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PSDC TR-21/22

AIR DISTRIBUTION STUDIES IN MULTI-ROOM SHELTERS

Final Report

By

O. W. SVAERI
N. I. STEIN

March 1967

OFFICE OF CIVIL DEFENSE
WORK ORDER DAHC20-67-W-0111
SUBTASK 1217A

By

PROTECTIVE STRUCTURES DEVELOPMENT CENTER
JOINT CIVIL DEFENSE SUPPORT GROUP
OFFICE OF THE CHIEF OF ENGINEER
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20315

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FOREWORD

This report presents an evaluation of the effectiveness of punkahs as primary and auxiliary air moving devices, observation of the associated air distribution patterns, and evaluation of the thermal response in a multi-room adiabatic mock-up shelter at the Protective Structures Development Center, Fort Belvoir, Virginia.

These tests were authorized and funded by the Office of Civil Defense and performed under Work Orders OCD-PS-65-17 (8 October 1964) and DAHC20-67-W-0111 (15 July 1966), subtask 1217A. The work was conducted during the period September 1965 through August 1966.

The authors wish to express their appreciation to all who participated in the tests. In particular, we wish to acknowledge the contributions of:

Mr. Cresson H. Kearny of the Oak Ridge National Laboratory for his contribution in formulating the basic concept of the directional punkah.

Mr. E. DeLauder of the Protective Structures Development Center for his development of the push-pull punkah.

Mr. R. F. Stellar is Chief of the Joint Civil Defense Support Group and Mr. M. M. Dembo is the Chief of the Protective Structures Development Center. All tests covered in this report were made under their supervision.

SUMMARY

AIR DISTRIBUTION IN AN EXPERIMENTAL MULTI-ROOM SHELTER

Ventilation studies for determining the effectiveness of manual air moving devices were conducted in the multi-room adiabatic mock-up shelter at the Protective Structures Development Center, Fort Belvoir, Virginia.

The air moving devices were adapted from the oriental "Punkah" (a device used to fan a room) by substituting polyethylene valve flaps, for the cloth, and fitting the unit to door or window openings. It proved to be an effective device for moving large quantities of air.

The air distribution and velocity patterns, within all shelter rooms for various configurations and ventilation rates, indicated that punkahs improve the thermal environment of the shelter. Series air flow, i.e., the total quantity of ventilating air sequentially moving from one room to another, proved to be the optimum arrangement. The observance of static pressure fluctuations, within the shelter rooms, resulted in no significant findings.

No significant differences in shelter environment were obtained when the punkahs were mounted in the lower versus the upper half of the doorways, i.e., supplying air or exhausting air (side rooms with single door openings). Baffles, in certain configurations, improve the shelter environment.

Punkahs are cheap, easily made, durable, storable indefinitely, and move large volumes of air at extremely low power requirements. They provide an inexpensive and efficient method of improving the ventilation and habitability of fallout shelter spaces.

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DETACHABLE SUMMARY

PSDC-TR-21/22

AIR DISTRIBUTION IN AN EXPERIMENTAL
MULTI-ROOM SHELTER

1967

Technical Report Prepared for

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By

O. W. Svaeri
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The Protective Structures Development Center
Joint Civil Defense Support Group
Fort Belvoir, Virginia

Ventilation studies for determining the effectiveness of punkah air moving devices were conducted in the multi-room adiabatic mock-up shelter at the Protective Structures Development Center, Fort Belvoir, Virginia.

A punkah consists of a rectangular oak or metal frame made to fit a door or window opening. The frame is covered with chicken wire, nylon netting or similar material to serve as a backstop for a series of polyethylene flaps (4" deep and as wide as the punkah). The flaps are double hemmed on one edge to swing on a wire hinge. The upper end of the punkah frame is hinged to the top of the door or window frame so the punkah can swing back and forth in the opening like a pendulum. The punkah is operated by pulling a cord attached to the closed-flap valve side setting air in motion in the direction

0

of the pull. At the end of the power stroke the punkah swings back as a pendulum. When the back stroke starts, the flap valves open and the air stream continues to flow through the open flap valves. Another pull on the cord repeats the cycle.

The 6-foot full size door punkah, used as the shelter prime air moving device, circulates a large volume of air and requires little power (4600 cfm @ 0.04 to 0.05 Hp). Side baffles increase the punkah's air moving capacity and provide safety guards by preventing shelter occupants from accidental contact with the swinging punkah.

The push-pull and 3-foot punkahs produced significant beneficial effects in "side rooms" (rooms with single access openings). They may also be used to distribute air within a shelter, substantially enhancing the comfort of the occupants by circulating the air around the occupants. There was no significant difference in environment when punkahs were mounted in the lower or upper half of the doorways supplying air to or from side rooms. Horizontal baffles installed in the side room doorways had a slight beneficial effect on the environmental conditions in the rooms when the 3-foot punkahs were mounted in the doorways. A floor to ceiling baffle, (3'x7') installed at a 45 degree angle at the doorway between the plenum and Room 2 (the ventilation air inlet opening to the shelter), served to deflect the incoming air directly toward the door openings to the two side rooms. This arrangement resulted in the lowest effective temperatures in the side rooms. Without the punkahs, this baffle creates adverse conditions in the side rooms by effectively blocking the exhaust air which normally escaped from the side rooms due to thermal convection currents.

Series air flow, i.e., the total quantity of ventilating air sequentially moving from one room to another, proved to be the optimum arrangement providing a maximum of usable shelter spaces.

Punkahs are cheap, of simple construction, durable and can be stored indefinitely under most conditions.

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this study was to determine the capabilities and effectiveness of various punkahs used both with and without air deflecting baffles to ventilate a multi-room experimental fallout shelter by oserving the distribution patterns of the ventilation air, thermal environment and air changes within the shelter rooms.

1.2 BACKGROUND

1.2.1 General. A critical factor in design for new and improvement of existing fallout shelter spaces is the provision of adequate ventilation for heat and moisture removal and maintenance of adequate air chemical environment. The probability that commercial electric power will be available after a nuclear attack is remote. Therefore, it is imperative that effective air moving devices, which can be manually operated with minimal energy expenditure, be made available for fallout shelters for the general population. One such device is a directional punkah, based on the pendulum-like fans used in the Orient. There are several variations of the punkah, some of which are shown in Figures 1.1, 1.2, 1.3 and 1.5. Another air moving device is the OCD developed package ventilation kit which consists of a bicycle driven propeller fan. It also has an auxiliary electric motor which can be used if electric power is available. This device is illustrated in Figure 1.4. Note that this unit may be driven by one or two operators. Both of these devices were used to ventilate an experimental four room fallout shelter constructed in the basement of Building 2591, Fort Belvoir, Virginia.

1.2.2 Criteria for Evaluation of Shelter Environment. The effectiveness of these devices in ventilating the experimental shelter was evaluated, using effective temperature, as a representative criterion of the habitability of the shelter rooms for various ventilation air quantities and conditions representing a typical hot summer design day in the Washington, D. C. area. The effective temperature is an empirical index developed by the American Society of Heating, Refrigeration, Ventilating and Air Conditioning Engineers and takes into account the combined effect temperature, humidity and air motion have on the comfort of human occupants. Detailed information on the effective temperature may be found in Reference 1. For the purposes of this report, the shelter is considered habitable if the effective temperature does not exceed 85 degrees.

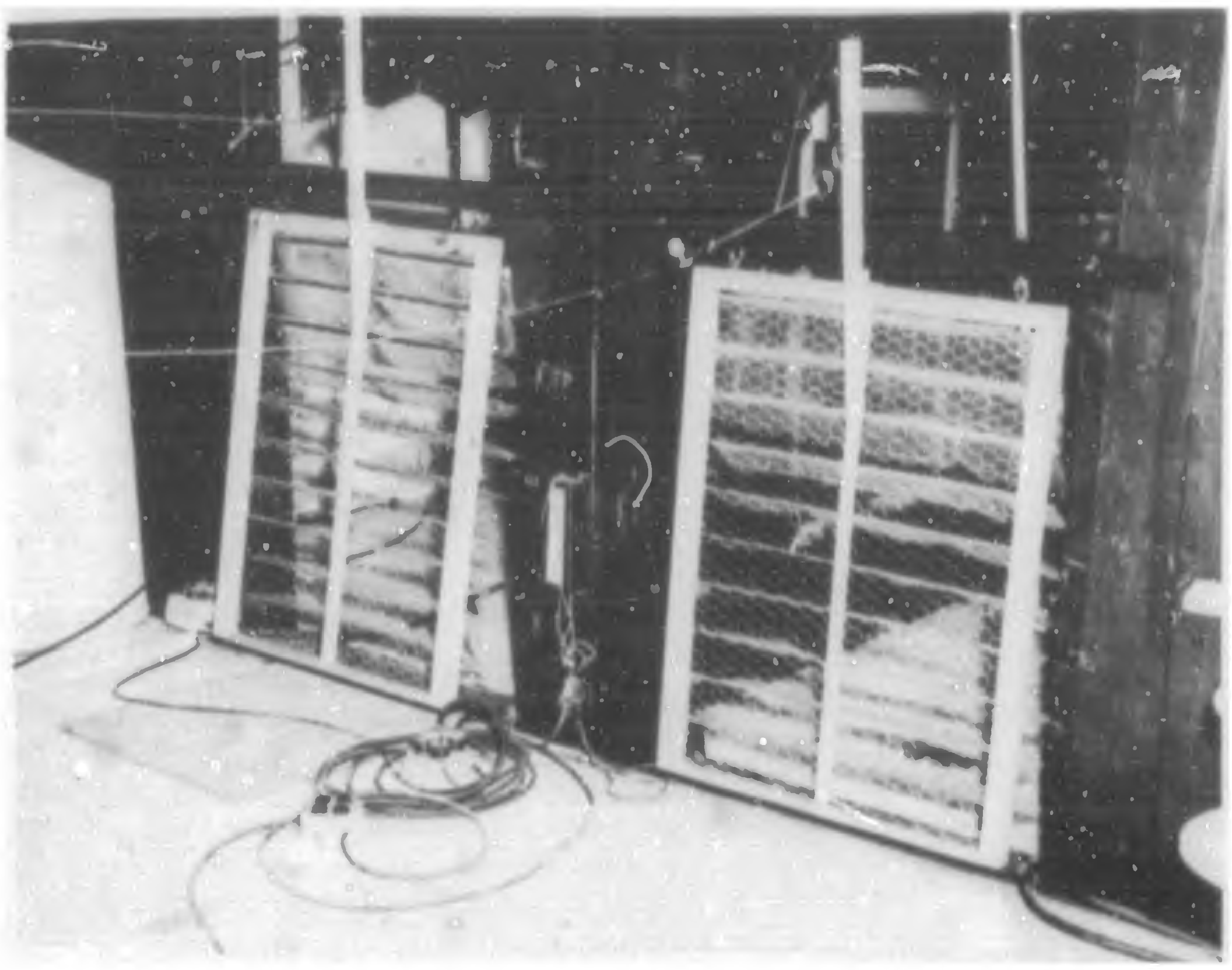


Figure 1.1 Three foot punkahs - lower portion of doorways. Three foot punkahs as an air supply device to two side rooms. Metal brackets on top facilitate mechanical powering of punkah from outside room; would not be provided for manually operated punkah.

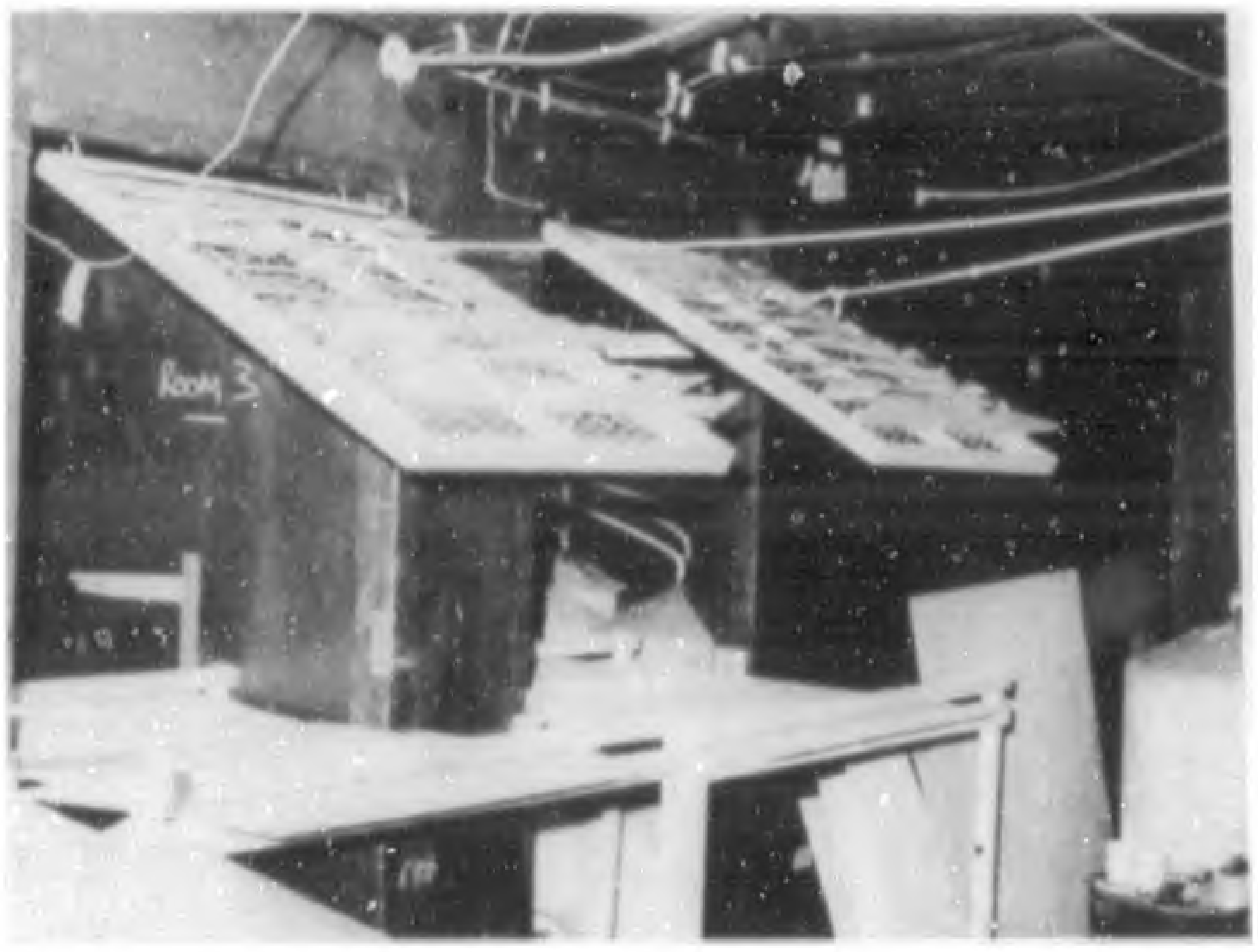


Figure 1.2 Three foot punkahs - upper portion of doorways. Three foot punkahs as exhaust devices. Note that horizontal baffles are also used here to prevent mixing of inlet and exhaust air.

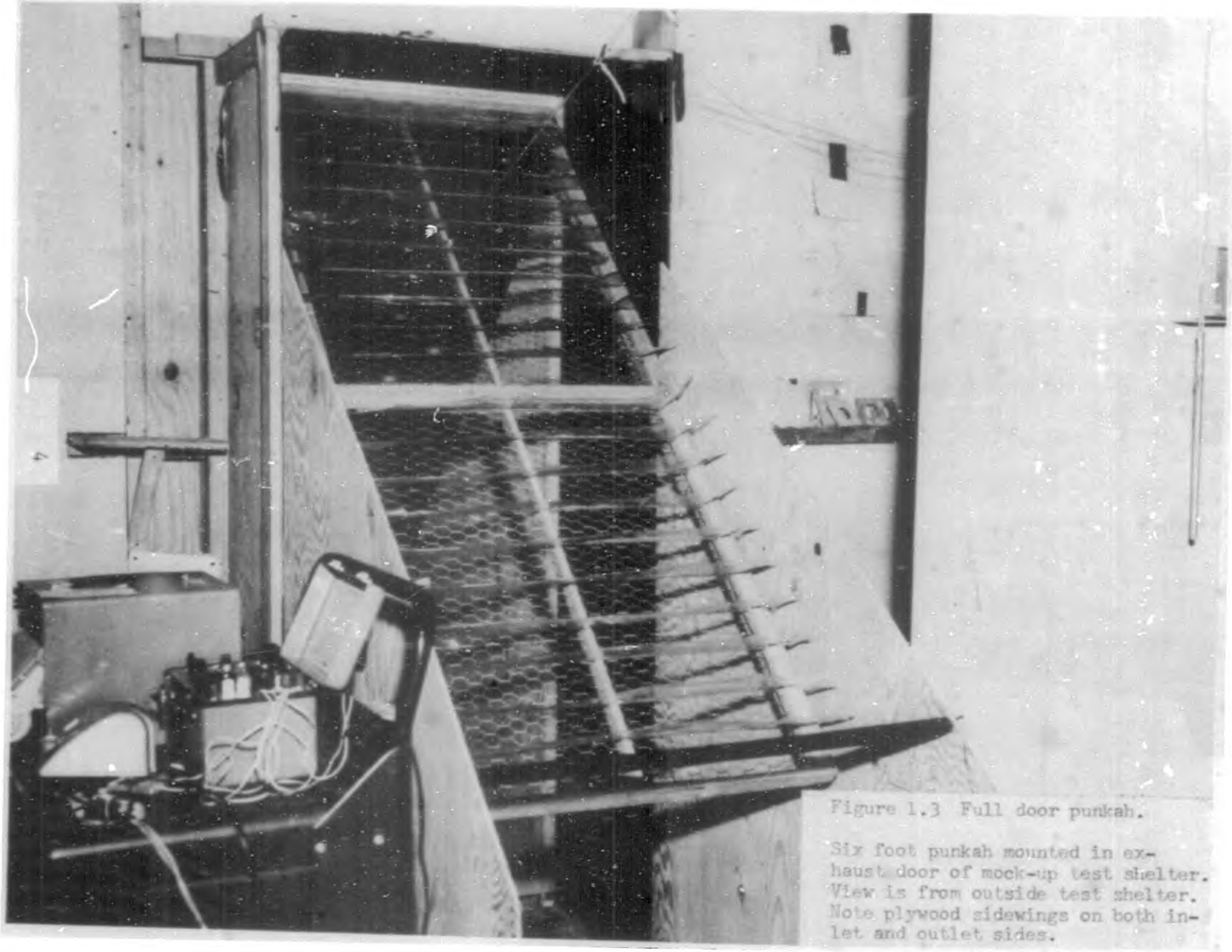


Figure 1.3 Full door punkah.

Six foot punkah mounted in exhaust door of mock-up test shelter. View is from outside test shelter. Note plywood sidewings on both inlet and outlet sides.

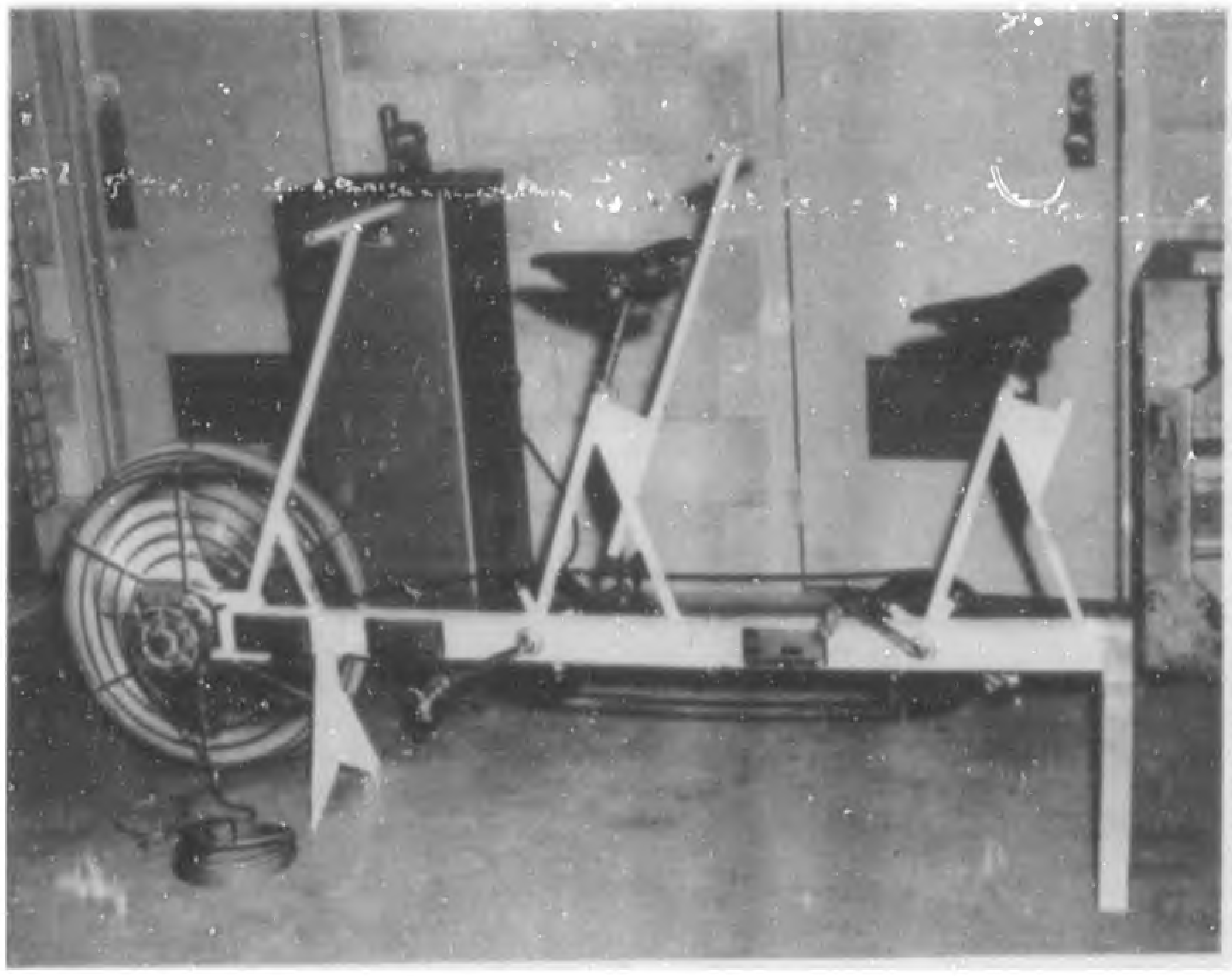


Figure 1.4 OCD Developed Package Ventilation Kit (PVK). Propeller fan which can be powered by electric motor or one or two persons pedaling.

Figure 1.5 Three foot punkah with horizontal baffle. Punkahs supplying ventilation to side rooms with horizontal baffles to separate inlet and outlet air.

CHAPTER 2

INVESTIGATION

2.1 DESCRIPTION OF EQUIPMENT AND TEST PROCEDURES

A four room ventilation test shelter was erected in the basement of Building 2591 at the PSDC. The location of the shelter and arrangement of the rooms are shown in Figure 2.1.

2.1.1 Experimental Shelter. This structure was of simple construction; 4 x 8 ft. prefabricated panels made of 1/4 inch thick plywood sheets and 2 x 4 framing. The panels were fastened together in a manner that would facilitate floor plan rearrangement. The ceiling of the shelter consisted of a layer of transparent vinyl plastic covered with 1 inch styrofoam slab insulation. The floor was covered with 2 inches of styrofoam slab insulation and sealed with a layer of 6 mil thick polyethylene sheeting, taped airtight against the walls. All joints in the shelter were sealed with adhesive tape. The finyl ceiling was sealed at the top plate of the walls with non-hardening adhesive so that each room was a separately sealed space. This was done to enable use of tracer gas techniques to determine air change rates in the various rooms during the tests. To minimize tracer gas absorption in the walls, all woodwork was painted with a non-absorbing paint. A flat black color was used to provide good contrast for the white titanium tetrachloride smoke for photographing and tracing air flow patterns. Controlled and conditioned air to ventilate the shelters was supplied through a plenum located at one end of the shelter. Details of the shelter construction are shown in Figure 2.2.

An identification number was assigned each of the four rooms. Rooms designated 1 and 2 had doors at either end providing cross ventilation. Rooms 3 and 4 had a single side door with no direct path of ventilated air and for purposes of this report are called "Siderooms".

As stated above, the floor, walls and ceiling were well insulated to minimize heat loss and provided an "adiabatic" structure where only ventilated air effected heat transfer. For all practical purposes, this was true because the same dry bulb temperature was maintained throughout the building housing the test Shelter. A discussion of the thermal design of the shelter is provided in Reference 3.

2.1.2 Simulated Occupants. One hundred simulated occupants (Simocs) were placed in the test shelter to simulate shelter occupancy. As the 1120 sq ft shelter would accommodate 112 occupants (10 sq ft per person), the 100 Simocs installed were operated at a slightly increased heat and evaporation rate to simulate 112 persons.

The Simocs illustrated in Figure 2.3 were developed by the National Bureau of Standards and later modified by the Engineering and Industrial Experiment Station of the University of Florida.

The Simoc consisted of two metal cylinders, one of slightly smaller dimensions which fit inside the other allowing an annular space for air circulation. A "huck" towelling covered the outer conical topped cylinder and the whole unit was placed in a sheet metal pan in the center of which was mounted an electrical resistance cone. Electricity was metered to the cone to assure a maximum heat input of 400 Btu/hr or 117 watts, representing the metabolic heat output of a person at rest. The metabolic moisture loss curve shown in Figure 2.4 is based on data obtained from Reference 2, ASHRAE Guide and Data Book, 1964. To simulate the moisture given off by a human, water was supplied to the top of the Simoc where it was absorbed in the huck towelling. The water evaporated from the towelling, expending part of the heat furnished by the electricial resistance cone. Water was supplied to the individual Simoc through a metering device manually adjusted to deliver amounts in accordance with the dry bulb temperature within the shelter. Thus, the sensible and latent heat output of a human in the shelter was closely approximated by the Simoc.

2.1.3 Environmental Control and Instrumentation Trailer. Conditioned air to ventilate the test shelter was supplied from the Environmental Control and Instrumentation Trailer depicted in Figure 2.5. The trailer is a mobile air conditioning plant capable of delivering air to shelters that can simulate the diurnal and seasonal variations in outdoor air temperatures and humidity conditions prevailing in many parts of the United States. The flexible supply and return air ducts between the trailer and the test building are easily discernible in Figure 2.5. Figure 2.6 shows the control cab of the trailer with miscellaneous instrumentation and controls used in the operation of the trailer, and the devices used to measure dry and wet bulb temperatures and humidity changes.

2.1.4 Ventilation Air. Conditioned air simulating typical hot summer weather in the Washington, D.C. area was supplied from the trailer at various rates. The typical design day or the diurnal variations in the psychrometric conditions of the air supplied to the shelter is indicated in Figure 2.7. This design day, developed by Professor Gonzales of the University of Florida, is based on records of five year averages obtained from the weather station at U. S. Army Davison Air Field at Fort Belvoir, Virginia. It represents a one percent day; i.e., the dry bulb and wet bulb temperatures shown will not be exceeded more than one percent of the time. During the tests performed by the University of Florida at PSDC (Reference 3), it was found that with a sufficiently long period of operation, ventilation could be supplied at a "steady state" condition and the shelter would respond with virtually the same effective temperatures as with diurnal temperature variations. This was determined by comparing temperature conditions obtained with air supplied at various steady state conditions with similar tests supplying the same quantity of air but following the diurnal variations. It was found that the shelter would respond within a +0.5° effective temperature 86 percent of the time. During the early phases of the PSDC tests, this was verified by supplying ventilation air at a steady state condition. It was also found that the shelter response was the same as under diurnal conditions within practical limits of accuracy.

The steady state conditions, which were selected for the tests, represented maximum, minimum and average air supply enthalpies which would occur during a diurnal cycle. The selected conditions were as follows:

	DB	WB	DP	Percent RH
Min.	76	73.1	72	88
Avg.	84.6	75.5	72	66
Max.	93	77.6	72	51

During the tests, the air flow rates were varied from 13.5, 18 to 22.5 cfm per occupant except when testing the 6' punkah with a supply of approximately 40 to 41 cfm/occ.

2.1.5 Air Moving Devices. While the ventilated air was supplied to the experimental shelter at maximum, minimum and average condition and at variable rates, the effects of several air moving devices were tested in the experimental shelter. Rooms 3 and 4, the so-called siderooms were investigated in particular. The primary air moving device tested was the punkah.

The punkahs used in the tests were build with rectangular wood or metal frames and made to fit within the test shelter door openings. The frames were covered with chicken wire to serve as a backstop for a series of polyethylene flaps (4 inches deep and as wide as the punkah, about 28 inches in this case). The flaps were double hemmed on one edge; to receive a wire hinge on which they could swing freely. The upper end of a punkah frame was hinged to the top of the door or window frame; the punkah then could swing with a pendulum-like motion. The punkah was pulled by a cord attached to the closed flap valve side. The swinging punkah caused air to be set in motion in the direction of the pull, called the power stroke. At the end of the power stroke, the punkah was allowed to swing back as a pendulum. As soon as the back stroke was started, the flap valves opened and the air stream set in motion during the power stroke continued to flow in the same direction through the now open flap valves. When the punkah had swung back completely, another pull on the cord repeated the cycle. See Figures 1.1, 1.2 and 1.3 for illustrations. References 6 and 7 described, in detail, how to construct a punkah from readily available materials.

Punkahs come in various sizes and types and can be mounted several ways. Figure 1.2 shows the 3 foot punkah used as an exhaust device in the upper half of a doorway. Figure 1.1 shows the same punkah in the lower half of a doorway supplying air. The punkahs can also be mounted in the ceiling of a shelter space and used to fan the occupants. If several punkahs are mounted in series, one delivering air to the next, they can be used in place of duct work to move air from one location to another.

The punkah shown in Figure 1.3 is referred to as the 6 foot or the "full size" punkah. It has a large air handling capacity and can be used both as a supply and exhaust device to ventilate shelters.

A further development of the punkah was the "push-pull" punkah shown in Figures 2.8 and 2.9. This variation (made for these studies) consisted of a full size door punkah which had its flaps arranged so that the air was exhausted at the top of the doorway and simultaneously supplied or pushed into the room through the lower half. The push-pull punkah was hinged slightly above its cent' ·. A disadvantage of this device was that it blocked the doorway completely. However, the manual operation could have been halted momentarily to allow shelter occupants to move in and out of the rooms.

During the tests at PSDC, the punkahs were all powered by electrically driven variable speed drive mechanisms geared down to speeds simulating manual operation.

In addition to the punkahs, the OCD-developed package ventilation kit (PVK) was used for a shelter exhaust fan. (The application of this device was tested in Reference 3.) It was not within the scope of this study to evaluate the characteristics or operation of this unit.

In conjunction with the punkahs and PVKs, various arrangements of plywood baffles were used to deflect and direct the ventilation air in order to prevent short circuiting of air currents and intermixing of exhaust and supply air.

2.1.6 Air Velocity Patterns. The effects of various baffle arrangements on the air distribution and velocity patterns within the shelter rooms were determined, using the white smoke from titanium tetra-chloride which was injected into the air stream by a smoke gun. On occasion, the magnitude of the air velocity vectors was determined by injecting smoke into the air to ascertain the direction of the velocity vector and then measuring its magnitude with a hot wire anemometer. Care was taken to hold the sensing wire of the anemometer perpendicular to the direction of the velocity vector for maximum accuracy and sensitivity of the meter.

Shelter configurations evaluated are shown in Figure 2.11 and typical shelter air distribution patterns and velocity magnitudes observed during the tests are presented in Appendix A. Note that similar measurements were taken at two levels in the shelter; i.e., 1' and 5' above the floor.

2.1.7 Static Pressure Measurements. The static pressures which existed within the shelter rooms during the various tests were measured with two inclined micro-manometers. The static pressure within the plenum was also measured with these instruments and was used to adjust the air flow of the PVK to equal that delivered by the Mobile Instrumentation and Control Trailer. The pressure within the plenum was zero when the air delivery from these two devices was exactly balanced. The pressure variations within the shelter rooms were extremely small, being in the range of one thousandths of an inch water gage. Thus, we were operating at the extreme limits of accuracy of these instruments.

2.1.8 Instrumentation and Data Recording. The temperatures within the test shelter were generally measured using copper-constantan thermocouples and were recorded once each hour on Honeywell multi-point recording potentiometers located in the operator's cab of the trailer. A total of 58 thermocouples and eleven temprature and wide range humidity sensing elements

(Hygrosensors) were used. Their locations are shown in Appendix F. From the data obtained by the Hygrosensors, the effective temperatures within the shelter rooms were determined using the ASAHRAE effective temperature chart.

To obtain a representative indication of shelter air temperatures for the various test configurations and air delivery rates, it was decided to establish an imaginary grid in each room for the purpose of fixing locations for shelter temperature measurements, see Figure 2.10 and Appendix B. The grid was established in two horizontal plans, 1 ft and 5 ft above the floor. The dry bulb and wet bulb temperatures were measured at these points by means of a battery driven motorized psychrometer. This procedure was referred to as a psychrometric traverse. A traverse was made when significant changes in shelter temperatures were expected. With the data obtained by the psychrometric traverse, the effective temperatures could then be determined at the grid locations, using the ASHRAE effective temperature chart. The average effective temperature in each room was calculated as well as the overall shelter average ET, thus making it possible to determine the relatively "warm and cool" areas within the shelter rooms for the various test configurations.

The dry bulb and wet bulb temperatures of the supply and exhaust air were also recorded.

The air flow from the trailer was measured by making a 16-point velocity traverse of the discharge opening of the trailer supply duct in the plenum, using an Alnor velometer. This method was used throughout the tests except when the 6 ft punkah was used as the prime air moving device.

~~Then a~~ Velocity traverses, ~~was~~ were made, when the punkah was used as the prime air mover, ~~of~~ at the ventilation air inlet door ~~located~~ between the plenum and Room 2 ~~using~~ with a hot wire anemometer.

The temperature of the supply and exhaust air was observed within the shelter rooms and continuously graphed during the tests. This served to illustrate the effects of the various test arrangements and was valuable to test personnel in detecting malfunctioning of equipment on errors in procedure. These curves are shown in Figures 2.12. They provided a simple way to determine when steady state conditions had been reached in the shelter, under which condition the temperature curves were observed to be level. The process was repeated over a two to four-hour period.

2.1.9 Shelter Configurations. The various shelter configurations tested were designated A through I and are shown in Figure 2.11. (Note that the PVK was used as an exhaust fan for most of the tests except when the 6 ft punkah was employed as the prime air exhaust device.)

PVKs, 3 ft punkahs, 6 ft push-pull punkahs, and a wide variety of baffle arrangements (side, horizontal, cross, air deflecting baffles, etc.) were tested in many configurations to determine what effects each combination had on shelter habitability, especially in the siderooms 3 and 4 which had only a single door opening.

During most of the tests, the ventilated air flowed from the plenum to Room 2, then to Room 1 and exhaust. However, other air flow paths were explored, such as series air flow and parallel air flow. See Figure 2.11, Configurations G and H.

Tests were also conducted on corridor-type, multi-room shelters. A brief discussion of these tests is presented in Appendix F.

2.1.10 Air Change Measurements. The tracer gas technique was used to determine the rate of air change in a room. A gas, usually carbon dioxide, was injected into a room and allowed to build up to a certain percent concentration. The gas supply was then turned off and a continuous record of the decay in gas concentration within the room was made over a period of time, using a gas analyzer and a millivolt recorder. By plotting the logarithm of percent concentration versus time, the slope of the decay curve was determined as a direct indication of the number of air changes per unit of time. A detailed description of this procedure and the difficulties experienced in using tracer gases are contained in Chapter 3, and Reference 3.

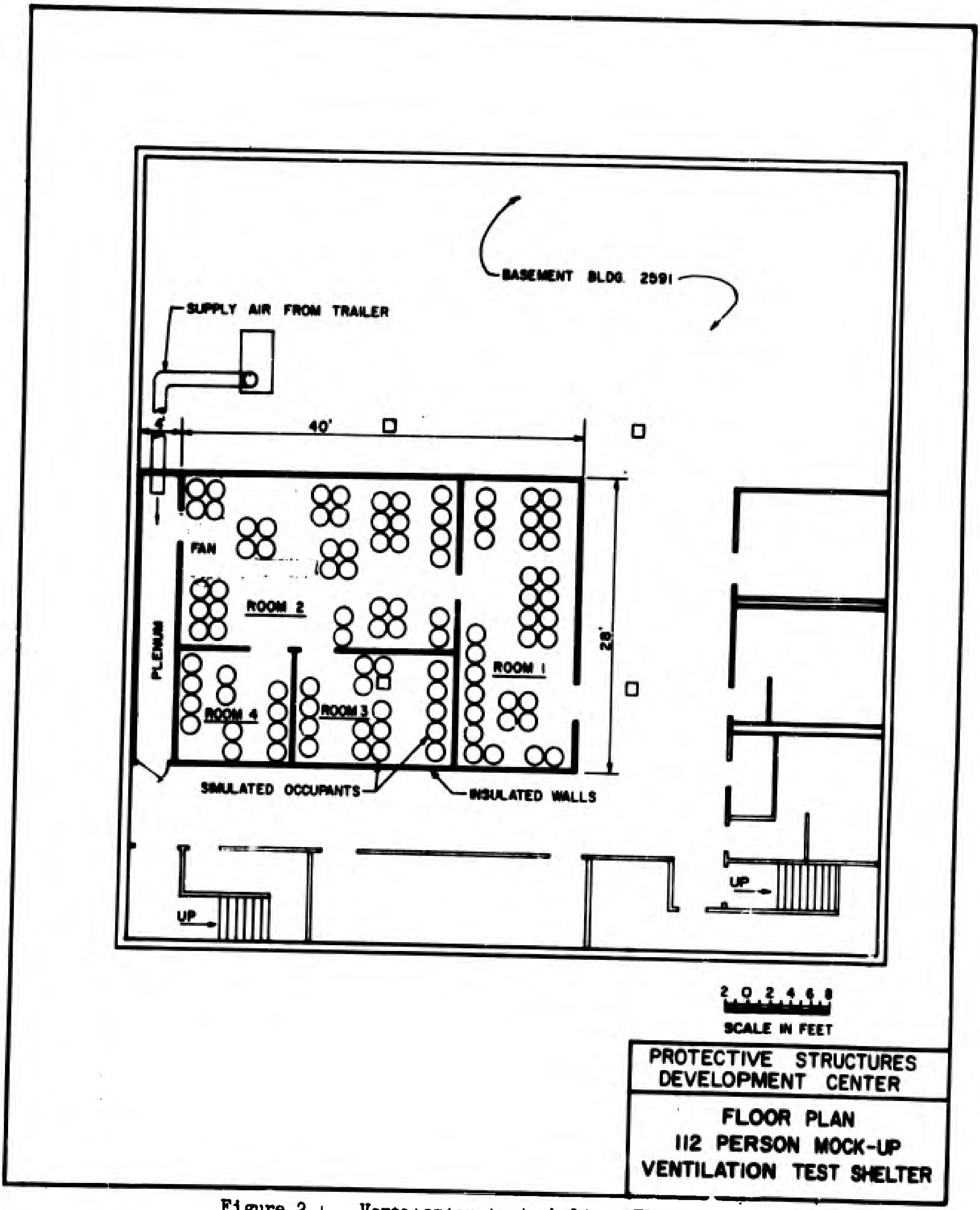
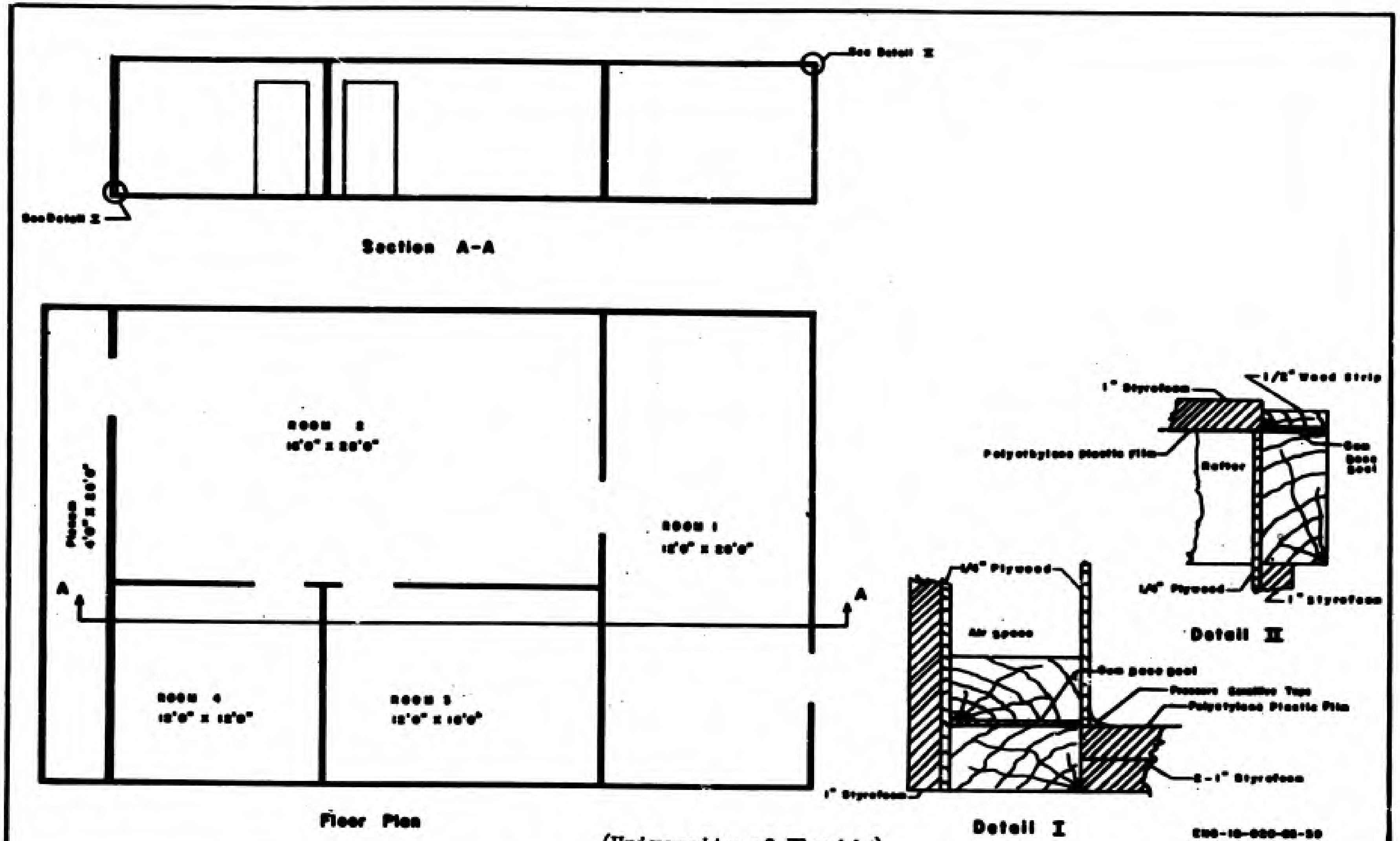


Figure 2.1 Ventilation test shelter, Floor Plan.



(University of Florida)

Figure 2.2 Ventilation test shelter, Sections and Details.

CROSS SECTION OF SIMOC
(No Scale)

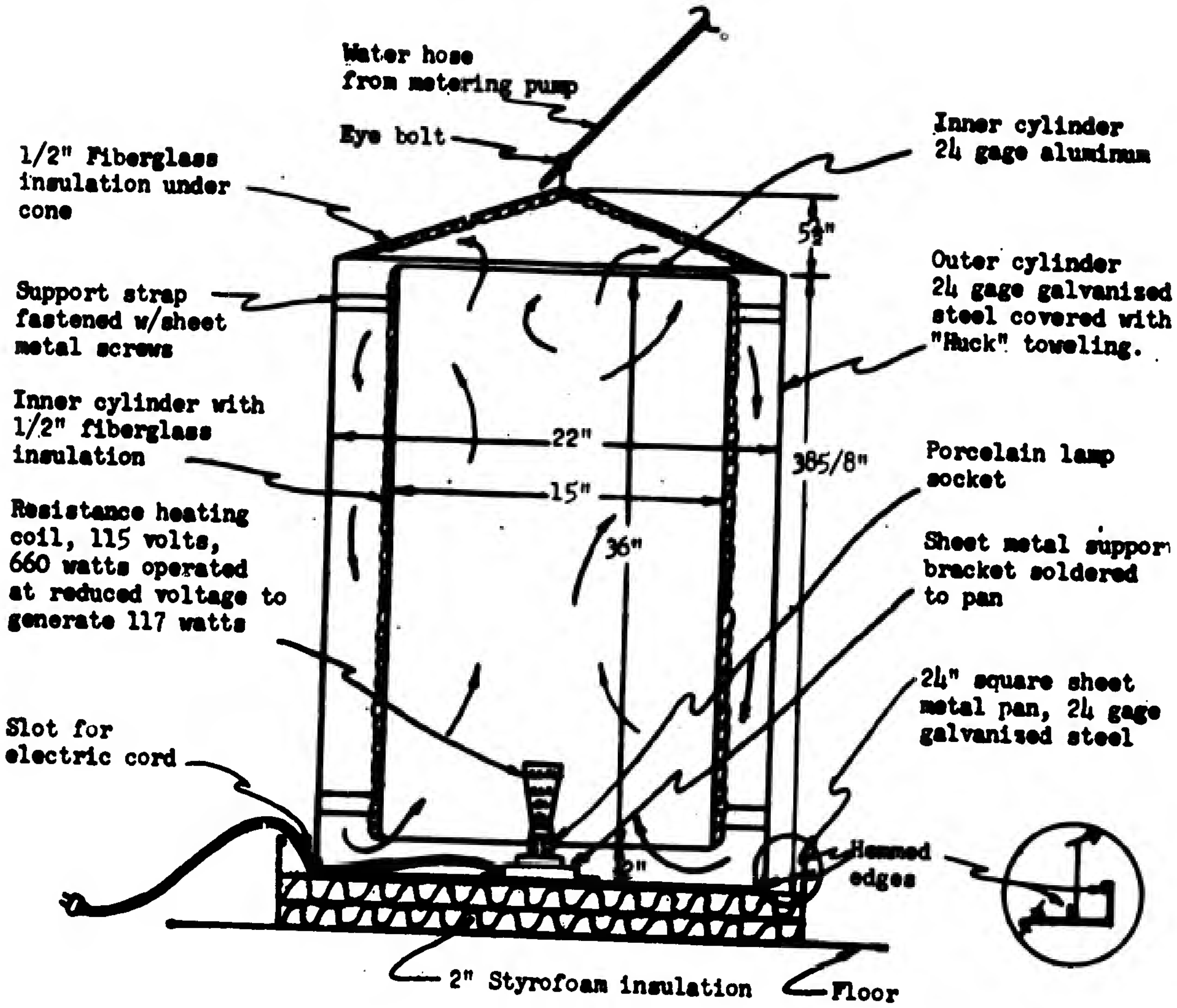


Figure 2.3 Cross section of SIMOC.

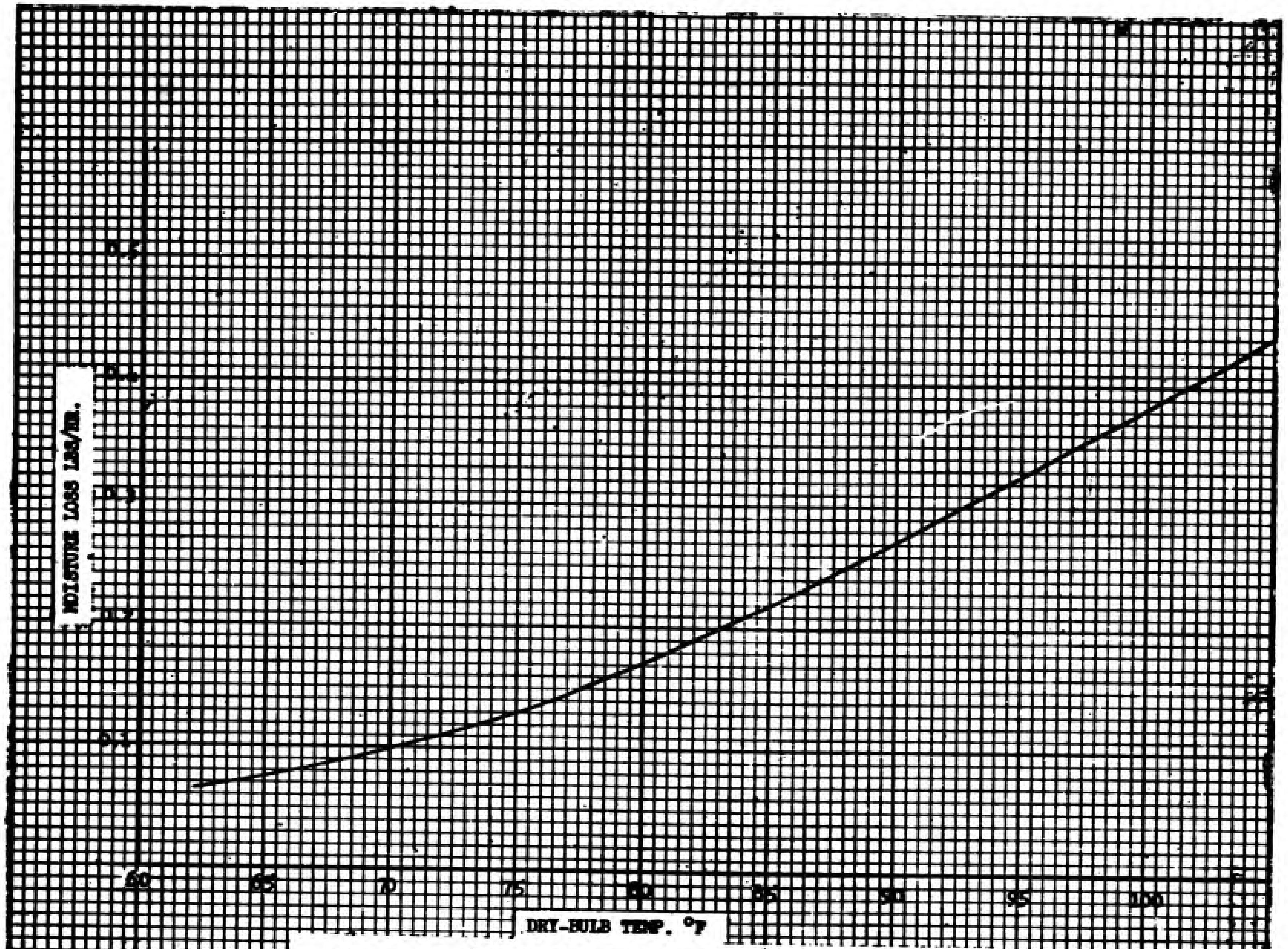


Figure 2.4 Metabolic moisture loss for 400 BTU/hr person.

