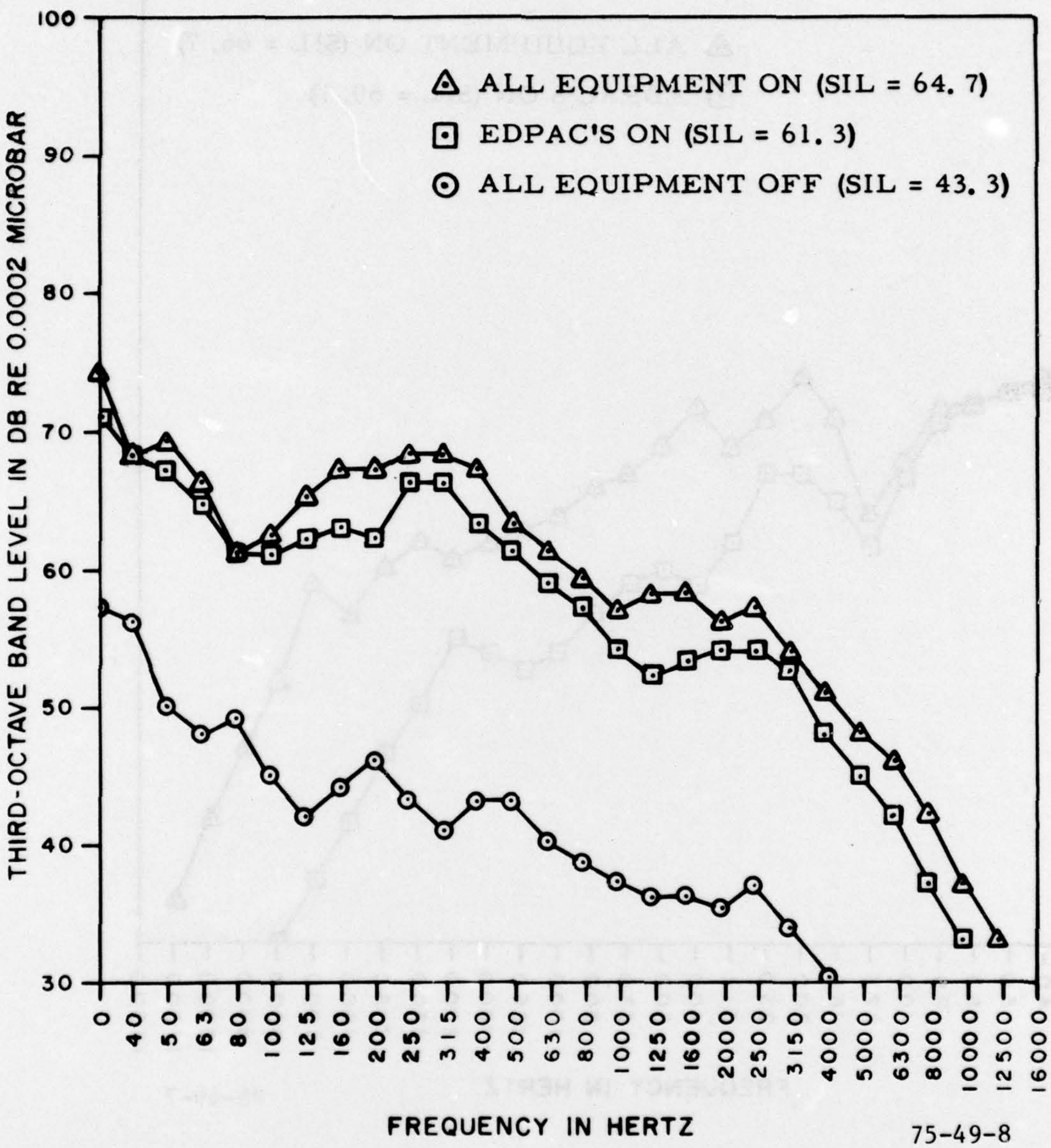

FIGURE 7. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 6