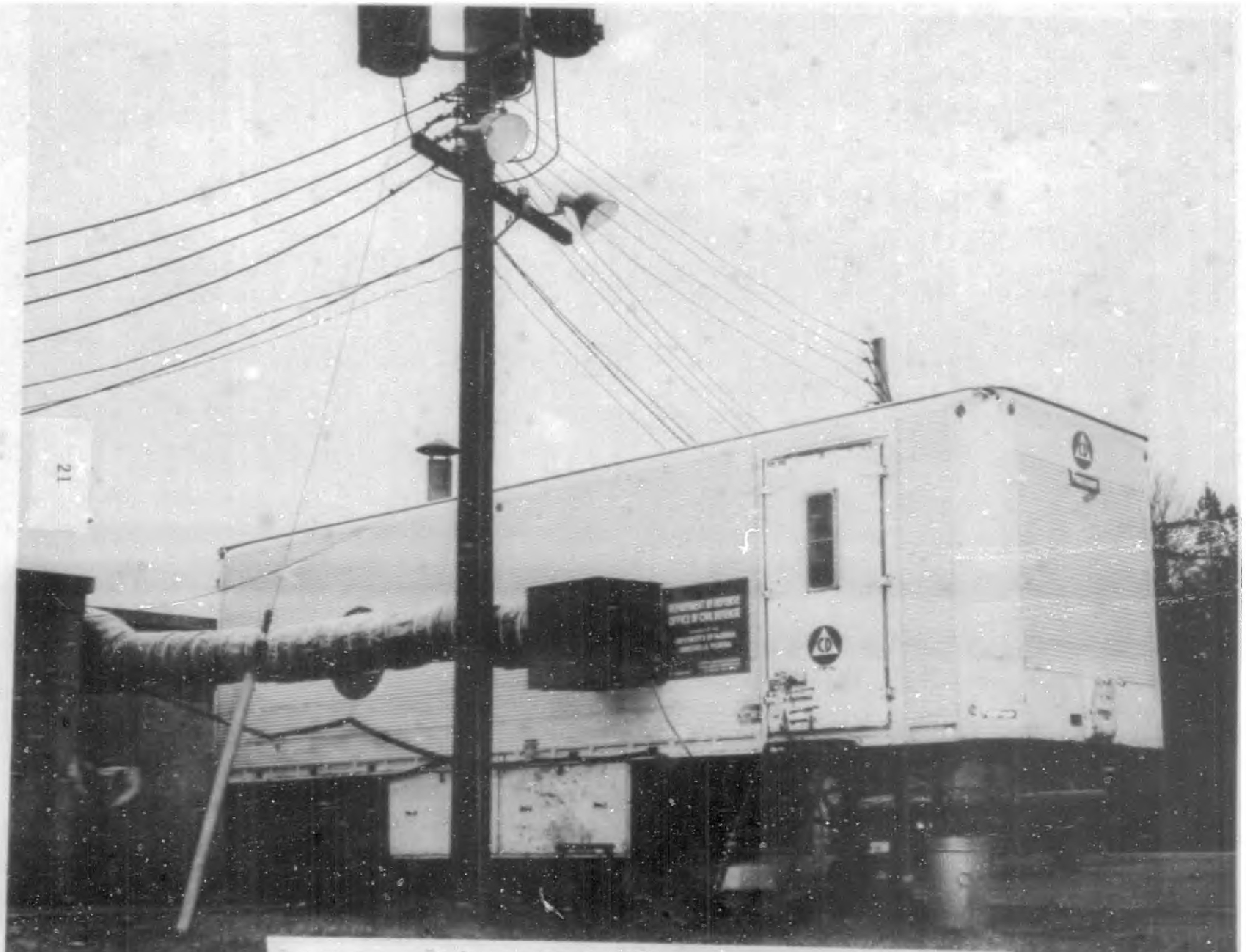
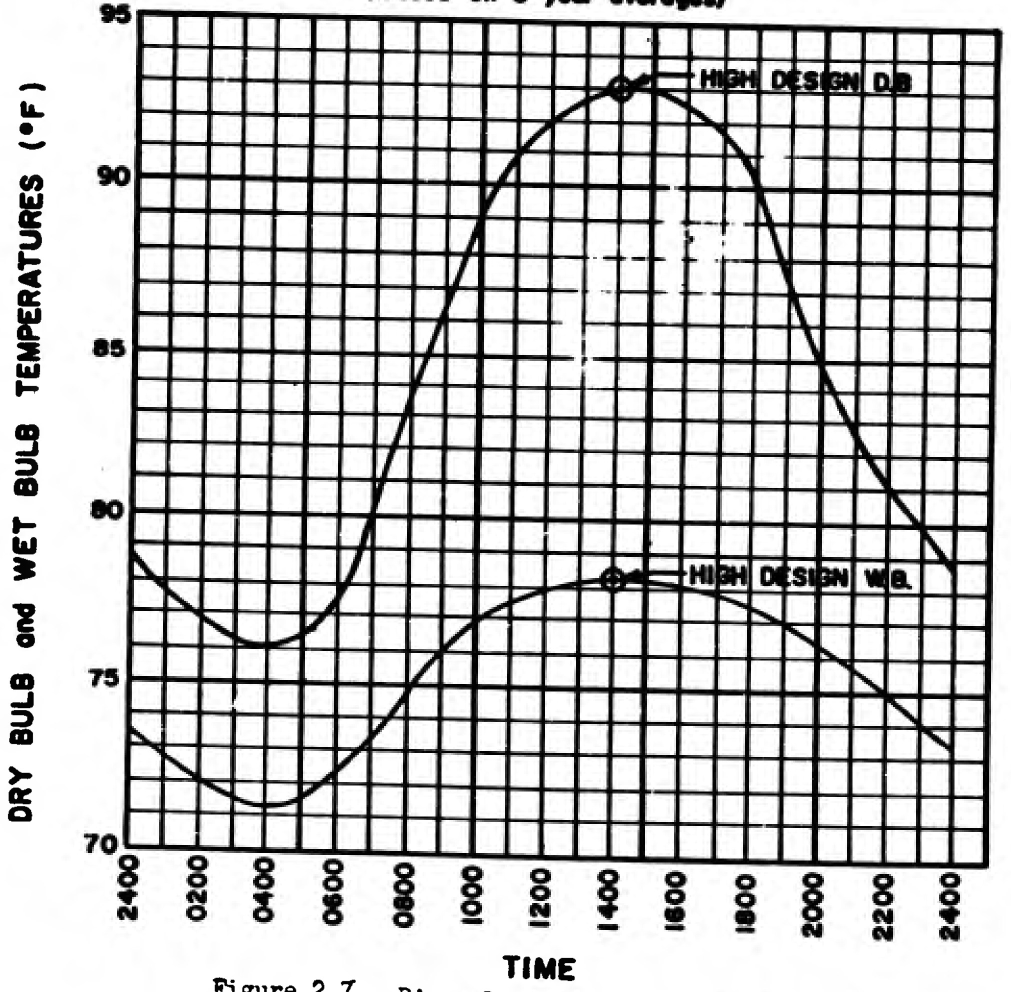


Figure 2.[illegible] Environmental Control and Instrumentation Trailer.

Figure 2.6 Operator's cab in Environmental Control and Instrumentation Trailer.

Shown are instruments for control of trailer and recording of test data.



DIURNAL VARIATION IN TEMPERATURE

FORT BELVOIR, VIRGINIA

(Based on 5 year averages)

Figure 2.7 Diurnal variation in temperature.

1% DESIGN DAY – SHELTER SUPPLY AIR CONDITIONS

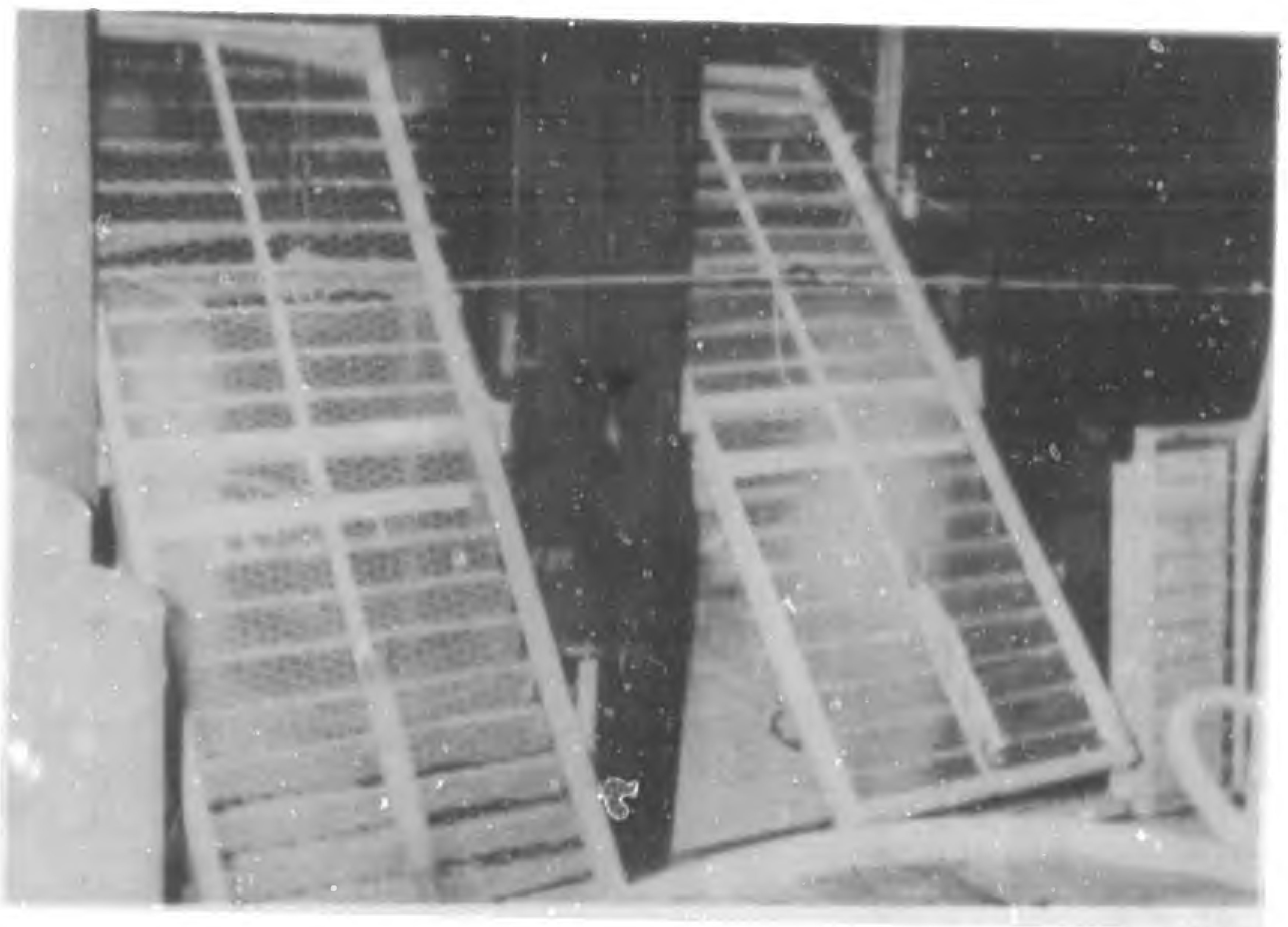


Figure 2.8 Push-pull punkahs.

Note center hinge; polyethylene flaps are installed on alternate sides of punkah. Top portion exhausts hot air from room while fresh air is pushed into room in lower half.

Figure 2.9 Push-pull punkahs in operation.

Rooms 3 and 4 are in background. Taped areas on walls are framed openings which can be opened or closed to change shelter ventilation configurations.

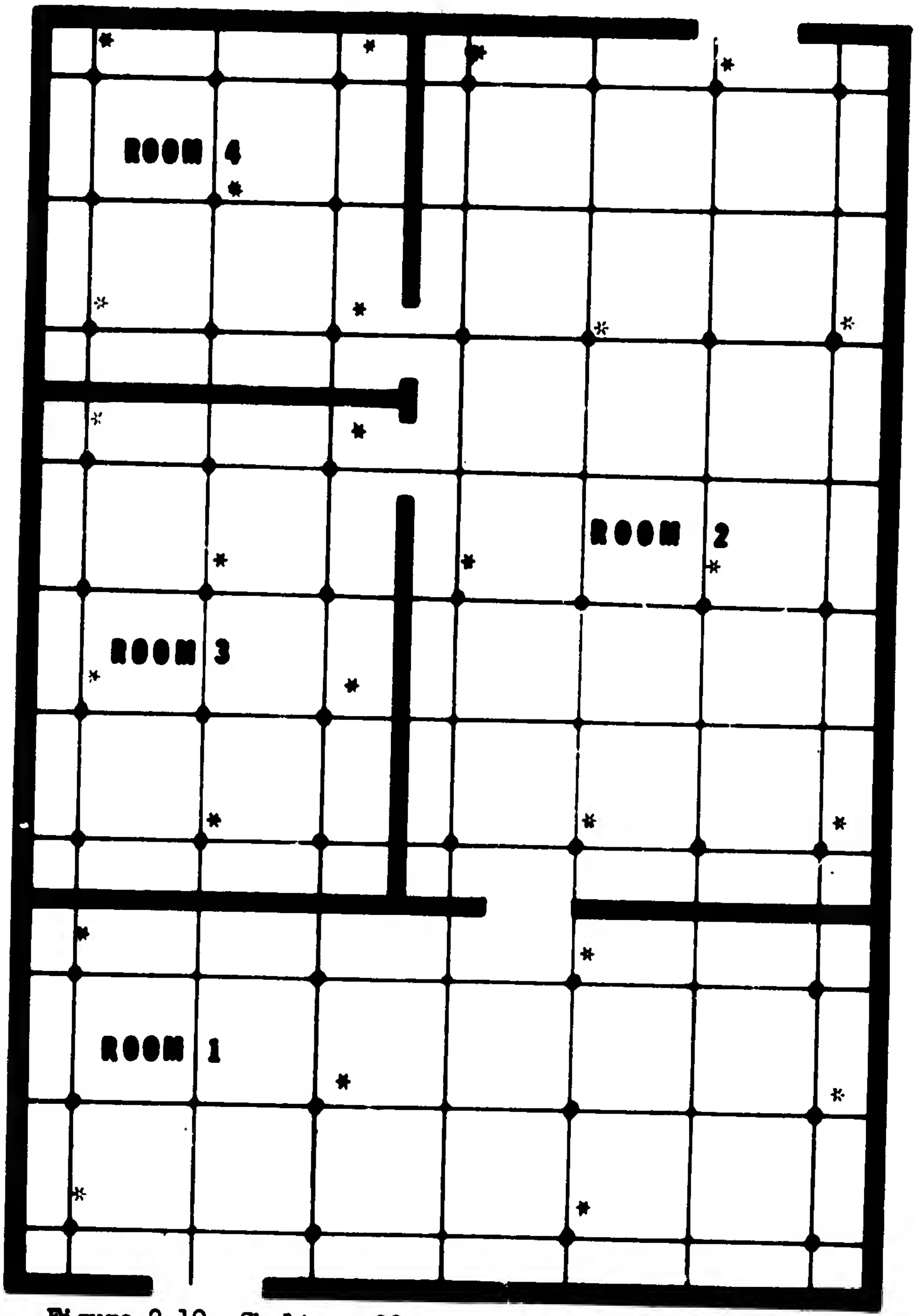
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO.________ CONFIG. NO._____ COND._______

VENTILATION RATE__________ CFM/OCC

OVERALL AVG. SHELTER E.T. ____________

AVG. E.T. OF ROOM 1_____ 2_____ 3_____ 4_____



CONFIG.

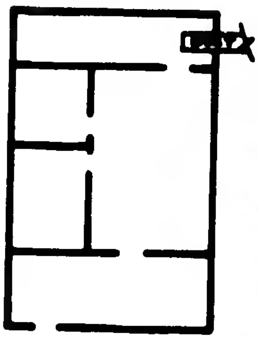


Figure 2.10 Shelter effective temperature patterns. The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

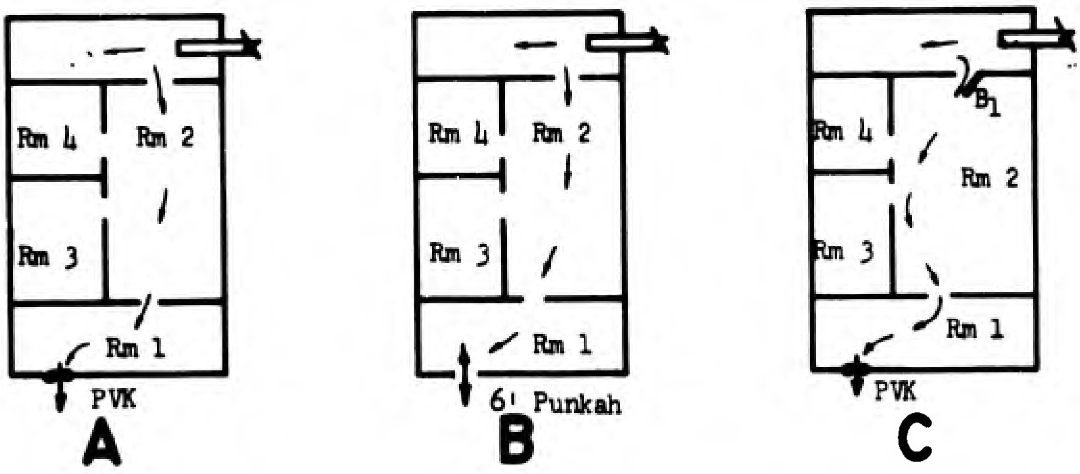
*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER VENTILATION CONFIGURATIONS

No Auxiliary Devices

6' Punkah Prime Air Moving Device - Exhaust Configuration

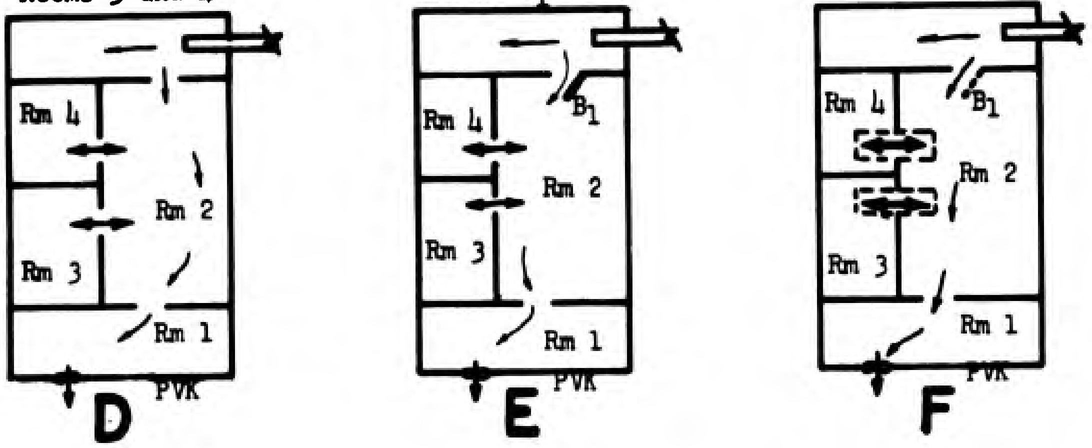
Baffle (B_1) at Supply Air Inlet Door



3' Punkahs in Doorways to Rooms 3 and 4

3' Punkahs & Baffle B_1

Punkahs & Miscellaneous Baffles (Horiz., Cross Baffles, Side Baffles)



Series Air Flow Room 4-2-3-1-Exhaust

Parallel Air Flow

Push-Pull Punkahs in Doorways to Rooms 3 and 4

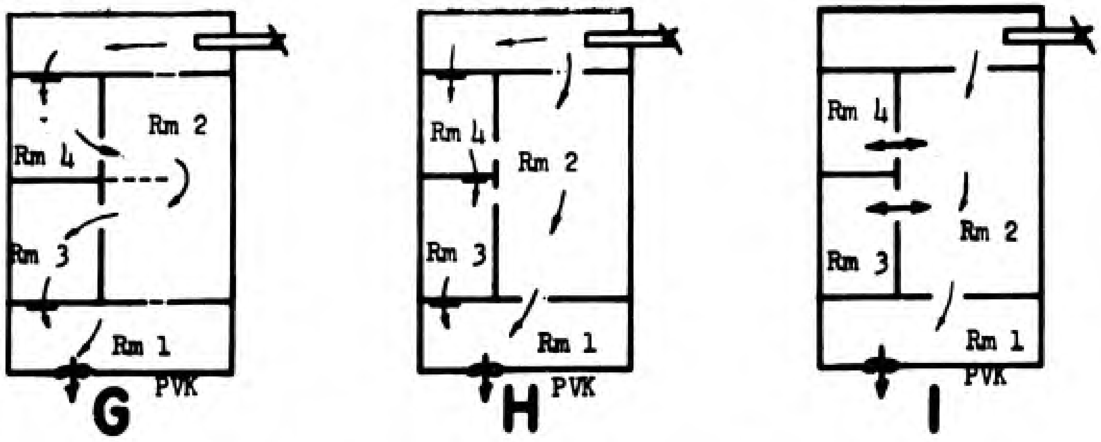


Figure 2.11 Shelter Ventilation Configurations

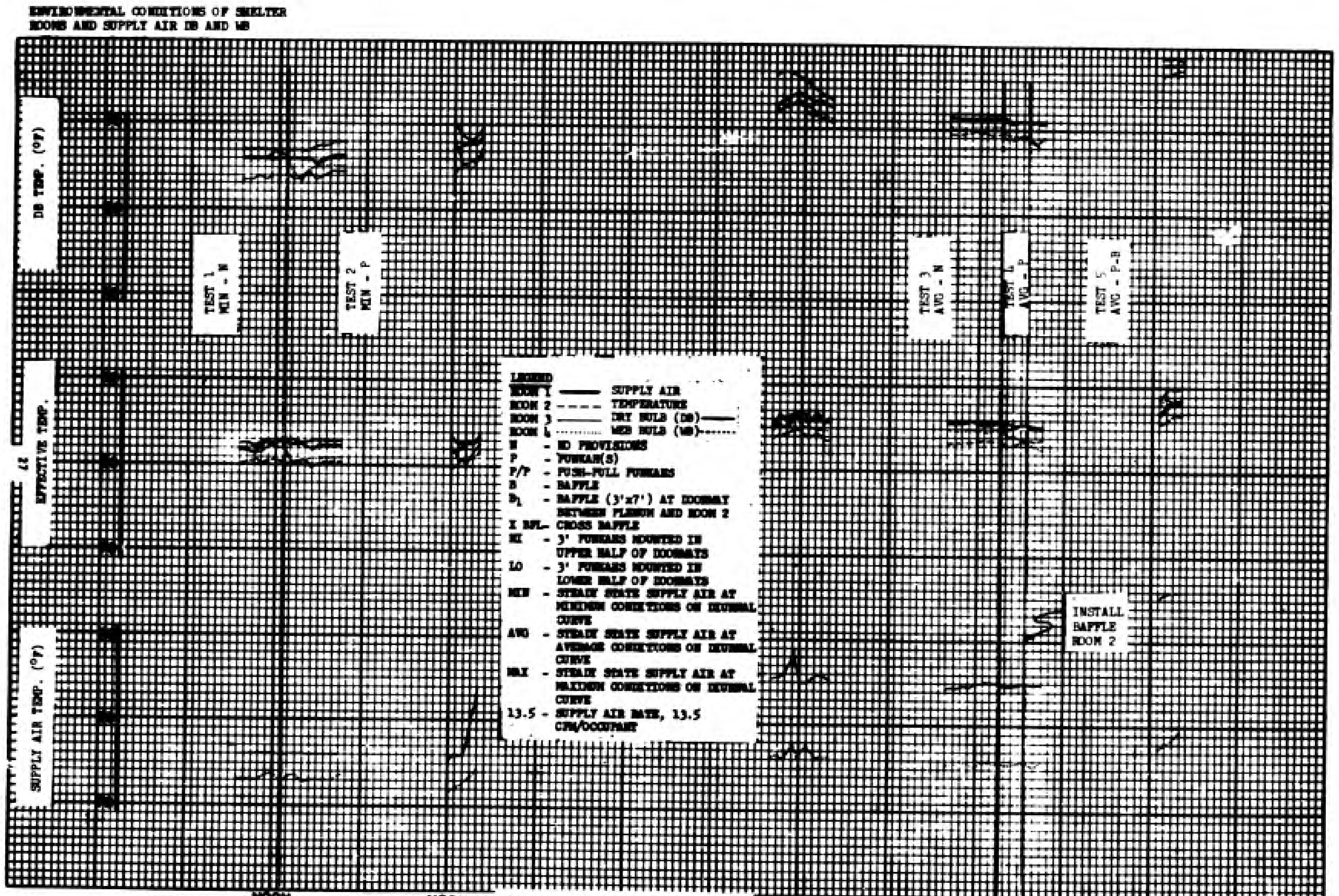


Figure 2.12 Plot of air supply and environmental conditions.

ENVIRONMENTAL CONDITIONS OF SHELTER ROOMS AND SUPPLY AIR 3B AND 4B

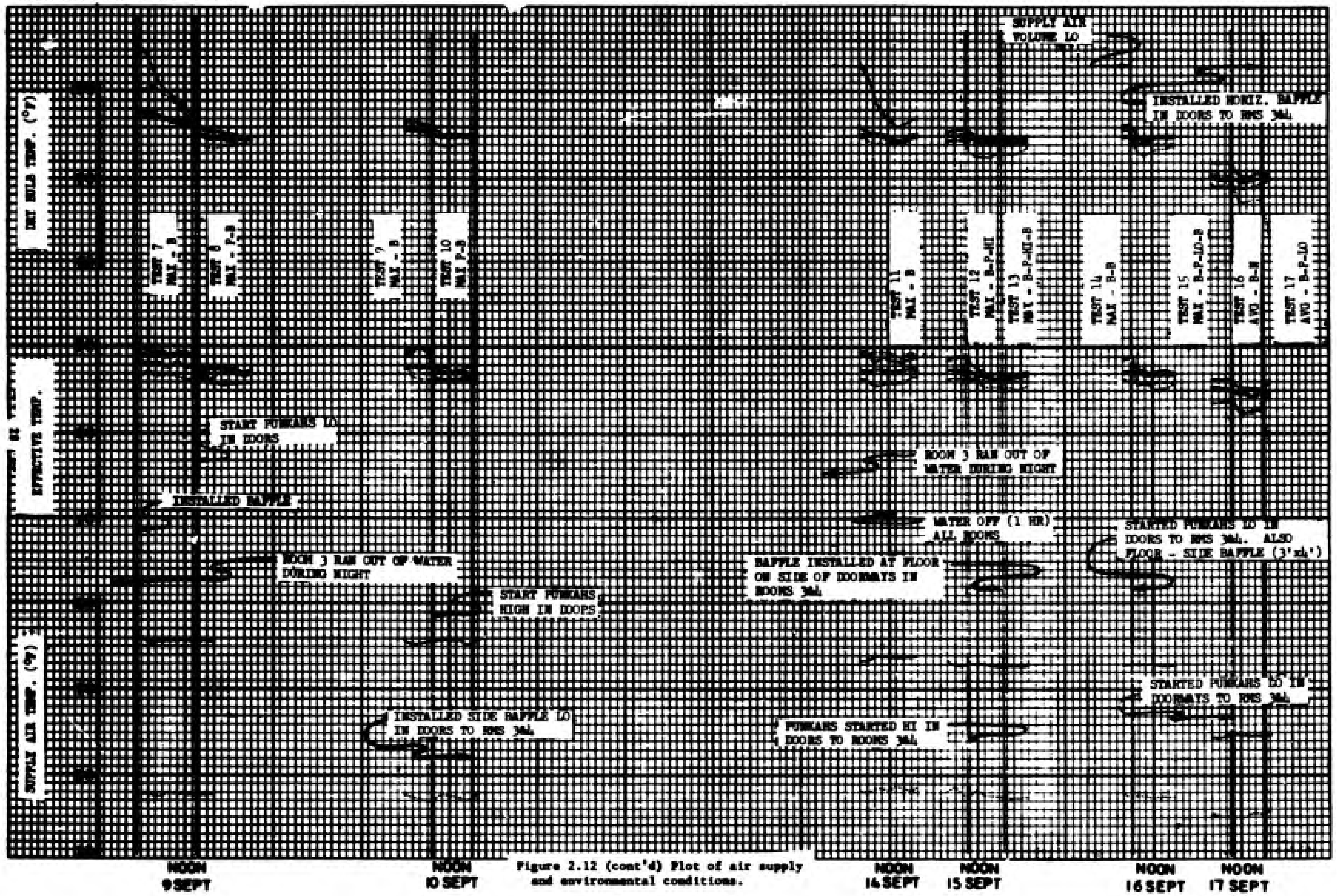


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

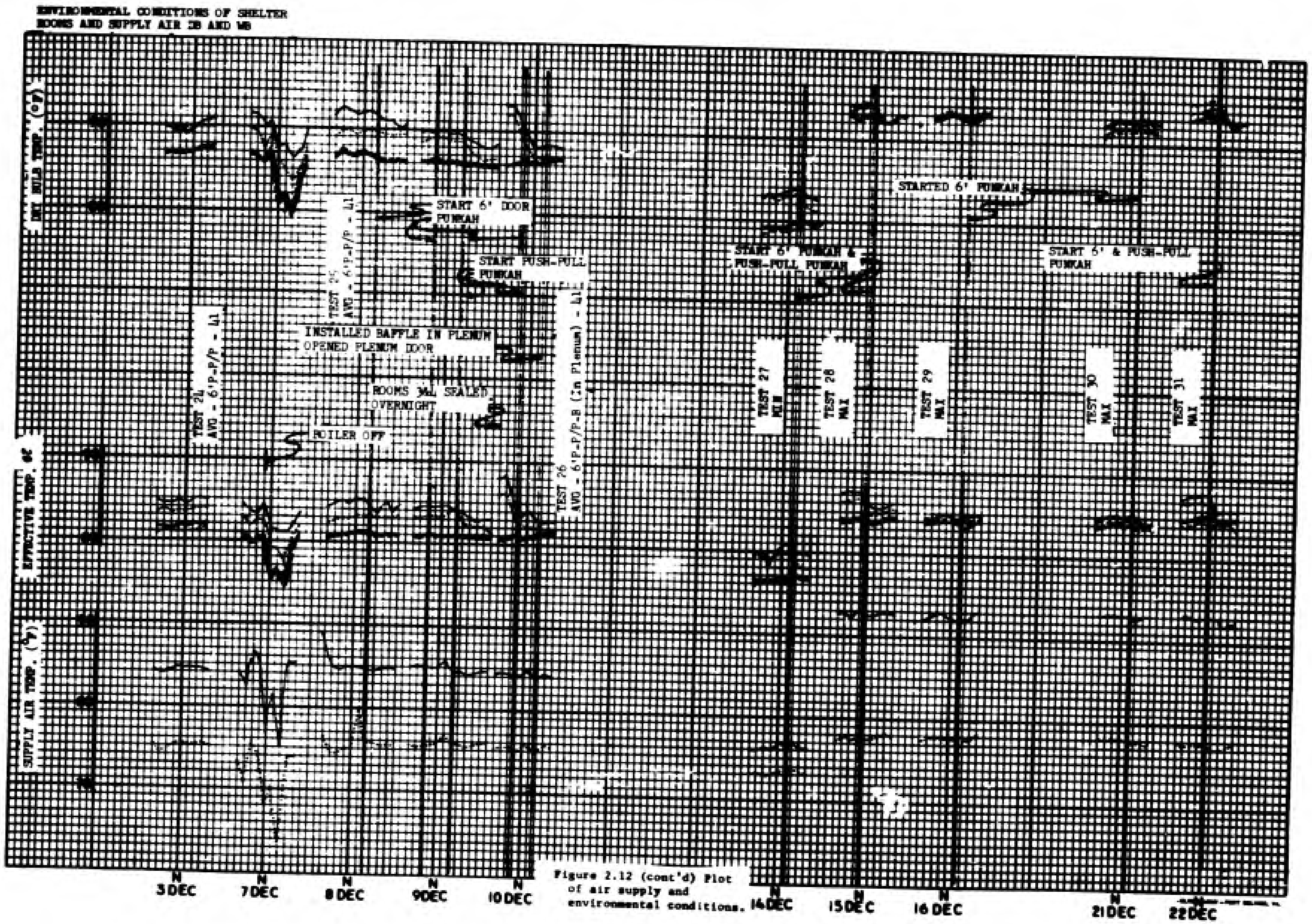


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

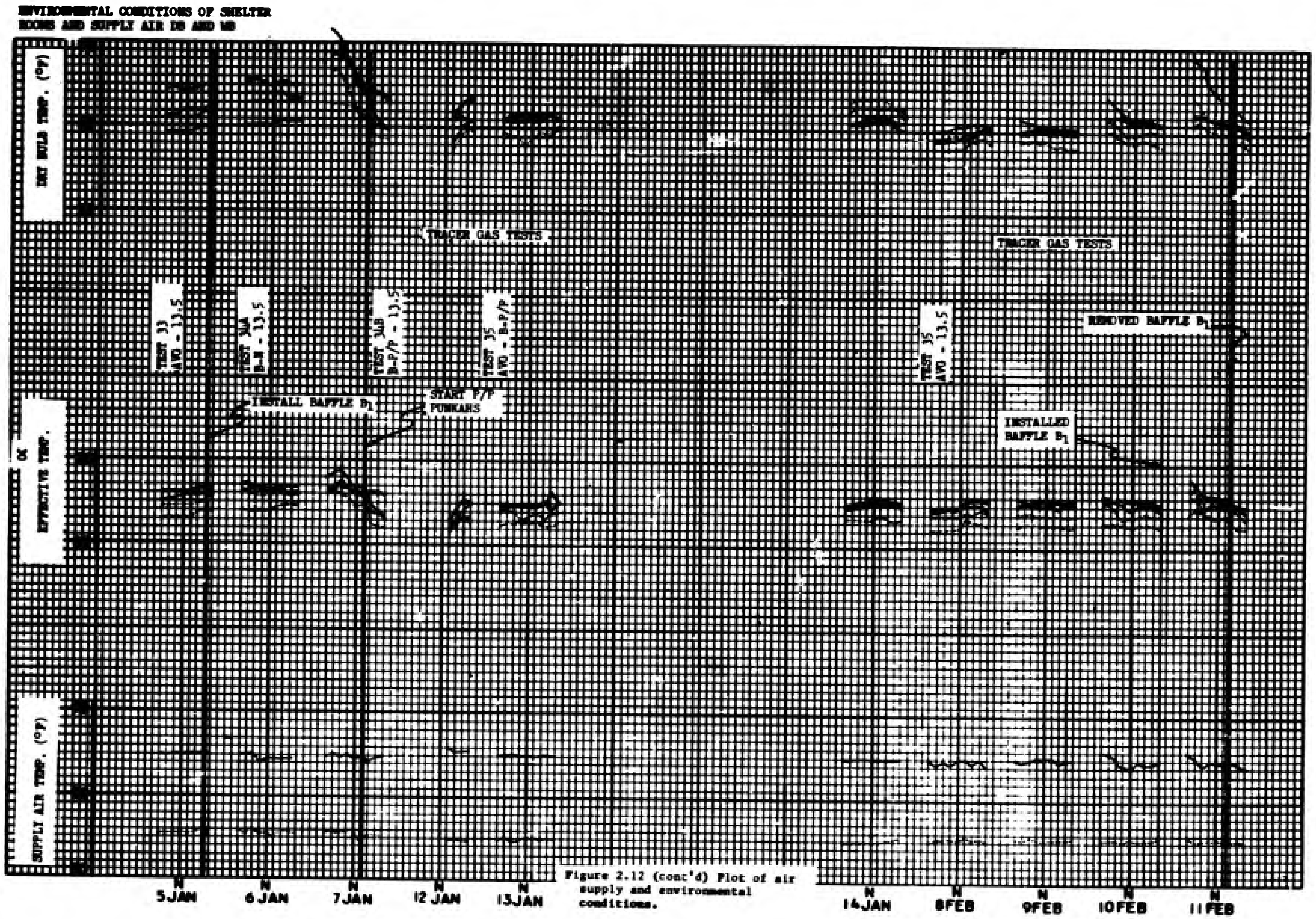


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

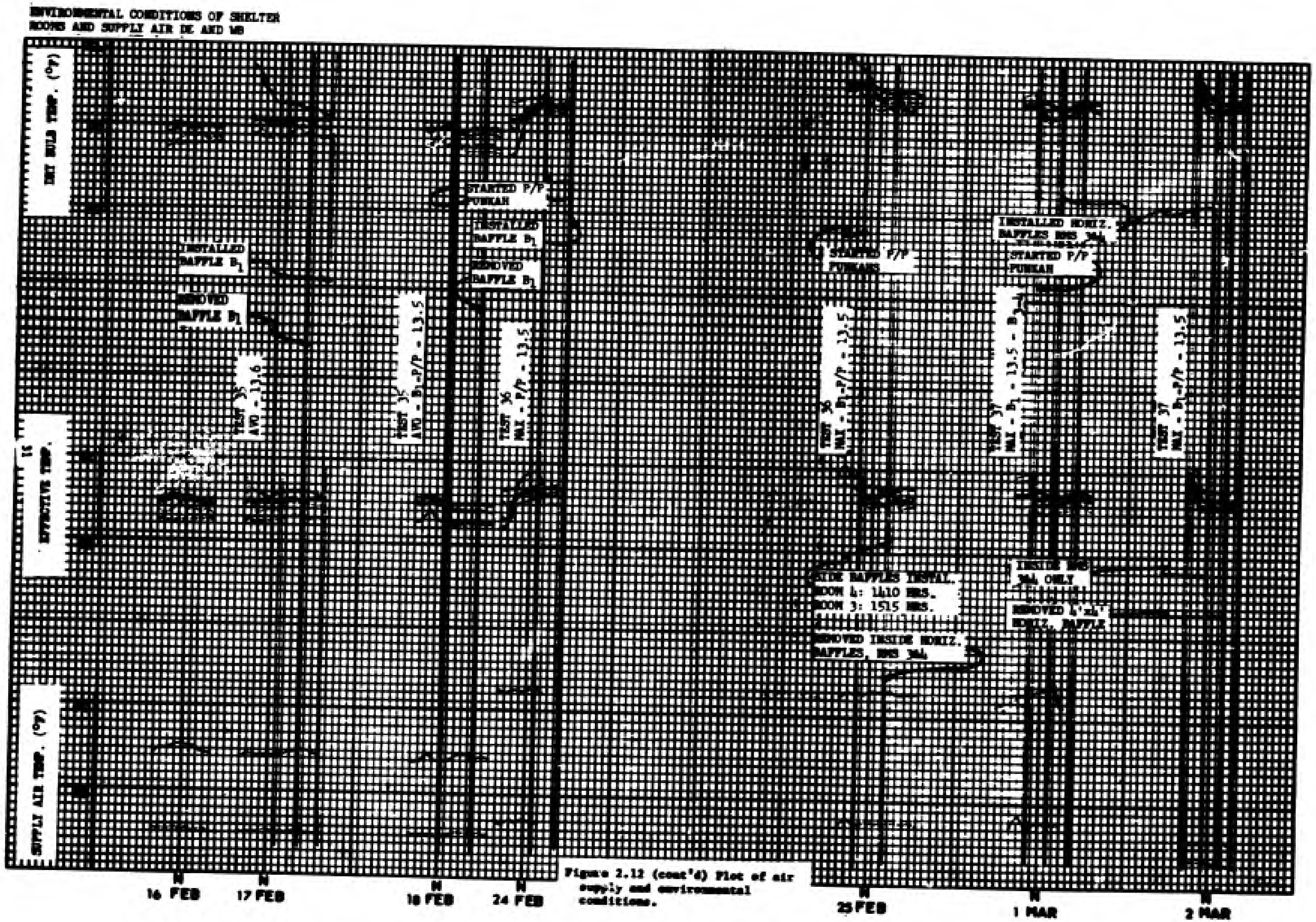


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

ENVIRONMENTAL CONDITIONS OF SHELTER ROOMS AND SUPPLY AIR DB AND WB

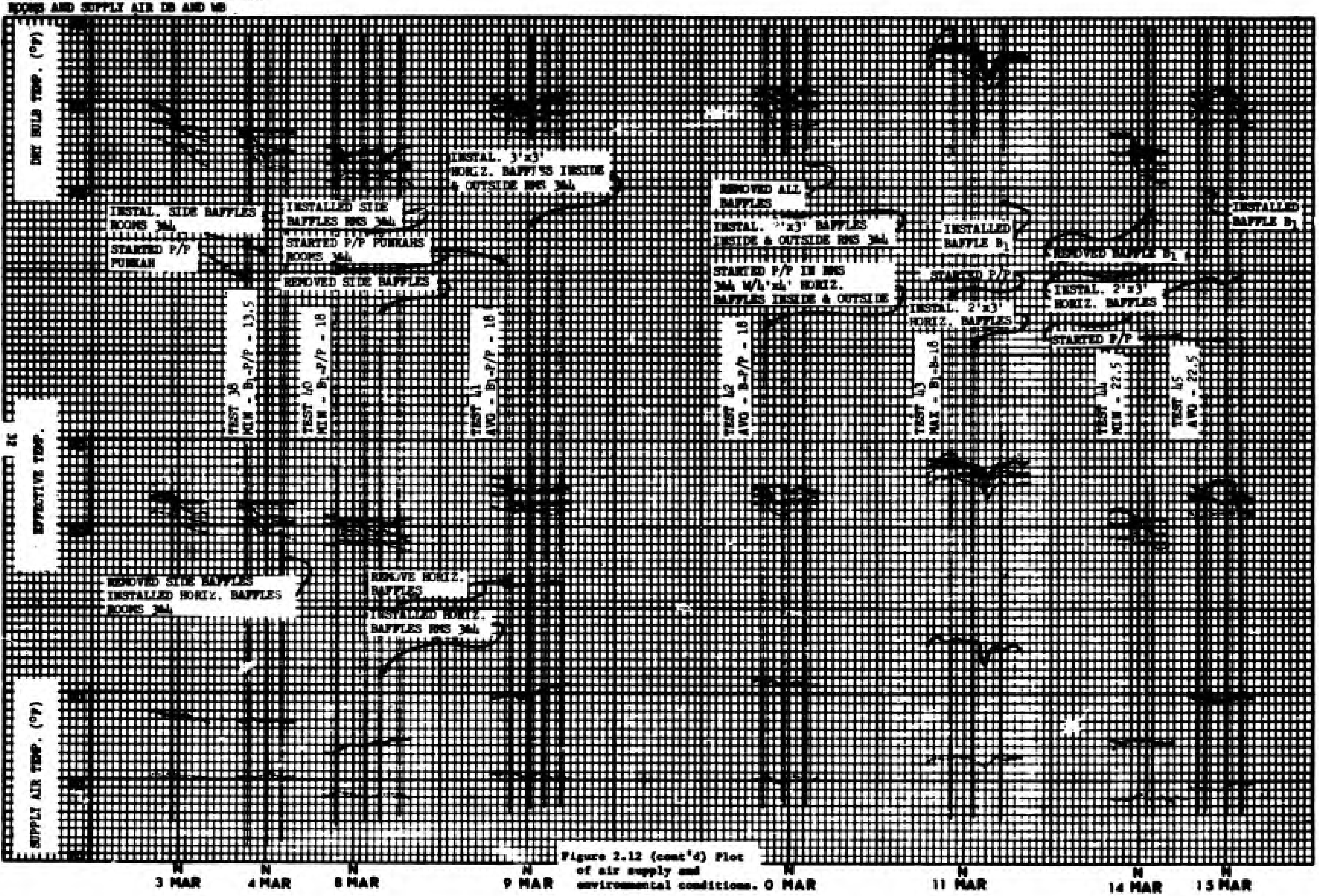


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

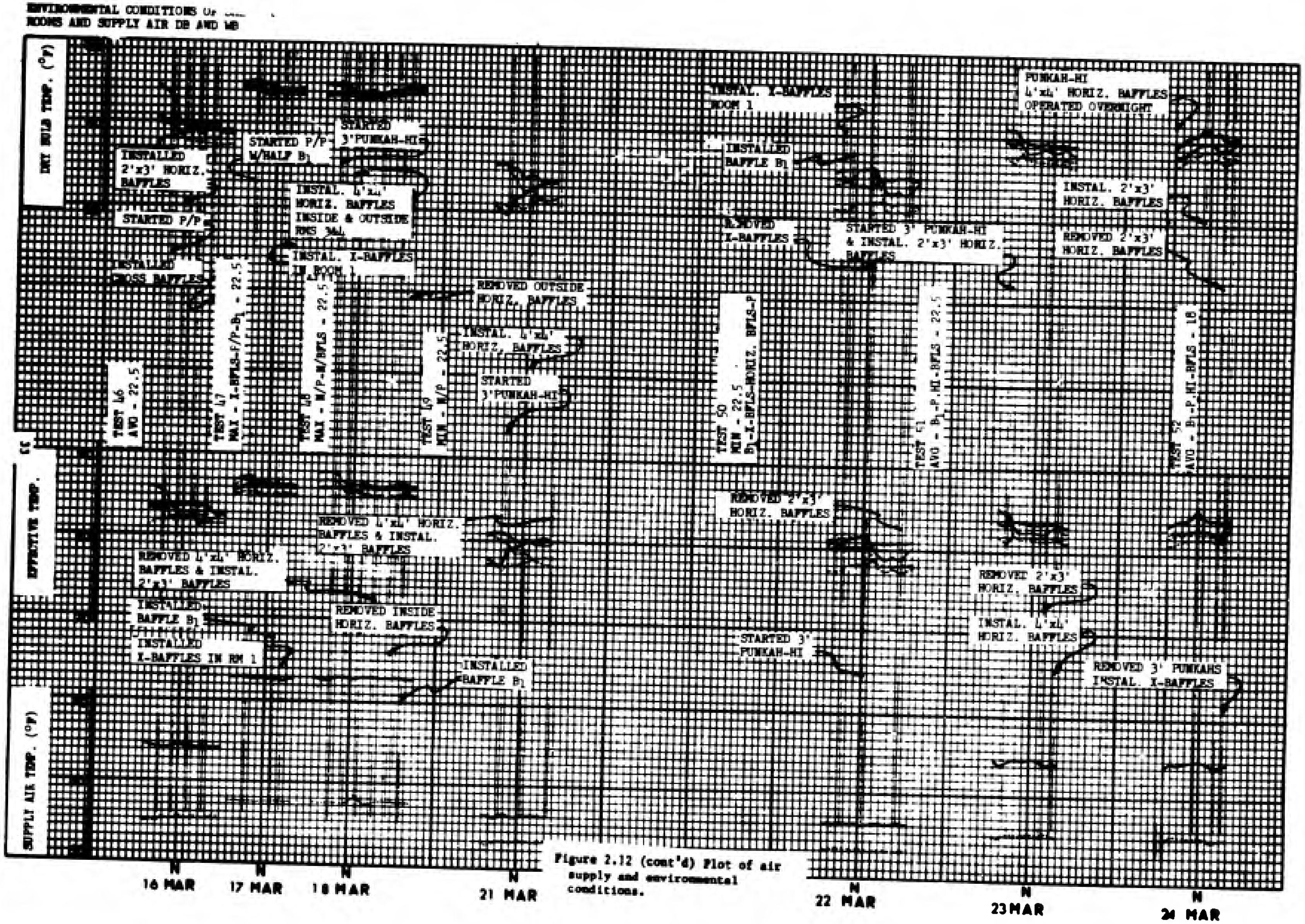


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

ENVIRONMENTAL CONDITIONS OF SHELTER
ROOMS AND SUPPLY AIR DB AND WB

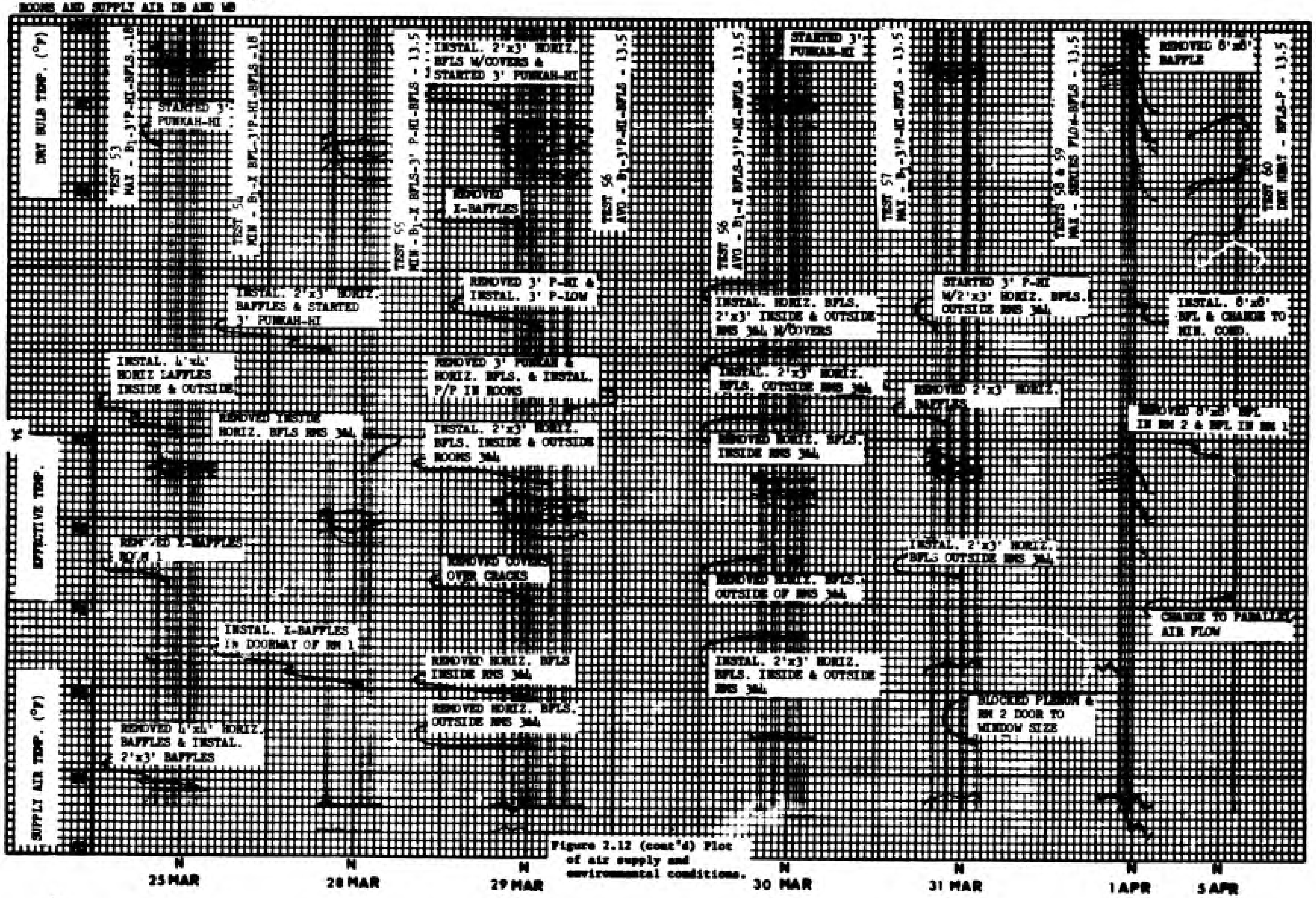


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

ENVIRONMENTAL CONDITIONS OF SHELTER
ROOMS AND SUPPLY AIR DB AND WB

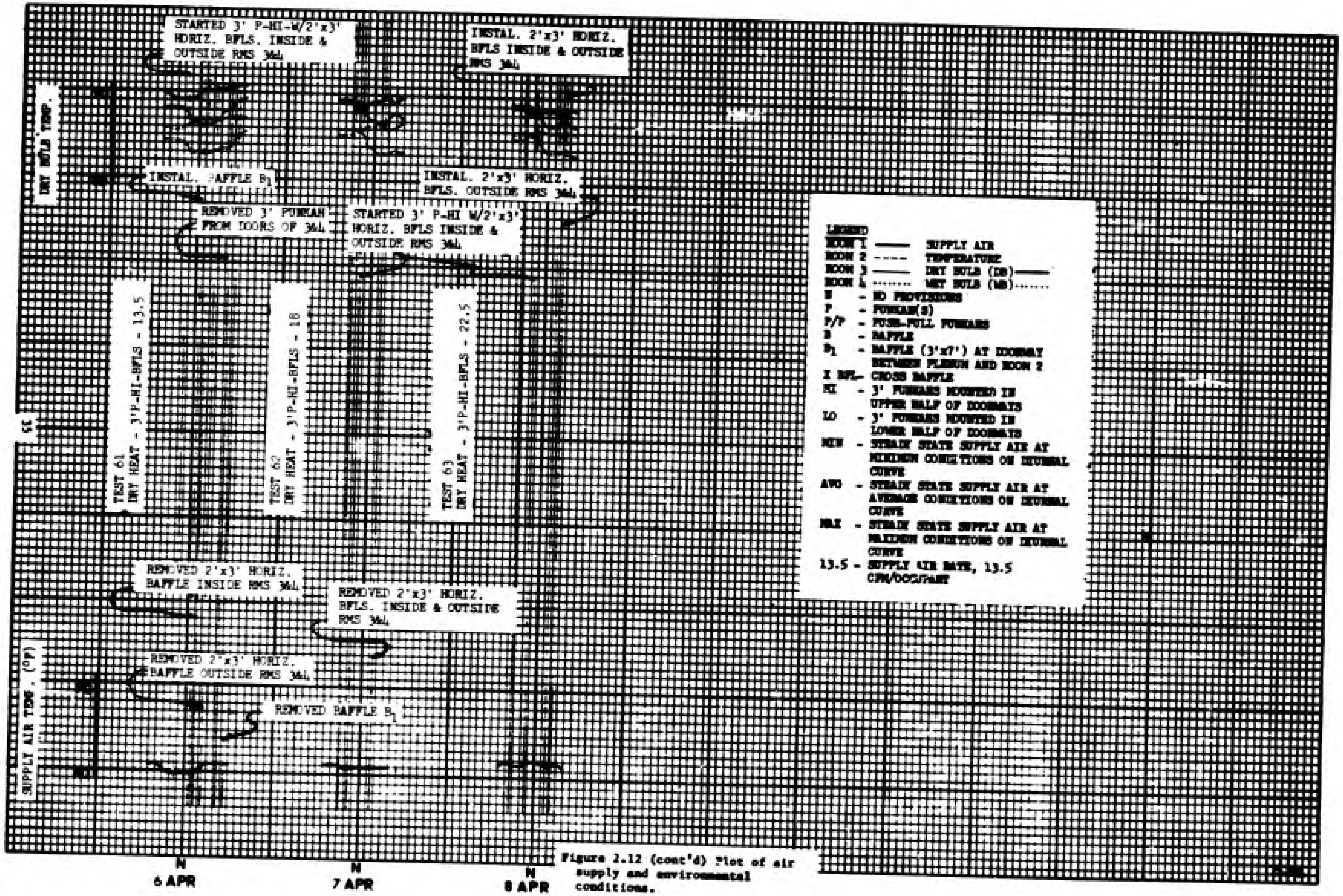


Figure 2.12 (cont'd) Plot of air supply and environmental conditions.

CHAPTER 3

DISCUSSION AND RESULTS

3.1 EFFECTIVENESS OF PUNKAHS

A series of tests was performed, using the tracer gas method to determine the air change rates in siderooms 3 and 4 using push-pull punkahs, 3 foot punkahs and various baffle arrangements in the doorways to these rooms. The sideroom air change rates were compared to the air change rates found by observing the thermal convection currents due to natural ventilation. The supply air quantities and temperature conditions were kept constant and the improvements in the environmental conditions within Rooms 3 and 4 were observed, which then could be attributed to the effects of the punkahs and various baffle arrangements.

3.1.1 Natural Ventilation. Carbon dioxide and helium were used as tracer gases. The air to the shelter was conditioned to the minimum, average and maximum on the diurnal cycle and was supplied at steady state conditions at these points. An analysis of the data in Table 3.1 indicates that air change rates in both Rooms 3 and 4, with natural ventilation, varied from 160 to 170 cfm in both rooms. Even though the cubic content of Room 3 was larger than Room 4 (1321 cubic feet vs. 1037 cubic feet), the total air change in the room due to the natural convection currents was largely the same. The size of the door openings in each was identical, 78 in x 32½ in. Thus, it was concluded that, for these tests, the ventilation rate due to thermal convection currents was independent of the size of the room and dependent only on the size of the door opening to the room. The difference in the dry bulb temperatures in the two rooms was not great enough to have any significant influence.

Since the total heat gain in the larger room would be greater than in the smaller room because of the larger number of occupants, it was expected that for the same ventilation rate the effective temperature in the larger room would be higher. This was generally found to be true in the tests as indicated by representative figures as follows:

Test No.	Air Flow	Condition	ET Room 3	ET Room 4
36	13.5 cfm/occ	Max.	88.9	87.4
43	18 cfm/occ	Max.	88.5	87.1
44	22.5 cfm/occ	Min.	81.9	81.2
45	22.5 cfm/occ	Avg.	85.0	84.0

3.1.2 Three Foot and Push-Pull Punkah Capacities. The average air change rate determined with CO_2, using the push-pull punkahs, was about 425 cfm and using the 3 foot punkahs was about 460 cfm (Table 3.1). From this data, it appears that the 3 foot punkahs circulated more air than the push-pull punkahs. It should be noted that the 3 foot punkahs operated at a rate of 33 oscillations per minute compared to the push-pull punkahs operating at 25 oscillations per minute.

A factor of 130 cfm should be added to the above capacity figures to correct certain errors inherent in the tracer gas method, as is explained in paragraph 3.2.4.

3.1.3 Effects of 3 Foot Punkahs. The effect of the 3 foot punkahs on reducing the effective temperatures within the siderooms is presented in Tables 3.2 and 3.3. Note that a reduction in the range of approximately one to five degrees occurred within Rooms 3 and 4. Since this is a decrease in the effective temperature, it represents a significant improvement in the comfort of shelter occupants. Note also that this decrease was obtained without a corresponding increase of any consequence in the effective temperatures in the other shelter rooms which were in the direct path of the air flow (Rooms 2 and 1).

It should also be noted that the temperature reduction was greatest when the inlet air deflecting baffle (B_1, See Figure 2.11) was used in conjunction with the punkahs. A detailed discussion of this test is furnished herein; Tables 3.2 and 3.3 provide representative figures illustrating the effect of the baffle.

Room 3, which was larger than Room 4, accommodated a greater number of occupants, and consequently had a greater internal heat load. Since the air moving capacity of the punkahs was relatively constant and the volume of air delivered to each room was about equal, as was expected, the temperatures in Room 3 exceeded those in Room 4, see tables 3.2 and 3.3.

The punkahs had a significant effect on the air distribution patterns within shelter rooms, as can be observed from the air velocity diagrams presented in Appendix A.

The air flow characteristics of a punkah are illustrated in Figure 3.1 (note sequence of picture numbers). These air flow patterns were drawn after observing numerous smoke tests. It should be noted that initially the air was set in motion behind the punkah by suction - not "pushed" ahead of it as might be expected. Once the air was set in motion it continued moving in the same direction through the open flaps during the back stroke. The next impulse was not imparted to the air until the suction effect of a new power stroke occurred.

3.1.4 Punkah Location. A disadvantage of the push-pull punkah is that it completely blocks the doorways to a sideroom. This is also true to a lesser extent with the 3 foot punkahs when mounted in the lower half of the doorways. However, this would be of relative unimportance in actual emergency conditions since the manual operation could be momentarily interrupted to allow persons to enter or leave the rooms.

3.1.5 Punkah Mounting. The location of the punkahs low in the doorways to the side rooms, supplying relatively cool air to the rooms, was thought to be the optimum utilization of these devices. However, due to excessive recirculation of air within the rooms and short circuiting between the exhaust air and supply air across the punkahs, the resultant difference in environmental conditions in the rooms were not appreciably effected by the change of position in the doorways. Location of the punkahs high in the doorways allows better access to the rooms. The difference in effective temperature observed in Siderooms 3 and 4, with punkahs mounted high or low, was about 0.5 degrees. This small reduction may not be worth the lack of accessibility. An advantage to the lower doorway mounting would be that the persons who would benefit from the operation would be supplying their own power, since the direction of the power stroke pull is toward the room.

In addition to the short circuiting between the exhaust air and the supply air when the punkahs were operated in the lower half of the doorways, the air within the rooms was also being recirculated continuously (velocity traverse, Test 4, Appendix A). Another observation was that the hot exhaust air from Room 4 exited with a downward momentum mixing with the air being supplied to Room 3. Thus, conditions were always worse in Room 3 than in Room 4. Using smoke, it was observed that the air pumped into Room 3 by the punkah would make a complete circle within the room by moving directly across the room, along the floor, to the opposite wall, rise to the ceiling and come back with a strong downward momentum at the doorway, then be sucked in by the discharge air stream from the punkah and be recirculated into the room.

In an attempt to eliminate this condition and cause the air to rise above the baffle, a 3 ft x 4 ft rectangular vertical baffle was installed adjacent to the floor at the edge of the doorways in Rooms 3 and 4. However, the air circulation patterns (smoke tests) indicated that the air within the rooms circumvented the baffle as may be noted in the velocity traverse diagrams for Tests 13 and 14 shown in Appendix A. Thus the baffle had very little effect on improving the conditions in the siderooms and the effective temperatures observed in the siderooms were essentially the same with or without baffles.

3.1.6 Effects of Horizontal Baffles. In another attempt to eliminate the short circuiting between the supply air and the exhaust air from the siderooms, a 4 ft by 4 ft horizontal plywood baffle was installed approximately 42 inches above the floor in the doorways to siderooms 3 and 4, as shown in Figures 1.2, 1.5 and tests 40 thru 56 in Appendixes A and B. The tests were conducted with punkahs operating in the doorways of the rooms and the baffles were tested in the following configurations:

a. Inside and outside Rooms 3 and 4.

b. Inside Rooms 3 and 4.

c. Outside Rooms 3 and 4.

Air from the trailer was supplied at rates ranging from 13.5 to 22.5 cfm/occupant and conditioned to the minimum, average and maximum points on the diurnal curve. In comparing the effects of the baffles on the environmental conditions, the following typical procedures were followed:

a. Establish steady state conditions.

b. Make a psychrometric traverse of the entire shelter.

c. Operate push-pull punkahs in the doorways to Rooms 3 and 4.

The 4 ft by 4 ft horizontal baffles were placed initially on both inside and outside of Rooms 3 and 4. These baffles were subsequently replaced by 3ft by 3ft horizontal baffles and later with 2ft by 3ft horizontal baffles and finally, the horizontal baffles were removed altogether. The above procedure was repeated with horizontal baffles on the inside only and then repeated again with the baffles on the outside only of Rooms 3 and 4. For each baffle arrangement, the shelter was allowed to stabilize and observations were made of the temperature conditions, particularly in Rooms 3 and 4.

During typical Test 48, the following effective temperatures were observed in the shelter rooms when supplied with a steady state ventilation rate of 22.5 cfm per occupant, conditioned to the maximum point on the diurnal curve:

Room	4'x4' Horiz. Baffles	2'x3' Horiz. Baffles	Outside Horiz. Baffles Only	No Horiz. Baffles
1	86.1	86.2	86.2	86.2
2	85.1	85.3	85.4	85.5
3	86.1	86.5	86.6	86.6
4	85.1	85.1	85.1	85.9

As a general observation, the size of the horizontal baffles had very little effect on conditions in Rooms 3 and 4, and when all horizontal baffles were removed, the effective temperatures in Rooms 3 and 4 increased slightly (0.5°-0.8°). Additional tests were conducted using other ventilation rates conditioned to the minimum average and maximum points on the diufnal curve, which indicated that similar reductions in effective temperatures occurred (Rooms 3 and 4) when horizontal baffles were installed either inside or outside of these rooms.

Based on the test data presented in Tables 3.2 and 3.3, it may be concluded that a nominal beneficial effect was experienced in Rooms 3 and 4 when horizontal baffles were installed in the doorways on both inside and outside of these rooms. The magnitude of the reduction in effective temperatures in Rooms 3 and 4 ranged from 0.2 to 1.5 degrees.

3.1.7 Effect of Vertical Baffle, B_1. In the normal exhaust configuration*, the air flow patterns were as follows: the supply air entered Room 2 from the plenum and moved directly through the room to the doorway to Room 1, then diagonally across Room 1 to the exhaust door. Since the air entered Room 2 at an angle, from the plenum, it had a tendency to sweep the wall directly opposite the doorways to siderooms 3 and 4. Thus, the maximum benefit of the supply air was not realized because some of it was exhausted before picking up its maximum heat and moisture load. To improve this condition, a 3ft by 7ft floor-to-ceiling vertical baffle was installed in the doorway between the plenum and Room 2 at a 45° angle to the edge of the doorway to deflect the supply air towards Rooms 3 and 4. This baffle was designated B_1, see configuration E, Figure 2.11. A series of tests was then conducted to evaluate the effects of this baffle on the environmental conditions within Rooms 3 and 4. Shelter temperature conditions were observed for the following configurations:

a. Effect of baffle B_1 with no auxiliary air moving devices (punkahs) being used.

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*NOTE: The "normal exhaust configuration" referred to in this paragraph and elsewhere in this report refers to the air flow from plenum, through Room 2, through Room 1, and finally to exhaust at the door in the exterior wall of Room 1 where the PVK was normally located. This is configuration A in Figure 2.11. However, for the same basic exhaust configuration, punkahs may be utilized in siderooms and the 6 foot punkah may replace the PVK. This corresponds to B, C, D, E, F, and I in Figure 2.11. All are basically identical to configuration A except for the auxiliary devices.

b. Effects of baffle B_1 with punkahs operating in doorways of Rooms 3 and 4.

By comparing the temperature reductions observed, shown in Tables 3.4 and 3.5, it can be noted that the lowest effective temperatures were attained in the siderooms (Rooms 3 and 4) when the baffle B_1 was used together with punkahs mounted in the doorways to these rooms. An increase in effective temperature resulted in Rooms 3 and 4 when the baffle B_1 was used without the punkahs. When the supply air stream was deflected directly toward the entrances to Rooms 3 and 4, the baffle itself became a causative factor in the resultant increase in effective temperature in these rooms. This resulted from the stream of supply air screening the doorways and suppressing the exit of exhaust air. Thus, the rooms were stagnated because the air was not being circulated into and out of the rooms. See Table 3.6 for comparison of test results.

Note that the effect of baffle B_1 in combination with the punkahs was not as pronounced as expected. In some tests there was a slight increase in the ETs in the rooms, probably due to errors in the test procedures. It is felt that the effect of baffle B_1 in deflecting the incoming air directly into the rooms where the punkahs pick up fresh air and deliver it to the siderooms will best enhance the environmental conditions.

3.1.8 Shelter Environmental Response to Series Air Flow. Several tests were conducted to evaluate the environmental conditions obtained with series air flow through the shelter. In analyzing the test results, a shelter space was considered habitable if the effective temperature was 85 degrees or less. Table 3.7a presents effective temperature data determined by various tests for a given air flow at average conditions in the normal exhaust configuration compared with a series air flow test performed by the University of Florida in the same shelter at an earlier date (Reference 3). A theoretical calculation of shelter conditions with series air flow was compared to actual test conditions obtained at maximum conditions in Table 3.7b (see Appendix H for sample calculations). Two air flow paths were compared.

a. Air entered Room 4 through 2ft by 3ft window opening from the plenum, through the opposite window opening and diagonally across Room 3, thence into Room 1 through its 2ft by 3ft window opening. From Room 1, the air entered Room 2 through the connecting doorway and finally was exhausted through an opening in the wall of Room 2 (Path 4-3-1-2-Exhaust). Results of this configuration were obtained from previous work by the University of Florida and from calculations shown in Appendix H.

b. Air entered Room 4 through a 2ft by 3ft window opening from the plenum, thence through the doorway into Room 2 where an 8ft by 8 ft plywood baffle from floor to ceiling had been installed between the doorways to Rooms 3 and 4 to force the air to sweep completely around Room 2 before entering Room 3. From Room 3, the air traversed through a 2ft by 3ft window opening into Room 1. At this point, the air was deflected by a plywood baffle installed at a 45 degree angle directing the air toward the south wall of Room 1 where it was exhausted by the PVK (Path 4-2-3-1-Exhaust, Figure 2.11G).

The average shelter effective temperature was obtained by weighting the individual room effective temperatures in proportion to the number of occupants, thus: Room 1-35/112, Room 2-45/112, Room 3-19/112, Room 4-13/112.

3.1.8.1 Air Flow Path 4-3-1-2-Exhaust. With an air flow rate of 13.5 cfm per occupant, conditioned to the average point on the diurnal curve, the series air flow Path 4-3-1-2-Exhaust provides usable space for 67 occupants in Rooms 1, 3 and 4 (see Table 3.7a).

By comparing the environmental conditions resulting from equivalent air flow rates in Table 3.7b with the air conditioned to the maximum point on the diurnal curve, Rooms 3 and 4 provide usable spaces for 32 occupants. However, for a normal exhaust configuration with the same air flow and conditions, none of the rooms would be habitable.

Neither the normal nor the series exhaust configuration produced an overall average shelter effective temperature of 85 degrees or less when supplied with 13.5 cfm per occupant at maximum conditions on the diurnal curve. An average reduction of 1.5 degrees effective temperature in the entire shelter was obtained with series air flow.

3.1.8.2 Air Flow Path 4-2-3-1-Exhaust. The representative results in the table below were obtained in Test No. 58, with an air flow rate of 13.5 cfm per occupant and conditioned to a maximum point on the diurnal curve.

Series Air Flow Effective Temperatures Path 4-2-3-1 (maximum conditions)

Room No.	Test 58 Series Flow	Test 36 Normal Exhaust Config.
1	87.8	87.8
2	85.8	86.1
3	85.9	86.7
4	84.2	85.9

The normal exhaust configuration shows the effective temperatures which prevailed in Test 36 with auxiliary air moving devices operating and air supplied at the same rate and conditioned to the maximum point on the diurnal curve. In view of the improved environmental conditions, especially in the siderooms 3 and 4, resulting from the series air flow, other series ventilation schemes were checked by calculation (Appendix H). The ventilation rate of 13.5 cfm per occupant at maximum supply condition was selected since actual test data was taken at this ventilation rate and could be used for comparison. Two other series ventilation paths, one beginning in Room 4 and the other in Room 2, were investigated by calculation. The effective temperatures obtained are listed in Tables 3.8a and 3.8b.

3.1.8.3 Evaluation of Series Air Flow.

(1) Average supply air conditions, Table 3.8a: Path 4-2-3-1-Exhaust by calculation (from small to large to small to large rooms) resulted in environmental conditions below 85 degrees effective temperature for 77 persons. Path 2-1-3-4-Exhaust by calculation (from large to large to small to small rooms) resulted in a habitable environmental

for 99 persons. Path 4-3-1-2-Exhaust from University of Florida 3 test (small to small to large to large rooms) provided an environment below 85 degrees effective temperature for 67 persons. However, at 85.2 degrees effective temperature, the entire shelter area (112 persons) could be utilized.

(2) Maximum supply air conditions, Table 3.8b: Path 4-2-3-1-Exhaust (from small to large to small to large rooms) by test resulted in habitability for only 13 persons with environmental conditions below 85 degrees effective temperature; Path 2-1-3-4-Exhaust by calculation (from large to large to small to small rooms) results in all rooms exceeding 85 degrees effective temperature; Path 4-3-1-2-Exhaust by calculation (small to small to large to large rooms) provides a habitable environment for 32 persons. Therefore, this ventilation scheme (4-3-1-2-Exhaust) apparently provided the best environmental conditions for the most occupants for this shelter.

3.1.9 Characteristics of 6 Foot Punkah. Figure 3.2 shows the arrangement of the test shelter as used to determine the operating characteristics of the 6 foot punkah with the punkah mounted, as an air exhaust device, in the door to Room 1. The test procedure was as follows:

Air was supplied from the ambient area surrounding the shelter via the Path Plenum - Room 2-Room 1-Exhaust with the punkah mounted in the shelter doorway. The pressure drop across the punkah was measured with two micromanometers (Figure 3.3) and the variation in pressure drop across the punkah was obtained by changing the size of the doorway opening indicated as Door I in Figure 3.2. Locations "A" and "B" indicate where pressure readings were taken. A typical test was started with the door completely blocked and then opened one foot at a time until the doorway was completely unobstructed. The process was then reversed. See Figure 3.4 for a typical test data sheet. Note that the maximum and minimum air velocities through the door were determined by means of a hot wire anemometer. The fluctuations were caused by the punkah pulsations. The air moving capacity was calculated on the basis of the average velocity and area of each opening. Tests were conducted, using a mechanical drive at 25 to 26 oscillations per minute. Throughout the tests, the punkah was operated so that the lower edge was lifted 39-1/4 in above its lowest point.

The angle of travel of the punkah was established for convenience during manual operation. Even though the tests were performed using a mechanical drive, the HP requirements were determined by operating the punkah manually.

Figures 3.5 and 3.6 are copies of data sheets of a typical capacity test and indicate the measured pressure variations across Door I as it was progressively closed one foot at a time from fully open to a complete closure. The number of oscillations per minute was maintained as uniform as possible.

Graphs were plotted from cfm as a function of the pressure drop and the percent of the free area of the inlet door opening. The air moving capacity of the punkah increased when side baffles were installed at either, or both, the inlet or discharge sides of the doorway.

Figures 3.7 through 3.14 show the punkah air moving capacities as follows:

Test No.	Description	Capacity
20	No provisions.	3700 cfm
21	Side baffles on inlet side.	4000 cfm
32	Side baffles on discharge side.	4450 cfm
22	Side baffles on both inlet and discharge sides.	4600 cfm

The apparent imbalance between the capacities found in Tests 21 and 32 was caused by a slight variation in the punkah speed. Difficulty was experienced with the variable speed drive and the punkah oscillations varied throughout the tests from 25 to 26 per minute. Test 22 was conducted at 25 osc/minute. It is judged that if 26 osc/min had been used, a capacity near 5000 cfm would have been attained.

The curves are based on the air volume measured during the tests, which was usually at 72°F with a barometric pressure of 29.7 inches Hg. For all practical purposes, this is standard conditions. In any event, only the static pressure and HP values are affected. Table 3.9 shows the corrected values for all tests.

The use of side baffles with the punkah increased its air handling capacity significantly by eliminating eddy currents at the doorway and backflow into the shelter. The side baffles are not space wasters since the punkah operates in the area effected. In addition to increasing the capacity of the punkah, the baffles serve as safety guards for the punkah (see Figure 3.19).

It is interesting to note that the use of side baffles with the push-pull punkah had only an adverse effect, if any, on its air handling capacity, a phenomenon as yet unexplained (see results for Tests 30, 31, 32, and 36).

The punkah for all practical purposes is a positive displacement pump until the pressure drop reaches about .02 inches of water, at which point the loss or "slip" in the pump becomes significant enough to materially reduce the air volume. (See performance curves, Figures 3.7 to 3.14.)

The capacity of the punkah can also be determined by calculation as shown in Figure 3.20.

It is interesting to note that physical travel of the punkah actually displaces a volume of only 2370 cfm as determined by calculations. However, the measured air volume in Door I is 4600 cfm (94 percent increase). Thus, one can conclude that the punkah is an air acceleration device which moves air by taking advantage of the inertia effects.

Figure 3.21 shows the overall set-up for determining horsepower required to operate the 6 foot punkah. The punkahs were operated manually during the power tests. Figure 3.22 shows one method used to determine the length of the power stroke; a grease pencil held to record the length of the stroke. It was also calculated mathematically as presented in Appendix D. The length of the power stroke was determined to be 31 inches and repeated 25 to 26 times per minute (number of oscillations).

Horsepower requirements were obtained by recording the variations in the force required to operate the punkah over a period of time. This was done by means of an electronic recorder calibrated to read force in pounds on a chart travelling at a uniform speed of 0.1 inch per second. The instrumentation is shown in Figure 3.23. The load cell mounted in the pull cord to the punkah is shown in Figure 3.24. It consists of a length of aluminum with an accurately determined cross sectional area and a strain gage mounted on both sides. These were wired in a Wheatstone Bridge circuit, and calibrated to read directly in pounds (Figure 3.25). In determining the power requirements, it was assumed that the force varied uniformly over the distance traversed by the punkah. Even if this assumption is not altogether true, the errors in the horsepower requirements would be negligible because of the small values involved.

Figure 3.26 is a typical section taken from the recorder chart showing the variations in force requirements during a typical punkah operating cycle. Sample calculations are also included.

Figures 3.15 and 3.16 show the variation in horsepower requirements with change in static pressure and air volume. Observe from these curves that the relative HP requirement is lowest when the air handling capacity is the largest, i.e., when the static pressure is at the maximum (Room 1 blocked), the air flow is zero, the Hp requirement is at the maximum.

From the data collected, one can conclude that the 6 foot punkah operating at 25-26 oscillations per minute will handle 4600 cfm and requires only 0.04 to 0.05 HP.

Similar tests were made for the other punkahs with the following results:

Types	Osc/Min	HP Required
3 ft punkah	33	0.009
Push-Pull punkah	24	0.002

3.2 DETERMINATION OF VENTILATION AIR CHANGES USING TRACER GAS

The rate of air change in the fallout shelter area, as caused by the use of various air moving devices, such as manually operated fans or blowers and punkahs in conjunction with or without baffles, was determined by using carbon dioxide as a tracer gas. The technique involves injecting a quantity of a given gas into a room, mixing it well with the air in the room and then measuring the decay of the gas concentration over a period of time.

The time rate of decay in tracer gas concentration in the test space is directly related to the number of air changes occurring in the room per unit time. This can be expressed by the equation:

$$- V \frac{dC}{dt} = XC \qquad (1)$$

Where: V = Volume of the space, cubic feet

C = Concentration of tracer gas at time

X = Volume of air entering (or leaving the space in unit time (ventilation rate)

t = Time, minutes

with C= Co at t = o, the solution of equation (1) is:

$$\frac{X}{V} = \ln(C_o/C)/t \qquad (2)$$

$N = \frac{X}{V}$ is the air change rate of a space; defined as the ratio of the time rate at which air is supplied to, or exhausted from, a space to the total volume of the space. The ventilation rate (X) can then be calculated by multiplying V, the volume of the space, by N, the number of air changes per minute. Typical decay curves are illustrated in Appendix E, Figures E.3, E.4, and E.5 for the three tracer gases used; carbon dioxide, helium and argon.

3.2.1 Apparatus. The gas concentration in the room was measured with a gas analyzer which continuously drew a sample of the contaminated room air. By comparing the change in conductivity of the contaminated room air with the conductivity of a standard sample of pure air, a continuous record of gas concentration vs. time was obtained. This was measured by means of a platinum spiral wire mounted in a small chamber and heated by a constant electrical current. As the concentration of the tracer gas varied in the sample, the heat loss from this heated wire varied; hence, its electrical resistance. This change in resistance was measured through a Wheatstone Bridge circuit, using a similar platinum wire in the other chamber containing the standard air. A simple circuit diagram of this apparatus is shown in Figure 3.27. The gas analyzer itself is pictured in Figure 3.28.

3.2.2 Sources of Error. It was known from the earlier experience of the University of Florida, which conducted similar tests, that certain anomalies existed in the tracer gas method (see Reference 3). One of the difficulties was the fact that when the tracer gas was ejected from the room, a certain amount of it mixed with the supply air entering the room and thus gave erroneous readings of the rate of decay. This is an inherent characteristic of the 3 foot and push-pull punkahs when the air is supplied from, and returned to, the same room through a single opening. This error tended to give results showing less decay or less air changes than really existed. It was assumed that the error was small, therefore, the values so obtained were accepted as a conservative indication of the true air change. Unfortunately, as the tracer gas tests progressed, large variations in the results indicated that there were other sources of error. Knowing the affinity between water and carbon dioxide, it was decided to perform some tests without supplying water to the Simocs and compare those values with the previous tests using wet Simocs. It was found that the values obtained with dry Simocs were about half those obtained with wet Simocs. Furthermore, tests performed on 14 January 1967, indicated that the decay rat varied with the length of time allowed between the tests. In other words, during the first test in the morning, when carbon dioxide was injected into a room with "clean", wet Simocs (i.e., no gas contamination present), the water on the Simocs would readily absorb the tracer gas and the analyzer would indicate a greater rate of decay than was truly caused by the air change in the room. In a test performed a short time later, some residual carbon dioxide was still present in the water on the Simocs; for this reason, the water did not absorb the injected carbon dioxide as readily as during the earlier test. Thus, the decreased decay rate indicated a lower air change rate than previously. This is illustrated in the following abstract from Table 3.10, for Test 35 on 14 January 1967:

Results of Four Tracer Gas Tests in Room 3

Time	Time Interval Between Tests	Air Flow
0900 Hrs	-	523 cfm
0955 Hrs	55 minutes	486 cfm
1045 Hrs	50 minutes	346 cfm
1545 Hrs	5 hours	511 cfm

Note that when five hours was allowed between tests, giving ample time for the gas absorbed during previous tests to disipate, the air change rate indicated was nearly equal to the one obtained for the initial test.

It is generally accepted that solubilities of gases in water decreases with temperature rise. Therefore, a number of tests were made with varying dry bulb temperatures (70°F to 95°F) in the sampling. No correlation was found between the air flow rates determined from the tracer gas tests and the dry bulb temperature variations in the shelter room; at least not quantitatively detectable within the limits of accuracy of the test instruments used. Also, similar tests were conducted with a range of humidity conditions in the test space which gave no correlation between the varying conditions and gas absorption. An extensive comparison was made of the three tracer gases to see if the percent concentration of tracer gas injected into the room had any effects on the results; no correlation between the rate of air change and the percent concentration of tracer gas absorbed could be established.

Other possible sources of errors in the tracer gas method were:

a. Insufficient mixing of the air and tracer gas in the test room.

b. Leak in sample intake line.

c. Excessive air change rates beyond the limits of the gas decay method and equipment calibration range.

3.2.3 Inert Tracer Gases. In order to eliminate the error caused by the tracer gas being absorbed in the water, helium was substituted for the carbon dioxide. The gas concentration analyzer was recalibrated for helium in accordance with the procedure set forth in Appendix E. At first, it appeared that helium was the answer to the problem; however, it was soon discovered that an error due to the tracer gas in the exhaust air mixing with the supply air and re-entering the room apparently was greater with helium than with carbon dioxide. This probably resulted from the high rate of diffusion which is characteristic of light gas such as helium. When helium was injected into a space, it almost immediately diffused throughout the entire space. To determine the importance of this, a sample intake device was attached to the gas analyzer in Room 2, approximately four feet outside the doorway to Room 4 (X_1 on Figure 3.29). Later, the sample intake device was placed in location X_2, approximately 20 feet away from the doorway to Test Room 4. In this doorway, the push-pull punkah was mounted in closed position, covering the test room into a semi-inclosed space. The clearance between the punkah frame and the door frame, as well as the openings between the punkah flaps, allowed air to enter the Test Room 4 from Room 2, when a small centrifugal fan was placed in Test Room 4 exhausting 580 cfm from the room. The only inlet opening for the air was the doorway between Rooms 4 and 2 in which the push-pull punkah was mounted. With the fan running, a steady stream of air entered Room 4 through this doorway. When helium was injected into

Room 4, it diffused so rapidly throughout the entire shelter that within seconds it could be detected in Room 2 at both locations X_1 and X_2. In spite of the fact that the air was moving in the direction of Room 4 from Room 2, the helium gas traveled "up-stream" against this flow and diffused throughout the shelter space apparently independent of the air flow that existed. Some of this escaped gas would re-enter the test room with the ventilating air and result in false readings of the decay rate. For this reason, the decay in concentration, using helium as a tracer gas, gave reading errors larger than did carbon dioxide. This is verified by the large variations in the results of the air flow rates when using helium tracer gas (see Table 3.9).

A third gas, argon, was used as it is more soluble in water than helium but much less so than carbon dioxide, it was hoped that it would yield better results. The gas analyzer apparatus was recalibrated following the same procedure used with helium. The calibration curves for both gases are shown in Figures D.3 and D.5. Figure D.4 is an enlargement of the lower part of the helium curve for easier read-out at low gas concentrations. A number of tests showed that the use of argon did not yield any more consistent or reliable results than did the use of carbon dioxide.

Figures 3.31 through 3.35 show typical decay curves obtained for the three tracer gases and the resulting plots of the data on logarithmic graph paper for determining the decay rate.

A factor of 130 cfm should be added to the flow rates given for a conservative correction of certain errors inherent in the results obtained by the tracer gas method.

3.2.4 Determination of Correction Factor. Due to the wide variations obtained in using the various tracer gases, a centrifugal blower was installed in Room 4 to exhaust a known quantity of air at a steady rate. The discharge duct extended to the open doorway to the outdoors in order to positively exhaust the tracer gas from the test shelter and avoid any recirculation from the area surrounding the test shelter. The objective was to perform a number of tracer gas tests and compare the air flow rates determined in this manner with the known rate that the centrifugal blower exhausted from the test room. The known rate was established, using a simple traverse of the air velocities in the discharge duct in accordance with established procedures set forth by ASME and AMCA test codes. The air flow was determined to be 580 cfm based on an average of a number of readings in the discharge duct, using both a hot wire anemometer and a deflecting vane type anemometer. During these tests the average air flow determined by the tracer gas method was as follows:

Average Air Flow Rates Obtained by Using Various Tracer Gases	No. of Tests	Exhaust Fan Duct Traverse
CO_2 - 475 CFM	14	580 CFM
HE - 451 CFM	27	580 CFM
A - 432 CFM	2	580 CFM

The above average values of a number of tests determined by the duct traverse, is considered to be the true value of the air flow rate existing in the true value of the air flow rate existing in the test room. Since the average air flow rate determined by tracer gas was 450 cfm, it might be appropriate, in order to obtain the correct value for the air flow rate, to add a factor of 130 cfm to the results obtained using the three tracer gases.

In view of the relatively high cost of argon and helium compared to that of carbon dioxide, similar reliability, it was decided that during future tests carbon dioxide would be used and the values obtained would be treated as approximating the actual air changes occurring in the rooms when utilizing various air moving devices.

TABLE 3.1

COMPARISON OF AIR FLOW RATES IN SIDEROOMS WITH AND WITHOUT PUNKAHS (CFM)

CO_2 TRACER GAS						HELIUM		ARGON
Push-Pull Punkahs		3-Foot Punkahs		W/O Punkahs		Push-Pull Punkahs		3-Foot Punkahs
Room 3	Room 4	Room 3 Hi	Room 4 Hi	Room 3	Room 4	Room 3	Room 4	Room 4 Hi
465	287*+	387	435	155	201	457*	613*+	557
523	242*+	538	483	141	108	399*	588*+	399*
486	253*+		465	191	176	398*	457	
346	200*+		520	181	187	511*	617+	
511	236*+		512				446	
359*	312*+		467					
401	482		572+					
290*+	431		404					
366*	454		385					
439*	377		530*					
363*	389		377*					
417	498							
396	385							
408	441							
	393							
	440							
Aver: 422	429	462	458	167	168	441	452	478

REMARKS: * Dry Simocs
+ Not Considered in Average
Hi Punkah Mounted in Upper Half of Doorway Exhausting Air From Room

TABLE 3.2

EFFECT OF PUNKAHS WITH BAFFLE B_1

Supply Air Condition	Ventilation Rate	Room No.	With B_1 W/O Punkah	With B_1 With Punkah	ET Reduction Due to Punkah Operation
Min.	13.5 cfm/occ.	3	83.0	81.1	1.9
"	"	4	82.8	79.0	3.8
"	"	3	82.5	81.1	1.4
"	"	4	82.0	78.4	3.6
Avg.	"	3	86.2	85.2	1.0
"	"	4	85.0	82.5	2.5
"	"	3	86.6	83.0	3.6
"	"	4	85.6	82.2	3.4
"	"	3	85.5	84.7	0.8
"	"	4	85.0	82.0	3.0
Max.	"	3	89.1	86.7	2.4
"	"	4	89.4	85.9	3.5
"	"	3	88.9	86.8	2.1
"	"	4	89.9	85.1	4.8
"	"	3	88.6	86.4	2.2
"	"	4	89.2	85.3	3.9
Min.	18.0 cfm/occ.	3	84.9	83.0	1.9
"	"	4	85.1	81.0	4.1
"	"	3	81.4	78.8	2.6
"	"	4	81.4	77.4	4.0
Avg.	"	3	84.6	82.3	2.3
"	"	4	85.7	81.8	3.9
"	"	3	85.0	83.0	2.0
"	"	4	85.0	81.9	3.1
Max.	"	3	89.0	85.2	3.8
"	"	4	89.1	86.8	2.3
Min.	22.5 cfm/occ.	3	81.9	79.8	2.1
"	"	4	81.2	78.1	3.1
"	"	3	81.6	79.0	2.6
"	"	4	81.6	77.4	4.2
Avg.	"	3	85.1	82.9	2.2
"	"	4	85.2	81.6	3.6
"	"	3	84.9	82.9	2.0
"	"	4	84.7	81.6	3.1

TABLE 3.3

EFFECT OF PUNKAHS WITHOUT BAFFLE B_1

Supply Air Condition	Ventilation Rate	Room No.	Without B_1 Without Punkah	Without B_1 With Punkah	ET Reduction Due to Punkah Operation
Min.	13.5 cfm/occ.	3	83.8	83.0	0.8
"	"	4	82.1	80.9	1.2
Avg.	"	3	85.9	85.2	0.7
"	"	4	84.8	83.4	1.4
Max.	"	3	88.9	86.5	2.4
"	"	4	87.4	85.1	2.3
Avg.	18.0 cfm/occ.	3	84.6	83.2	1.4
"	"	4	83.5	82.0	1.5
Max.	"	3	88.5	86.2	2.3
"	"	4	87.1	85.1	2.0
Min.	22.5 cfm/occ.	3	81.0	80.2	0.8
"	"	4	79.9	78.6	1.3
"	"	3	81.0	79.0	2.0
"	"	4	79.9	77.4	2.5
Avg.	"	3	85.0	82.9	2.1
"	"	4	84.0	81.9	2.1
"	"	3	84.1	82.9	1.2
"	"	4	83.8	81.9	1.9
Max.	"	3	87.1	86.5	0.6
"	"	4	86.6	85.6	1.0

TABLE 3.4

EFFECTIVE TEMPERATURE COMPARISON
EFFECTS OF HORIZONTAL BAFFLES

ROOM 3 - PUNKAHS OPERATING						
CFM	Cond.	Horizontal Baffles Inside and Outside	Horizontal Baffles Inside	Horizontal Baffles Outside	No Horiz. Baffles	ΔET Max. Diff.
13.5	Max.	87.6	87.6		87.6	0
13.5	Min.	80.0			81.1	-1.1
13.5	Min.	80.1		81.0	81.8	-1.7
13.5	Avg.	83.1		83.1	84.2	-1.1
13.5	Max.			86.4	87.2	-0.8
18	Min.	82.1			83.0	-0.9
18	Avg.	82.3				
18	Avg.	83.0			83.2	-0.2
22.5	Min.	79.0			79.8	-0.8
22.5	Avg.	82.6			82.9	-0.3
22.5	Avg.	82.5				
22.5	Max.	86.1		86.6	86.5	-0.4
22.5	Min.	79.8			80.2	-0.4
22.5	Min.	79.0			80.1	-1.1
						Avg. -0.8

TABLE 3.5

EFFECTIVE TEMPERATURE COMPARISON
EFFECTS OF HORIZONTAL BAFFLES

ROOM 4 -- PUNKAHS OPERATING					
Horizontal Baffles Inside and Outside	Horizontal Baffles Inside	Horizontal Baffles Outside	No Horiz. Baffles	Δ ET Max. Diff.	Remarks
86.5	86.5		86.5	0	B_1 in place
78.5			79.1	-0.6	"
78.5		78.2	78.1	+0.4	"
81.9		81.8	82.0	-0.2	"
		85.3	85.5	-0.2	"
80.4			81.0	-0.6	"
81.8					"
81.3			82.0	-0.7	W/O B_1
77.5			78.1	-0.6	B_1 in place
81.4			81.6	-0.2	"
81.5					"
85.1		85.1	85.6	-0.5	"
77.3			78.6	-1.3	"
77.4			77.7	-0.3	"
				Avg. -0.5	

TABLE 3.6
EFFECTS OF BAFFLE B_1 AND PUNKAHS ON ENVIRONMENTAL CONDITIONS IN SIDE ROOMS

TEST NO.	SUPPLY COND.	AIR FLOW	ROOM NO.	ET		▲ ET	ET W/PUNKAHS		▲ ET
				W/B_1	W/O B_1		W/B_1	W/O B_1	
1	MIN.	13.5	3 4		83.8 82.1				
2	"	"	3 4					83.0 80.9	
38, 39	"	"	3 4	83.0 82.8			81.1 79.0		
55	"	"	3 4	82.5 82.0			81.1 78.4		
3	AVG.	"	3 4		85.9 84.8				
4	"	"	3 4					85.2 83.4	
5	"	"	3 4				84.8 82.4		
16, 17	"	"	3 4	86.2 85.0			85.2 82.5		
33, 34A 34B	"	"	3 4	86.6 85.6	85.8 84.6	+0.8 +1.0	83.0 82.2		
35	"	"	3 4	86.7 85.1	84.5 83.5	+1.7 +1.6			
56	"	"	3 4	85.5 85.0			84.7 82.0		
6	MAX.	"	3 4		88.5 87.8				
7	"	"	3 4	89.1 89.1					
8	"	"	3 4				86.9 85.9		
9	"	"	3 4	89.4 89.4					
10	"	"	3 4				87.6 86.1		
12, 13	"	"	3 4				86.9 85.4		
14, 15	"	"	3 4				87.2 85.9		
36	"	"	3 4	89.1 89.4	88.9 87.4	+0.2 +2.0	86.7 85.9	86.5 85.1	+0.2 +0.8
37	"	"	3 4	88.9 89.9			86.8 85.1		
57	"	"	3 4	88.6 89.2			86.2 85.3		
40	MIN.	18	3 4	84.9 85.1			83.0 81.0		
54	"	"	3 4	81.4 81.4			78.8 77.4		
41, 42	AVG.	18	3 4	84.6 85.7	84.6 83.5	0 +2.2	82.3 81.8	83.2 82.0	-0.9 -0.2
52	"	"	3 4	85.0 85.0			83.0 81.9		0 -0.1
43	MAX.	18	3 4		88.5 87.1		86.2 85.0	86.2 85.1	
53	"	"	3 4	89.0 89.1			85.2 86.8		
44	MIN.	22.5	3 4	81.9 81.2			79.8 78.1	79.0 77.4	+0.8 +0.7
49	"	"	3 4		81.0 79.9			80.2 78.6	
50	"	"	3 4	81.6 81.6	81.1 80.1	+0.5 +1.5	79.0 77.4		
45	AVG.	"	3 4	85.1 85.2	85.0 84.0	+0.1 +1.2	82.9 81.6		
46	"	"	3 4		84.1 83.8		82.5 81.5	82.9 81.9	-0.4 -0.4
51	"	"	3 4	84.9 84.7			82.9 81.6		
47, 48	MAX.	"	3 4		87.1 86.6		86.4 85.2	86.5 85.6	-0.1 -0.4

TABLE 3.7

EFFECTIVE TEMPERATURE COMPARISON BETWEEN NORMAL EXHAUST CONFIGURATION AND SERIES AIR FLOW

(a) Average Supply Conditions

TEST NO.	NORMAL EXHAUST CONFIGURATION**					SERIES AIR FLOW**++					
	ROOM NO.				OVERALL AVERAGE ET	ROOM NO.				OVERALL AVERAGE ET	OVERALL Δ ET BETWEEN AVERAGES
	1	2	3	4		1	2	3	4		
3	86.4	83.3	86	84.8	84.9	83.5	85.2	81.5	80.2	83.4	1.5
16	85	83.5	86.2	85	84.6						1.2
34	86	84.5	86.6	85.8	85.5						2.1
56	85.2	83.3	85.5	85	84.5						1.1

**Based on 13.5 CFM per occ. @average supply condition - no punkahs operating.
++Based on University of Florida tests for series path 4-3-1-2-exhaust.

(b) Maximum Supply Conditions

TEST NO.	NORMAL EXHAUST CONFIGURATION*					SERIES AIR FLOW*+					
	ROOM NO.				OVERALL AVERAGE ET	ROOM NO.				OVERALL AVERAGE ET	OVERALL Δ ET BETWEEN AVERAGES
	1	2	3	4		1	2	3	4		
7	88.9	87.7	90	90.1	88.8	85.9	87.5	84.9	83.9	86.1	2.7
8	88.5	87.2	88.5	87	87.8						1.7
13	88	86.5	88.1	87	87.3						1.2
15	88.3	86.2	88.3	86.6	87.2						1.1
36	87.9	86.2	87	86.1	86.8						0.7

*Based on 13.5 CFM per occ. @maximum supply condition - no punkahs operating.
+Based on theoretical calculations for series path 4-3-1-2-exhaust.

TABLE 3.8

SERIES AIR FLOW

ROOM NO.	NUMBER OCCUPANTS	EFFECTIVE TEMPERATURES*		
		PATH 4-2-3-1-EXHAUST	PATH 2-1-3-4-EXHAUST	PATH 4-3-1-2-EXHAUST
1	35	85.3	84	83.5
2	45	82.5	82.1	85.2
3	19	84	85	81.5
4	13	80	85.5	80.2
		Overall ET = 83.3	Overall ET = 83.6	Overall ET = 83.4

*Shelter response based on average supply conditions at 13.5 CFM per occupant.