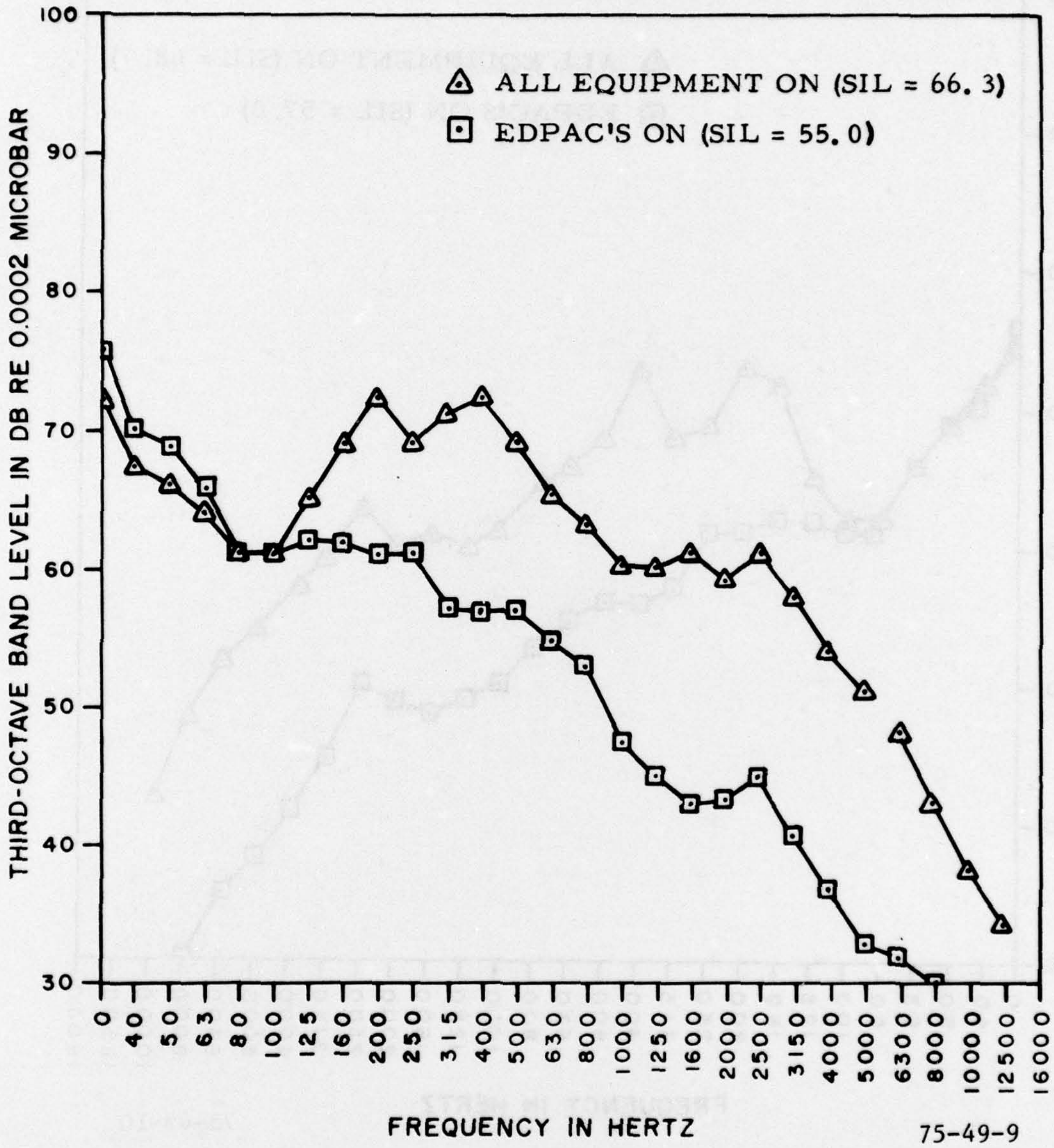

FIGURE 8. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 7

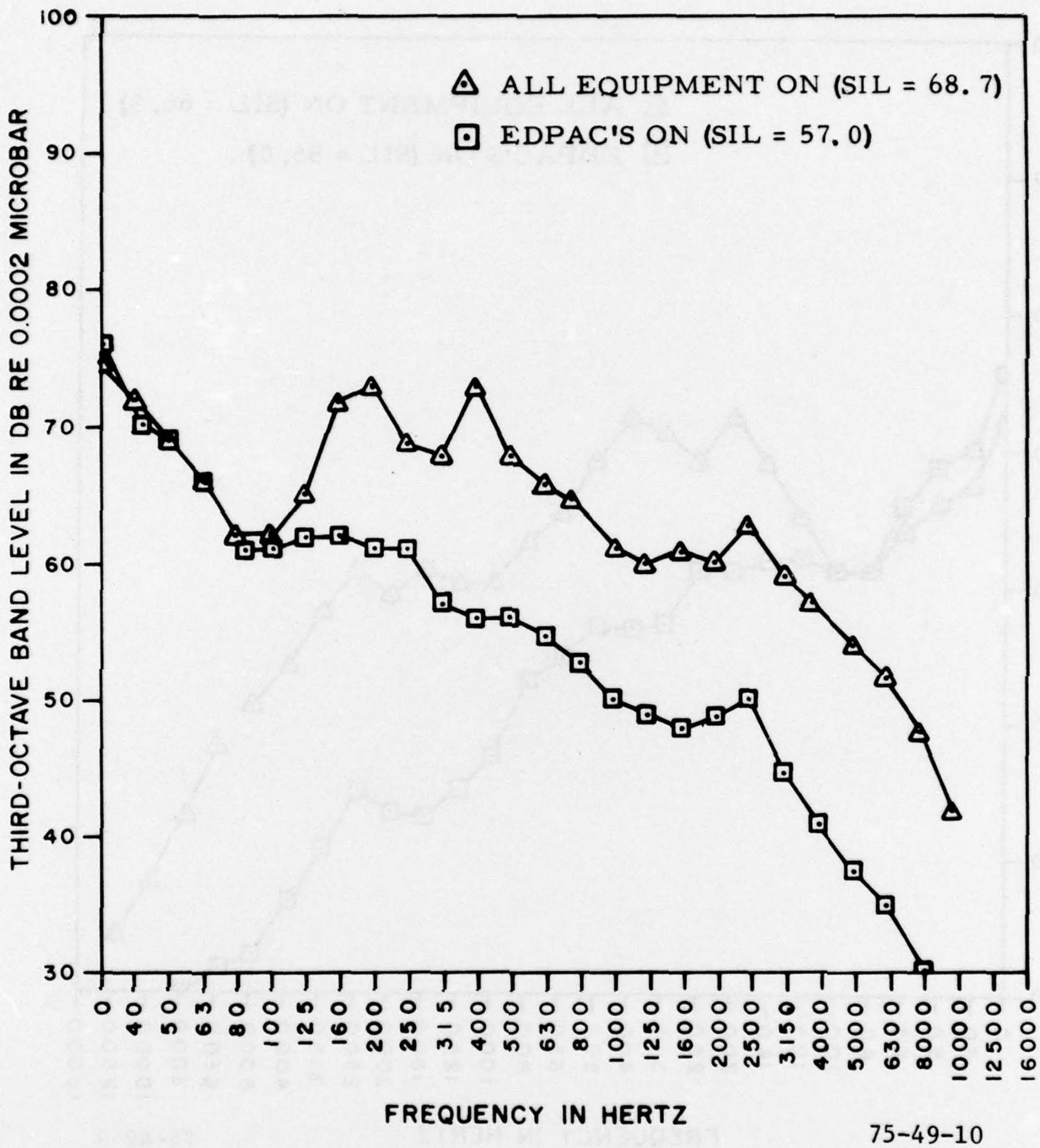

FIGURE 9. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 8