ROOM NO.	NUMBER OCCUPANTS	EFFECTIVE TEMPERATURES**			
		PATH 4-2-3-1-EXHAUST ACTUAL TEST DATA		PATH 2-1-3-4-EXHAUST	PATH 4-3-1-2-EXHAUST
		Data Sheets	Log		
1	35	88.6	87.8	86.5	85.9
2	45	86.1	85.8	85.4	87.5
3	19	87.1	85.9	87.2	84.9
4	13	84.8	84.2	87.5	83.9
		Overall ET = 86.2		Overall ET = 86.3	Overall ET = 86.1

**Shelter response based on maximum supply conditions at 13.5 CFM per occupant.

TABLE 3.9

CONVERSION OF TEST DATA TO STANDARD CONDITIONS FOR THE PUNKAH PUMP PRIME AIR MOVING DEVICE

TEST NO.	TEST CONDITIONS	SP		CFM		HP	
		TEST	STANDARD	TEST	STANDARD	TEST	STANDARD
20	B=29.65 RH=32% TEMP=72	0.035	0.0355	0	0		
		0.027	0.0274	1308	1308		
		0.021	0.0213	2487	2487		
		0.019	0.0193	3358	3358		
		0.0175	0.0177	3593	3593		
		0.015	0.0152	3665	3665		
		0.0135	0.0137	3721	3721		
		0.0125	0.0127	3803	3803		
21	B=29.77 RH=32.3% TEMP=71.5	0.050	0.0507	0	0		
		0.039	0.0395	1548	1548		
		0.0255	0.0258	2554	2554		
		0.0115	0.0116	3250	3250		
		0.020	0.0203	3734	3734		
		0.010	0.0101	3981	3981		
		0.009	0.0091	4153	4153		
		0.009	0.0091	3889	3889		
22	B=29.65 RH=26% TEMP=70.7	0.0625	0.0633	0	0	0.057	0.058
		0.0405	0.0410	1576	1576	0.047	0.048
		0.0325	0.0329	2741	2741	0.045	0.046
		0.0255	0.0258	3747	3747	0.040	0.041
		0.0215	0.0218	4114	4114	0.047	0.048
		0.0195	0.0198	4611	4611	0.039	0.040
		0.019	0.0192	4444	4444	0.041	0.042
		0.017	0.0172	4610	4610	0.042	0.043
23	B=29.94 RH=36% TEMP=73.6	0.0445	0.0451	1710	1710		
		0.028	0.0284	3927	3927		
		0.0195	0.0198	4607	4607		
32	B=30.36 RH=32% TEMP=72	0.050	0.050	0	0		
		0.0375	0.0375	1668	1668		
		0.0315	0.0315	3228	3228		
		0.0275	0.0275	4162	4162		
		0.025	0.025	4109	4109		
		0.021	0.021	4293	4293		
		0.0195	0.0195	4393	4393		
		0.0195	0.0195	4472	4472		

TABLE 3.10

SUMMARY SHEET- TRACER GAS TESTS

TEST NO.	TIME	DATE	ROOM	CFM	GAS - % CONC.	SIMOCS			REMARKS
						WET	—DRY		
27	1510	12/14/65	3	417	CO_2 (2.40)	X		Min. Cond.	Push-pull (P/P) punkahs on.
27	1615	12/14/65	4	447	CO_2 (1.75)	X		" "	" " " "
28	1030	12/15/65	3	155	CO_2 (2.80)	X		Max. cond.	Natural air flow.
28	1000	12/15/65	4	201	CO_2 (3.20)	X		" "	" " "
28	1235	12/15/65	3	396	CO_2 (2.25)	X		" "	P/P on.
28	1530	12/15/65	4	385	CO_2 (2.20)	X		" "	" "
29	1055	12/16/65	3	885	CO_2 (1.25)	X		" "	Parallel air flow, P/P off.
29	1030	12/16/65	4	587	CO_2 (2.25)	X		" "	" " " " "
29	1330	12/16/65	3	555	CO_2 (1.30)	X		" "	" " " main exhaust punkah on.
29	1400	12/16/65	4	514	CO_2 (1.60)	X		" "	" " " " " " "
31	1105	12/22/65	3	141	CO_2 (2.60)	X		" "	Natural air flow.
31	1045	12/22/65	4	108	CO_2 (1.70)	X		" "	" " "
31	1345	12/22/65	3	513	CO_2 (2.10)	X		" "	P/P and main exh. punkahs on.
31	1425	12/22/65	4	334	CO_2 (2.00)	X		" "	" " " " " "
33R	1655	1/7/66	3	191	CO_2 (3.95)	X		Avg. cond.	Natural air flow.
33R	1625	1/7/66	4	176	CO_2 (3.45)	X		" "	" " "
34A		1/6/66	3	181	CO_2 (4.15)	X		" "	Baffle B_1 in place, natural air flow.
34A		1/6/66	4	187	CO_2 (4.00)	X		" "	" " " " " " "
34B	1350	1/7/66	3	408	CO_2 (1.95)	X		" "	" " " " P/P on.
34B	1420	1/7/66	4	440	CO_2 (3.20)	X		" "	" " " " " "
35	1230	1/10/66	4	287	CO_2 (4.25)		X	Not cond.	P/P on, side baffles in Room 4.
35	1310	1/10/66	4	253	CO_2 (2.80)		X	" "	P/P on, side baffles inside & outside.
35	1350	1/10/66	4	191	CO_2 (1.55)		X	" "	" " " " " " "
35	1510	1/10/66	4	242	CO_2 (4.10)		X	" "	" " " " " " "
35	1600	1/6/66	4	200	CO_2 (4.80)		X	Not cond.	P/P on, side baffles outside.
35	1520	1/11/66	4	236	CO_2 (6.80)		X	" "	Side baffles inside & outside, P/P on.
35	1000	1/12/66	4	312	CO_2 (4.80)		X	" "	(70°F room temp.), P/P on.
35	1540	1/12/66	4	482	CO_2 (4.63)	X		Avg. cond.	P/P on.
35	0830	1/13/66	4	431	CO_2 (4.35)	X		" "	" " side baffles outside.
35	0925	1/13/66	4	454	CO_2 (3.82)	X		" "	" " side baffles inside & outside.
35	1020	1/13/66	4	377	CO_2 (6.5)	X		" "	" " no baffles.

TABLE 3.10

SUMMARY SHEET- TRACER GAS TESTS

TEST NO.	TIME	DATE	ROOM	CFM	GAS	- % CONC.	SIMOCS WET	SIMOCS DRY	REMARKS
35	1325	1/13/66	4	389	CO_2	(4.95)	X		Avg. cond. P/P on, no baffles.
35	1445	1/13/66	4	498	CO_2	(4.7)	X		" " " " " "
35	1525	1/13/66	3	465	CO_2	(3.65)	X		" " " " " "
35	0900	1/14/66	3	523	CO_2	(3.88)	X		" " " " " "
35	0955	1/14/66	3	486	CO_2	(3.4)	X		" " " " " "
35	1045	1/14/66	3	346	CO_2	(2.00)	X		" " " " " "
35	1545	1/14/66	3	511	CO_2	(4.05)	X		" " " " " " 5 hrs. elapsed since previous tests.
35	0830	1/17/66	3	359	CO_2	(4.5)		X	Not cond. P/P on (70°F room temp)
35	1310	1/17/66	3	401	CO_2	(4.00)		X	" " " " (88.5°F).
35	1545	1/17/66	3	512	CO_2	(4.3)	X		" " " "
35	0855	1/18/66	3	290	CO_2	(3.8)		X	" " " " (70°F).
35	0924	1/18/66	3	366	CO_2	(4.00)		X	" " " " (75°F).
35	1110	1/18/66	3	439	CO_2	(1.82)		X	" " " " (82°F).
35	1450	1/18/66	3	363	CO_2	(3.95)		X	" " " " (95°F).
35	1535	1/19/66	3	457	He	(3.00)		X	" " " " (73°F).
35	1605	1/19/66	3	259	CO_2	(4.83)		X	" " " " (73°F).
35	1015	1/20/66	3	192	CO_2	(3.45)		X	" " " " (72°F).
35	1100	1/20/66	3	399	He	(0.3)		X	" " " " (72°F).
35	1505	1/24/66	3	398	He	(1.2)		X	" " " " (71.5°F).
*35	1430	1/24/66	3	841	He	(0.18)		X	" " " "
35	1000	1/25/66	3	511	He	(3.4)		X	" " " " (74°F).
*35	1410	1/25/66	4	112	He	(0.6)		X	" " (73.5°F) Small centrifugal blower on in
35	1410	1/25/66	4	138	He	(0.84)			test room, exhaust config. (575 CFM)
35	1610	1/25/66	4	449	CO_2	(2.32)		X	" " (73.5°F) " (575 CFM) " " "
35		1/26/66	4	613	He	(3.85)		X	" " (74°F) " (580 CFM) " " "
35	1020	1/27/66	4	588	He	(3.6)		X	" " (71.5°F) " (573 CFM) " " "
35	1535	1/28/66	4	469	Ar	(2.86)		X	" " (72°F) " (590 CFM) " " "

*Questionable (Low % Concentration)

TABLE 3.10

SUMMARY SHEET- TRACER GAS TESTS

TEST NO.	TIME	DATE	ROOM	CFM	GAS - % CONC.		SIMOCS		REMARKS
							WET	DRY	
*35	1400	2/3/66	4	457	He	(2.1)	X		Heat on. (86°F, 56%RH) Small centrifugal blower on in test room, exhaust config. (585 CFM).
35	1550	2/3/66	4	617	He	(3.05)	X		" " (83°F, 29%RH) " (585 CFM) " " " "
35	0900	2/4/66	4	446	He	(2.42)	X		" " (85°F, 84%RH) " (601 CFM) " " " "
35	1030	2/4/66	4	394	Ar	(6.4)	X		" " (81°F, 41%RH) " (601 CFM) " " " "
35	1345	2/4/66	4	439	CO_2	(3.55)	X		" " (79.5°F, 33%RH) "(601 CFM) " " " "
35	1520	2/4/66	4	431	CO_2	(4.15)	X		" " (80°F, 65%RH) " (575 CFM) " " " "
35	1545	2/4/66	4	456	CO_2	(4.14)	X		" " (80°F, 57%RH) " (575 CFM) " " " "
35	0850	2/7/66	4	441	CO_2	(4.11)		X	Not cond. (75°F, 19.5%RH)" (597 CFM) " " " "
35	1215	2/7/66	4	429	CO_2	(3.93)	X		Avg. cond.(88°F, 62%RH) " (597 CFM) " " " "
35	1245	2/7/66	4	414	CO_2	(3.42)	X		" " (89°F, 64%RH) " (597 CFM) " " " "
35	1240	2/8/66	4	366	He	(3.08)	X		" " (90°F, 66%RH) " (563 CFM) " " " "
35	1340	2/8/66	4	712	He	(5.0)	X		" " (90.5°F, 67%RH)" (563 CFM) " " " "
35	1445	2/8/66	4	505	He	(2.4)	X		" " (90°F, 66%RH) " (563 CFM) " " " "
35	1445	2/8/66	4	544	He	(2.4)	X		" " (90°F, 66%RH) " (563 CFM) " " " "
35	1630	2/8/66	4	681	He	(4.72)	X		" " (90°F, 66.5%RH)" (594 CFM)" " " "
35	1630	2/8/66	4	610	He	(4.72)	X		" " (90°F, 66.5%RH)" (594 CFM) " " " "
35	1000	2/9/66	4	481	He	(1.51)	X		" " (91.5°F, 66%RH)" (571 CFM) " " " "
35	1100	2/9/66	4	382	He	(0.74)	X		" " (91°F, 64.5%RH)" (571 CFM) " " " "
35	1100	2/9/66	4	424	He	(0.74)	X		" " (91°F, 64.5%RH)" (571 CFM) " " " "
35	1310	2/9/66	4	390	He	(0.58)	X		" " (90°F, 67%RH) " (571 CFM) " " " "
35	1400	2/9/66	4	340	He	(0.46)	X		" " (90°F, 66%RH) " (571 CFM) " " " "
35	1440	2/9/66	4	456	He	(1.26)	X		" " (90°F, 66%RH) " (571 CFM) " " " "
35	1540	2/9/66	4	485	He	(1.95)	X		" " (90°F, 66.5%RH)" (594 CFM) " " " "
35	1625	2/9/66	4	477	He	(1.65)	X		" " (90°F, 66%RH) " (594 CFM) " " " "
35	0915	2/10/66	4	482	He	(1.76)	X		" " (92°F, 65.5%RH)" (567 CFM) " " " "
35	1015	2/10/66	4	531	CO_2	(3.25)	X		" " (91.5°F, 65.5%RH)(567 CFM) " " " "
*35	1100	2/10/66	4	370	CO_2	(1.75)	X		" " (90.5°F, 65.5%RH)(567 CFM) " " " "

*Questionable (Low % Concentration)

TABLE 3.10

SUMMARY SHEET- TRACER GAS TESTS

TEST NO.	TIME	DATE	ROOM	CFM	GAS - % CONC.		SIMOCS		REMARKS
							WET	DRY	
35	1115	2/10/66	4	469	CO_2	(3.24)	X		Avg. Cond. (90°F, 67.5%RH) Small centrifugal blower on in test room, exhaust config. (567 CFM)
35	1415	2/10/66	4	280	He	(1.12)	X		" " " (90.5°F, 65.5%RH) " (558 CFM) " " "
35	1545	2/10/66	4	250	He	(0.58)	X		" " " (90.5°F, 68%RH) " (558 CFM) " " "
35	1615	2/11/66	4	247	He	(2.9)	X		" " " (90.5°F, 65%RH) " (558 CFM) " " "
35	1105	2/14/66	4	319	He	(1.18)		X	Not cond. (63°F, 43%RH) " (587 CFM) " " "
35	1235	2/14/66	4	276	He	(1.80)		X	" " " (66°F, 32.5%RH) " (587 CFM) " " "
35	1500	2/14/66	4	407	He	(1.12)		X	Not cond. (70°F, 32%RH) Oscill. fans installed mixing air in room. Small centrifugal blower on in test room, exhaust config. (587 CFM)
35	1600	2/14/66	4	333	He	(1.14)		X	" " " (70°F, 29%RH) " (587 CFM) " " "
35	1230	2/15/66	4	399	He	(.51)		X	" " " (72°F, 38%RH) " (587 CFM) " " "
35	1345	2/15/66	4	503	He	(.51)		X	" " " (72°F, 38%RH) " (587 CFM) " " "
35	1345	2/15/66	4	390	He	(1.12)		X	" " " (72.5°F, 31%RH)" (587 CFM) " " "
35	0830	2/16/66	4	317	He	(.95)	X		Avg. cond. (89°F, 77.5%RH)" (492 CFM) " " "
35	1010	2/16/66	4	309	He	(.885)	X		" " " (89.5°F, 76%RH)" (492 CFM) " " "
35	1100	2/16/66	4	312	He	(.68)	X		" " " (89.5°F, 77.5%RH) (492 CFM) " " "
35	1330	2/16/66	4	420	CO_2	(5)	X		" " " (89.5°F, 67%RH)" (492 CFM) " " "
35	1330	2/16/66	4	463	CO_2	(5)	X		" " " (89.5°F, 67%RH)"
35	1415	2/16/66	4	417	CO_2	(3.5)	X		" " " (89.5°F, 78%RH)" (492 CFM) " " "
35	1515	2/16/66	4	432	CO_2	(3.6)	X		" " " (89.5°F, 68.5%RH) (492 CFM) " " "
35	0900	2/17/66	4	620	He	(.91)	X		" " " (90.5°F, 67.5%RH) " (492 CFM) Sampling tube in disch. duct from exh. fan.
35	0935	2/17/66	4	440	CO_2	(3.7)	X		" " " " (492 CFM) " " " " "
53	0900	3/25/66	4	798	He	(0.54)	X		Max. cond. (97.7°DB, 57%RH), Baffle B_1, 3' punkahs(Hi) (remove blower)
53	0920	3/25/66	4	435	CO_2	(4.25)	X		" " " " " " "
53	1420	3/25/66	4	483	CO_2	(0.72)	X		" " (94.5°DB, 56.5%RH) " " " " "
53	1525	3/25/66	4	465	CO_2	(2.20)	X		" " " " " " "

TABLE 3.10

SUMMARY SHEET- TRACER GAS TESTS

TEST NO.	TIME	DATE	ROOM	CFM	GAS -	% CONC.	SIMOCS WET	SIMOCS DRY	REMARKS
53	1355	3/25/66	3	387	CO_2	(2.60)	X		Max. Cond. (95.5°F, 67.5%RH), Baffle B_1, 3' punkahs (Hi)
54	1015	3/28/66	3	538	CO_2	(2.05)	X		Min. cond. (83°F, 70.5%RH) " " " "
54	1110	3/28/66	4	520	CO_2	(3.25)	X		" " (81°F, 72%RH) " " " "
54	1330	3/28/66	4	557	Ar	(4.00)	X		" "
55	1445	3/29/66	4	512	CO_2	(2.15)	X		" " (81.5°F, 73.5%RH) " " " "
55	1540	3/29/66	4	529	CO_2	(3.03)	X		" " " " 3' punkah (Lo)
56	0930	3/30/66	4	467	CO_2	(1.40)	X		Avg. cond. (88°F, 77%RH) " " " " (Hi)
56	1520	3/30/66	4	572	CO_2	(3.15)	X		" " (88°F, 65%RH) " " " " "
57	0900	3/31/66	4	404	CO_2	(3.35)	X		Max. cond. (94.5°F, 58%RH) " " " " "
57	1050	3/31/66	4	385	CO_2	(2.55)	X		" " (93.5°F, 59%RH) " " " " "
63	1110	4/8/66	4	530	CO_2	(3.85)		X	Not cond. (86°F, 22%RH) " " " " "
63	1345	4/8/66	4	377	CO_2	(3.00)		X	" " " " " " "
63	1415	4/8/66	4	399	Ar	(2.65)		X	" " " " " " "

TYPICAL AIR FLOW PATTERNS OF 3 FT. PUNKAH

POWER STROKE

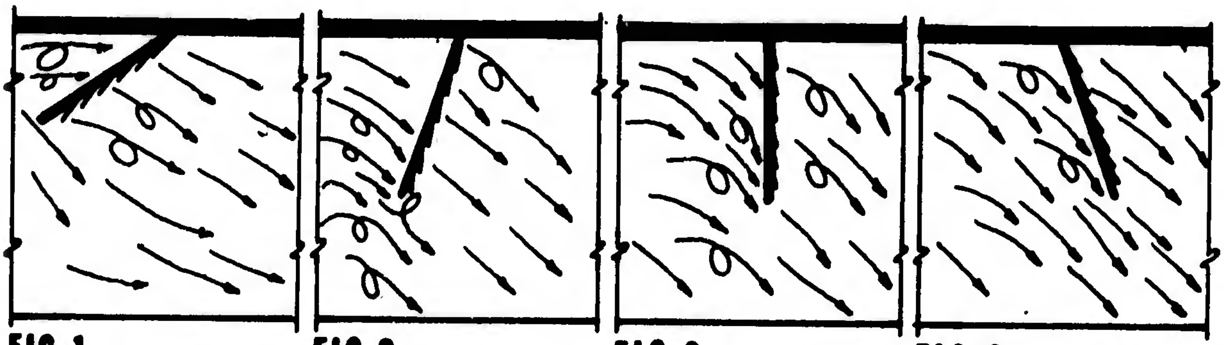


FIG.1 FIG.2 FIG.3 FIG.4

BACK STROKE

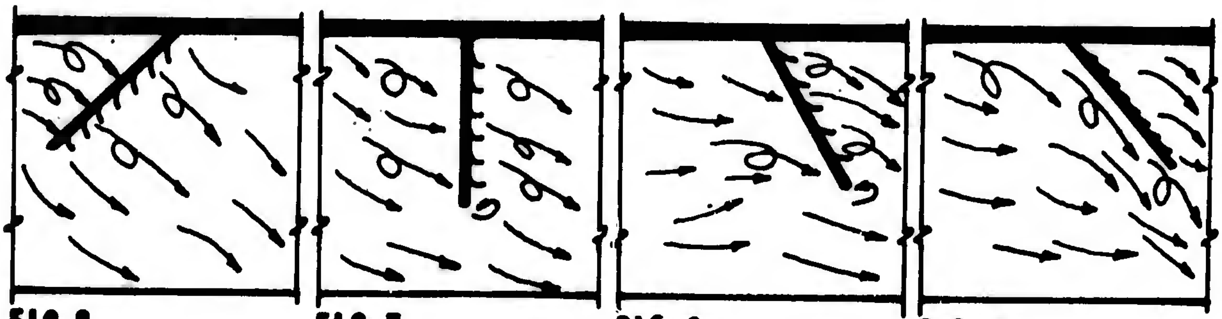


FIG.8 FIG.7 FIG.6 FIG.5

SEQUENCE OF PUNKAH CYCLE

FIG.1	BEGINNING OF POWER STROKE (Flaps Closed)
FIG.2	1/4 POWER STROKE
FIG.3	NEARLY CENTER OF POWER STROKE
FIG.4	3/4 POWER STROKE
FIG.5	END OF POWER STROKE
FIG.6	BEGINNING OF BACK STROKE (Flaps Open)
FIG.7	CENTER OF BACK STROKE
FIG.8	END OF BACK STROKE

Figure 3.1

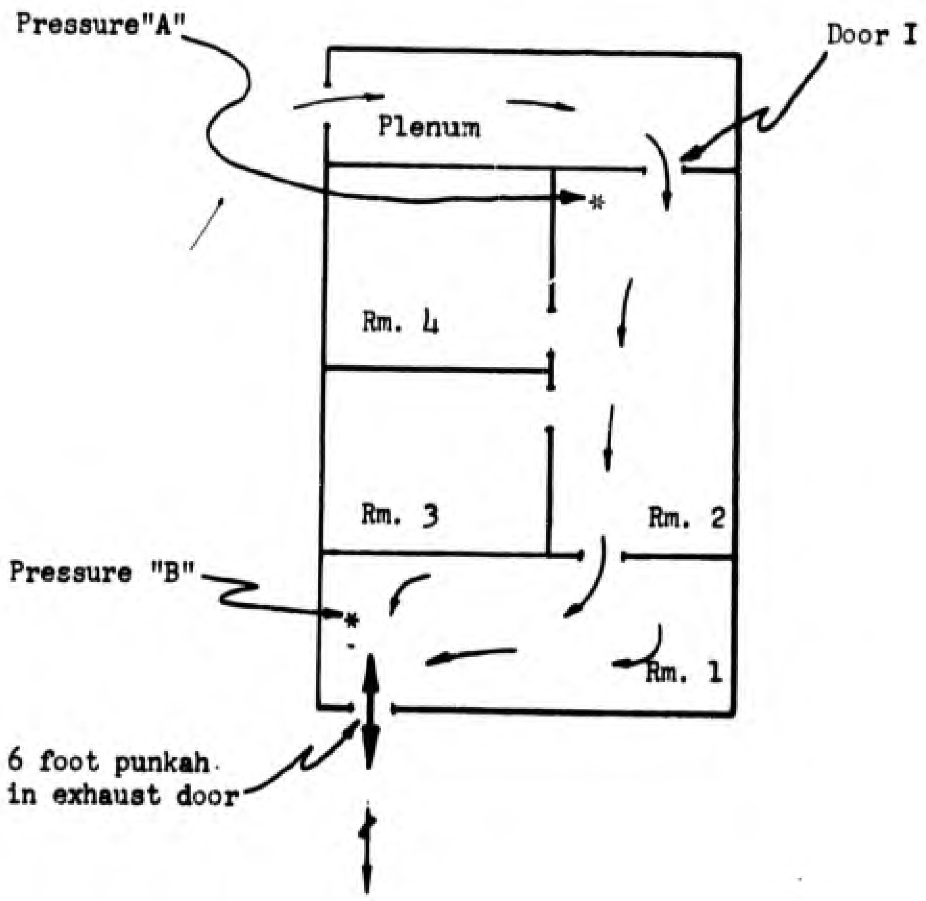


FIGURE 3.2 Plan of Test Set-up for Determination of Characteristics of 6 foot Punkah

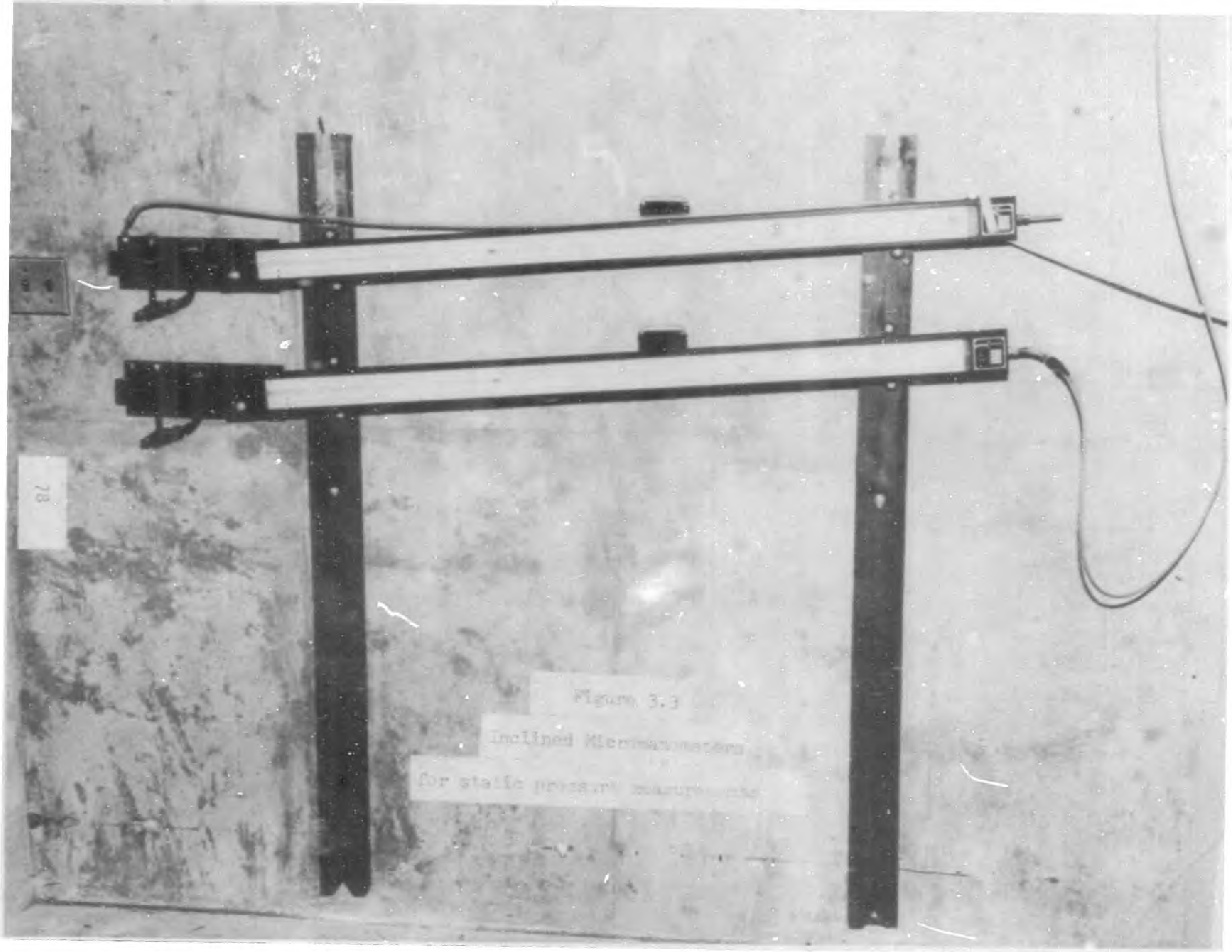


Figure 3.3

Inclined Micromanometers

for static pressure measurements

PSDC DATA SHEET

PUNKAH PUMP PRIME AIR MOVING DEVICE

DATE 23 NOV TIME 1305 OBSERVER ED/JC TEST NO. 20

VELOCITY TRAVERSE - DOOR I

		10"	12"	10"	
12"	177.5	0.833 ft² 350 213 75	1.0 ft² 350 250 150	0.833 ft² 325 238 150	198.3 cfm
12"	108.3	250 130 10	350 250 150	300 225 150	187.5
12"	108.3	250 130 10	350 263 175	325 237 150	197.4
12"	87.5	200 105 10	375 275 175	300 225 150	187.5
12"	85.	200 102 5	375 288 200	325 250 175	208.3
12"	85.	200 103 5	375 275 175	325 250 175	208.3
6½"	83.4	0.451 ft² 300 185 70	0.541 ft² 375 288 200	0.451 ft² 350 275 200	124.0
	735.0 CFM		155.8		1311.3 CFM

325 — Max. velocity reading
238 — Avg. " "
150 — Min. " "

72½"

32"

1756.8

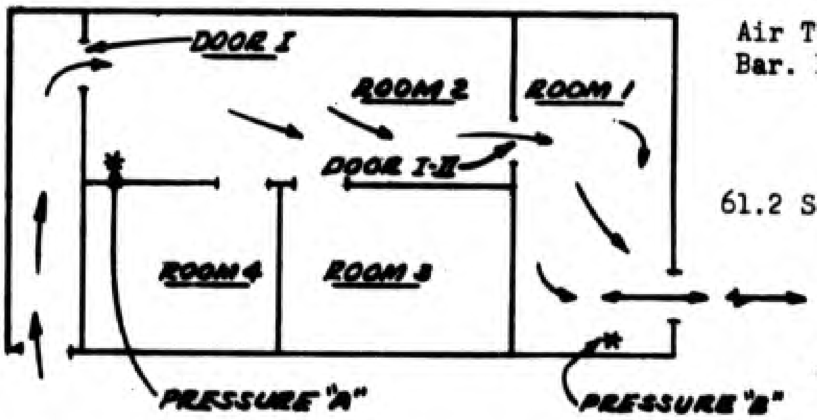
CALCULATED AIR VOLUME 3803 CFM

Figure 3.4

PSDC DATA SHEET

PUNKAH PUMP PRIME AIR MOVING DEVICE

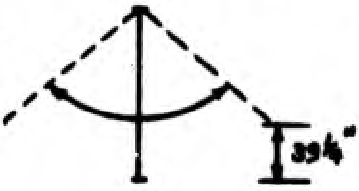
DATE 23 NOV. TIME 1300-1630 OBSERVER ED/JC/OWS TEST NO. 20



Air Temp. 72°F DB
Bar. Press 29.65" Hg

61.2 Sec/25 OSC

60.6 Sec/25 OSC



AIR FLOW BOTTOM OF DOOR	TEST #	PRESS "A"	PRESS "B"	OSC/MIN
	I	-0.009 to -0.061	-0.019 to -0.051	
*	II	-0.01 to -0.045	-0.015 to -0.039	
**	III	-0.008 to -0.036	-0.011 to -0.031	
Outward	IV	-0.006 to -0.03	-0.01 to -0.028	25
Outward	V	-0.005 to -0.026	-0.009 to -0.026	25
Outward	VI	-0.003 to -0.022	-0.008 to -0.022	-
Outward	VII	-0.002 to -0.02	-0.006 to -0.021	25
Outward	VIII	-0.001 to -0.02	-0.005 to -0.02	25
Manual	IX	-0.002 to -0.018	-0.006 to -0.021	26
	X			
	XI			
	XII			

NO SIDE BAFFLES

NOTE:
Test I: Door I Blocked
Test IX: Door I Wide Open

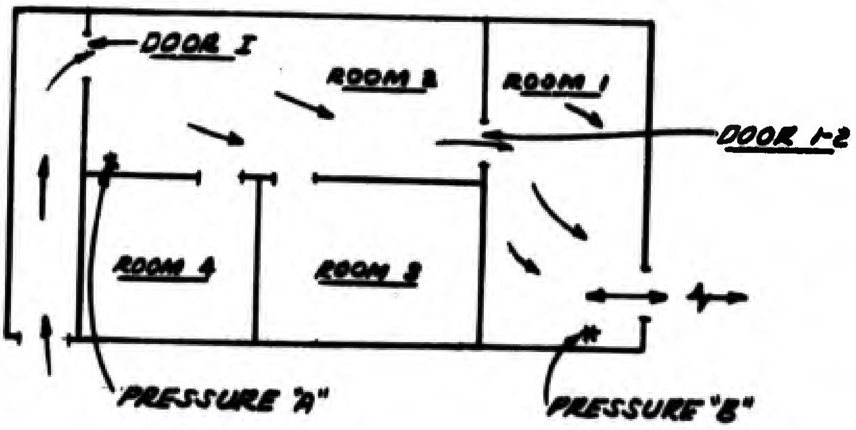
*Backflow, sides and bottom
**Some backflow at sides

Figure 3.5

PSDC DATA SHEET

PUNKAH PUMP PRIME AIR MOVING DEVICE

DATE 23 NOV. TIME 1300-1630 OBSERVER OWS/ED/JC TEST No. 20



TEST #	AVG. PRESS "A"	AVG. PRESS "B"	AREA DOOR I (FT^2) 17.44	AIR VOLUME DOOR (CFM) 1	DOOR 1-2
I	-0.035	-0.035	0% Open	Blocked	-
II	-0.0275	-0.027	15.3%	1308	1406
III	-0.022	-0.021	30.6%	2487	2100
IV	-0.018	-0.019	45.9%	3358	2796
V	-0.0155	-0.0175	61.2%	3593	3095
VI	-0.0125	-0.015	76.4%	3665	3531
VII	-0.011	-0.0135	91.7%	3721	3700
VIII	-0.0105	-0.0125	100%	3803	3972
Manual IX	-0.010	-0.0135			
X					
XI					
XII					

NO BAFFLES

Figure 3.6

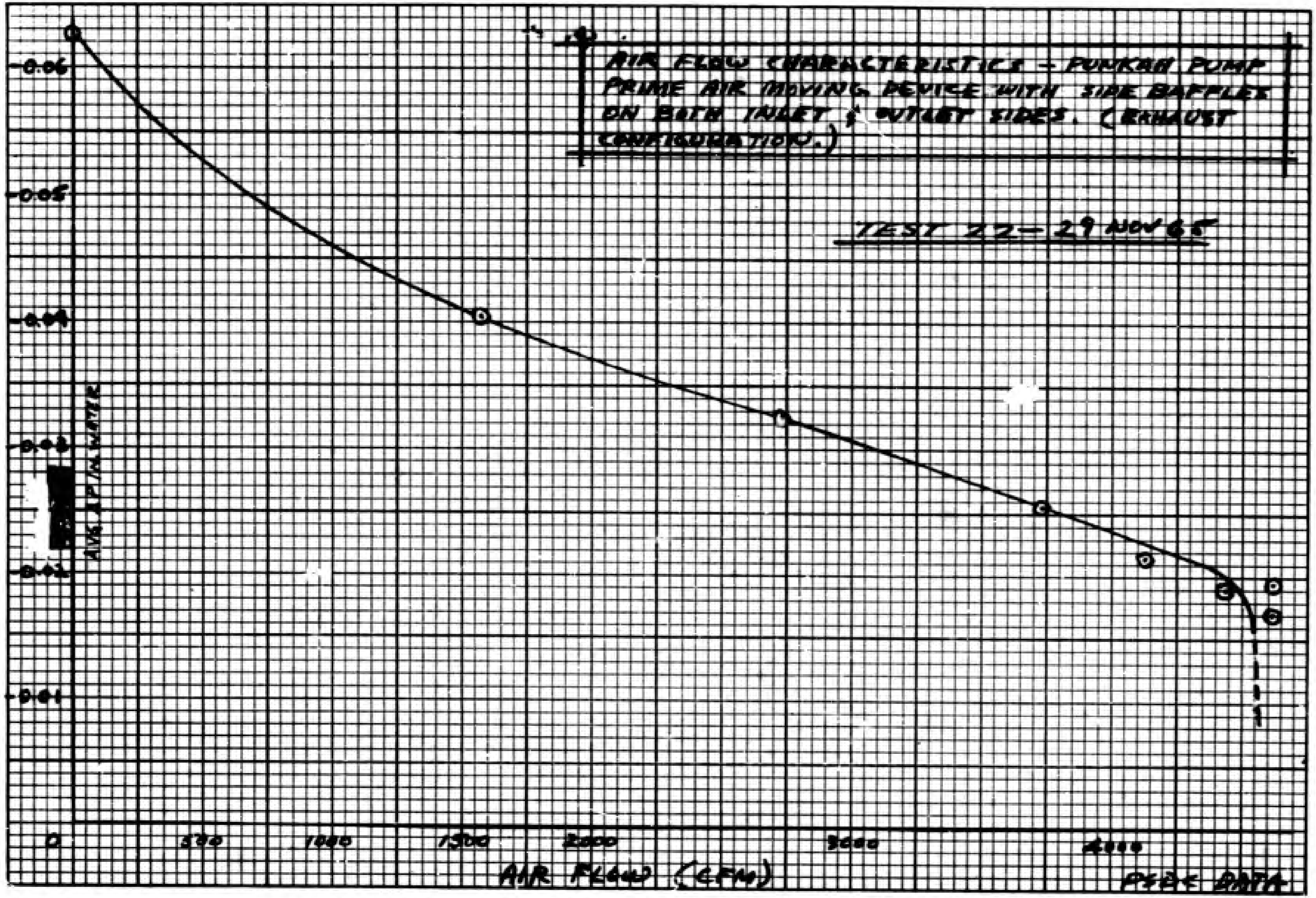

AIR FLOW CHARACTERISTICS – PUNKAH PUMP PRIME AIR MOVING DEVICE WITH SIDE BAFFLES ON BOTH INLET & OUTLET SIDES. (EXHAUST CONFIGURATION.)
TEST 22 – 29 NOV 65
-0.06
-0.05
-0.04
-0.03
[redacted]
-0.02
-0.01
AVG ΔP IN WATER
0
500
1000
1500
2000
3000
4000
AIR FLOW (CFM)
PS&E DATA

Fig. 3.7

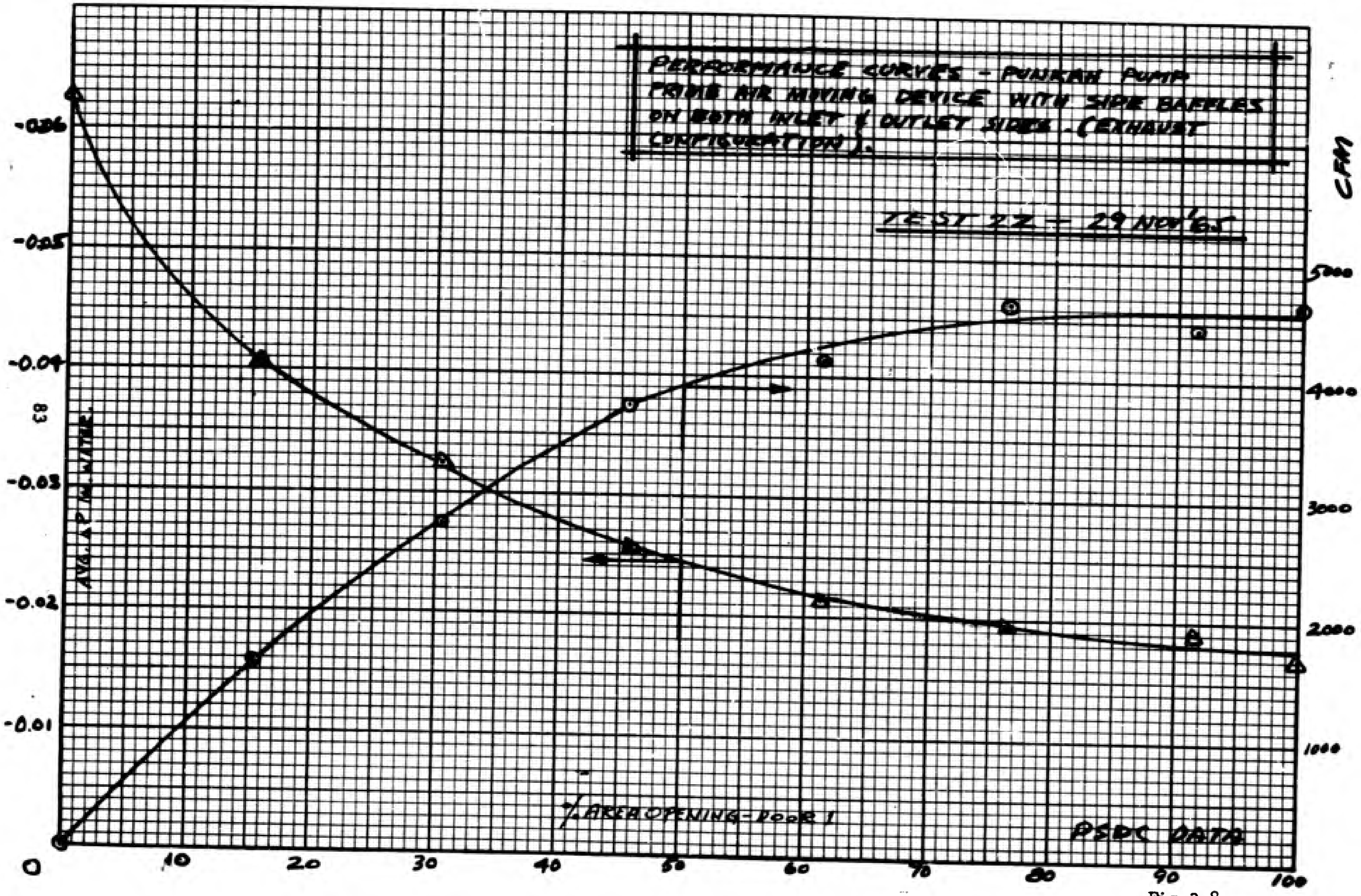

PERFORMANCE CURVES - PUNKAH PUMP PRIME AIR MOVING DEVICE WITH SIDE BAFFLES ON BOTH INLET & OUTLET SIDES. (EXHAUST CONFIGURATION).
TEST 22 - 29 NOV '65
CFM
5000
4000
3000
2000
1000
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0
AVG. ΔP IN. WATER.
10
20
30
40
50
60
70
80
90
100
% AREA OPENING - DOOR I
PSDC DATA

Fig. 3.8

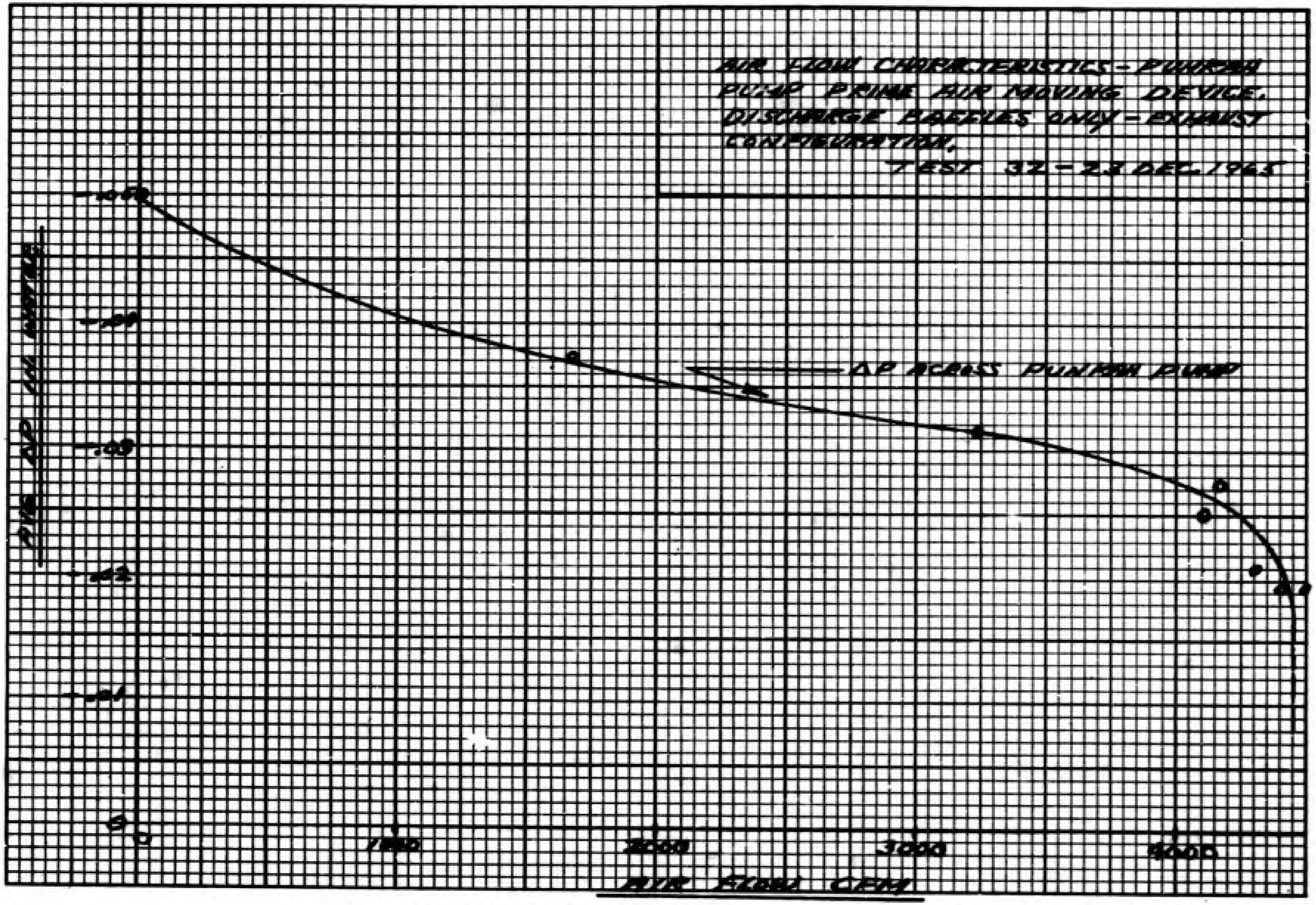


Fig.3.9 PSDC DATA

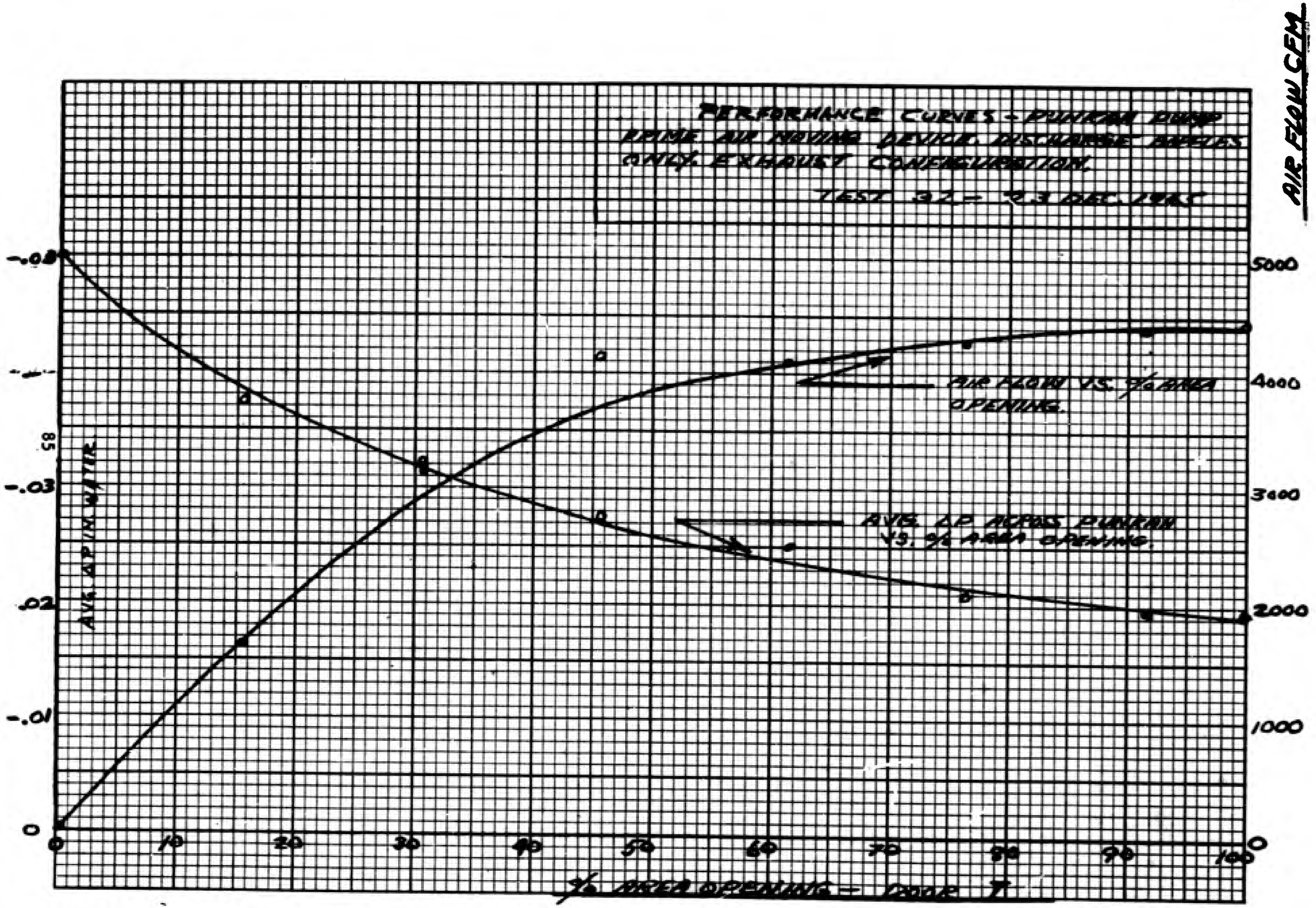

PERFORMANCE CURVES - PUNKAH PUMP
PRIME AIR MOVING DEVICE. DISCHARGE BAFFLES
ONLY, EXHAUST CONFIGURATION.
TEST 32 - 23 DEC. 1965
AIR FLOW CFM
5000
4000
3000
2000
1000
0
-.05
-.03
.02
-.01
0
AVG. ΔP IN. WATER
AIR FLOW VS. % AREA OPENING.
AVG. ΔP ACROSS PUNKAH VS. % AREA OPENING.
0
10
20
30
40
50
60
70
80
90
100
% AREA OPENING - DOOR