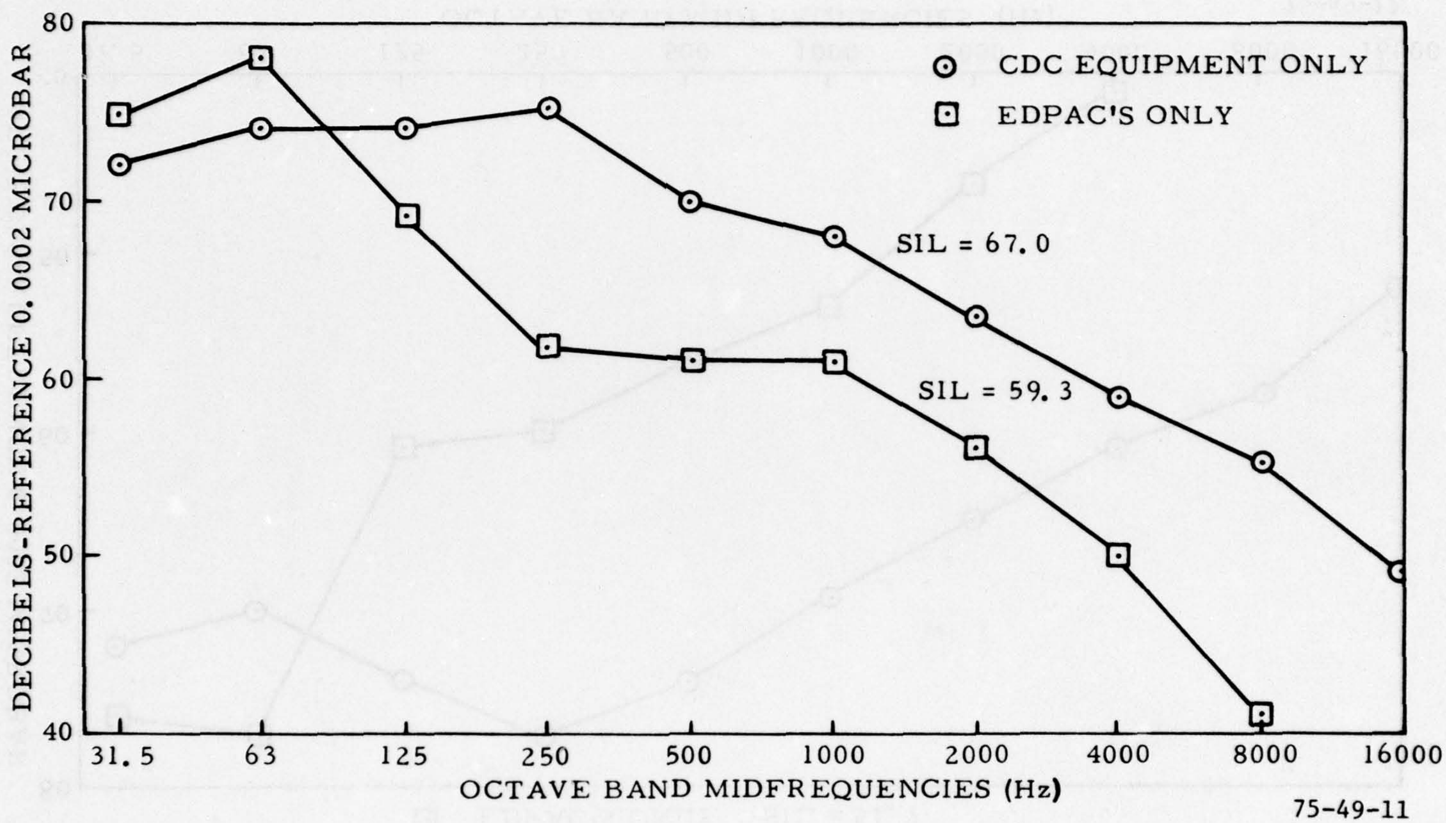

FIGURE 10. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 9