Fig.3.10

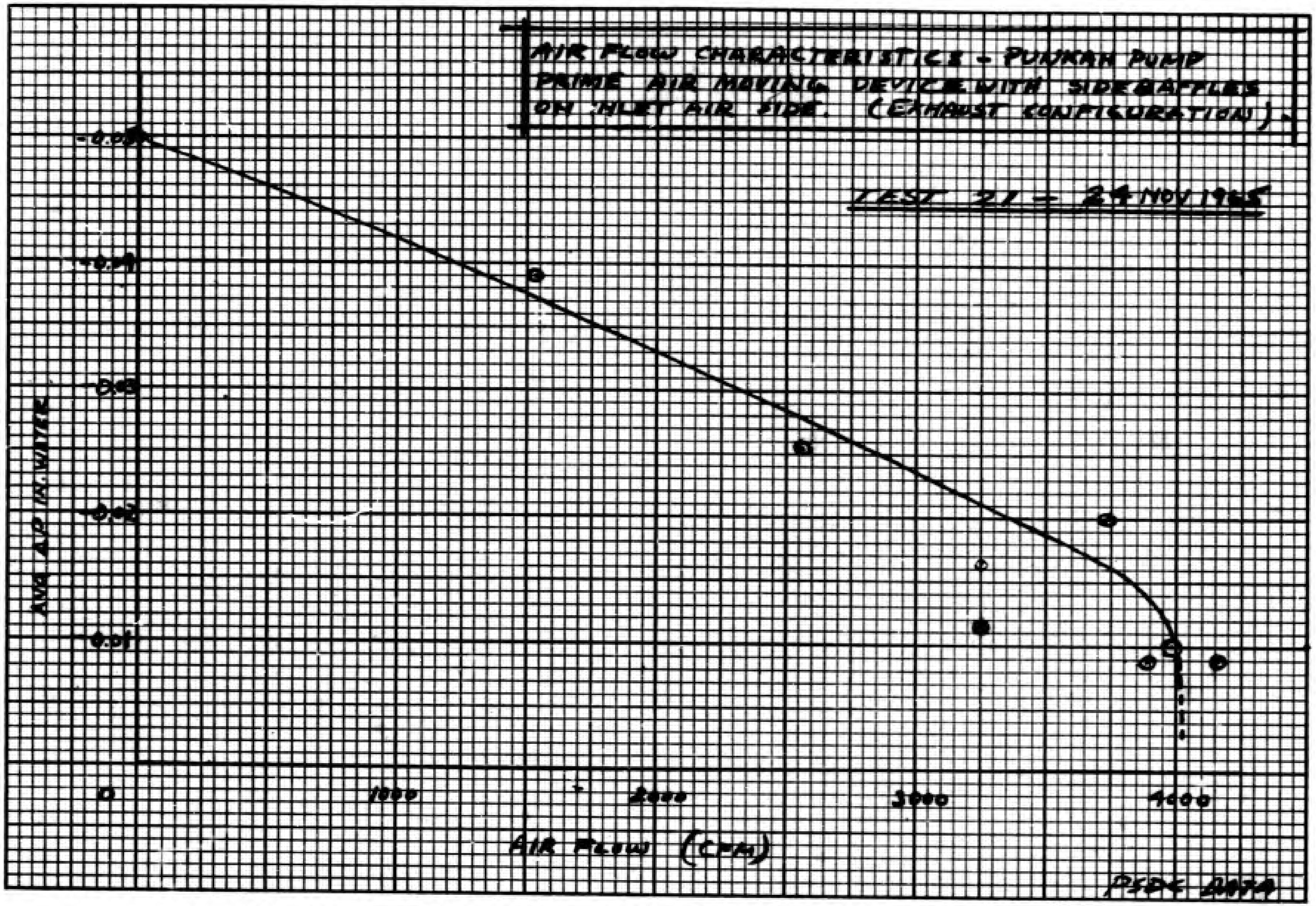

AIR FLOW CHARACTERISTICS - PUNKAH PUMP
PRIME AIR MOVING DEVICE WITH SIDEBAFFLES
ON INLET AIR SIDE. (EXHAUST CONFIGURATION).
TEST 21 - 24 NOV 1965
-0.05
-0.04
0.03
0.02
0.01
AVG. ΔP IN. WATER
0
1000
2000
3000
4000
AIR FLOW (CFM)
PSDC DATA

Fig.3.11

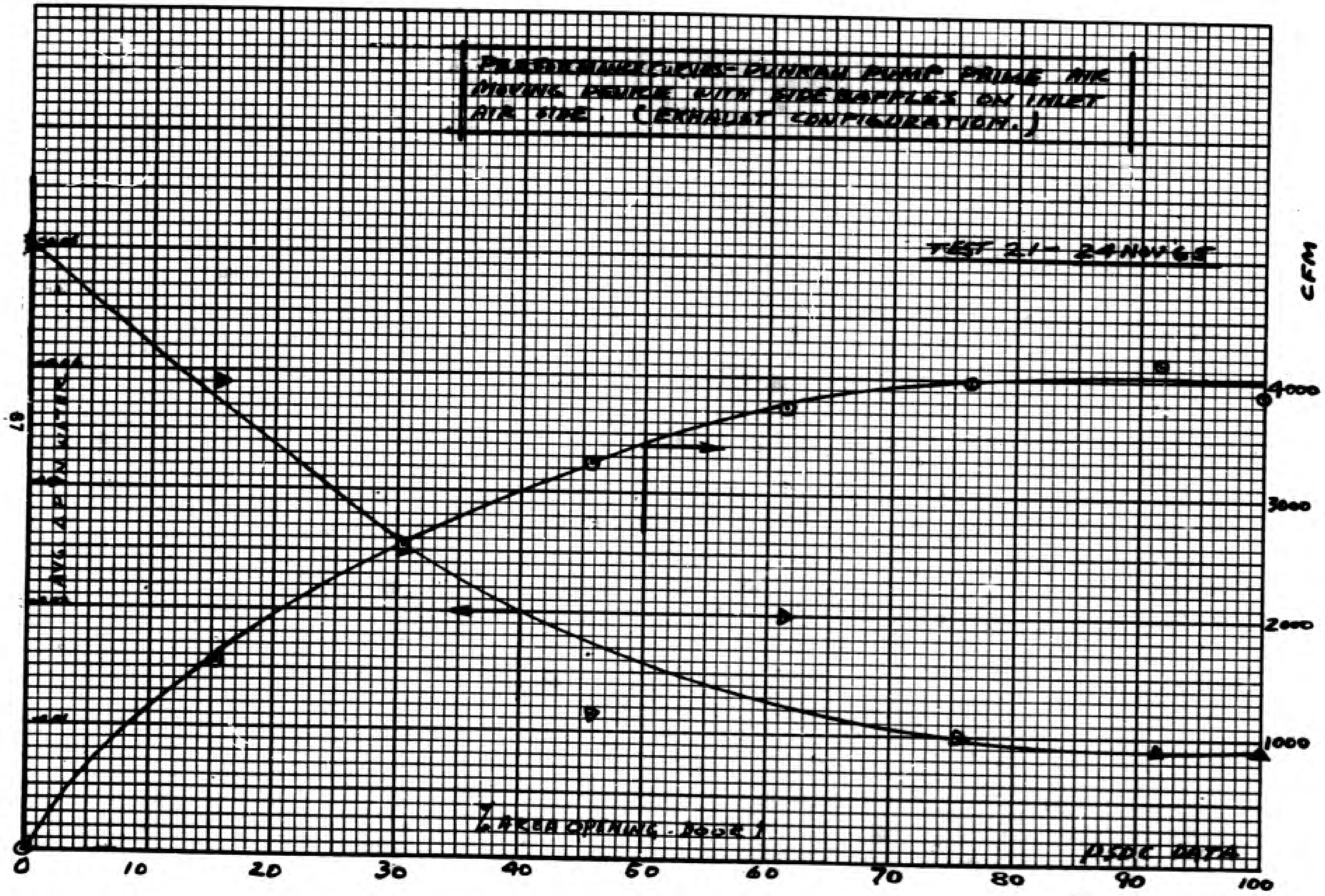
PRESSURE CURVES-DUNHAM PUMP PRIME AIR MOVING DEVICE WITH SIDE BAFFLES ON INLET AIR SIDE. (EXHAUST CONFIGURATION.)
TEST 21 - 24 NOV 65
CFM
4000
3000
2000
1000
AVG. ΔP IN WATER
% AREA OPENING - DOOR 1
0
10
20
30
40
50
60
70
80
90
100
ASDC DATA

Fig.3.12

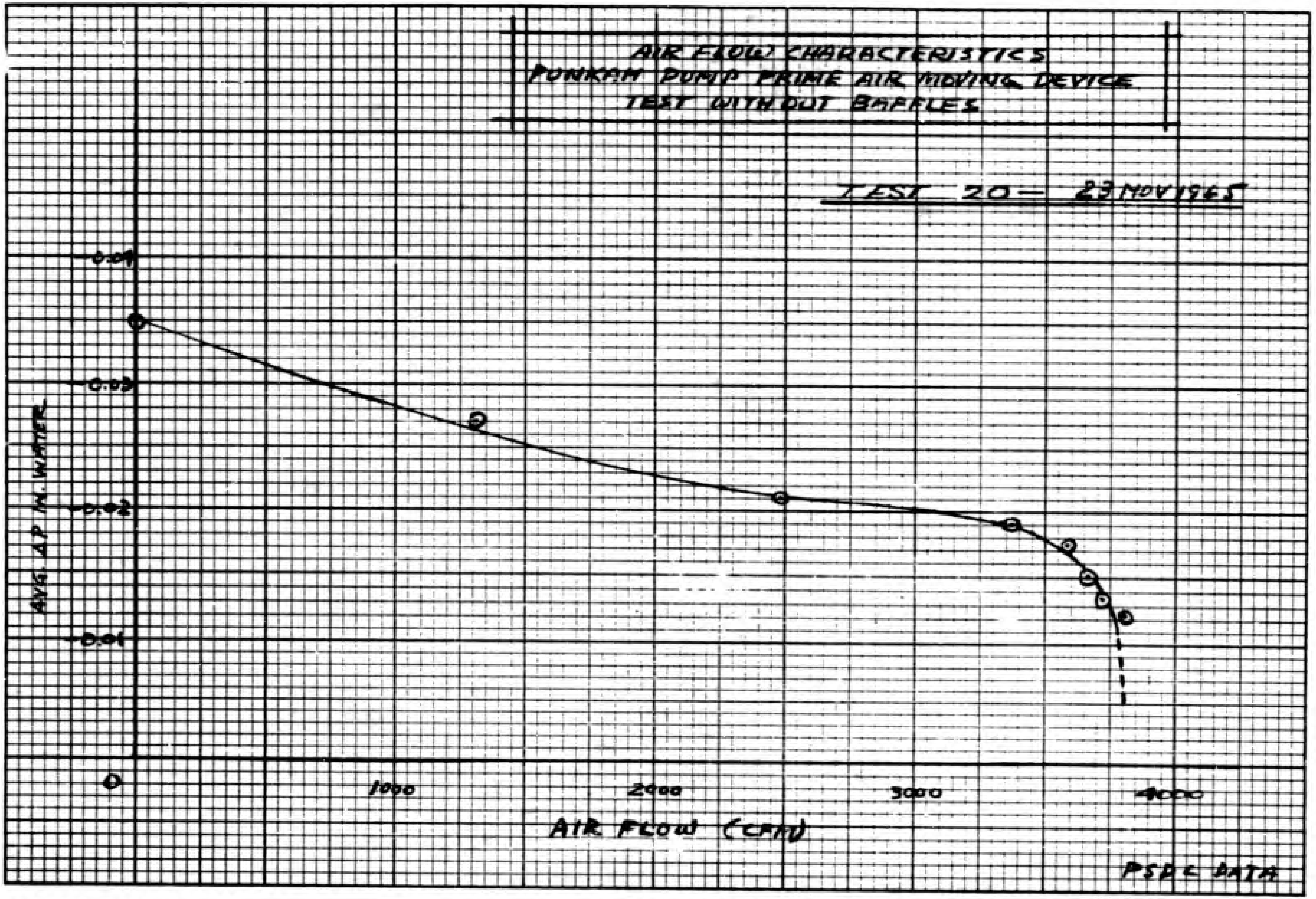

AIR FLOW CHARACTERISTICS
PUNKAH PUMP PRIME AIR MOVING DEVICE
TEST WITHOUT BAFFLES
TEST 20 — 23 NOV 1965
AVG. ΔP IN. WATER
0.04
0.03
0.02
0.01
0
1000
2000
3000
4000
AIR FLOW (CFM)
PSPC DATA

Fig.3.13

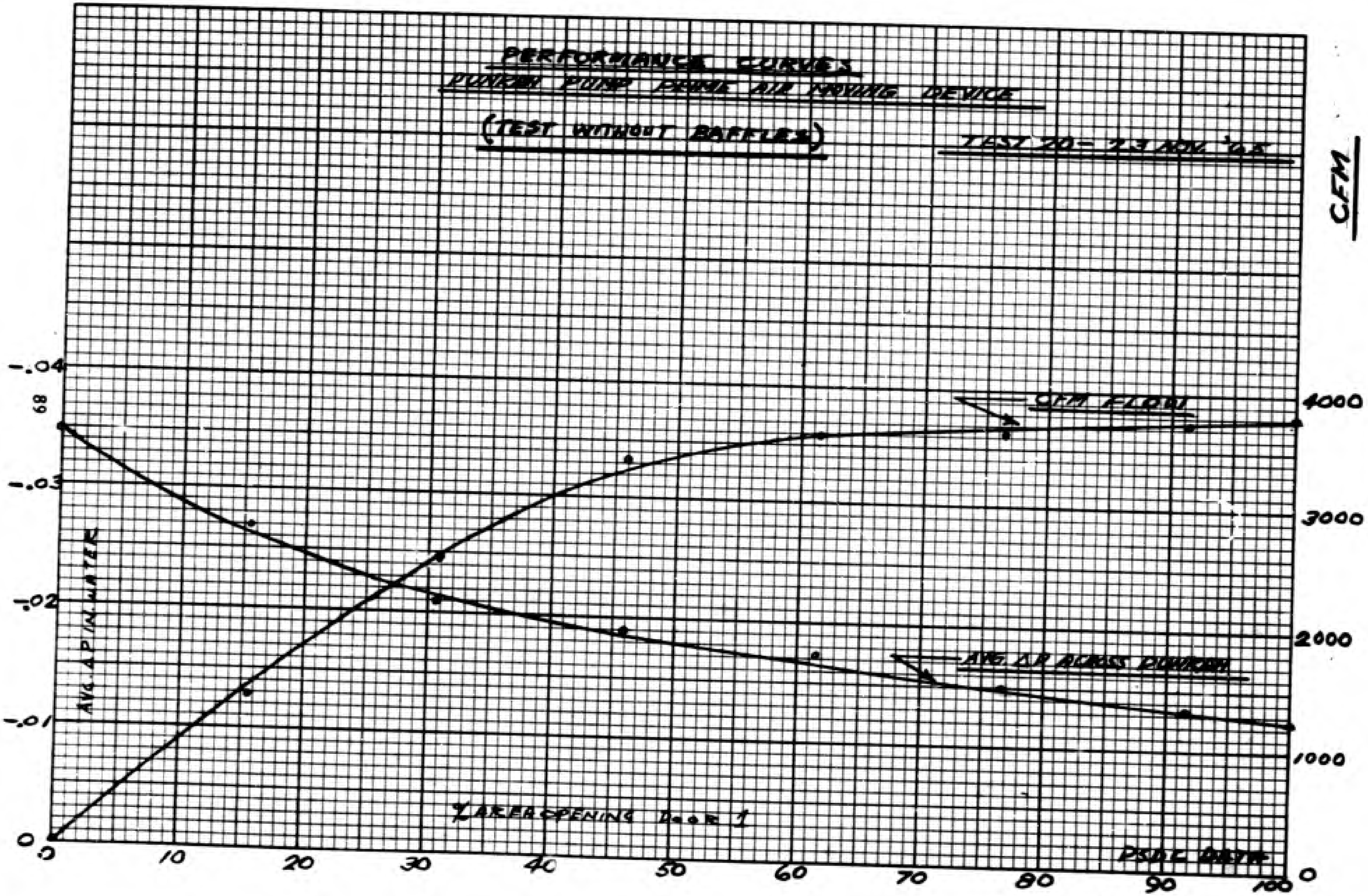

PERFORMANCE CURVES
DUNKER PUMP PRIME AIR MOVING DEVICE
(TEST WITHOUT BAFFLES)
TEST 20 - 23 NOV '65
CFM
4000
3000
2000
1000
0
CFM FLOW
AVG ΔP ACROSS DUNKER
AVG. ΔP IN. WATER
-.04
-.03
-.02
-.01
0.0
% AREA OPENING Door 1
0
10
20
30
40
50
60
70
80
90
100
PSDC DATA

Fig.3.14

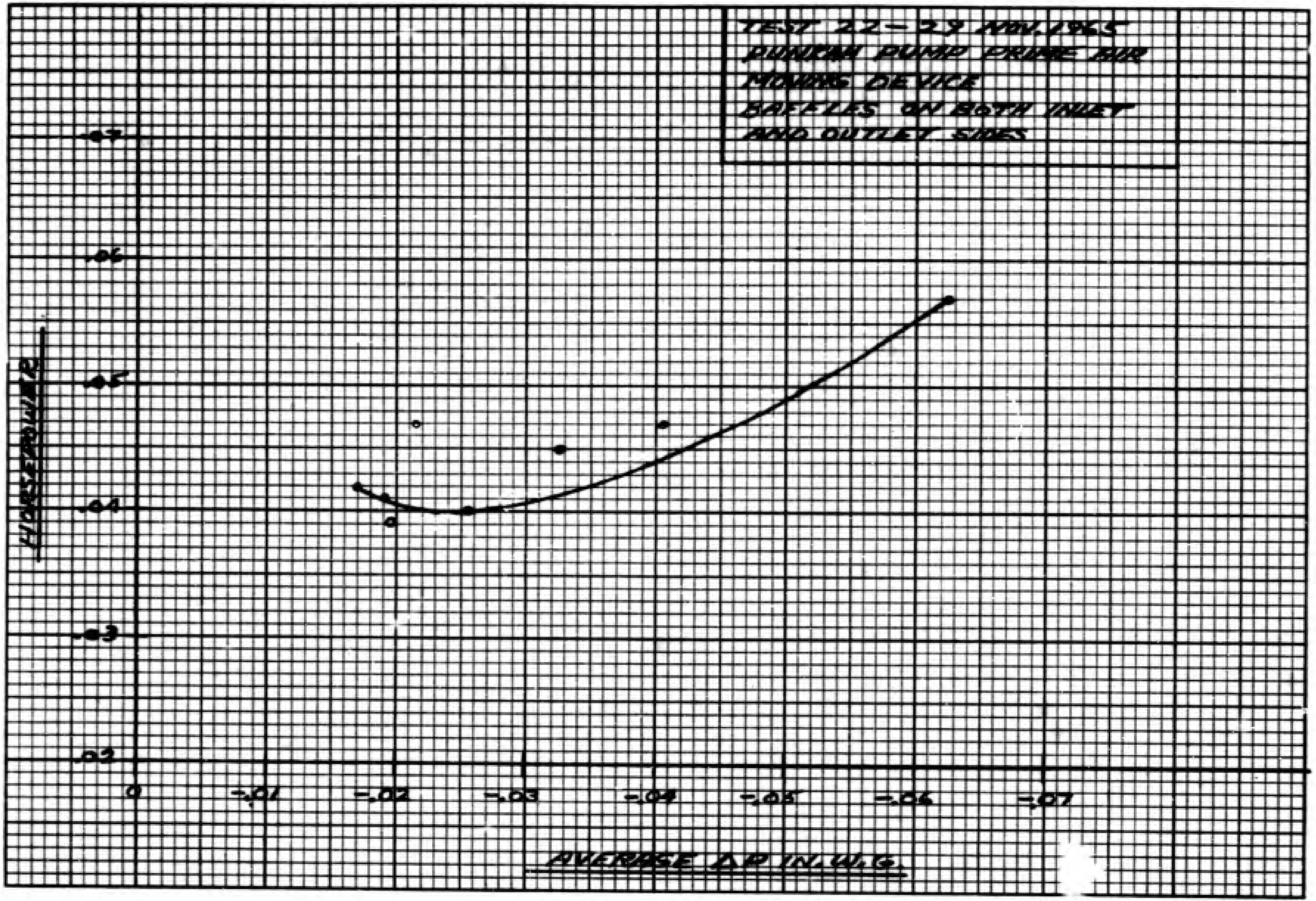

TEST 22-29 NOV. 1965
DUNHAM PUMP PRIME AIR
MOVING DEVICE
BAFFLES ON BOTH INLET
AND OUTLET SIDES
HORSEPOWER
.07
.06
.05
.04
.03
.02
0
-.01
-.02
-.03
-.04
-.05
-.06
-.07
AVERAGE ΔP IN. W.G.

Fig. 3.15

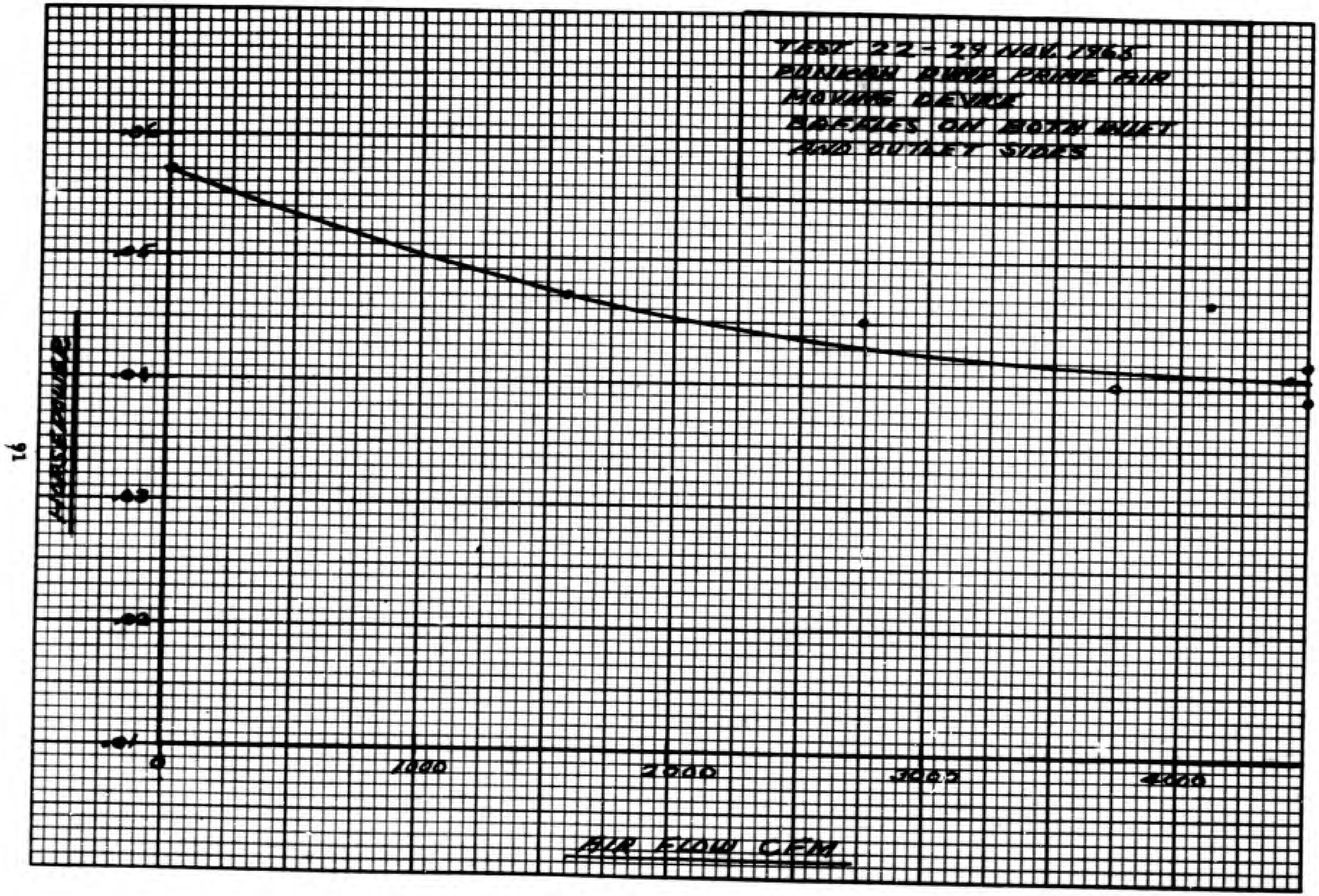

TEST 22 - 29 NOV. 1965
[illegible] PUMP PRIME AIR
MOVING DEVICE
BAFFLES ON BOTH INLET
AND OUTLET SIDES
HORSEPOWER
.06
.05
.04
.03
.02
.01
0
1000
2000
3000
4000
AIR FLOW CFM

Fig.3.16

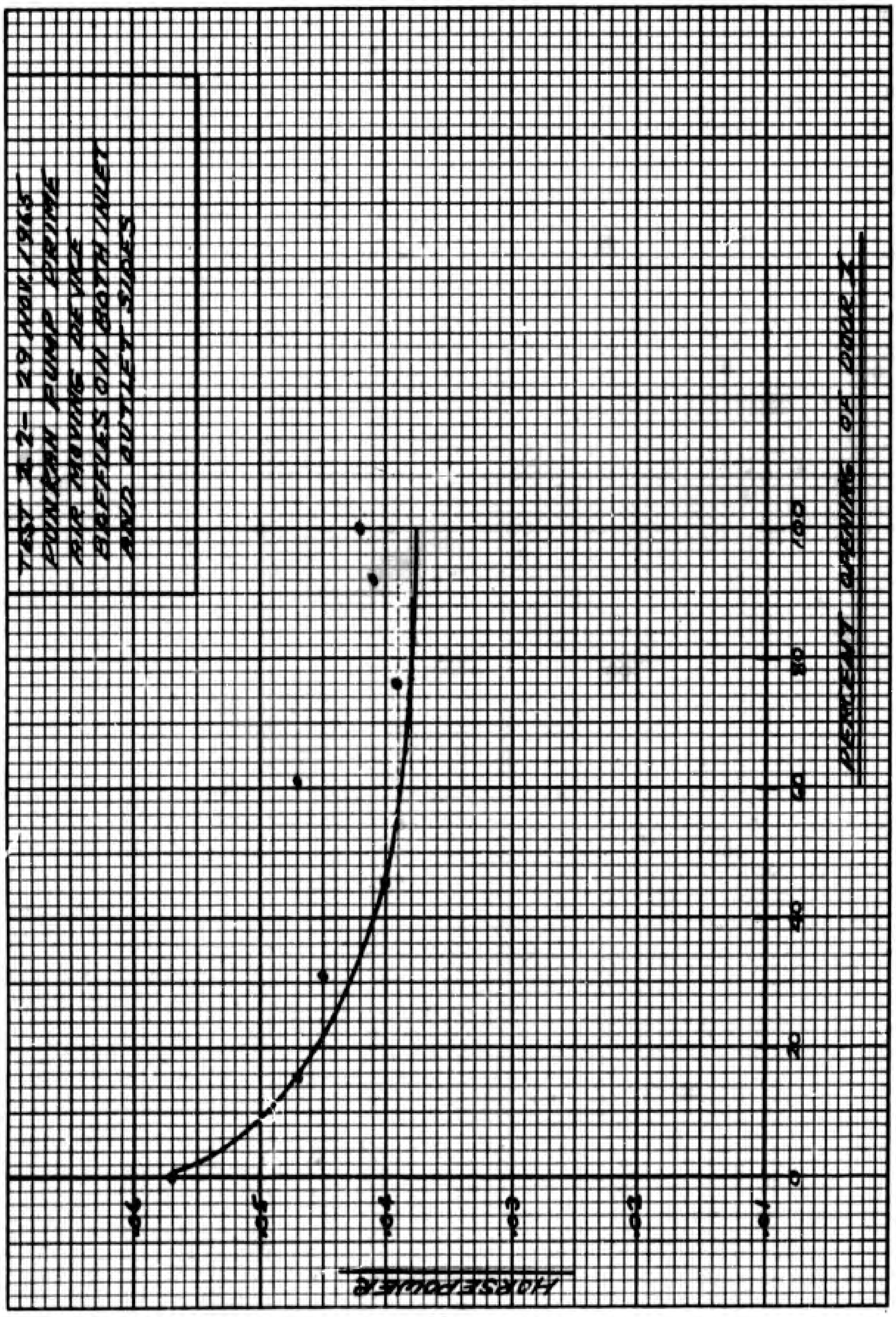

TEST 2.7- 29 NOV.1965
PUNJAB PUMP PRIME
AIR MIXING DEVICE
BAFFLES ON BOTH INLET
AND OUTLET SIDES
HORSEPOWER
.06
.05
.04
.03
.02
.01
0
20
40
60
80
100
PERCENT OPENING OF DOOR X

Fig.3.17

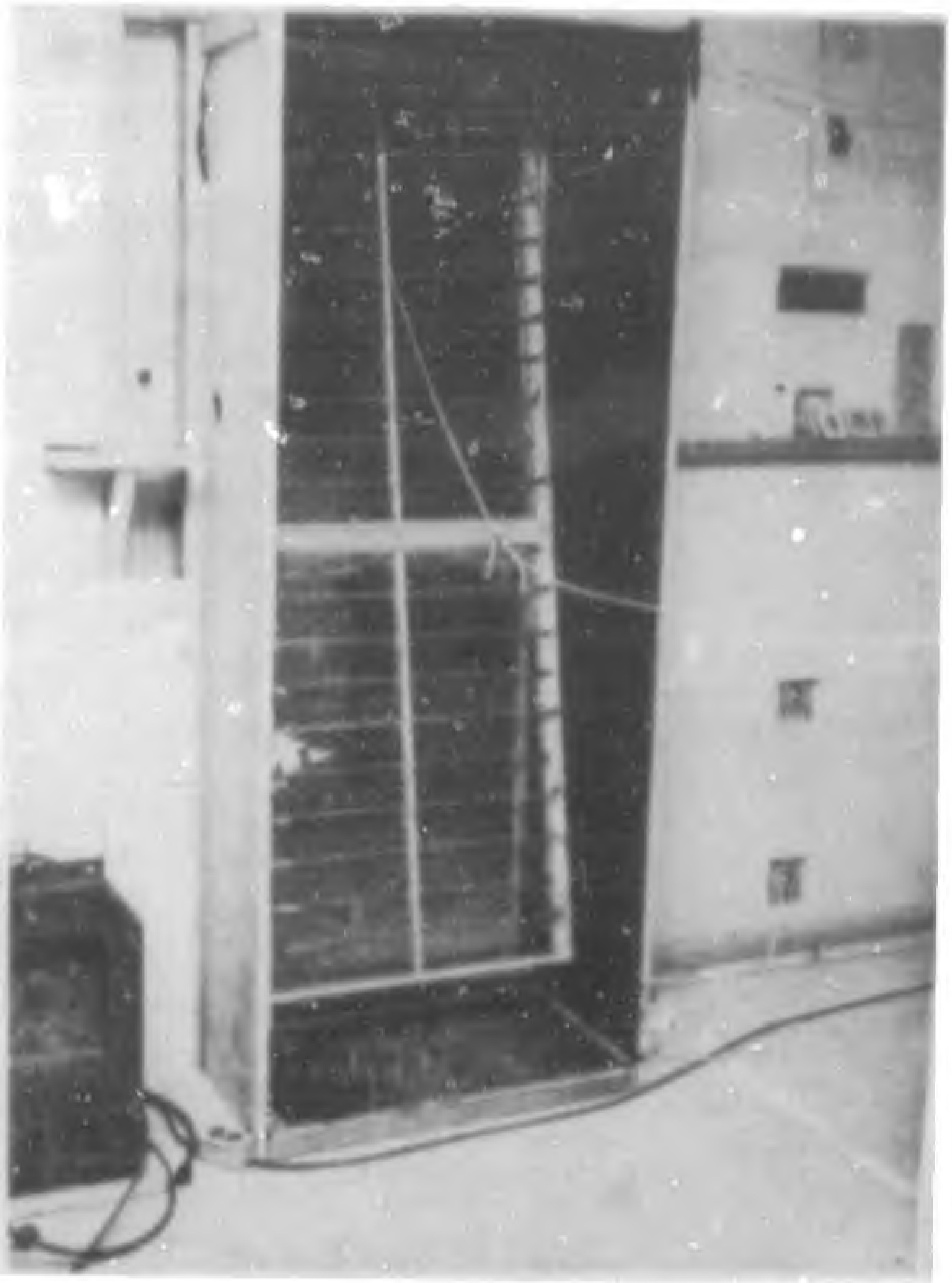
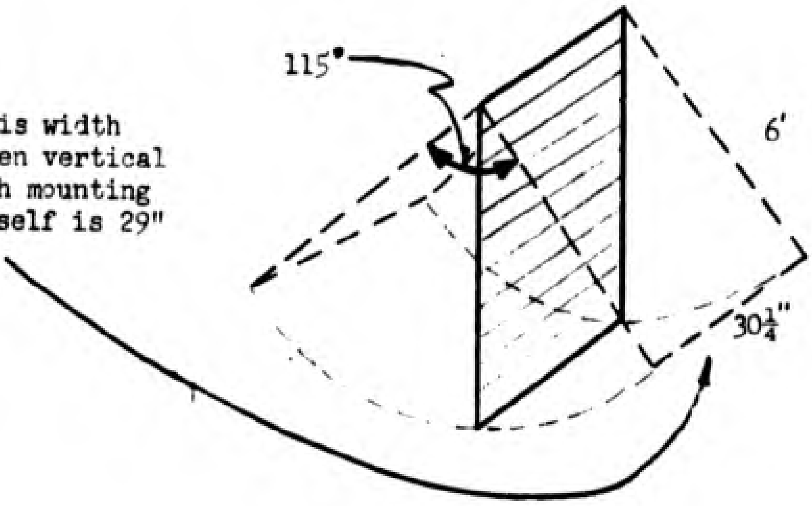


Figure 3.18 Six foot punkah mounted in exhaust door of test shelter. Eighteen inch deep plywood frame on outside of door acts as a side baffle on the discharge side of the punkah pump (see text).

Figure 3.19 Another view of the six foot punkah from the inside of the test shelter. The plywood side baffles are on the inlet side since punkah is used as an exhaust device. Hygrosensor head measuring DB temperature and percent relative humidity hangs from ceiling.



Dimension shown is width of opening between vertical members of punkah mounting frame. Punkah itself is 29" wide.

Capacity of Main 6 Foot Punkah by Volumetric Displacement Method.

Volumetric Displacement of Punkah:

$$\text{Volume} = (\pi R^2 H)\left(\frac{\text{Angular Displacement}}{360^\circ}\right)(\text{Oscillations/Min})$$

Where:

$R = 6$ Ft.

$H = 2.52$ Ft.

Angular Displ. = 115°

Oscill/Min = 26

Volume - CFM

$$\text{Volume} = \pi \text{ x}36\text{x}2.52'\text{x}\frac{115^\circ}{360^\circ}\text{ x}26$$

Volume = 2369 CFM (Calculated Displacement)

Measured Air Volume:

Volume Determined by Velocity

Traverse Method of Door I = 4600 CFM

Figure 3.20

Figure 3.21 Test arrangement for horsepower measurement six foot full door punkah.

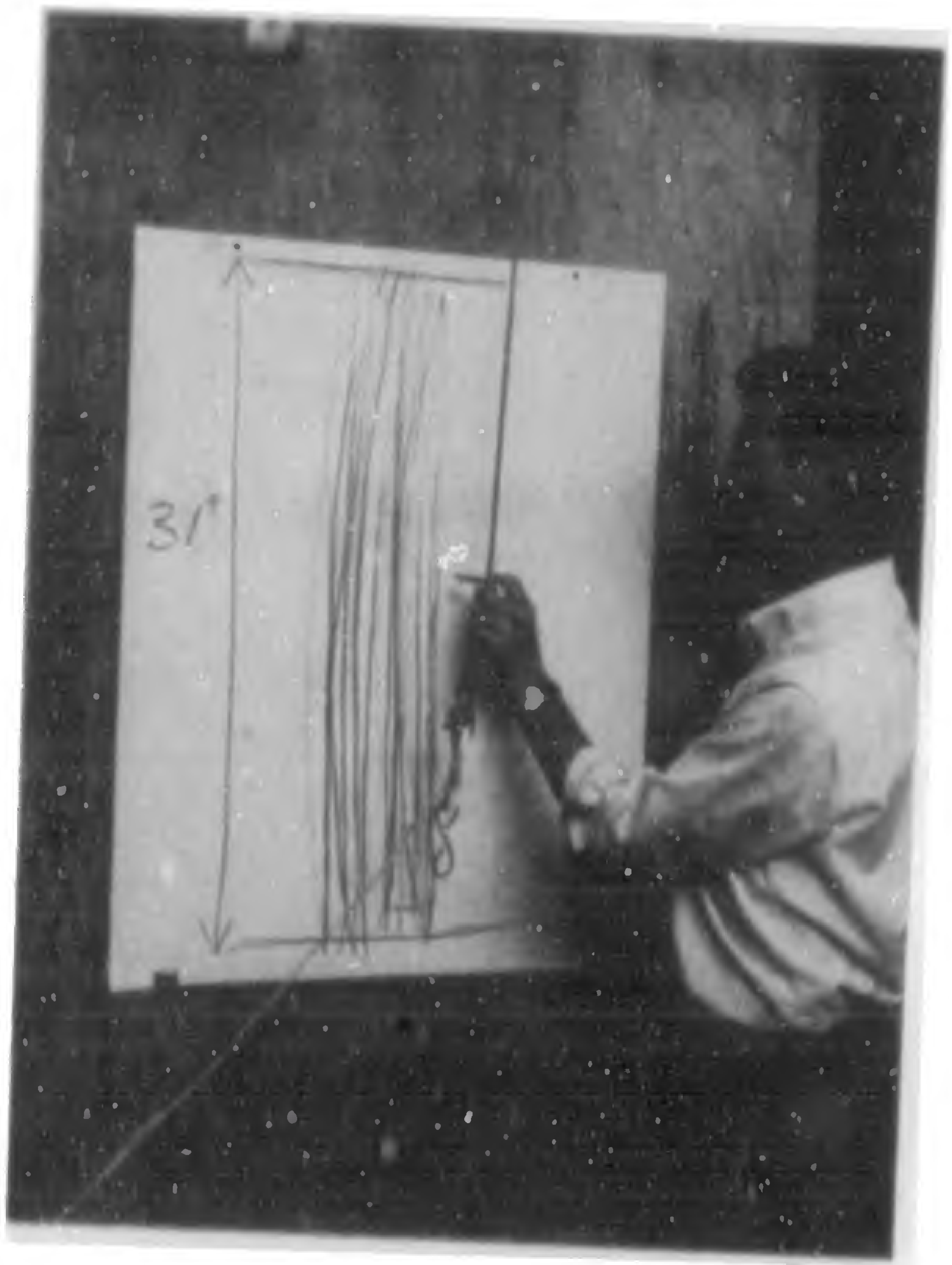


Figure 3.22 Measuring length of stroke.

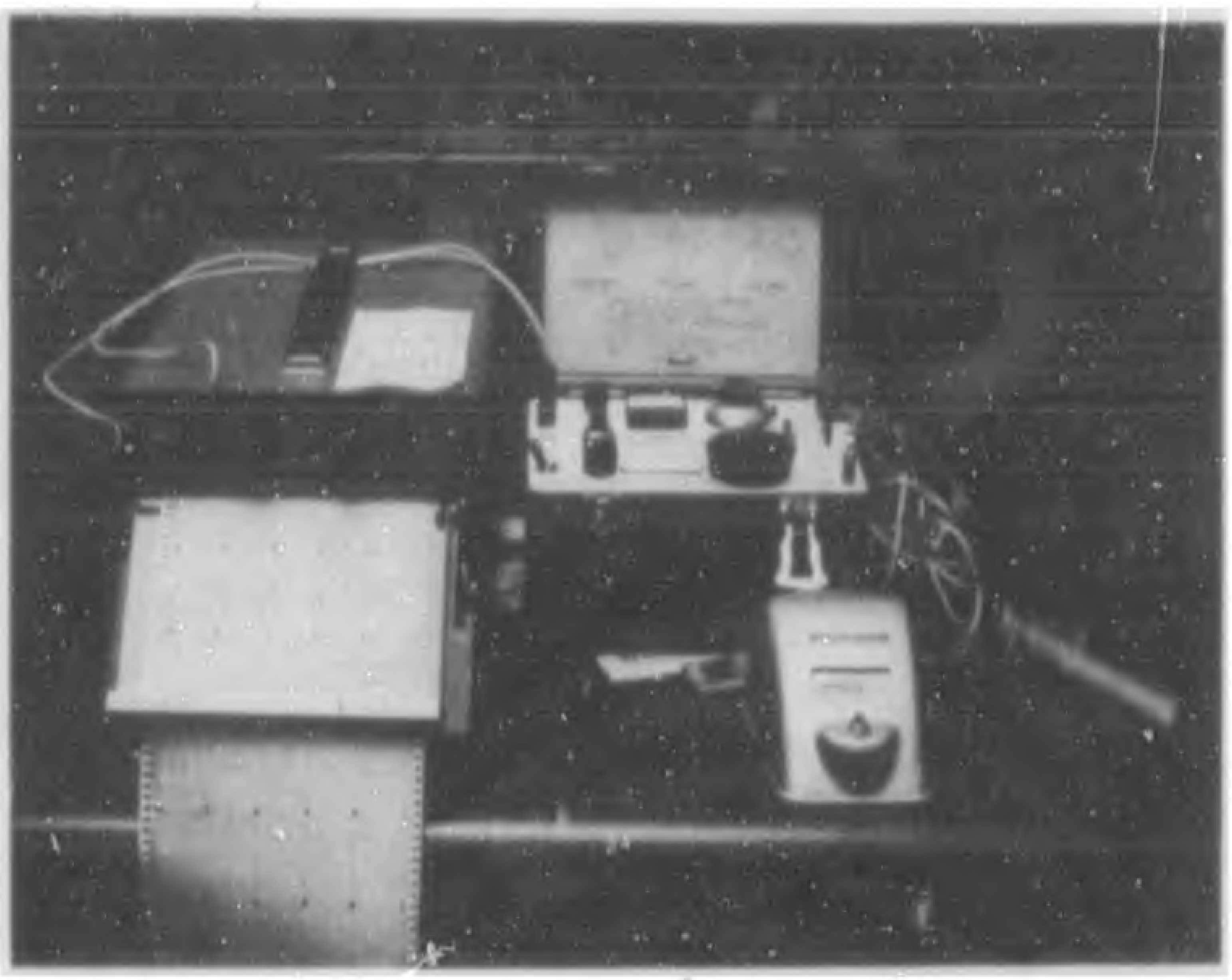


Figure 3.23 Instrumentation for determining horsepower requirements.

Recorder on left registers output of a Wheatstone bridge circuit which is imbalanced due to force operating punkah actuating a strain gage installed in pull cord. Electric timer is located on right in foreground; Budd strain gage internal bridge circuit in background.

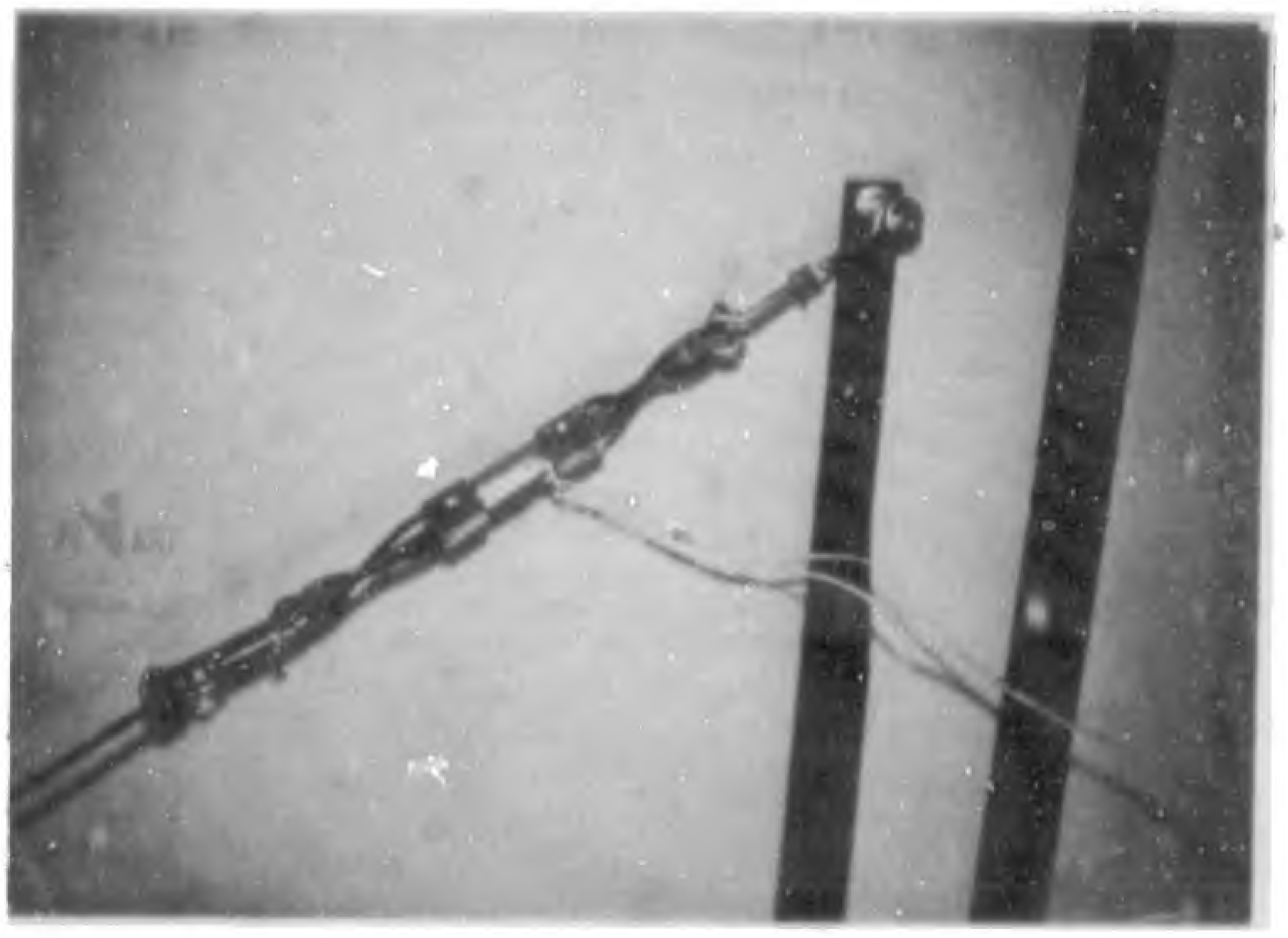
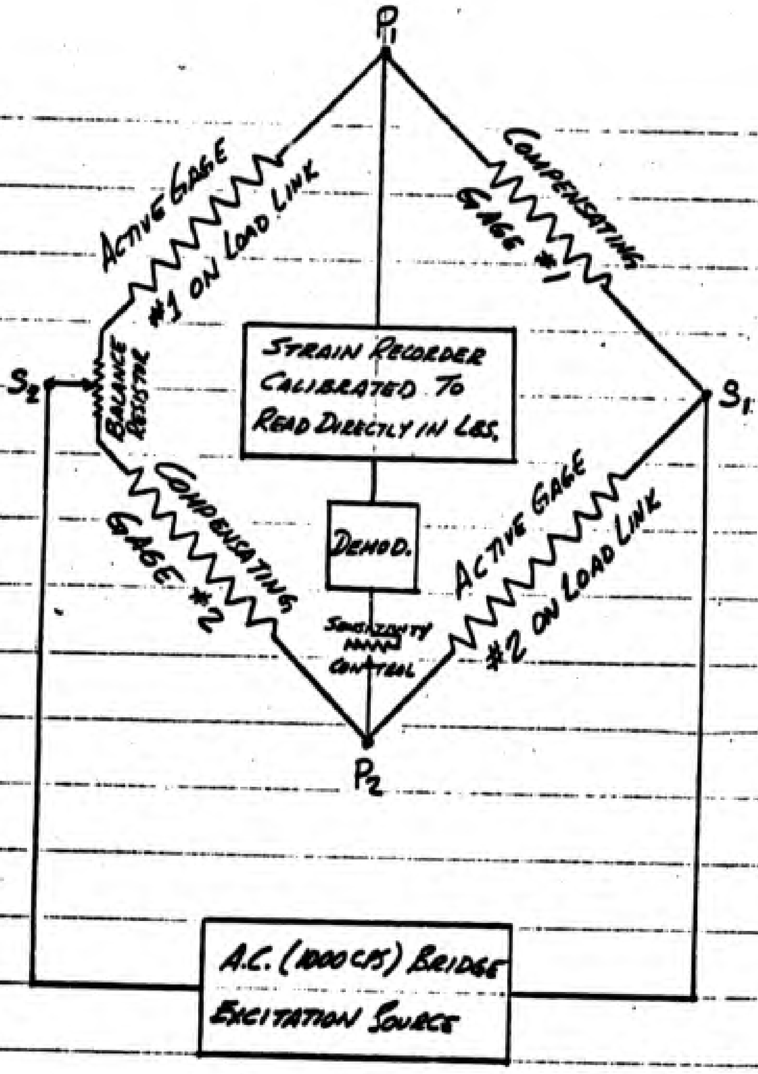


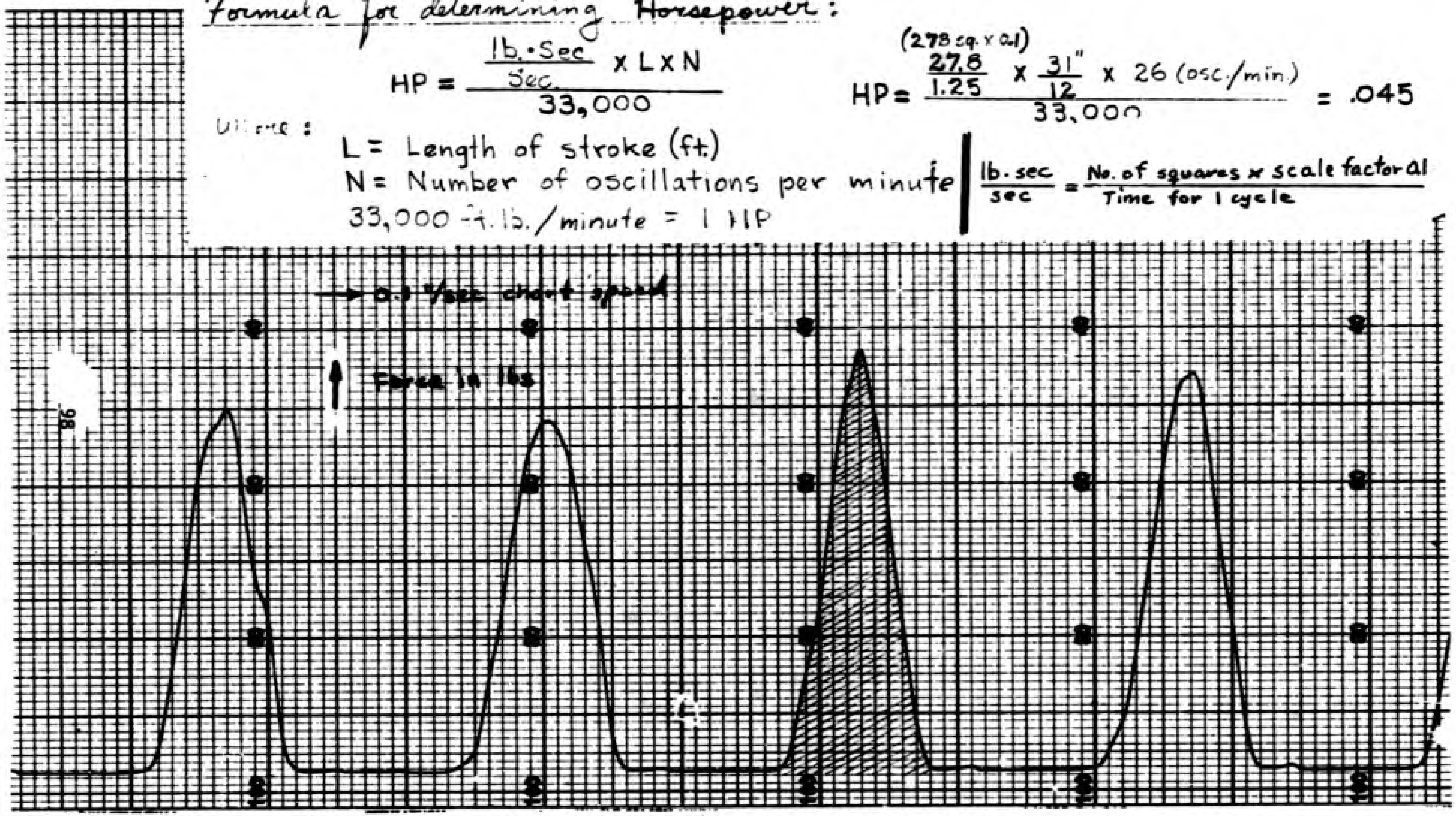
Figure 3.24 Strain gage link in punkah pull cord.



ELECTRONIC LOAD MEASUREMENT SET-UP
FOR MEASURING PUNKAH PULL FORCE

Load Link Constructed of 6061 Aluminum Alloy
Strain Gages - BLH, SR-4, Type A-1, G.F.=2.05, Rs=120Ω
Strain Measuring Device - Budd Portable Strain Indicator #P-350
Strain Recorder - Honeywell Electronik 19, recording potentiometer

Figure 3.25 Wheatstone bridge circuit for measuring pull force.



Formula for determining ~~Horsepower~~:

$$HP = \frac{\frac{lb.\cdot Sec}{Sec.} \times L \times N}{33{,}000}$$

Where:

L = Length of stroke (ft.)

N = Number of oscillations per minute

33,000 ft.lb./minute = 1 HP

$$HP = \frac{\overset{(278\,sq.\times .01)}{\frac{27.8}{1.25}} \times \frac{31''}{12} \times 26\ (osc./min.)}{33{,}000} = .045$$

$$\frac{lb.\,sec}{sec} = \frac{\text{No. of squares} \times \text{scale factor .01}}{\text{Time for 1 cycle}}$$

Figure 3.26 Horsepower calculations.

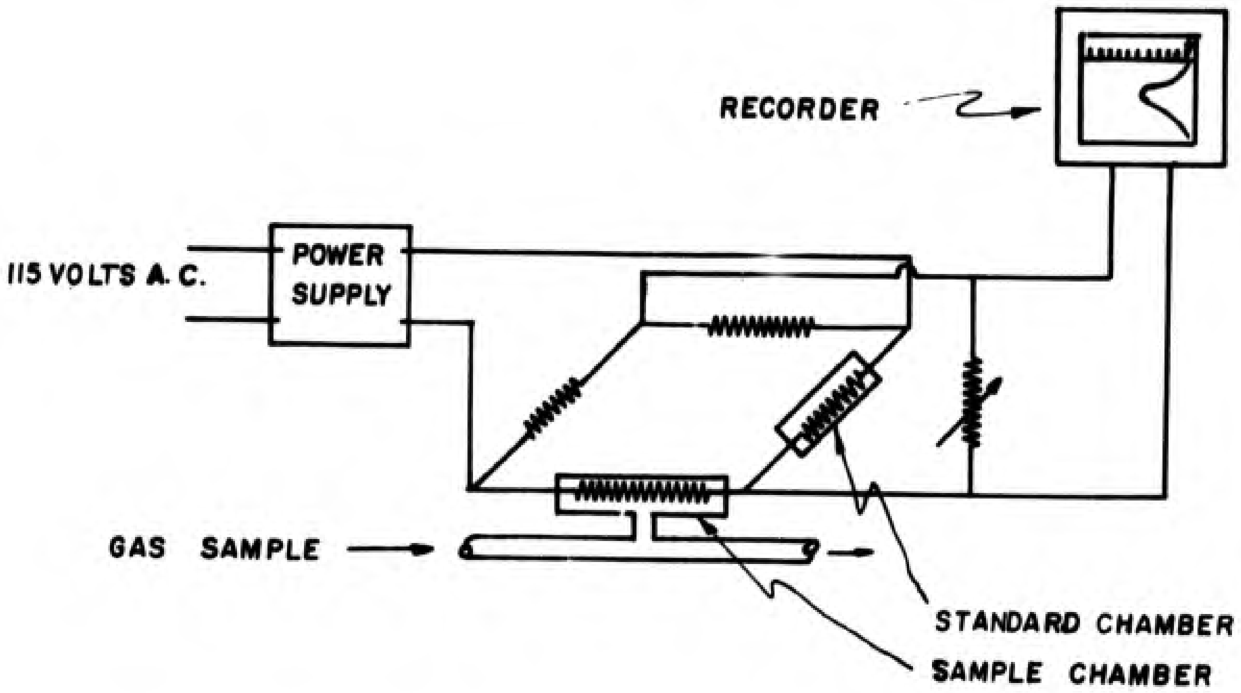


Figure 3.27 Gas analyzer - Schematic wiring diagram.

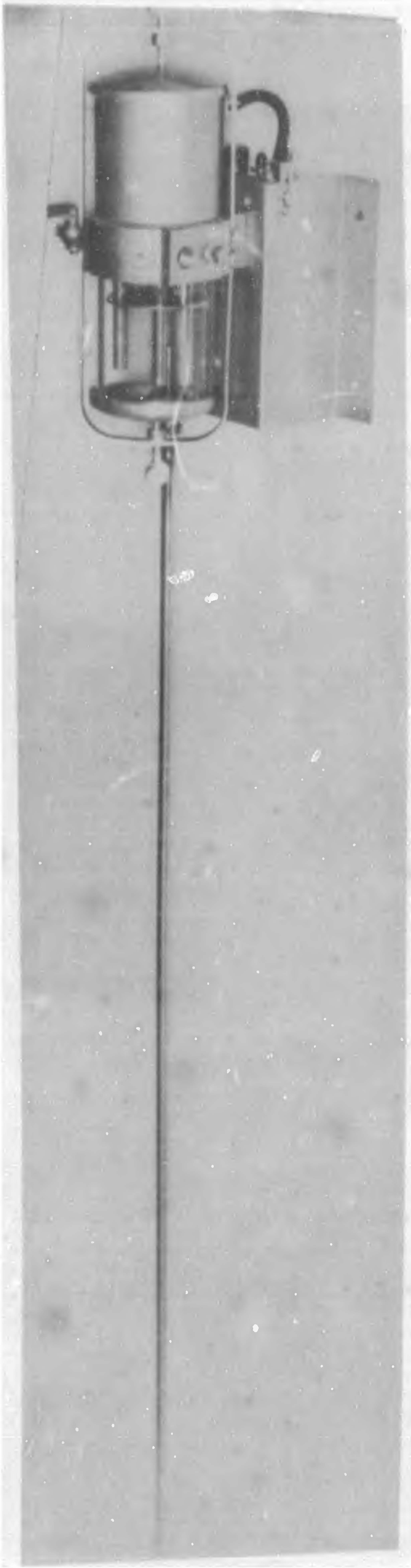


Figure 3.28 Gas analyzer.

Used to determine decay of tracer gas in shelter rooms to obtain ventilation air flow rates.

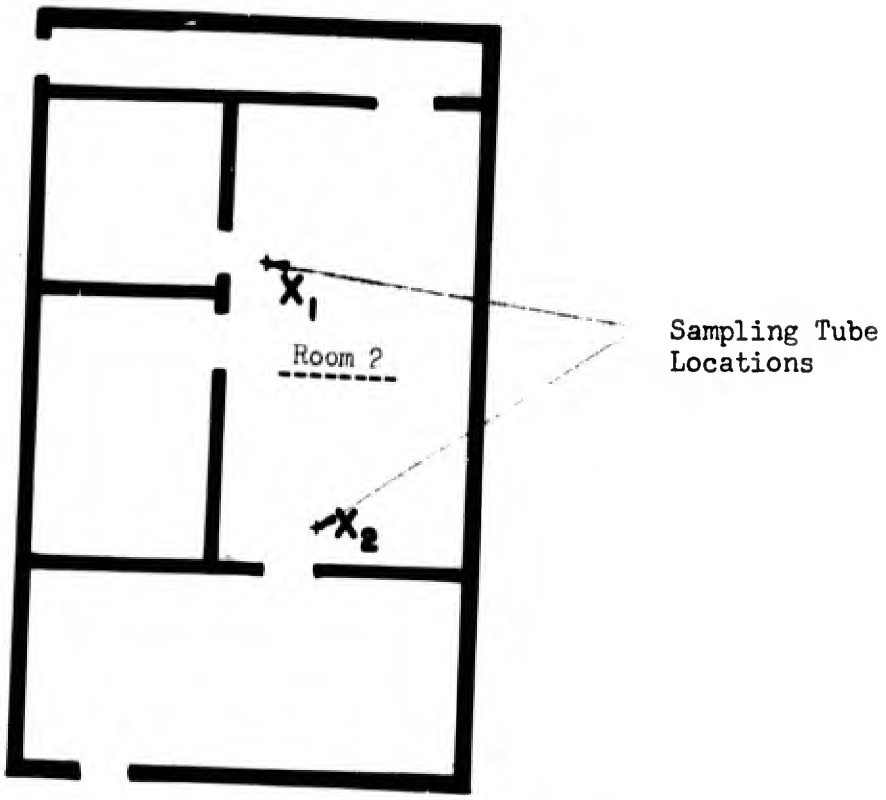


Figure 3.29 Gas sampling tube locations.

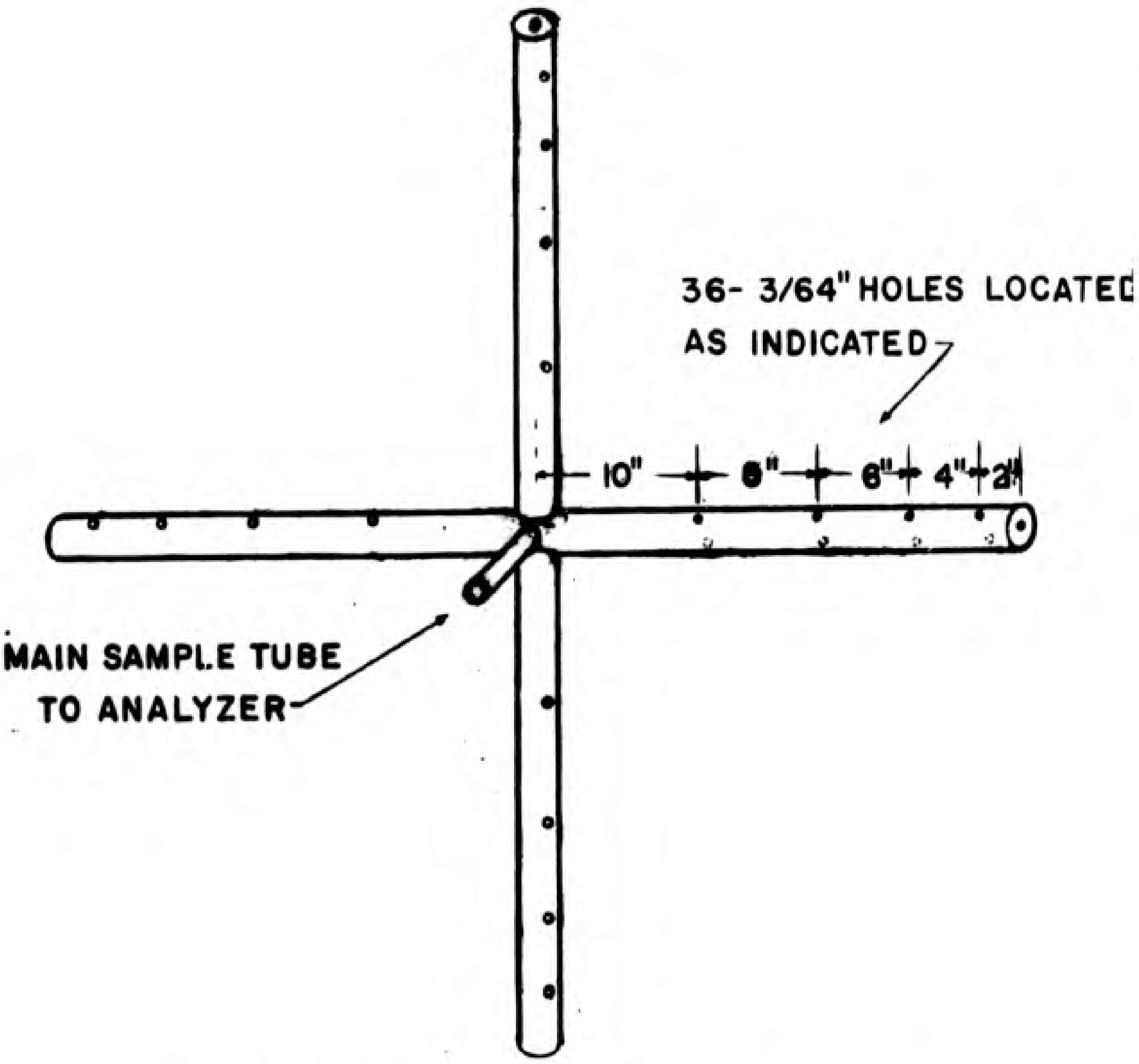
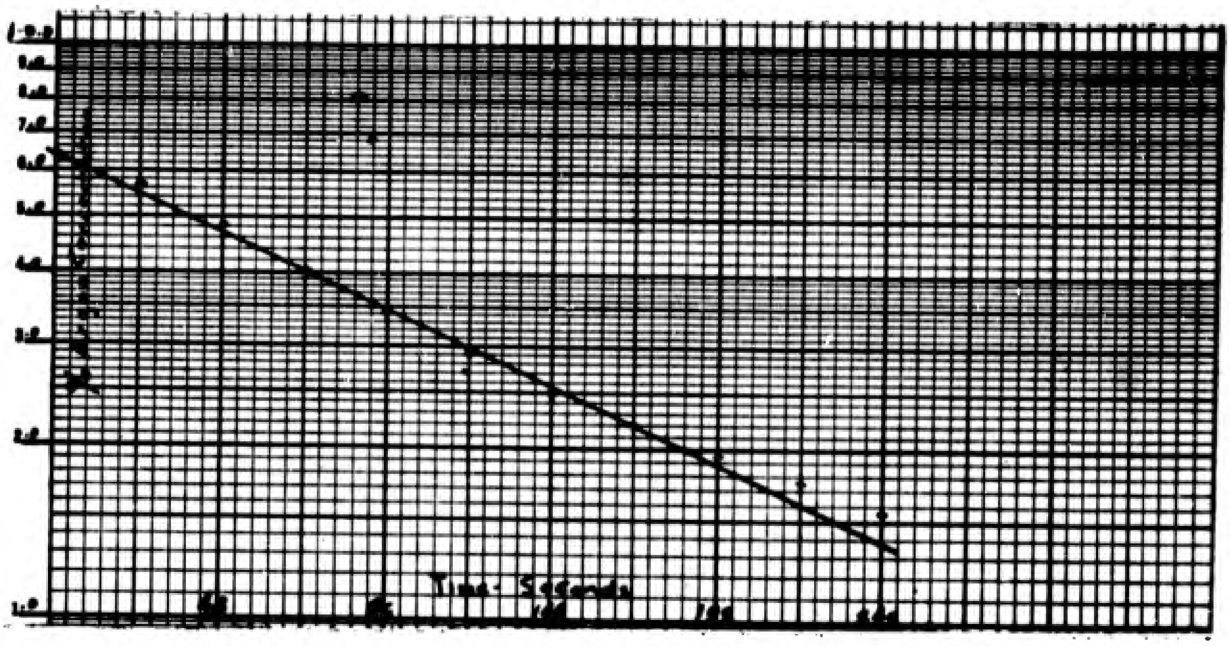


Figure 3.30 Gas analyzer sample intake manifold.

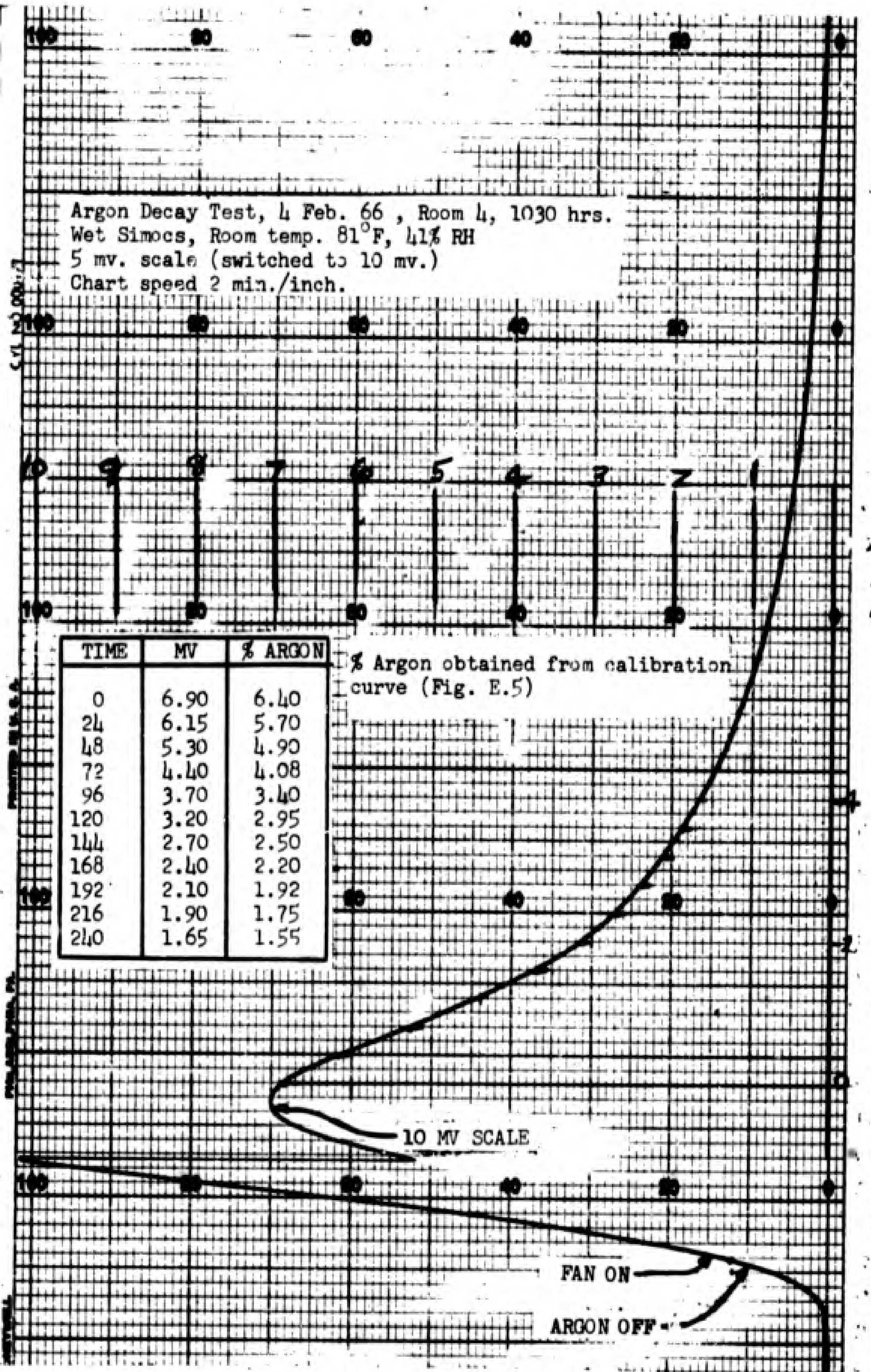
Argon Gas Decay Test- Room 4



$$N = \frac{\ln 6.40 - \ln 1.40}{4} = 0.38$$

$$Q = 0.38 \times 1037 = 394 \text{cfm}$$

Figure 3.31 Airflow for room 4- argon gas decay test.



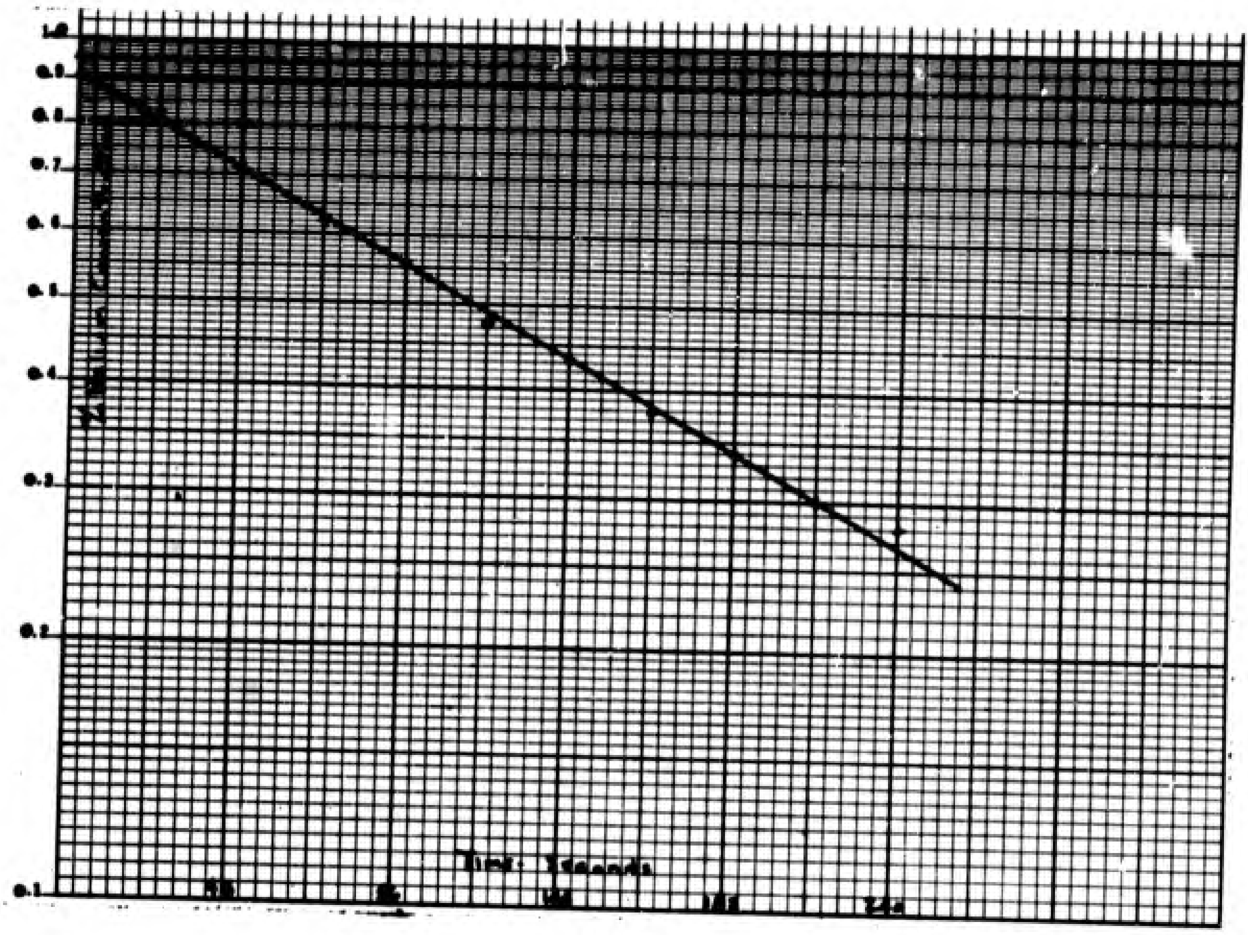
Argon Decay Test, 4 Feb. 66 , Room 4, 1030 hrs.
Wet Simocs, Room temp. 81°F, 41% RH
5 mv. scale (switched to 10 mv.)
Chart speed 2 min./inch.

TIME	MV	% ARGON
0	6.90	6.40
24	6.15	5.70
48	5.30	4.90
72	4.40	4.08
96	3.70	3.40
120	3.20	2.95
144	2.70	2.50
168	2.40	2.20
192	2.10	1.92
216	1.90	1.75
240	1.65	1.55

% Argon obtained from calibration curve (Fig. E.5)

Figure 3.32 Argon gas decay test,recorder strip chart.

Helium Gas Decay Test- Room 4

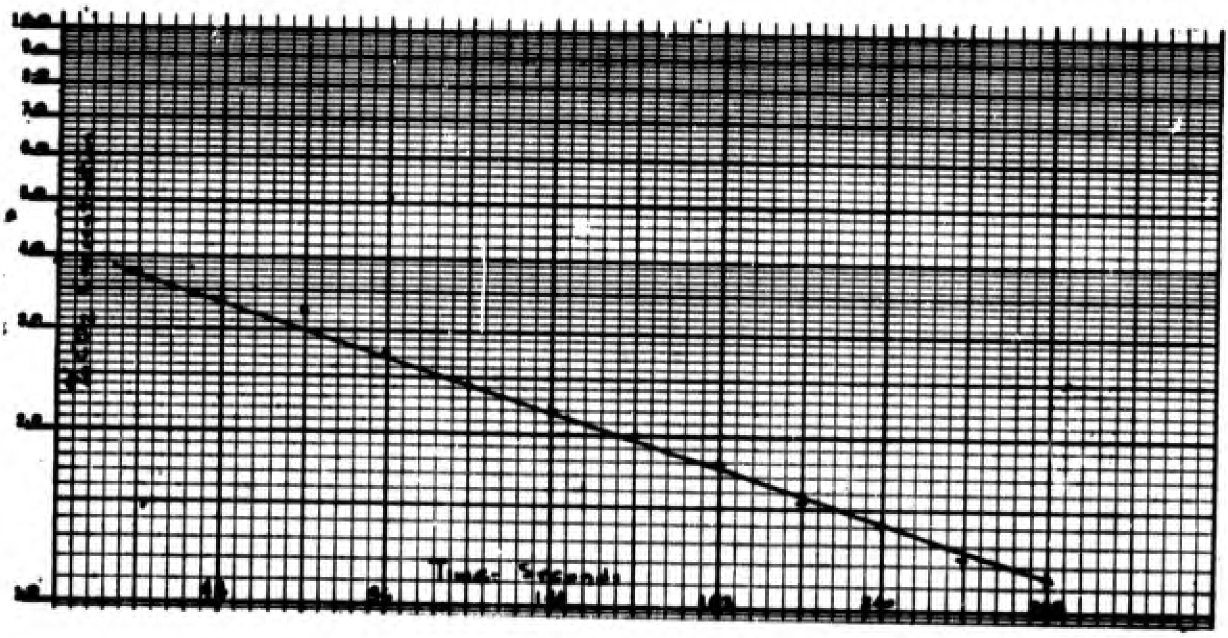


$$N = \frac{\ln 0.90 - \ln 0.265}{4} = 0.306$$

$$Q = 0.306 \times 1037ft^3 = 317cfm$$

Figure 3.33 Airflow for room 4- helium gas decay test.

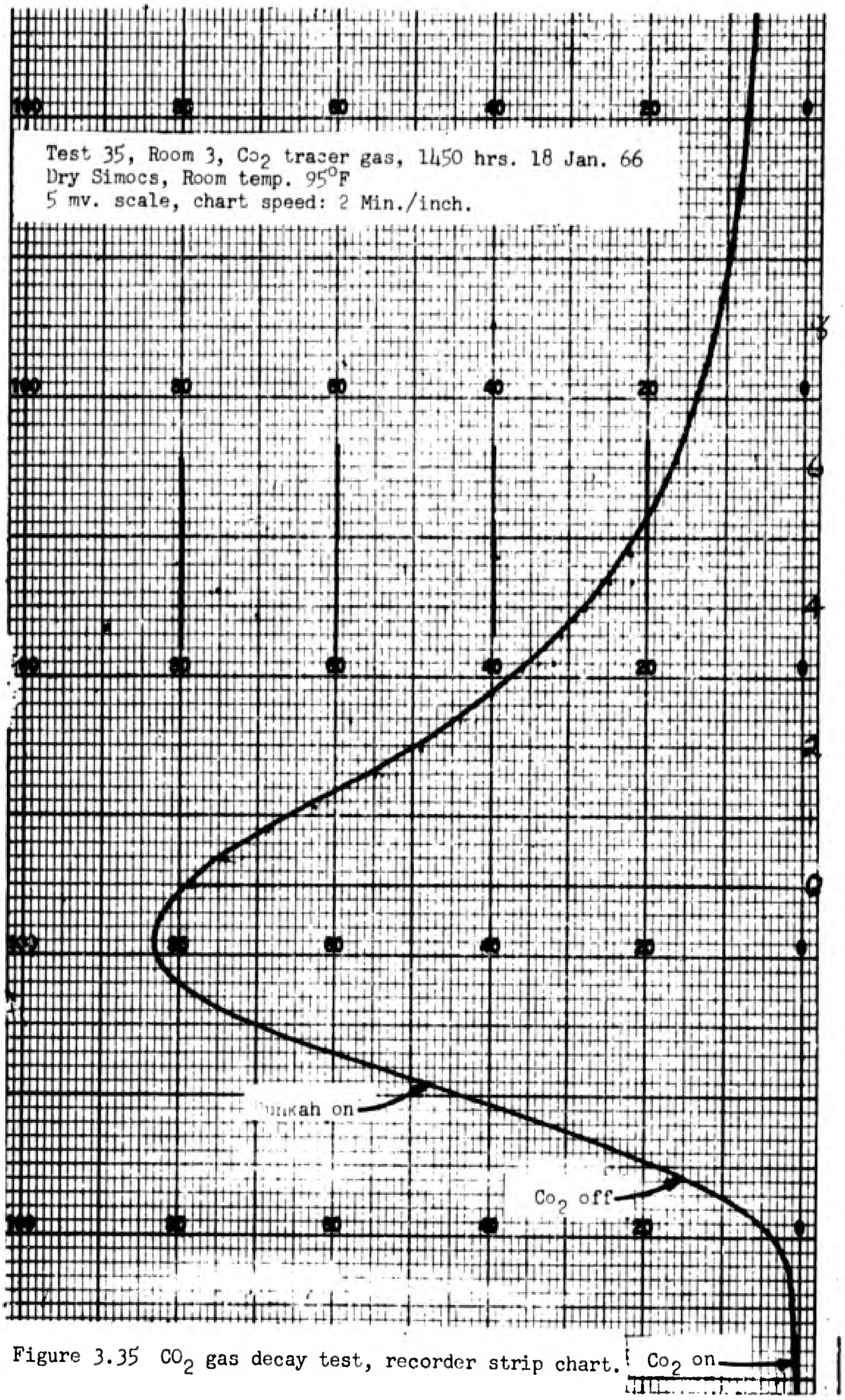
CO_2 Gas Decay Test- Room 3



$$N = \frac{\ln 3.40 - \ln 1.15}{4} = 0.275$$

$$Q = 0.275 \times 1321 ft^3 = 363 cfm$$

Figure 3.34 Airflow for room 3 - CO_2 gas decay test.



Test 35, Room 3, Co$_2$ tracer gas, 1450 hrs. 18 Jan. 66
Dry Simocs, Room temp. 95°F
5 mv. scale, chart speed: 2 Min./inch.

Figure 3.35 CO$_2$ gas decay test, recorder strip chart.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Punkahs are versatile air moving devices well suited for ventiling fallout shelters. They have a high air handling capacity coupled with very low power requirements. The most important advantages and disadvantages of the punkahs are:

a. <u>ADVANTAGES</u>

1. Low power requirements.
2. Large air handling capacity.
3. Low cost and durable.
4. Indefinite storage capabilities except in extremely moist areas.
5. Simple operation, and readily convertible from supply to exhaust configuration and vice versa.
6. Simple construction and can be constructed of materials which are readily available anywhere.
7. In addition to being used as the prime air supply or exhaust device to a shelter, punkahs can be used to provide a more equitable distribution of available air in the shelter.

b. DISADVANTAGES

1. Possible misunderstanding by the uninitiated in the proper application of the punkah in various shelter configurations.

2. Obstruction to access through door openings in shelters.

4.1.1 Full Door Sized (6 ft.) Punkah. The full door sized punkah, when used as the prime air moving device in the shelter, was capable of circulating large volumes of air requiring very small power requirements (4600 cfm at 0.04 to 0.05 Hp.). In conjunctionwith side baffles, there was a definite improvement in the air moving capacity of the punkah. The baffles also act as safety guards, preventing shelter occupants from accidentally being struck with the swinging punkah.

4.1.2 Push-Pull and 3 Foot Punkahs. The push-pull and 3 ft. punkahs produced significant beneficial effects in siderooms; i.e., rooms with single access openings. These devices may also be used to distribute air within a shelter and substantially enhance the comfort of the occupants by moving air over the occupants body. The comparison of high or low mounting of the 3 foot punkah in doorways did not result in any significant findings.

4.1.3 Baffles. Horizontal baffles installed in the doorways to the siderooms, approximately 42 in. above the floor and extending from 2 to 4 ft. both inside and outside the rooms, had a slightly beneficial effect on the environmental conditions in the rooms when used together with the 3 ft. punkahs mounted both in the upper and lower half of the doorways. Effective temperatures were observed to be reduced from 0.2 of a degree to

1.5 degrees with individual shelter rooms. The size of the horizontal baffles appeared to be of relatively little significance; i.e., 2 ft by 3 ft baffles had nearly the same effect as those 4 ft by 4 ft.

4.1.4 Air Distribution and Velocity Patterns. Observations were made of the air distribution and velocity patterns within all shelter rooms for the various shelter configurations and ventilation rates. It was noted that punkahs have a significant influence on air distribution and air movement within a shelter. Also, that the air flow rate caused by natural convection currents, in rooms with only a single door opening, was independent of the room size. However, the size of the door opening and the temperature difference between inlet and outlet air influenced the flow. For rooms with the same size door opening, the larger room would be the warmest because of the larger internal heat load. This is true because the internal load was applied on a square foot basis, therefore, the larger the room, the larger the load. The same conditions were found when punkahs of a given capacity were used in the doorways to these same rooms.

It appears series air flow; i.e., where the total quantity of ventilating air supplied to a shelter moves in sequence from one room to another, is an efficient ventilation arrangement. The maximum number of usable shelter spaces was gained with this configuration, based on an average effective temperature not exceeding 85 degrees.

Observations made of the static pressure fluctuations within the shelter room throughout the test, produced no significant results except for the tests involving the capacity of the 6 ft. door punkah.

Due to deficiencies noted in the tracer gas method, there are wide discrepancies in the air flow rate calculations for the shelter rooms. Resolution of these difficulties was not possible under the tight time schedule imposed for the test program.

4.2 RECOMMENDATIONS

1. That consideration be given to the feasibility of including the punkah as a Civil Defense stock item.

2. That wherever feasible, punkahs be provided as a ventilating device to increase shelter capacity, improve shelter environment, and make available otherwise unusable shelter spaces.

REFERENCES

1. ASHRAE Guide and Data Book, Fundamentals and Equipment, 1965-66, Chapter 7.

2. ASHRAE Guide and Data Book, Applications, 1964, Chapter 3.

3. Taylor, D. W., Gonzales, J. O. (University of Florida), PSDC-TR-17, Air Distribution in a Multi-Room Shelter Using a Package Ventilation Kit prepared for Protective Structures Development Center, Fort Belvoir, Virginia.

4. Svaeri, O. W., PSDC-TR-6, Evaluation of 200-Person Shelter (Ventilation) AD 615640, Protective Structures Development Center, Fort Belvoir, Virginia.

5. Kearny, C. H., ORNL-TM-1155, Mechanized Durability Tests of a Six-Foot Punkah - Pump, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

6. Kearny, C. H., ORNL-TM-1154, Manual Shelter-Ventilating Devices for Crowded Shelters Cooled by Outside Air - A Preliminary Report, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

7. Kearny, C. H., How to Make a Home-made, Large-Volume, Efficient Fallout Shelter Ventilating Pump: The Punkah-Pump, Privately printed by C. H. Kearny, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

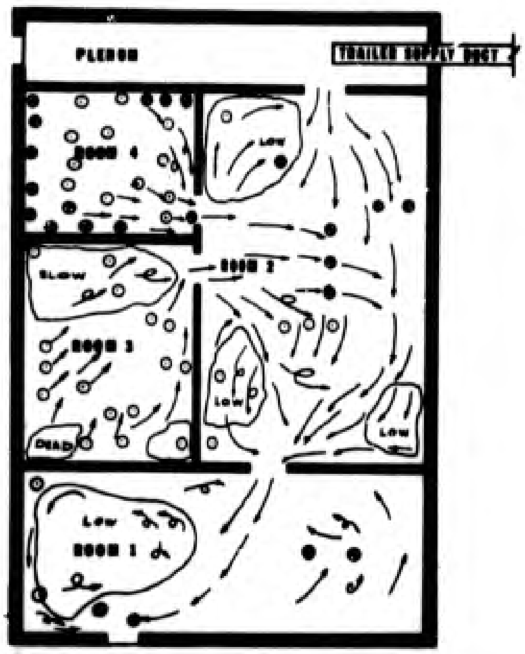
APPENDIX A

SHELTER VELOCITY PATTERNS

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 3 CFM/OCC. 13.5 COND. AVG.

REMARKS: No provisions. Room 1 not traversed since the velocity patterns would be identical to traverses made previously. See Test 50 for typical air flow patterns in Room 1.



HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 3 CFM/OCC 13.5 COND. AVG.

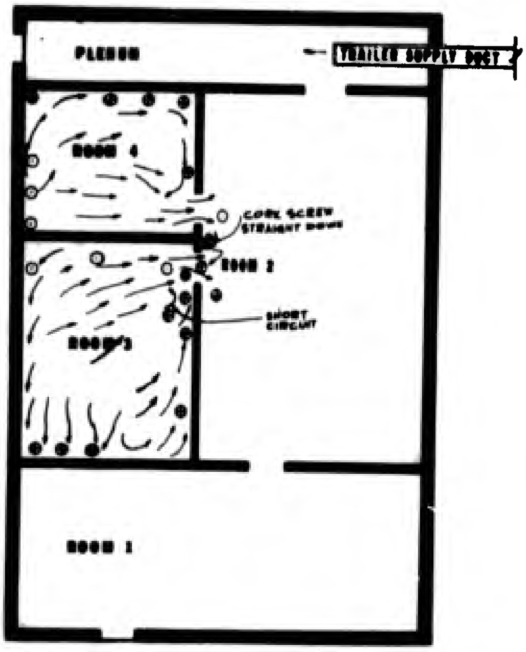
REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 4 CFM/OCC 13.5 COND. AVG.

REMARKS: With 3' punkahs mounted low in doors to Rooms 3 and 4. Rooms 2 and 1 not traversed.

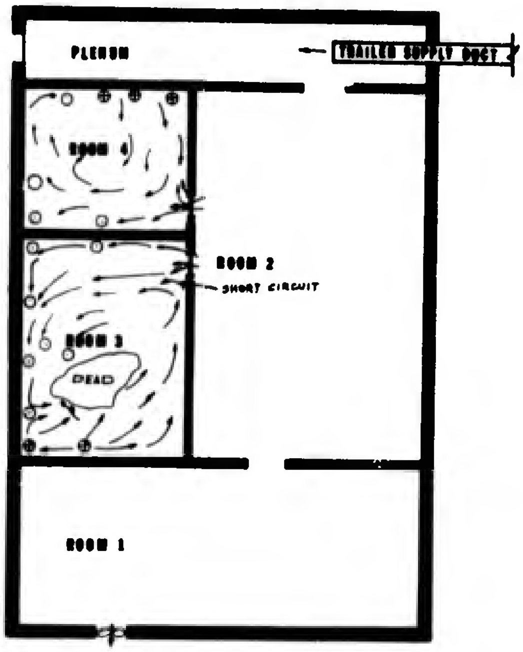


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 4 CFM/OCC 13.5 COND. AVG.

REMARKS:

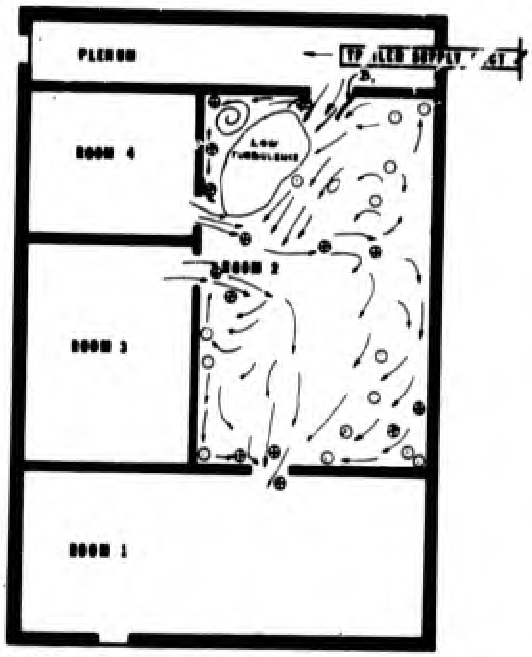


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 5 CFM/OCC 13.5 COND. AVG.

REMARKS: With 3'x7' baffle (B_1) and punkahs in lower half of doors to Rooms 3 and 4.

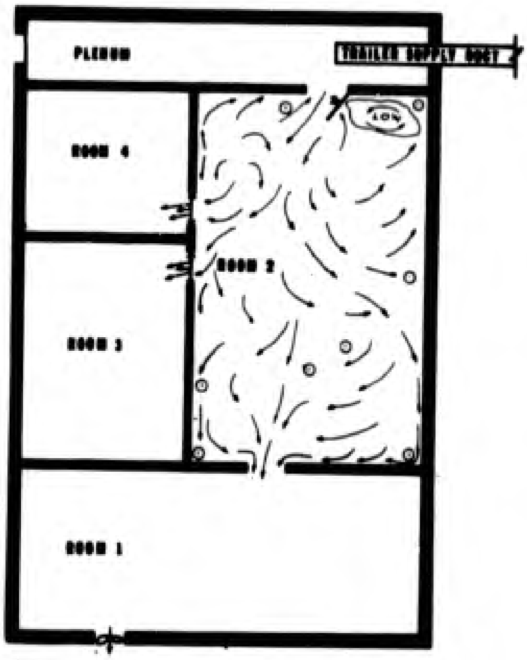


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Sept. TEST NO. 5 CFM/OCC 13.5 COND. AVG.

REMARKS:

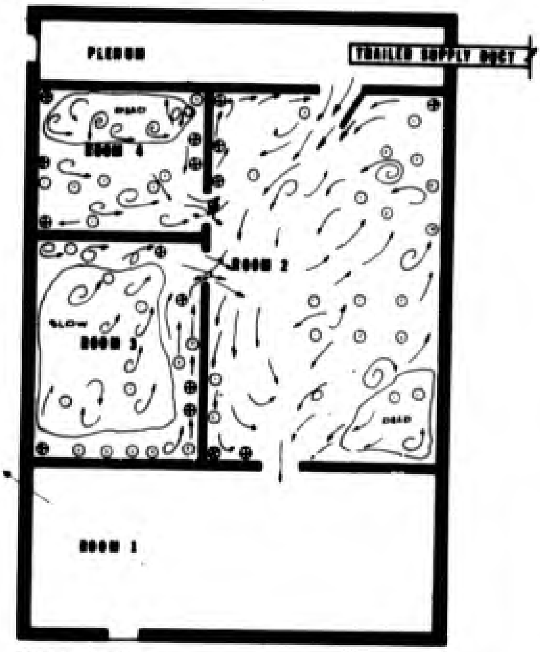


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Sept. TEST NO. 7 CFM/OCC 13.5 COND. MAX.

REMARKS: With inlet baffle (B_1) in Room 2. Room 1 not traversed since no changes in previously obtained patterns are anticipated.

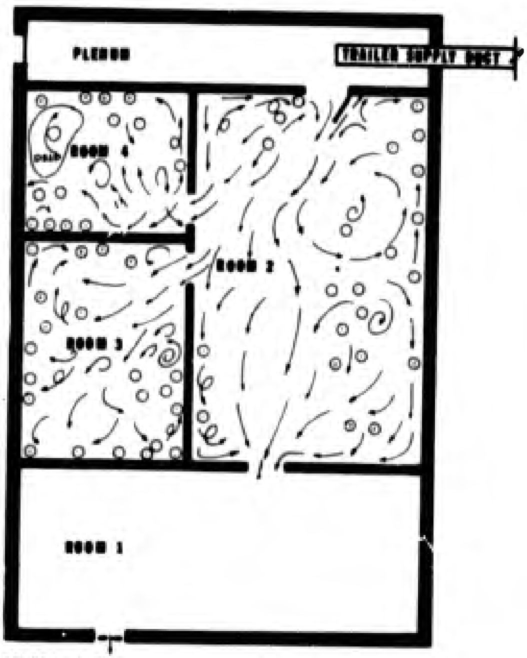


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Sept. TEST NO. 7 CFM/OCC 13.5 COND. MAX.

REMARKS:

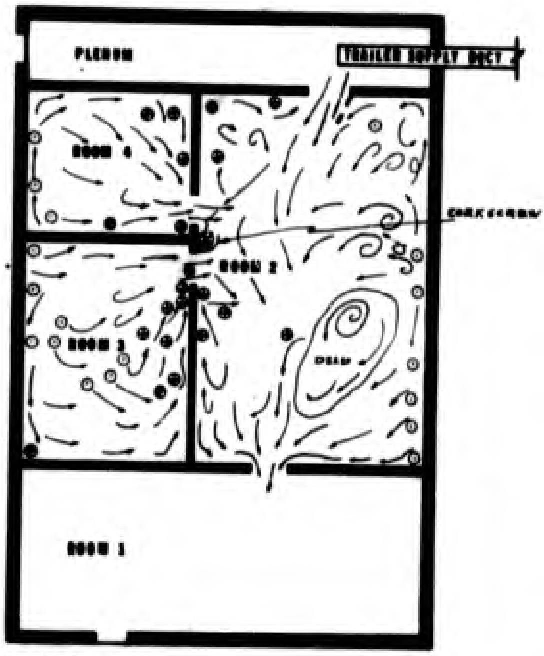


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Sept. TEST NO. 8 CFM/OCC 11.5 COND. MAX

REMARKS: 3' punkahs mounted low in doors to Rooms 3 and 4. Baffle B_1 in place, Room 2. Room 1 not traversed since no change in pattern anticipated.

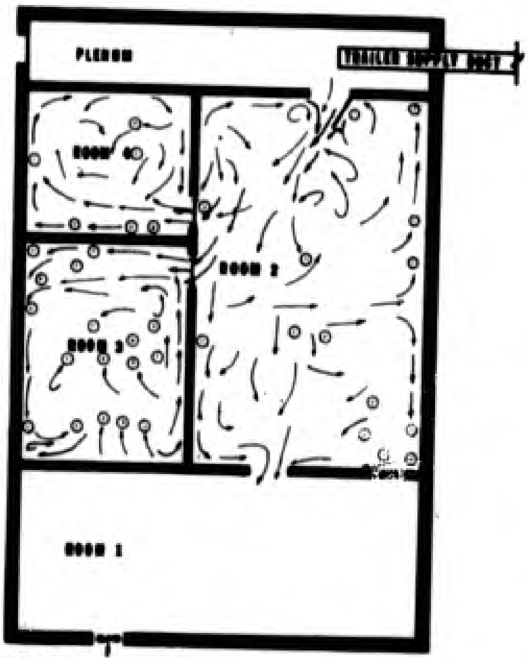


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Sept. TEST NO. 8 CFM/OCC 11.5 COND. MAX.

REMARKS:

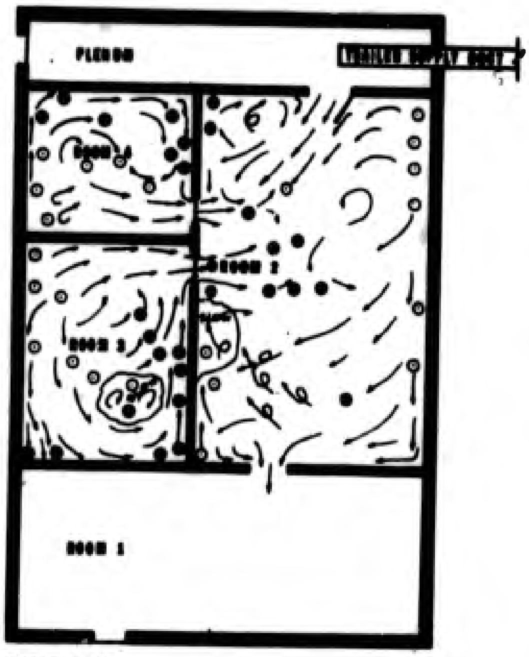


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 10 Sept. TEST NO. 10 CFM/OCC 11.5 COND. MAX.

REMARKS: 3' Punkahs high in doorways to Rooms 3 and 4. Baffle B_1 in place - Room 2.



HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 10 Sept. TEST NO. 10 CFM/OCC 11.5 COND. MAX.