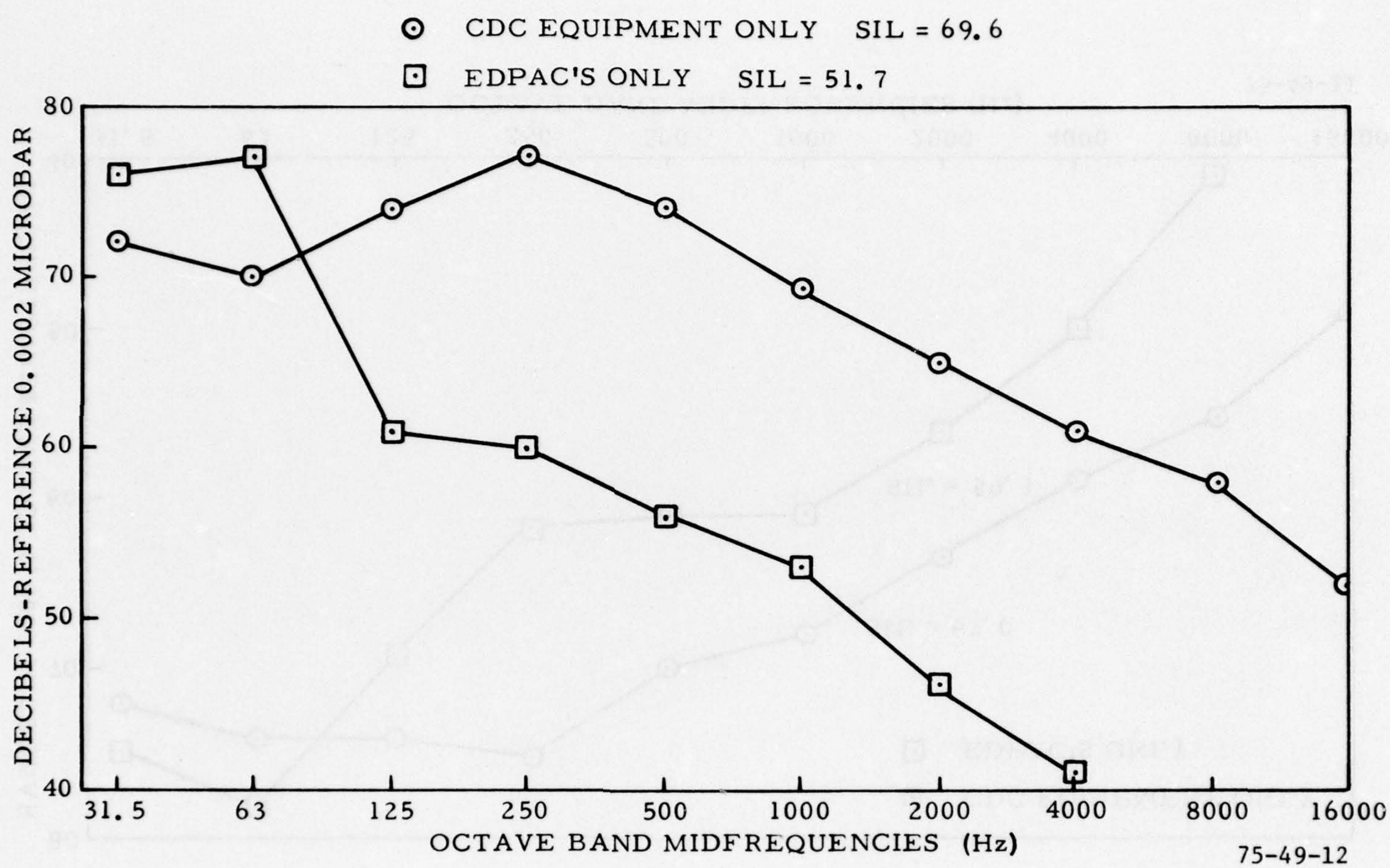

FIGURE 11. NOISE LEVEL VERSUS FREQUENCY, BOSTON ARTCC, POSITION 10

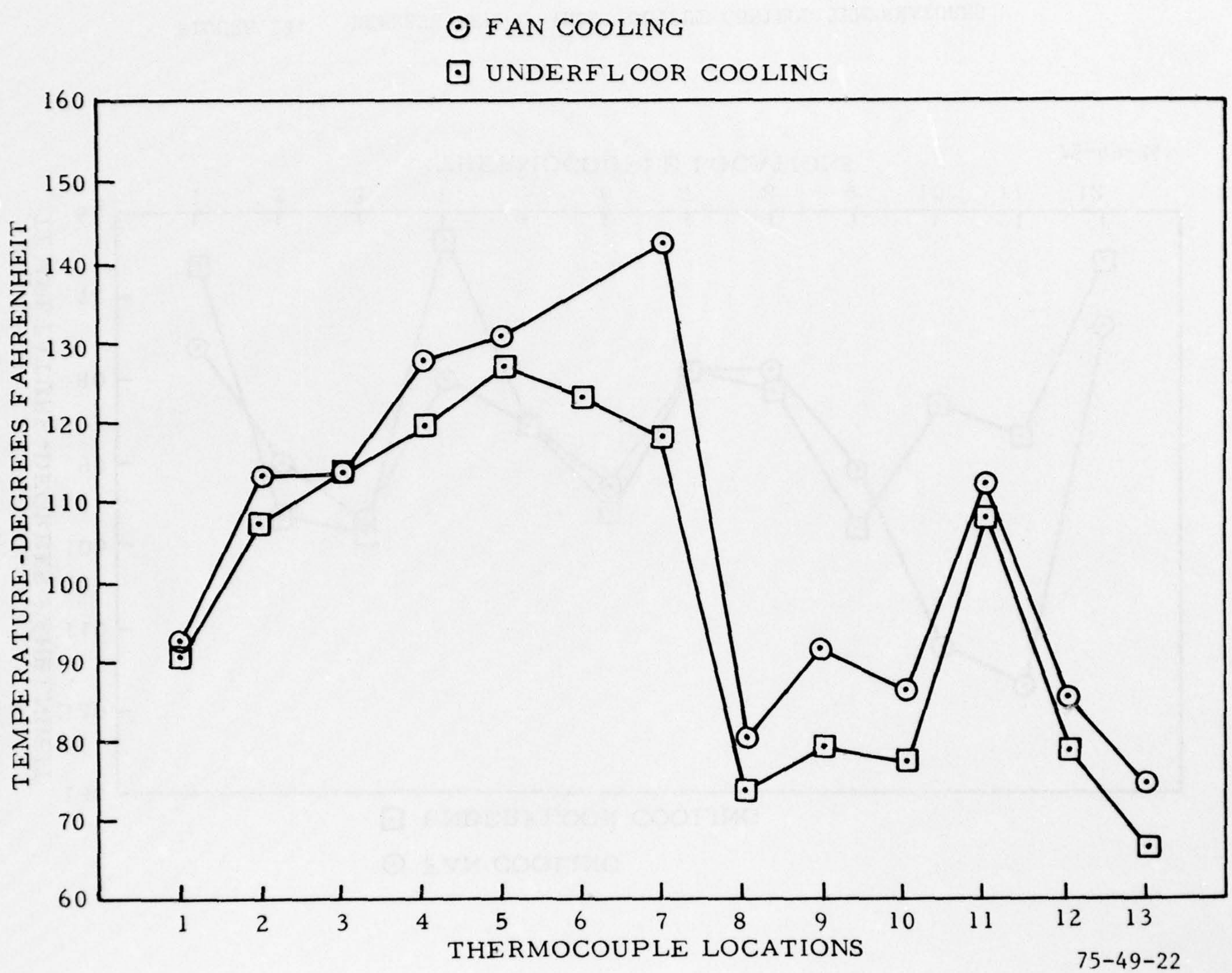

FIGURE 12. DISPLAY GENERATOR CABINET TEMPERATURES