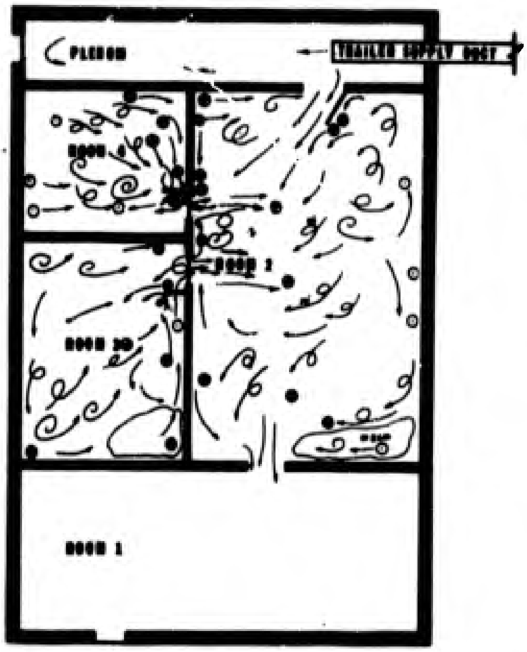
REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 15 Sept. TEST NO. 11 CFM/OCC 13.5 COND. MAX.

REMARKS: Baffle B1 in door, Room 2. 3' Punkahs high in Rooms 3 and 4. 3'x4' baffles on floor inside Rooms 3 and 4 on side of door openings.

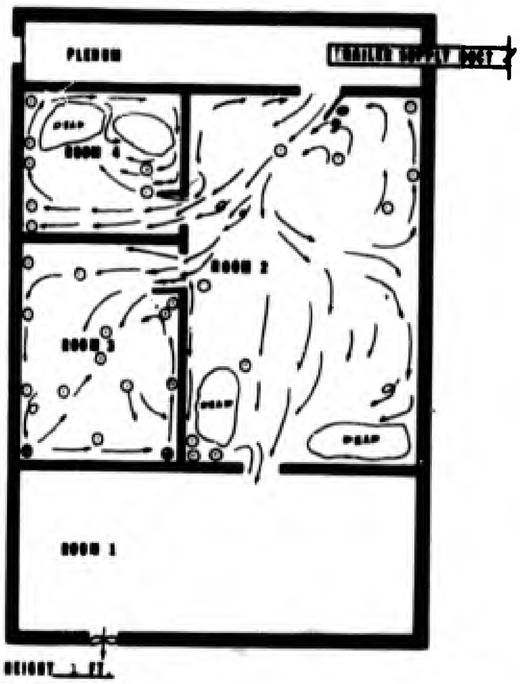


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 15 Sept. TEST NO. 11 CFM/OCC 13.5 COND. MAX.

REMARKS:

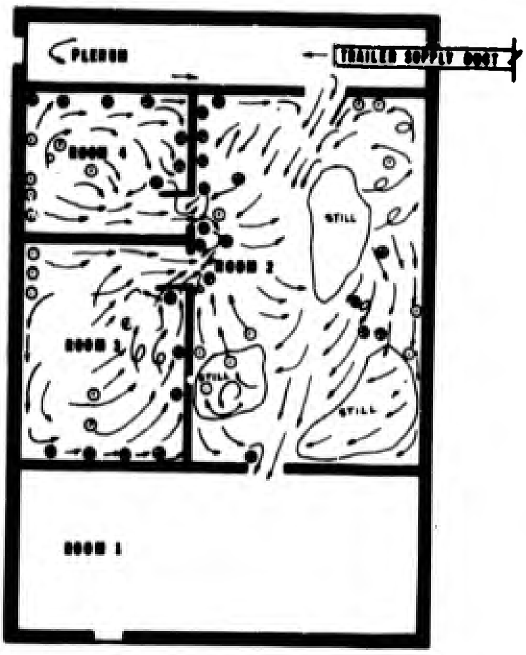


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Sept. TEST NO. 15 CFM/OCC 13.5 COND. MAX.

REMARKS: Baffle B1 in door, Room 2; 3' punkahs mounted low in doorways to Rooms 3 and 4. 3'x4' baffle near floor to the side of door openings inside Rooms 3 and 4.



HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Sept. TEST NO. 15 CFM/OCC 13.5 COND. MAX.

REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Dec. **TEST NO.** 24 **CFM/OCC** 11 **COND.** AVG.

REMARKS: Full size door punkah operating - exhaust configuration with inlet and outlet side baffles. Push-pull punkahs not operating. Trailer and auxiliary fan supplying air to plenum.

HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Dec. **TEST NO.** 24 **CFM/OCC** 11 **COND.** AVG.

REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Dec. **TEST NO.** 25 **CFM/OCC** 11 **COND.** AVG.

REMARKS: Full size door punkah - exhaust configuration. Inlet and outlet side baffles. Push-pull punkahs in Rooms 3 and 4. As compared to Test 24, air circulation in Rooms 3 and 4 was substantially improved due to push-pull punkahs.

HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 9 Dec. **TEST NO.** 25 **CFM/OCC** 11 **COND.** AVG.

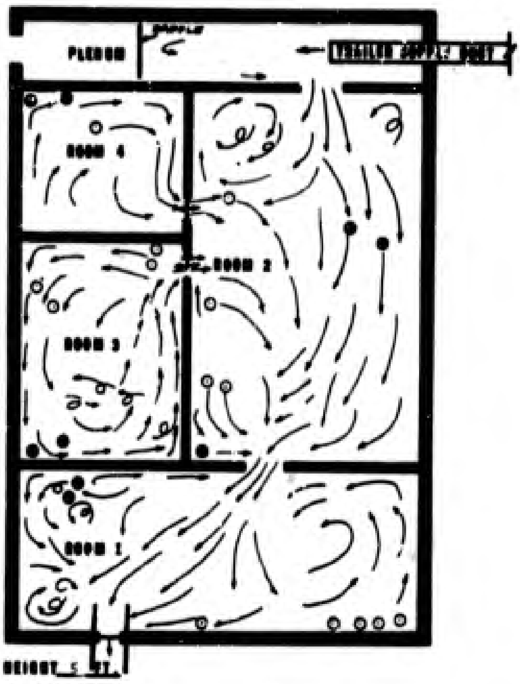
REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 10 Dec. TEST NO. 26 CFM/OCC 41 COND. AVG.

REMARKS: Full size door punkah - exhaust configuration. Inlet and outlet side baffles. Push-pull punkahs in Rooms 3 and 4. Baffle in plenum.

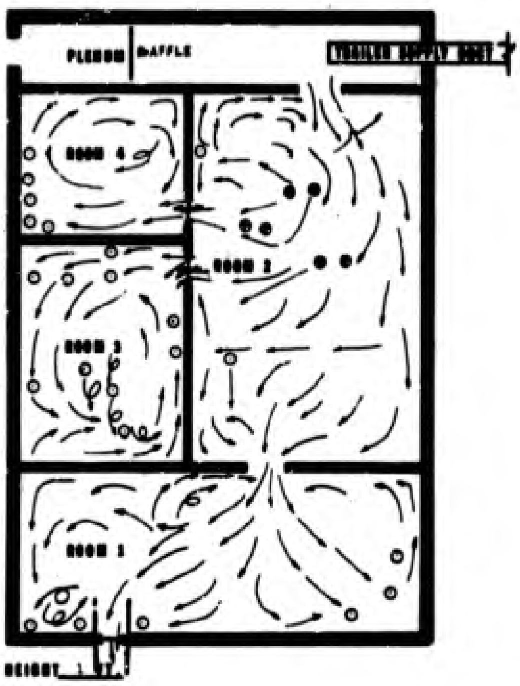


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 10 Dec. TEST NO. 16 CFM/OCC 41 COND. AVG.

REMARKS:

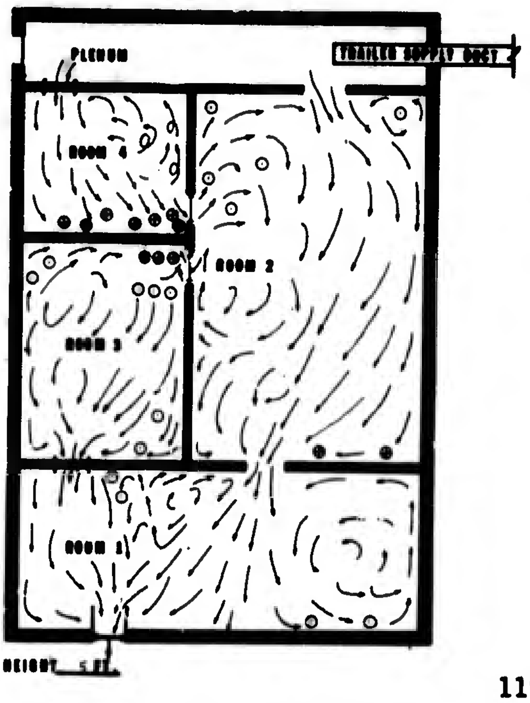


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Dec. TEST NO. 29 CFM/OCC 41 COND. MAX.

REMARKS: Parallel air flow. Main exhaust punkah in operation. Push-pull punkahs not operating just blocking doorways to Rooms 3 and 4. Ventilation windows in use, Rooms 4, 3 and 1.

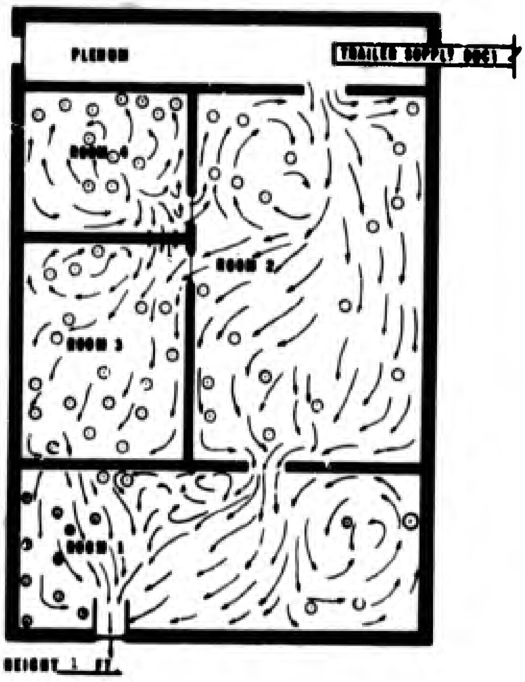


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Dec. TEST NO. 29 CFM/OCC 41 COND. MAX.

REMARKS:

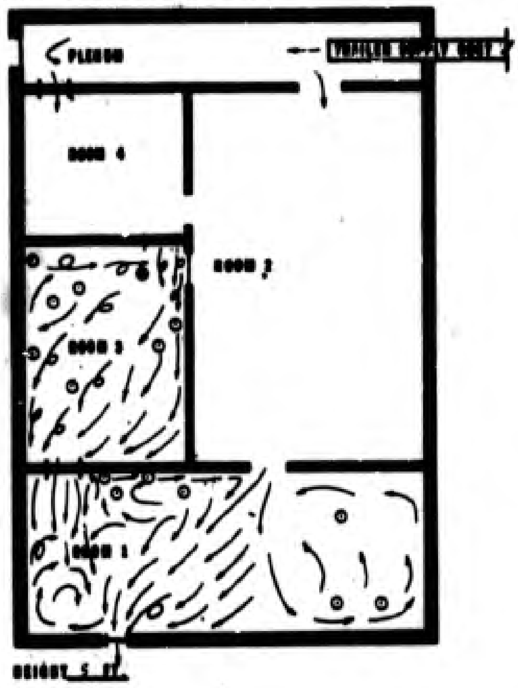


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 21 Dec. **TEST NO.** 30 **CFM/OCC** 3000 **COND.** MAX.

REMARKS: Parallel air flow thru "windows" in partitions to Rooms 1, 3 and 4. 6' exhaust punkah operating - no side baffles. Velocity patterns in Rooms 4 and 2 same as for Test 29.

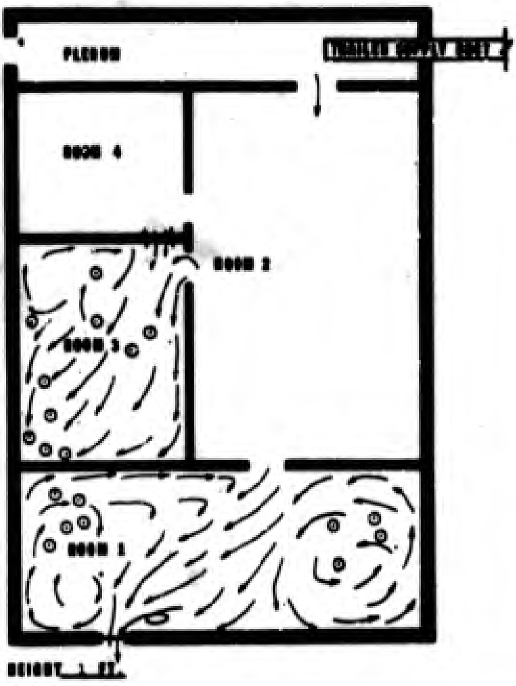


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 21 Dec. **TEST NO.** 30 **CFM/OCC** 3000 **COND.** MAX.

REMARKS:

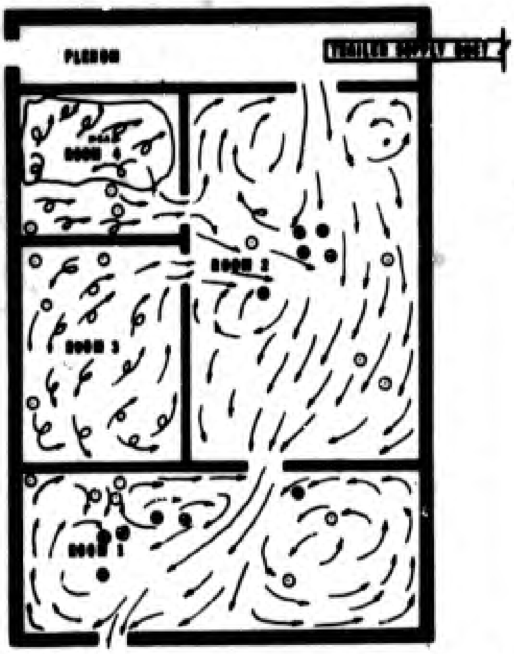


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 22 Dec. **TEST NO.** 31 **CFM/OCC** 3000 **COND.** MAX.

REMARKS: Maximum condition - no punkahs operating. All punkahs propped open in side room doorways and exhaust door in Room 1. No baffles. Compare with traverse made at 1400 hours.



Very little air flow in both Rooms 3 and 4.

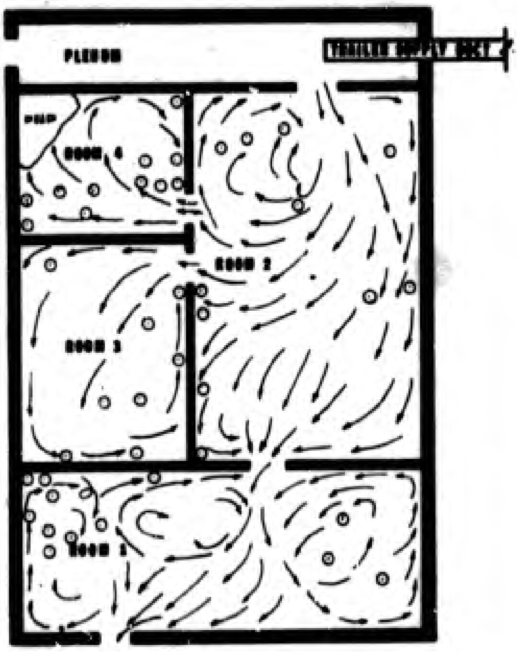
HEIGHT 5 FT.

TIME 0930 Hours.

SHELTER VELOCITY PATTERNS

DATE: 22 Dec. **TEST NO.** 31 **CFM/OCC** 3000 **COND.** MAX.

REMARKS:



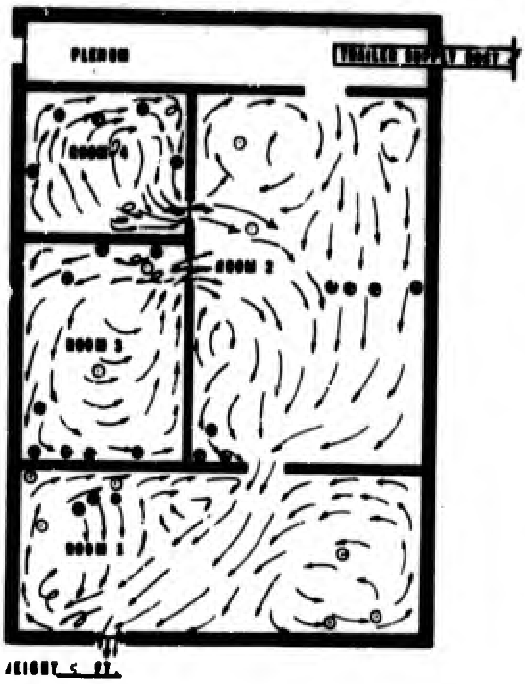
Very little air flow in both Rooms 3 and 4.

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 22 Dec. TEST NO. 11 CFM/OCC 3000 COND. MAX.

REMARKS: Maximum conditions. Push-pull and main exhaust punkahs in operation. No baffles. Compare with traverse made at 0930 hours.



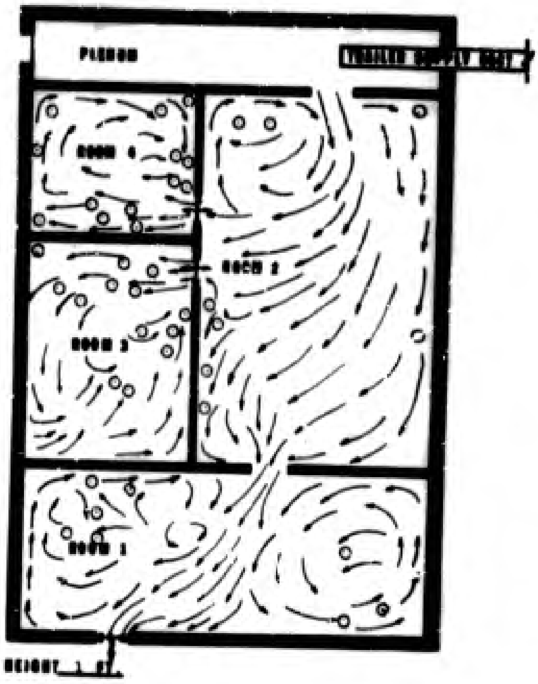
HEIGHT 5 FT.

TIME 1100 Hours

SHELTER VELOCITY PATTERNS

DATE: 22 Dec. TEST NO. 11 CFM/OCC 3000 COND. MAX.

REMARKS:

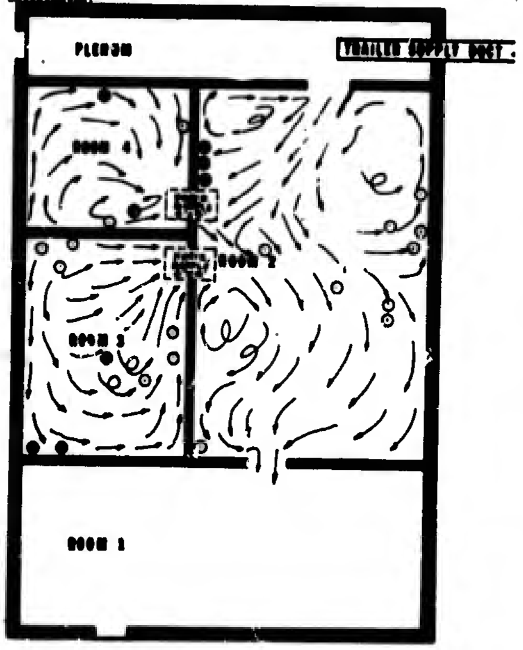


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Mar. TEST NO. 10 CFM/OCC 18.0 COND. MIN.

REMARKS: Push-pull punkah operating, baffle B1 in place, horizonta (4'x4') baffles in place inside and outside Rooms 3 and 4. Traverse n made at Room 1 because no significant difference in air flow patterns anticipated.

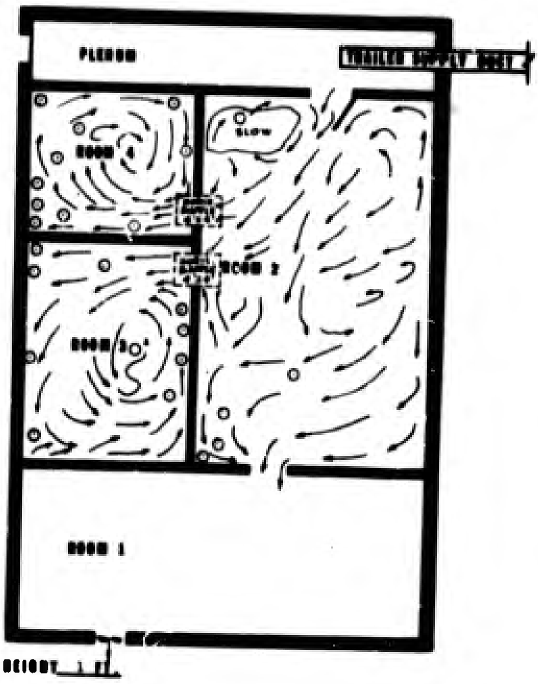


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Mar. TEST NO. 10 CFM/OCC 18.0 COND. MIN.

REMARKS:

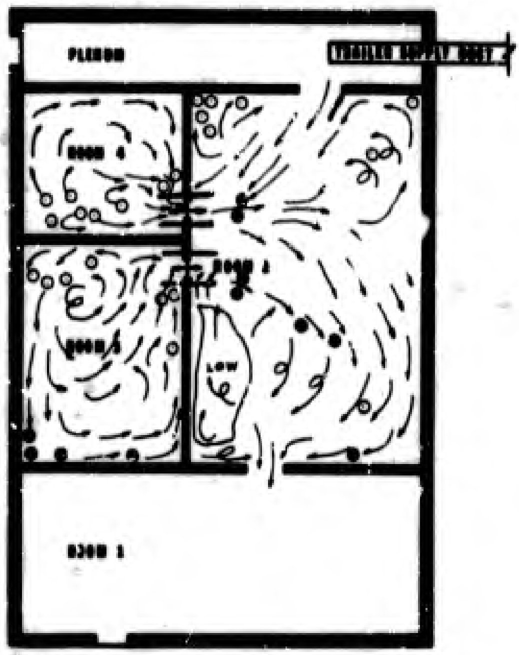


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Mar. TEST NO. 10 CFM/OCC 18.0 COND. MIN.

REMARKS: Push-pull punkahs operating, baffle B1 in place. 3'x7' side baffles inside and outside Rooms 3 and 4. Room 1 not traversed since no change is deemed probable.

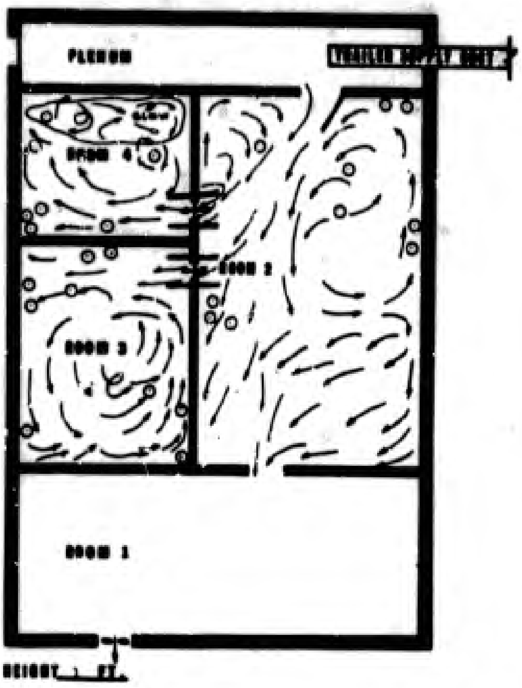


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 8 Mar. TEST NO. 10 CFM/OCC 18.0 COND. MIN.

REMARKS:

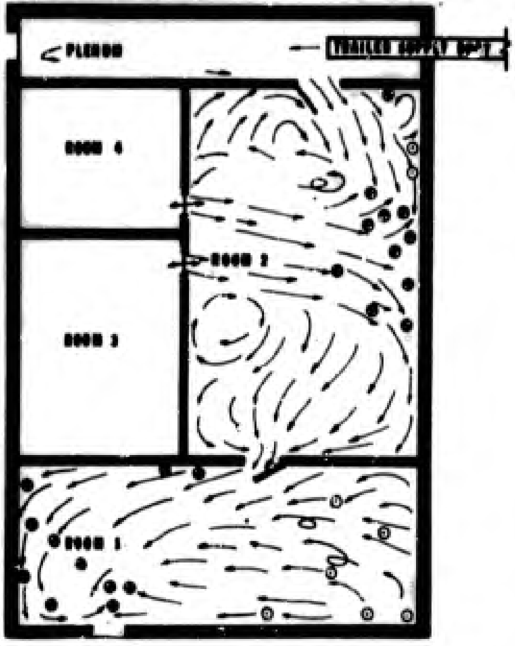


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Mar. TEST NO. 16 CFM/OCC 22.5 COND. AVG.

REMARKS: Push-Pul. punkahs operating. Installed 30"x39" cross baffles in Rooms 1 and 2 - top half facing north, bottom half facing south. Did not traverse Rooms 3 and 4 because no change in air patterns expected.

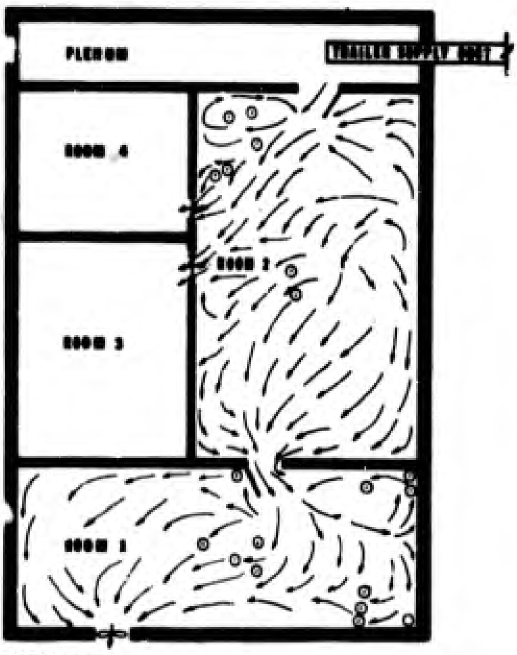


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 16 Mar. TEST NO. 16 CFM/OCC 22.5 COND. AVG.

REMARKS:

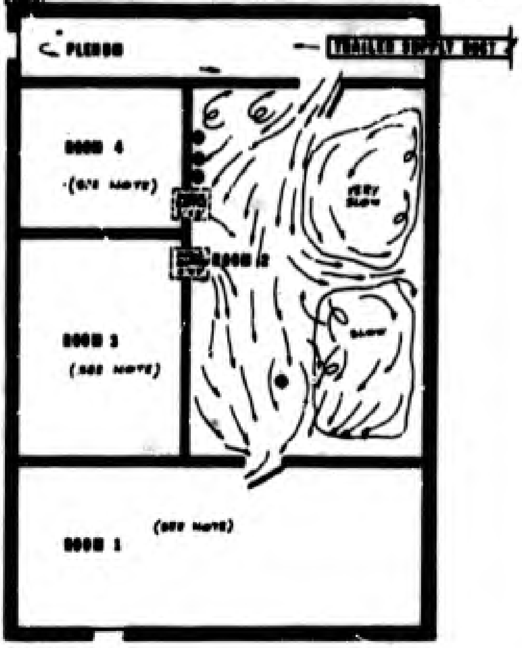


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. **TEST NO.** 50 **CFM/OCC** 22.5 **COND.** MIN.

REMARKS: Compare this traverse with traverse taken at 1225 hours to observe effect in Room 2 of cross baffle in Room 1, if any. Baffle B_1 in place. 2'x3' horiz. baffles inside and outside Rooms 3 and 4. Cross baffle in Room 1 in place.



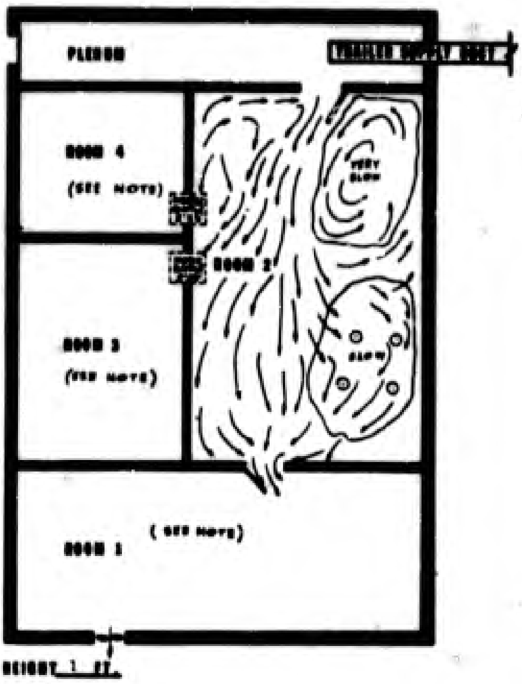
HEIGHT 5 FT.

TIME 1015 Hours

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. **TEST NO.** 50 **CFM/OCC** 22.5 **COND.** MIN.

REMARKS:



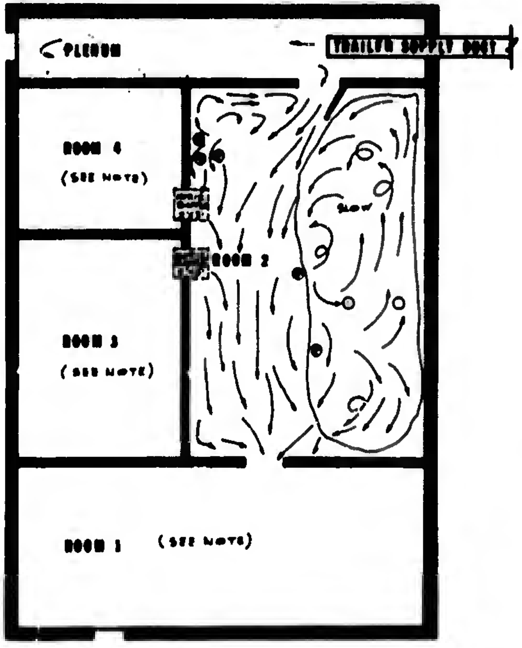
HEIGHT 1 FT.

TIME 1015 Hours

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. **TEST NO.** 50 **CFM/OCC** 22.5 **COND.** MIN.

REMARKS: Compare this traverse with traverse taken at 1015 hours to observe effect in Room 2 of cross baffle in Room 1, if any. Baffle B_1 in place. 2'x3' horiz. baffles inside and outside Rooms 3 and 4. Cross baffle in Room 1 removed



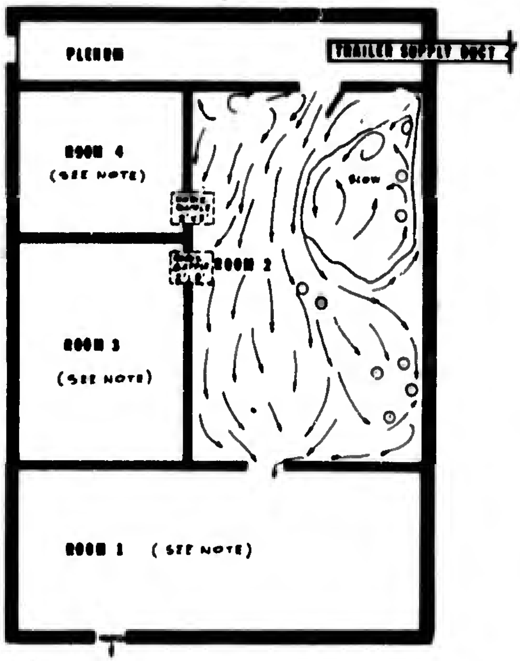
HEIGHT 5 FT.

TIME 1225 Hours

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. **TEST NO.** 50 **CFM/OCC** 22.5 **COND.** MIN.

REMARKS:



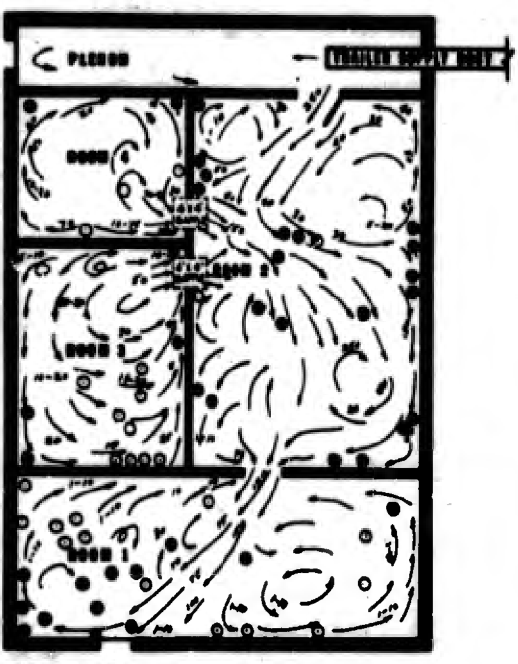
HEIGHT 1 FT.

TIME 1225 Hours

SHELTER VELOCITY PATTERNS

DATE: 4 Mar. TEST NO. 52 CFM/OCC 18 COND. AM.

REMARKS: 3' punkahs operating high in doors to Rooms 3 and 4. 4'x4' horizontal baffles and baffle B_1 in place.



HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 4 Mar. TEST NO. 52 CFM/OCC 18 COND. AM.

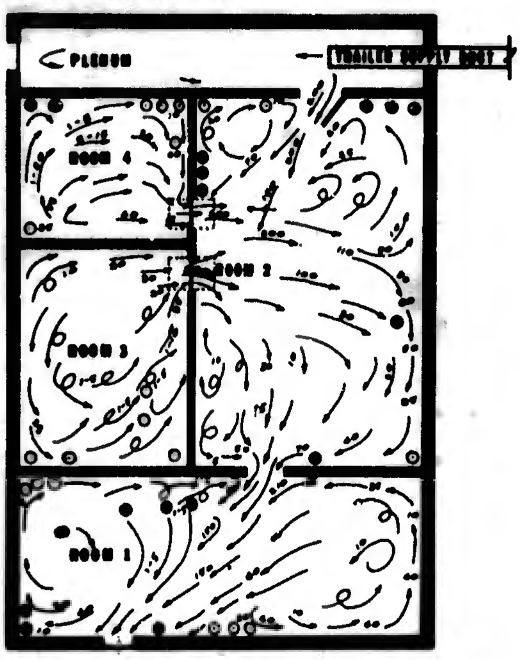
REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. TEST NO. 50 CFM/OCC 22.5 COND. MM

REMARKS: Velocity magnitude test - entire shelter. Maximum air flow. Baffle B_1 in place. 3' punkahs operating - high. 2'x3' horizontal baffles inside and outside Rooms 3 and 4.



HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 22 Mar. TEST NO. 50 CFM/OCC 22.5 COND. MM

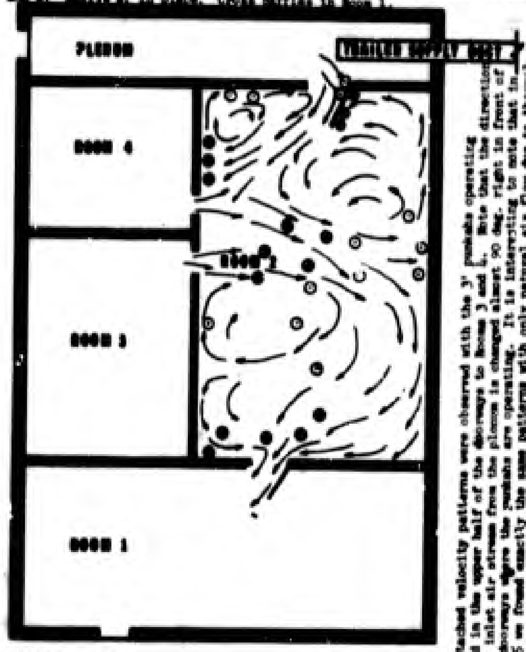
REMARKS:

HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 28 Mar. TEST NO. 54 CFM/OCC 18 COND. MIN.

REMARKS: Test with window size air inlet opening between plenum and Room 2. Doorway between plenum and Room 2 reduced to window size (48"x30"). 3' punkahs operating in doorways to Rooms 3 and 4. Horizontal baffles outside Rooms 3 and 4. Baffle B_1 in place. Cross baffles in Room 1.



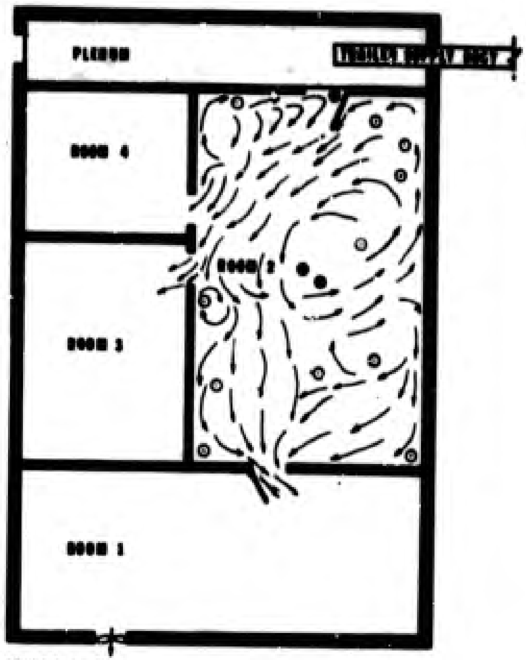
HEIGHT 5 FT.

NOTE: The attached velocity patterns were observed with the 3' punkahs operating mounted in the upper half of the doorways to Rooms 3 and 4. Note that the direction of the inlet air stream from the plenum is changed almost 90 deg. right in front of these doorways where the punkahs are operating. It is interesting to note that in Test 55 we found exactly the same patterns with only natural air flow due to thermal convection currents. The velocities were of smaller magnitudes but the patterns were the same. This may in part be contributed to the fact that the air flow had been changed from 18 cfm/occ. during Test 54 to 13.5 cfm/occ. for Test 55.

SHELTER VELOCITY PATTERNS

DATE: 28 Mar. TEST NO. 54 CFM/OCC 18 COND. MIN.

REMARKS:

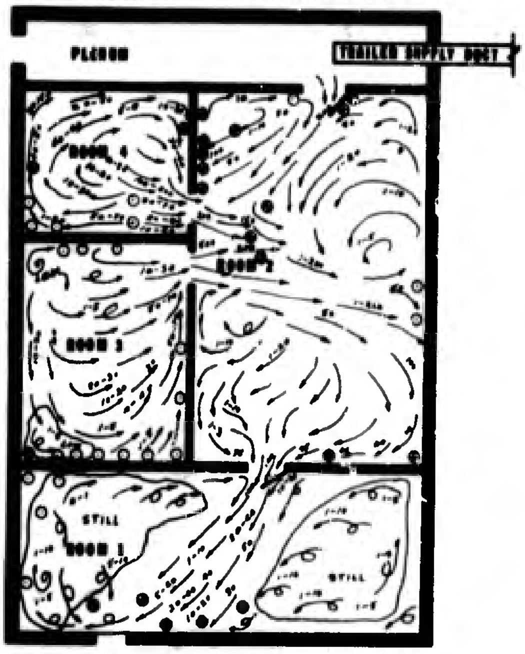


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 29 Mar. TEST NO. 55 CFM/OCC 13.5 COND. MIN.

REMARKS: Baffle B_1 in place. 3' punkahs high in doorways to Rooms 3 and 4. 2'x3' horizontal baffles inside and outside Rooms 3 and 4. Cracks between horizontal baffles covered. Cross baffles in Room 1.

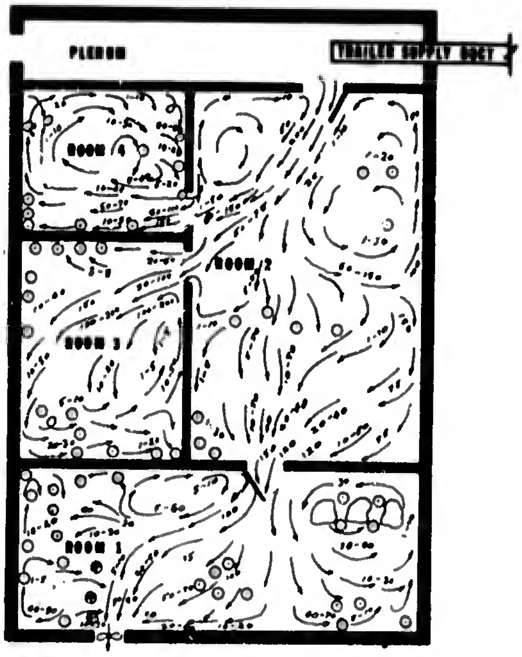


HEIGHT 5 FT.

SHELTER VELOCITY PATTERNS

DATE: 29 Mar. TEST NO. 55 CFM/OCC 13.5 COND. MIN.

REMARKS:

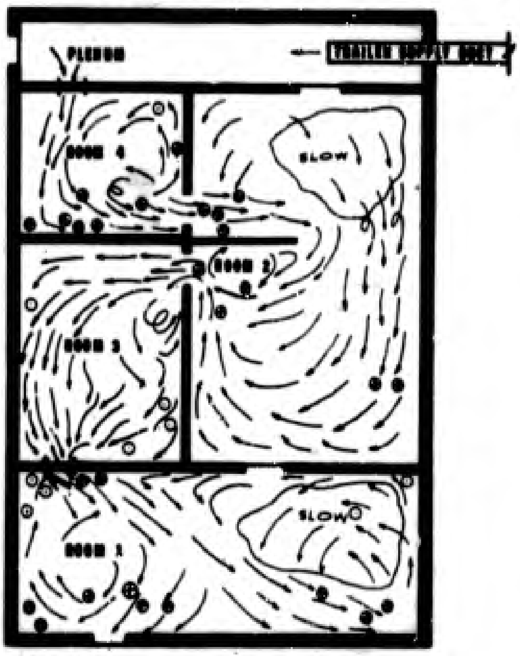


HEIGHT 1 FT.

SHELTER VELOCITY PATTERNS

DATE: 1 Apr. **TEST NO.** 58 **CFM/OCC** 11.5 **COND.** MAX.

REMARKS: Series air flow. Air entering thru "window" in Room 4. 8'x8' baffle in Room 2, 45° baffle in Room 1. Door between plenum and Room 2 and door between Rooms 1 and 2 blocked.

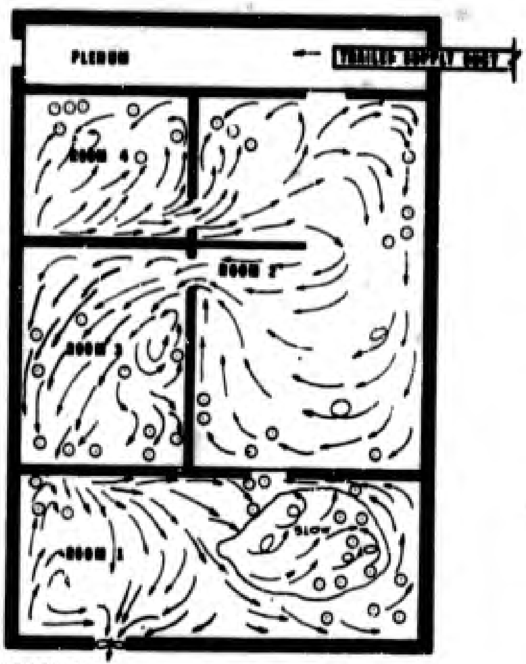


HEIGHT 5 **FT.**

SHELTER VELOCITY PATTERNS

DATE: 1 Apr. **TEST NO.** 58 **CFM/OCC** 11.5 **COND.** MAX.

REMARKS:

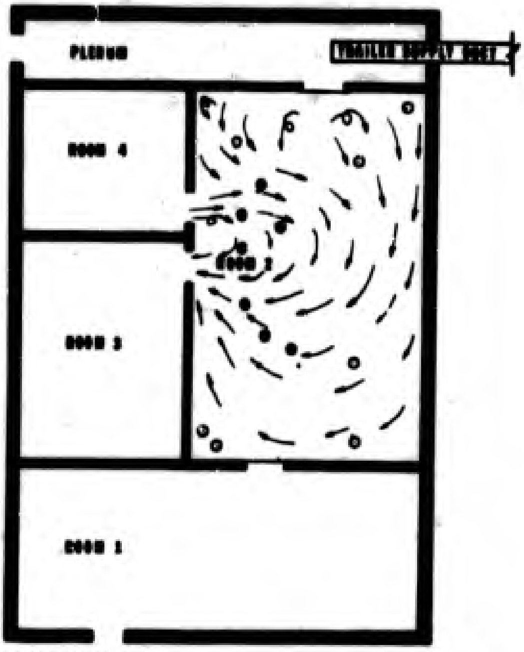


HEIGHT 1 **FT.**

SHELTER VELOCITY PATTERNS

DATE: 4 Apr. **TEST NO.** 59 **CFM/OCC** 11.5 **COND.** NONE

REMARKS: Series air flow - without the large baffle in Room 2. Unconditioned air.

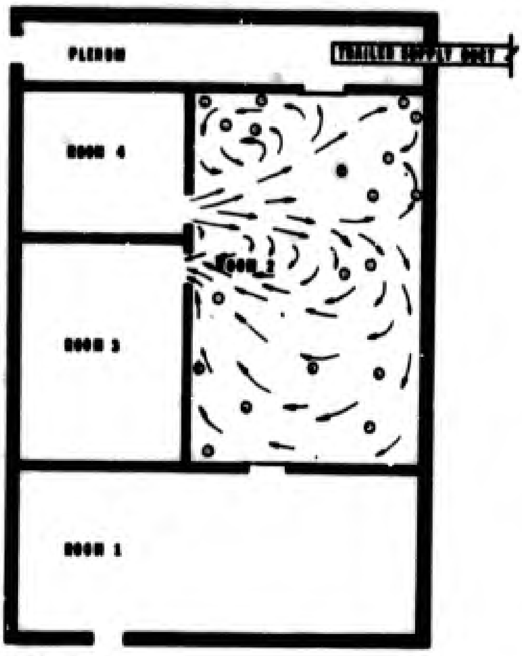


HEIGHT 5 **FT.**

SHELTER VELOCITY PATTERNS

DATE: 4 Apr. **TEST NO.** 59 **CFM/OCC** 11.5 **COND.** NONE

REMARKS:



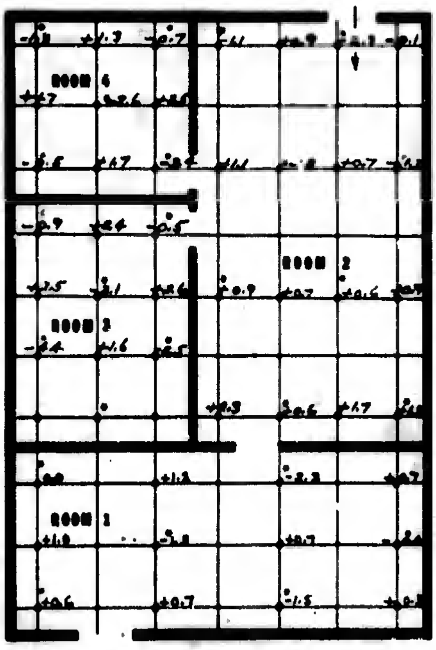
HEIGHT 1 **FT.**

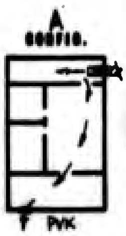
APPENDIX B

SHELTER EFFECTING TEMPERATURES PATTERNS

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 1(10:22) CONFIG. NO. A COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 81.2
AVG. E.T. OF ROOM 1 82.5 2 79.3 3 82.5 4 81.5



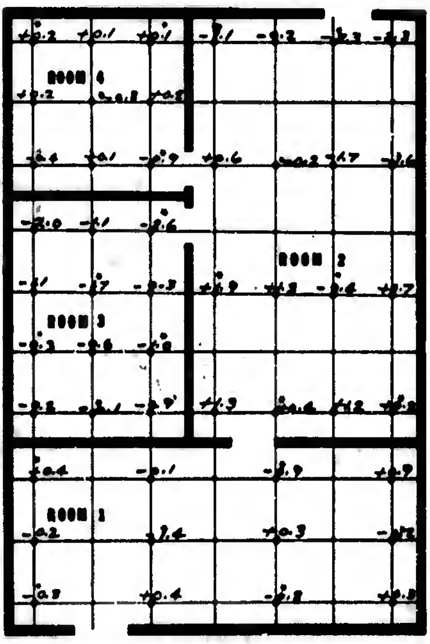


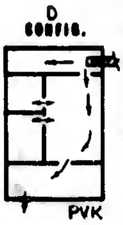
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 2 CONFIG. NO. D COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 81.5
AVG. E.T. OF ROOM 1 82.7 2 78.7 3 84.1 4 80.9



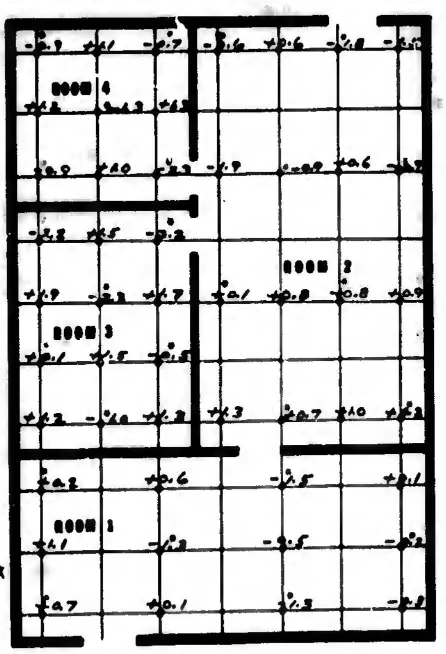


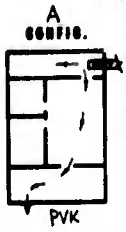
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 3(10:40) CONFIG. NO. A COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 84.9
AVG. E.T. OF ROOM 1 86.4 2 82.3 3 86 4 84.8



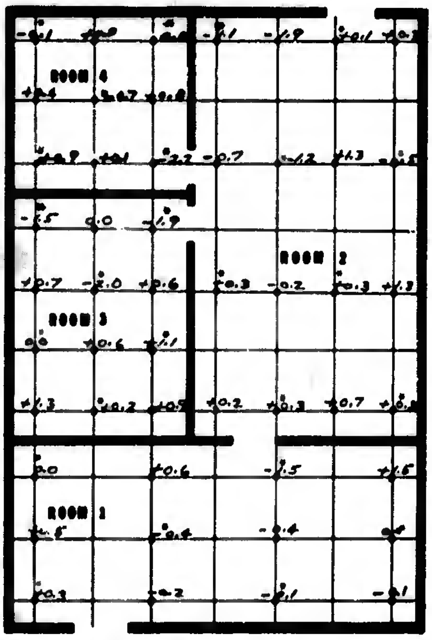


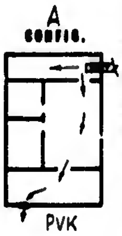
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 7 CONFIG. NO. A COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 88.2
AVG. E.T. OF ROOM 1 88.9 2 83.7 3 90 4 90.1



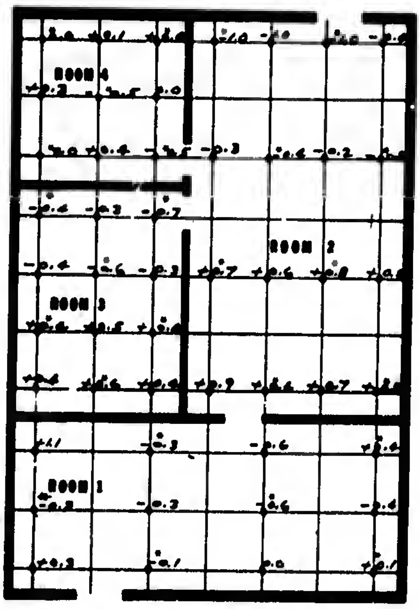


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

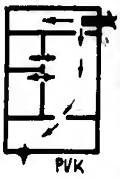
*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 8 (13:00) CONFIG. NO. E COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.8
AVG. E.T. OF ROOM 1 88.5 2 87.2 3 88.5 4 87



E
CONFIG.