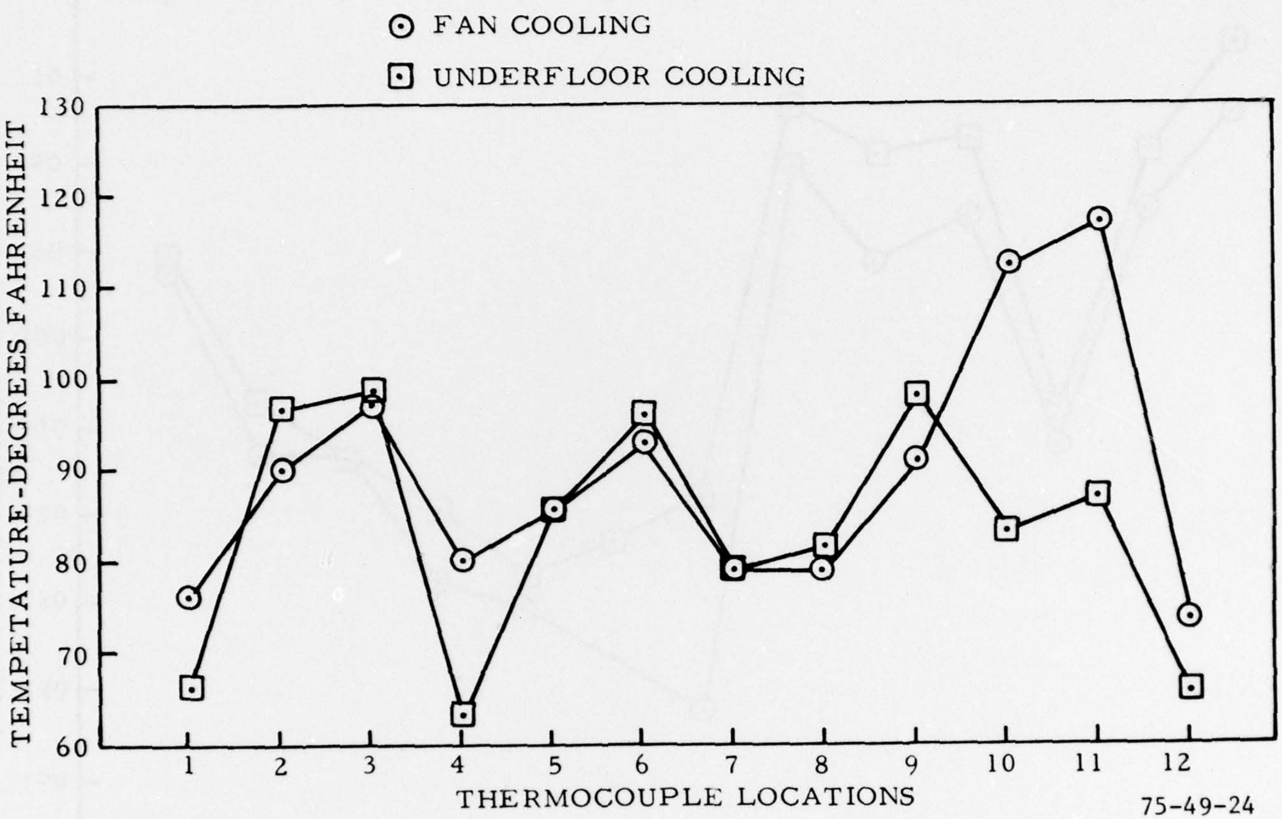

FIGURE 13. REFRESH MEMORY INPUT/OUTPUT CONTROL TEMPERATURES