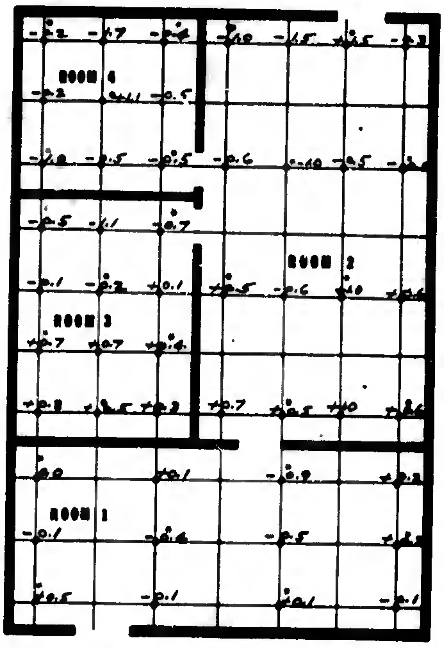


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

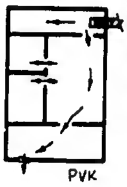
*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 12 CONFIG. NO. D COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.3
AVG. E.T. OF ROOM 1 88 2 86.5 3 88. 4 87



D
CONFIG.

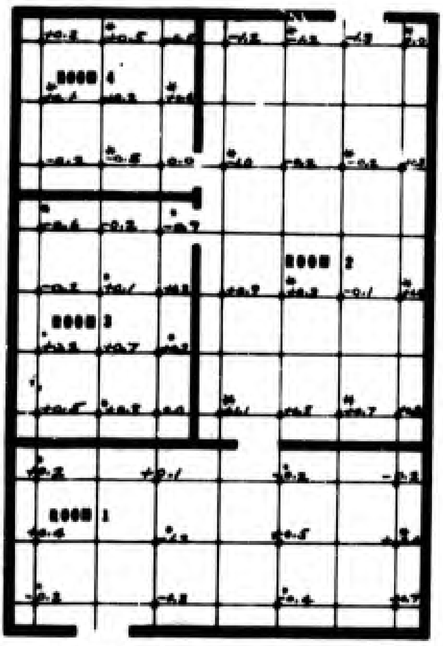


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 15 CONFIG. NO. E COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.2
AVG. E.T. OF ROOM 1 88.3 2 86.2 3 88.3 4 86.6



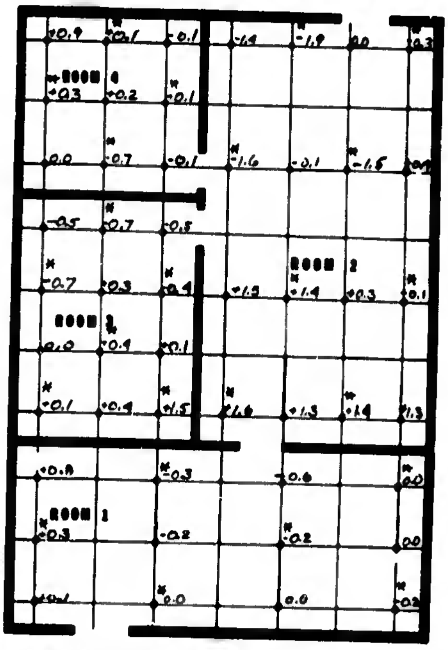
E
CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

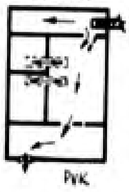
*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 17 CONFIG. NO. F COND. AVG.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 85
AVG. E.T. OF ROOM 1 86 2 83.5 3 86.5 4 85.



F
CONFIG.

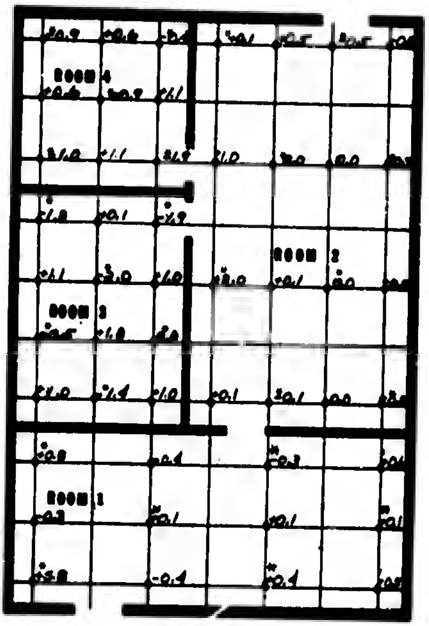


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 24 CONFIG. NO. B COND. AVE.
VENTILATION RATE 41 CFM/OCC
OVERALL AVG. SHELTER E.T. 82.9
AVG. E.T. OF ROOM 1 82.4 2 82. 3 85. 4 83.9

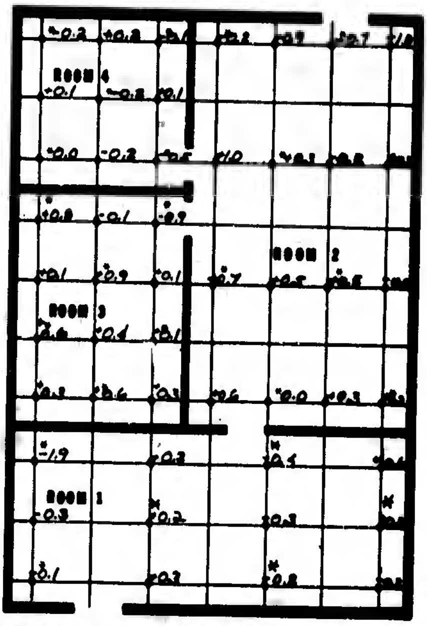


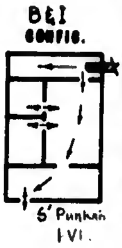
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 25 CONFIG. NO. B&I COND. AVE.
VENTILATION RATE 41 CFM/OCC
OVERALL AVG. SHELTER E.T. 82.4
AVG. E.T. OF ROOM 1 82.3 2 81.5 3 83.7 4 83.



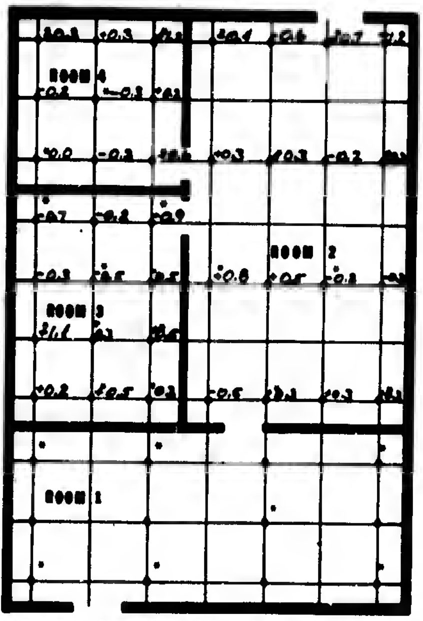


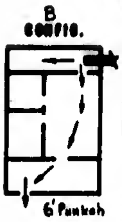
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 26 CONFIG. NO. B COND. AVE
VENTILATION RATE 41 CFM/OCC
OVERALL AVG. SHELTER E.T. 82.2
AVG. E.T. OF ROOM 1 – 2 81.7 3 83.7 4 82.8



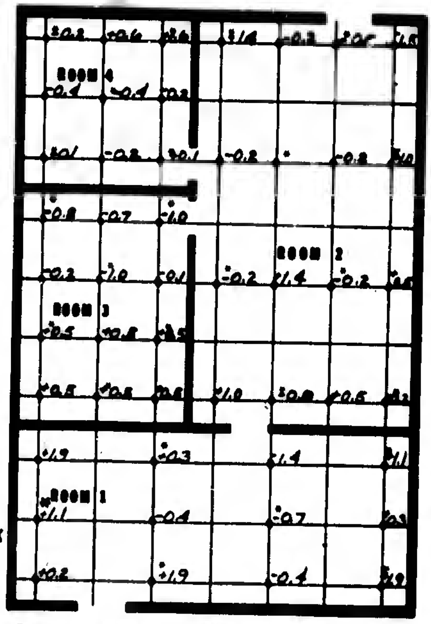


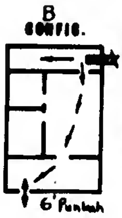
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 27 CONFIG. NO. B COND. MIN.
VENTILATION RATE 41 CFM/OCC
OVERALL AVG. SHELTER E.T.
AVG. E.T. OF ROOM 1 78.9 2 77.5 3 80. 4 79.4



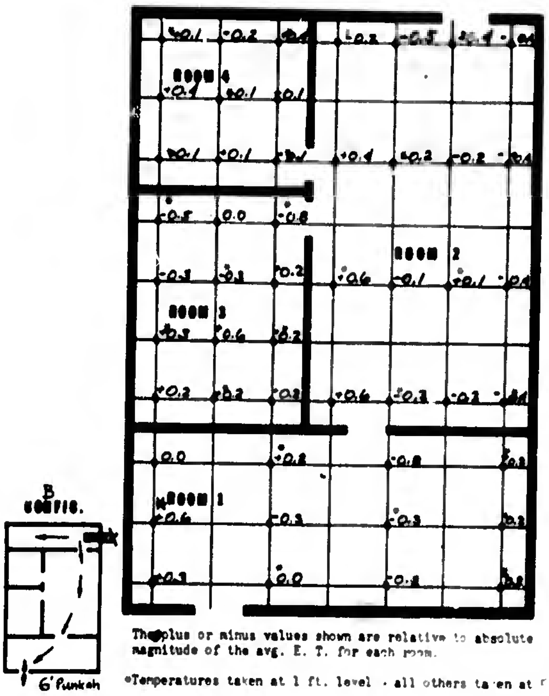


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 28 CONFIG. NO. B COND. MAX.
VENTILATION RATE 40 CFM/OCC
OVERALL AVG. SHELTER E.T. 85.8
AVG. E.T. OF ROOM 1 85.8 2 85.4 3 86.8 4 86.1

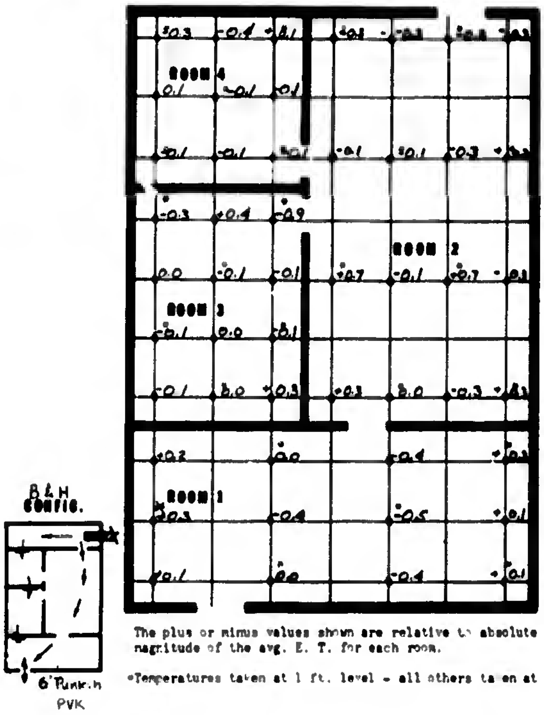


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 29 CONFIG. NO. B & H COND. MAX.
VENTILATION RATE 41 CFM/OCC
OVERALL AVG. SHELTER E.T.
AVG. E.T. OF ROOM 1 85.9 2 85.3 3 86.1 4 85.9

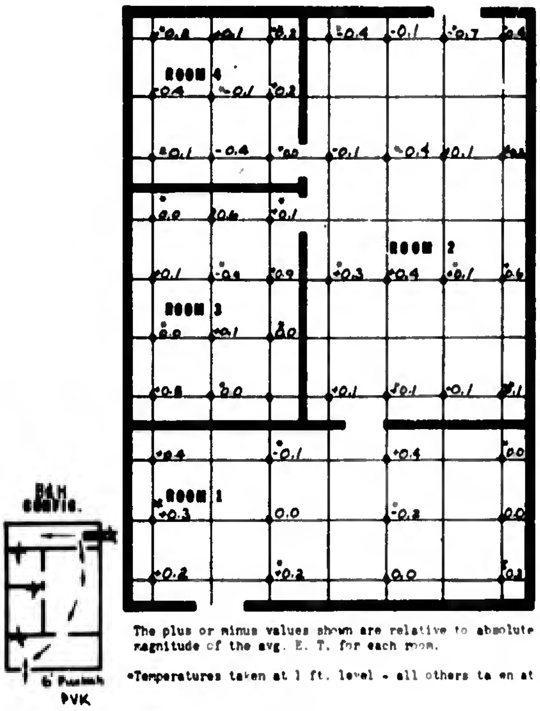


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 30 CONFIG. NO. B & H COND. MAX
VENTILATION RATE 26.6 CFM/OCC
OVERALL AVG. SHELTER E.T. 85.4
AVG. E.T. OF ROOM 1 86.2 2 84.9 3 85.4 4 84.7

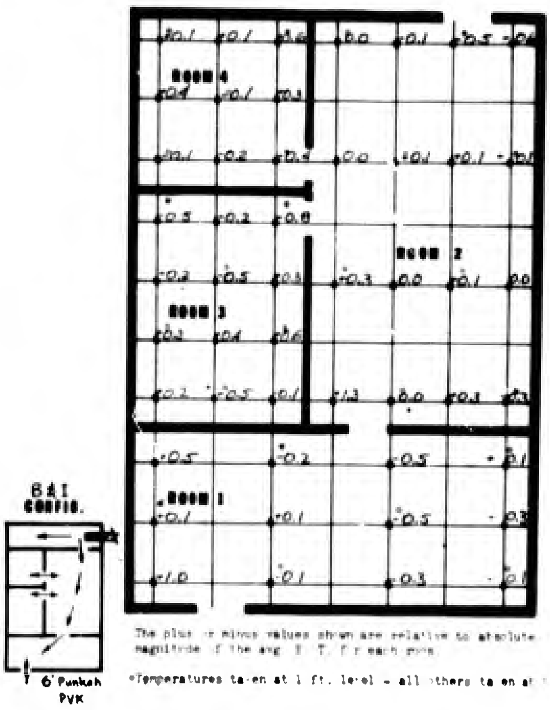


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 31 (15:00) CONFIG. NO. B & I COND. MAX.
VENTILATION RATE 27 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.1
AVG. E.T. OF ROOM 1 86.5 2 85.5 3 87.0 4 86.1

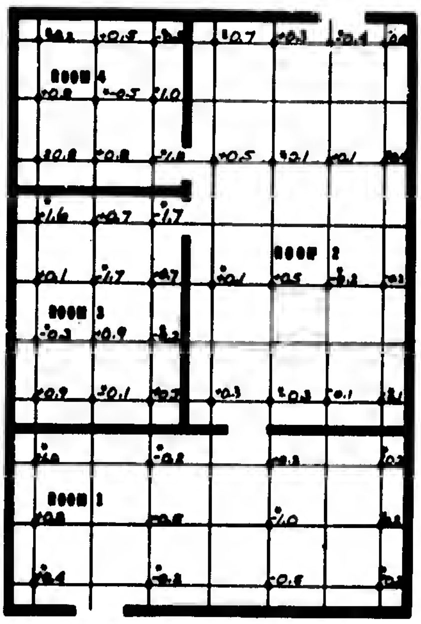


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

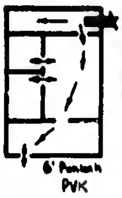
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 31 (10:00) CONFIG. NO. B&I COND. MAX.
VENTILATION RATE 27 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.1
AVG. E.T. OF ROOM 1 87 2 85.9 3 89.1 4 88.1



The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

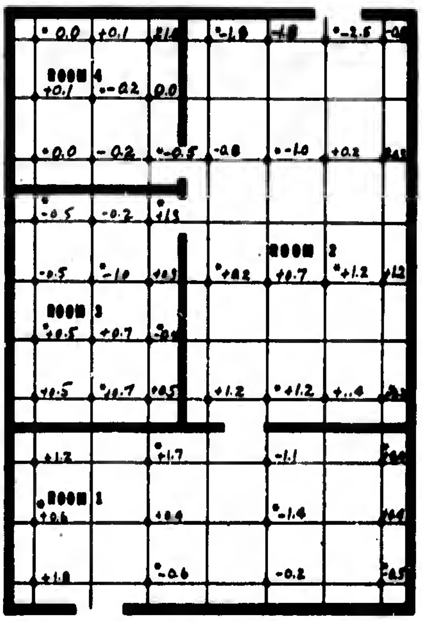
B&I CONFIG.



•Temperatures taken at 1 ft. level - all others taken at 5 ft.

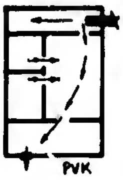
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 34B (15:00) CONFIG. NO. I COND. AVE.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 84.7
AVG. E.T. OF ROOM 1 86.6 2 83.8 3 84.5 4 83.0



The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

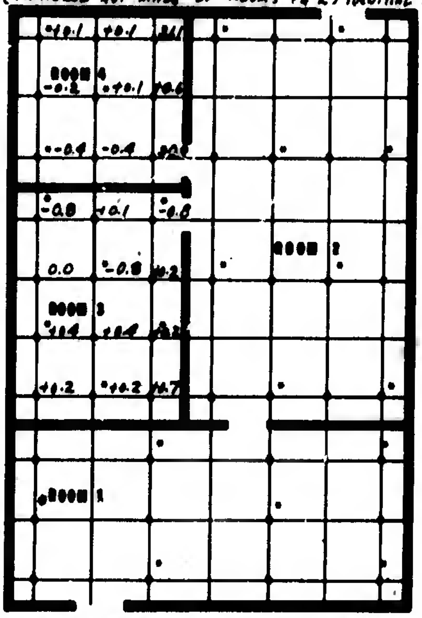
I CONFIG.



•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 35 (15:45) CONFIG. NO. F COND. AVE.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.9
AVG. E.T. OF ROOM 1 84.9 2 82.8 3 84.8 4 83.4
(TRAVERSE NOT MADE OF ROOMS 1 & 2) IDENTICAL TO 4 TRA



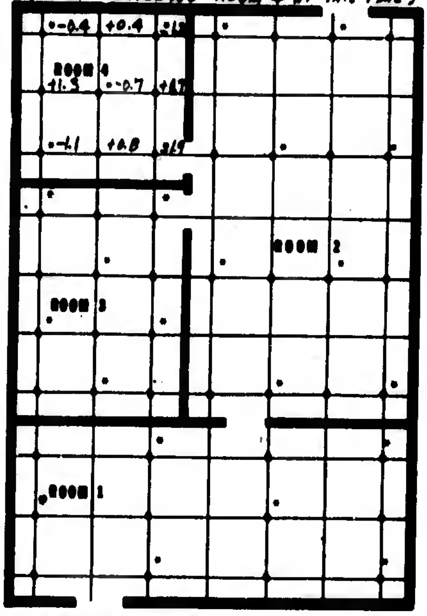
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

F CONFIG.

•Temperatures taken at 1 ft. level - all others taken at 5 ft

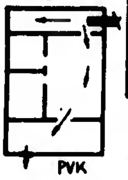
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 36 (09:30) CONFIG. NO. A COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 89.2
AVG. E.T. OF ROOM 1 ____ 2 ____ 3 ____ 4 89.2
(ONLY TRAVERSED ROOM 4 AT THIS TIME)



The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

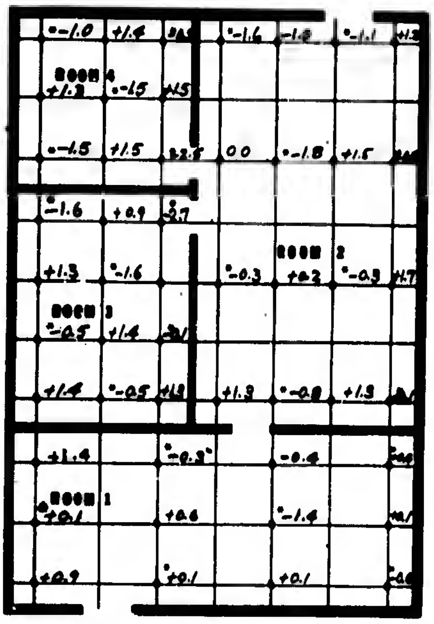
A CONFIG.



•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 35 (10:10) CONFIG. NO. F COND. AVE.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 84.3
AVG. E.T. OF ROOM 1 84.9 2 82.8 3 85.6 4 855



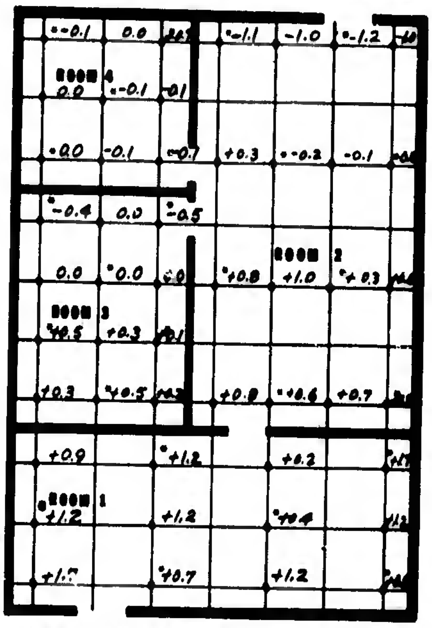
F CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

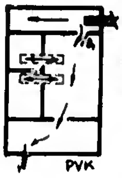
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 36 (13:30) CONFIG. NO. F COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.8°
AVG. E.T. OF ROOM 1 87.9 2 86.2 3 87.0 4 86.1



F CONFIG.

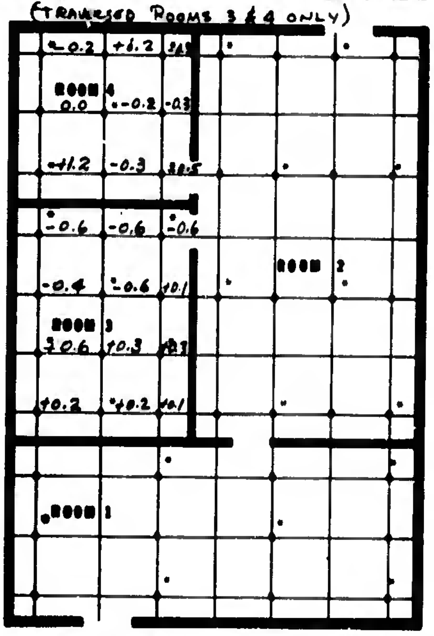


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 36 (14:00) CONFIG. NO. F COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.1°
AVG. E.T. OF ROOM 1 ____ 2 ____ 3 87.9 4 86.3
(TRAVERSED ROOMS 3 & 4 ONLY)



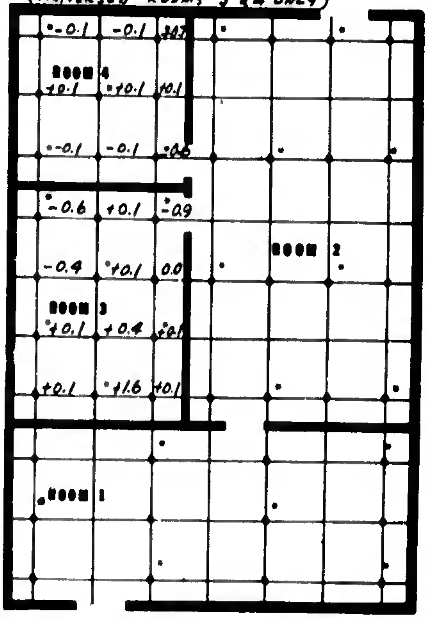
F CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 36 (17:40) CONFIG. NO. C COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.0°
AVG. E.T. OF ROOM 1 ____ 2 ____ 3 87.9 4 86.1
(TRAVERSED ROOMS 3 & 4 ONLY)



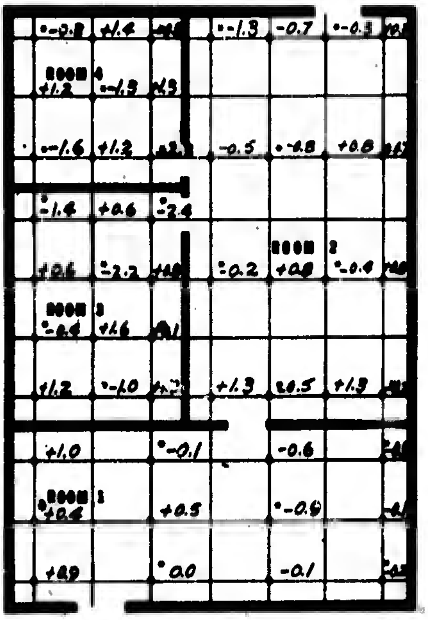
C CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

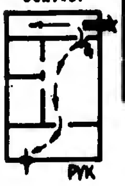
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 37 (09:00) CONFIG. NO. C COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 88.0°
AVG. E.T. OF ROOM 1 88.1 2 86.7 3 89.4 4 89.0



C CONFIG.

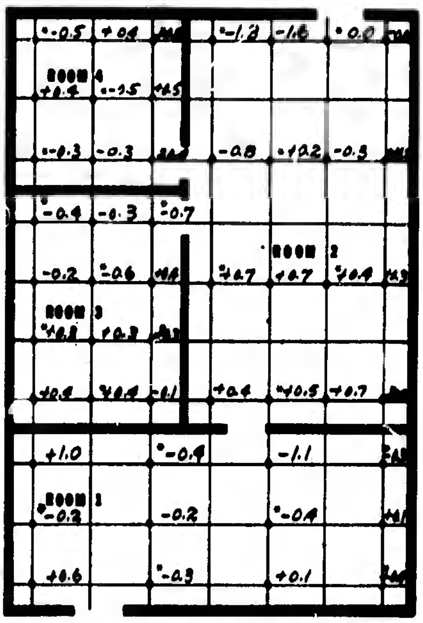


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 37 (1545) CONFIG. NO. F COND. MAX.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.4°
AVG. E.T. OF ROOM 1 88.4 2 86.8 3 87.6 4 86.5



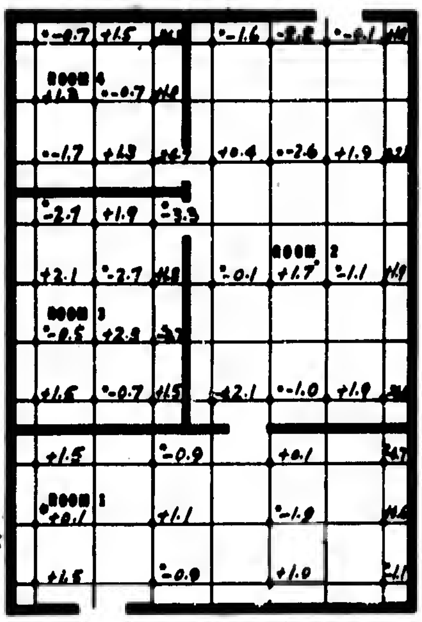
F CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

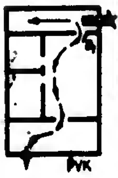
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 38 (10:15) CONFIG. NO. C COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 81.7
AVG. E.T. OF ROOM 1 82.9 2 80.1 3 82.7 4 82.7



C CONFIG.

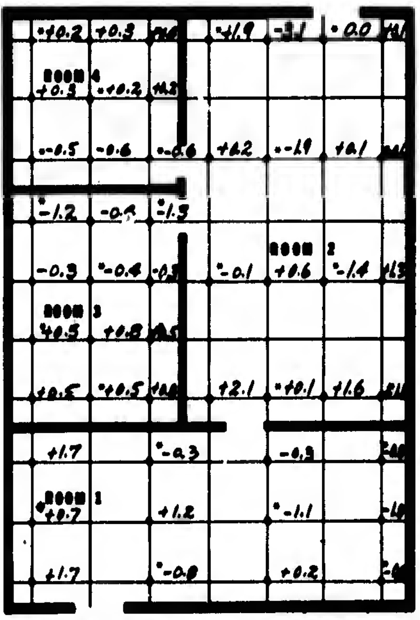


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

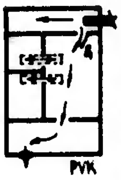
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 38 (1415) CONFIG. NO. F COND. MIN.
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 80.9
AVG. E.T. OF ROOM 1 82.3 2 78.9 3 81.4 4 79.8



F CONFIG.

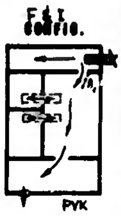


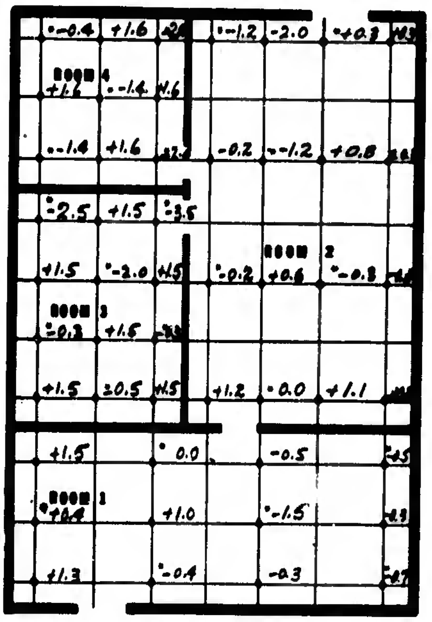
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 f

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 40(09:15) CONFIG. NO. F&I COND. MIN.
VENTILATION RATE 10.0 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.9°
AVG. E.T. OF ROOM 1 80.5 2 78.2 3 81.5 4 81.4



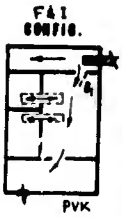


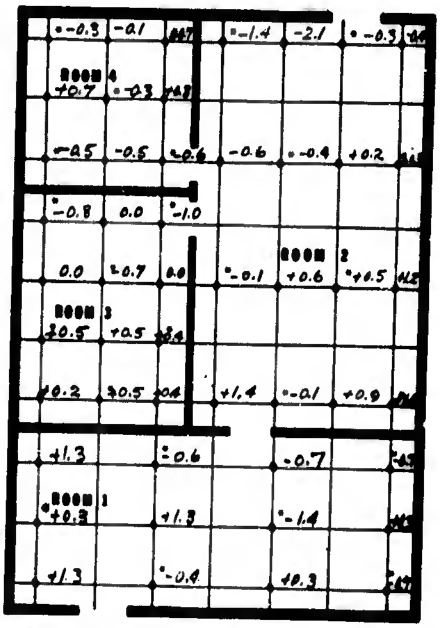
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 40(15:45) CONFIG. NO. F&I COND. MIN.
VENTILATION RATE 10 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.6°
AVG. E.T. OF ROOM 1 80.7 2 78.6 3 80.0 4 78.8



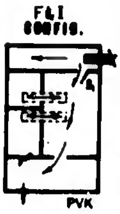


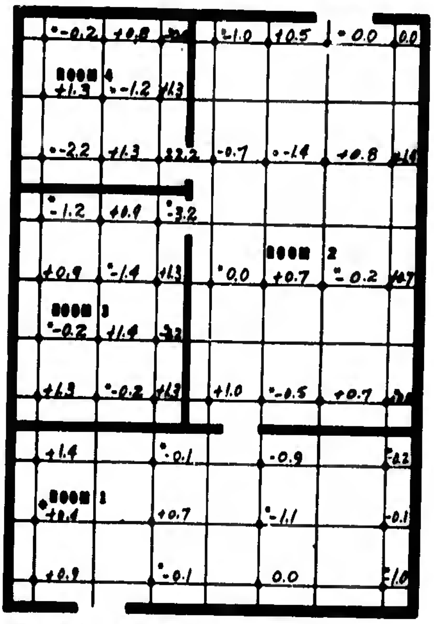
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 41 CONFIG. NO. F&I COND. AVE.
VENTILATION RATE 10 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.9
AVG. E.T. OF ROOM 1 84.1 2 82.5 3 85.2 4 86.2



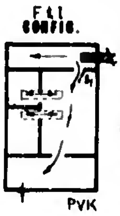


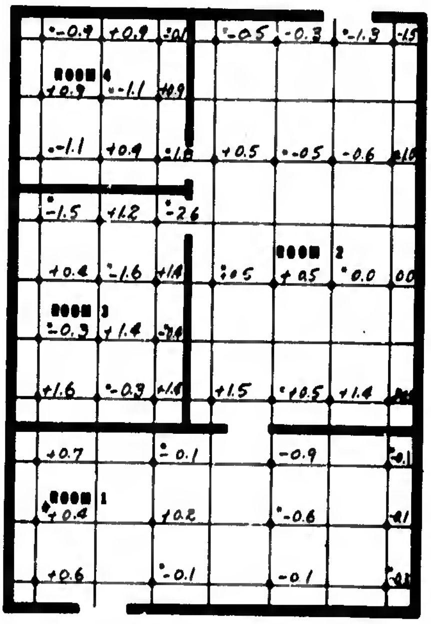
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 42(08:10) CONFIG. NO. F&I COND. AVE
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.8
AVG. E.T. OF ROOM 1 85.1 2 82.5 3 84.6 4 84.1



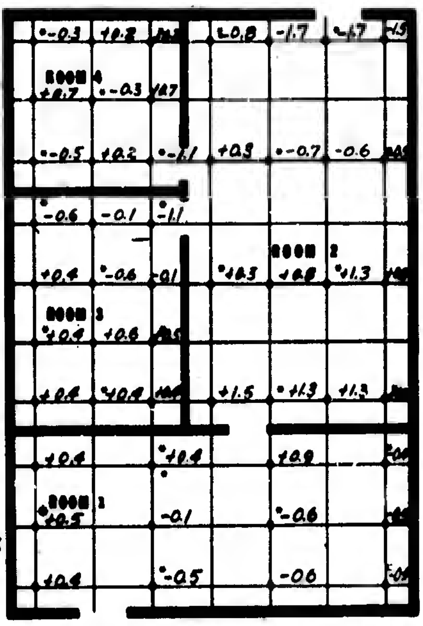


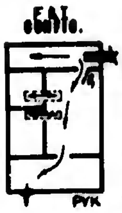
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 f

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 42(13:25) CONFIG. NO. F&I COND. AVE.
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.7
AVG. E.T. OF ROOM 1 85.6 2 82.7 3 83.6 4 82.3



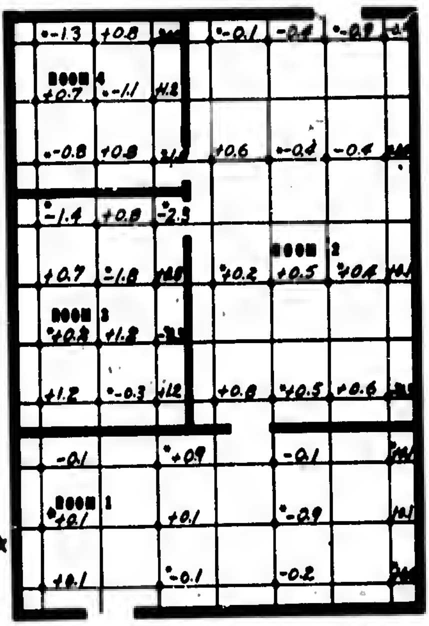


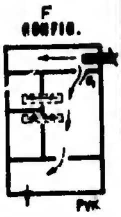
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 43(10:00) CONFIG. NO. F COND. MAX.
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.3
AVG. E.T. OF ROOM 1 88.1 2 86.4 3 88.3 4 87.3



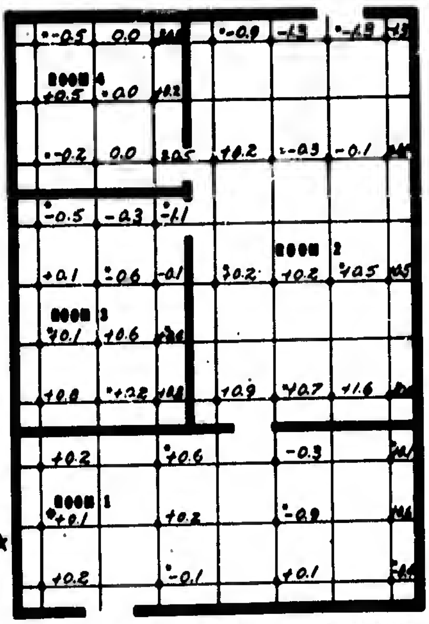


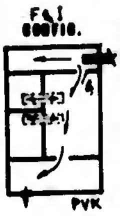
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 43(13:20) CONFIG. NO. F&I COND. MAX.
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.9
AVG. E.T. OF ROOM 1 87.9 2 86.3 3 87.1 4 86.0



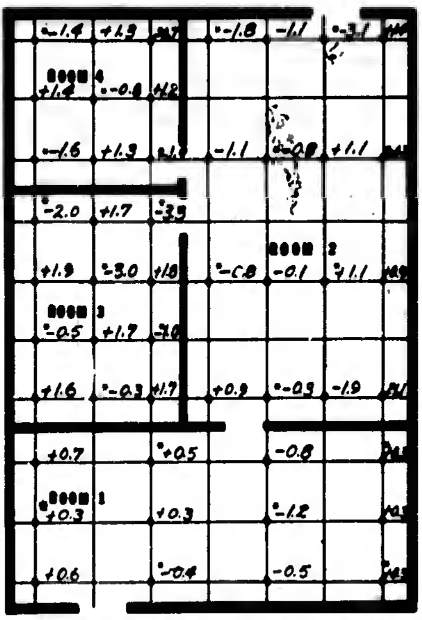


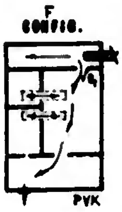
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 44(10:00) CONFIG. NO. F COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.9
AVG. E.T. OF ROOM 1 80.7 2 78.1 3 81.3 4 81.7



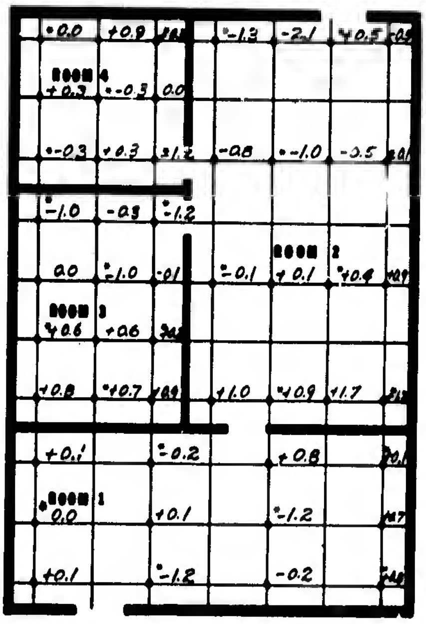


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

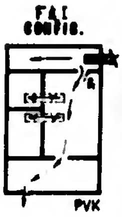
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 44(13:35) CONFIG. NO. F&I COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.2
AVG. E.T. OF ROOM 1 81.2 2 78.1 3 79.3 4 78.2



F&I CONFIG.

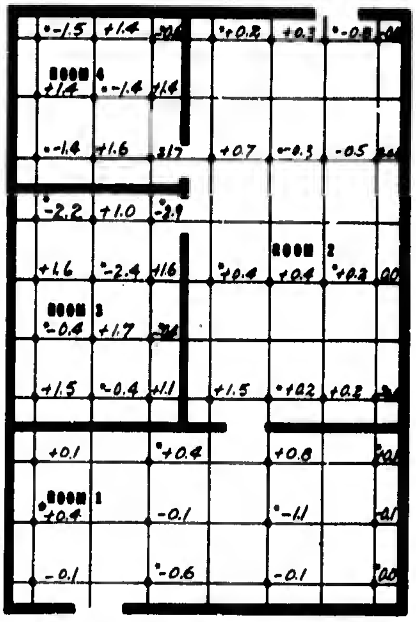


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

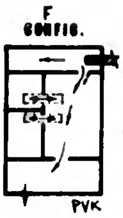
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 45(08:40) CONFIG. NO. F COND. AVE.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.2
AVG. E.T. OF ROOM 1 84.1 2 81.8 3 84.4 4 83.6



F CONFIG.

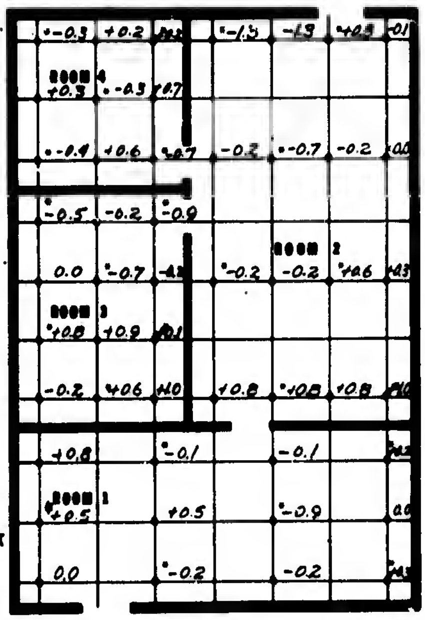


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

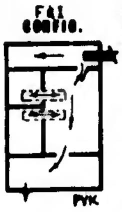
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 45(15:00) CONFIG. NO. F&I COND. AVE.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.0
AVG. E.T. OF ROOM 1 84.2 2 82.2 3 82.2 4 82.3



F&I CONFIG.

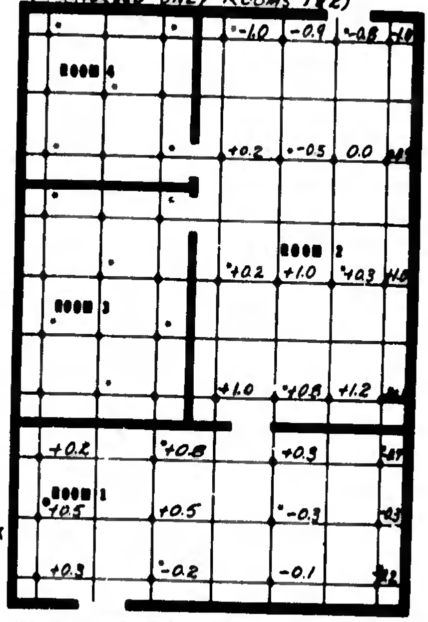


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

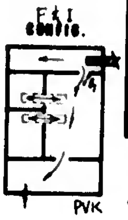
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 46 CONFIG. NO. F&I COND. AVE.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 82.8
AVG. E.T. OF ROOM 1 83.7 2 82.0 3 ___ 4 ___
(TRAVERSED ONLY ROOMS 1&2)



F&I CONFIG.

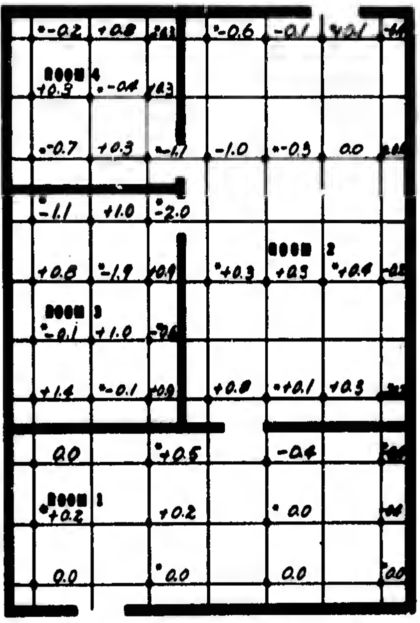


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

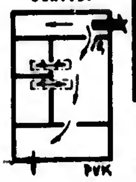
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 47(09:30) CONFIG. NO. F COND. MAX.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.7
AVG. E.T. OF ROOM 1 87.0 2 85.7 3 88.1 4 87.2



F
CONFIG.

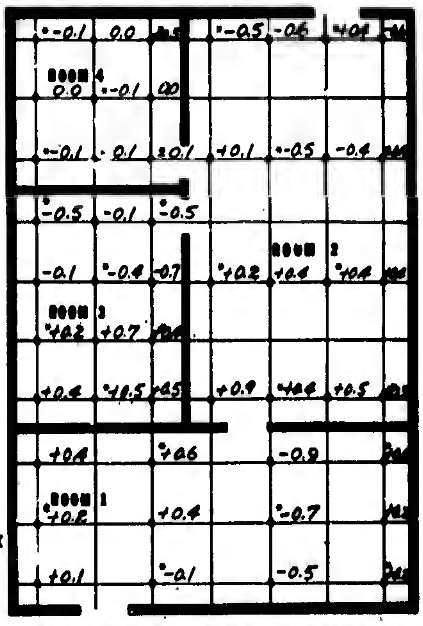


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

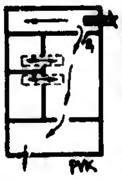
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 47(13:05) CONFIG. NO. F&I COND. MAX
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.2
AVG. E.T. OF ROOM 1 86.9 2 85.6 3 86.6 4 86.1



F&I
CONFIG.

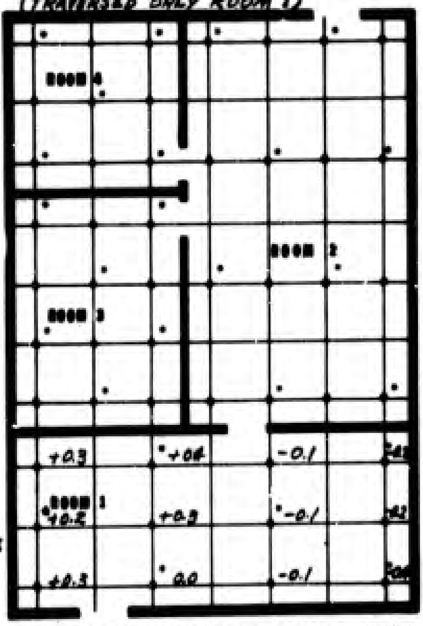


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 47(1600) CONFIG. NO. F&I COND. MAX.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.6
AVG. E.T. OF ROOM 1 86.6 2 ____ 3 ____ 4 ____
(TRAVERSED ONLY ROOM 1)



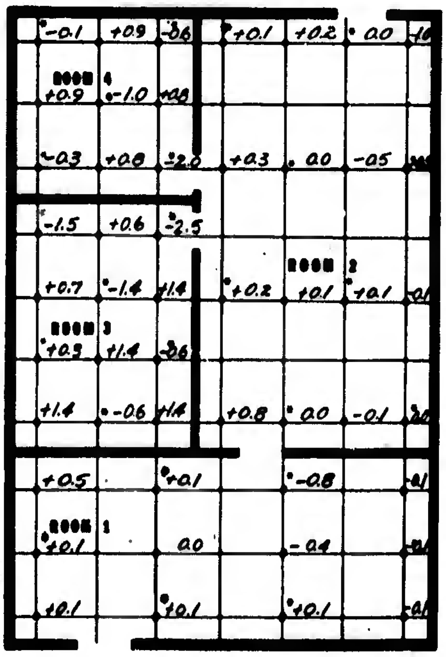
F&I
CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 48(09:00) CONFIG. NO. F COND. MAX.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.0
AVG. E.T. OF ROOM 1 86.9 2 86.0 3 88.6 4 88.1



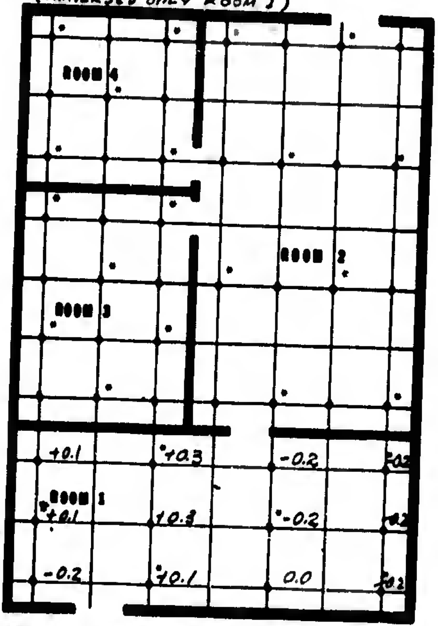
F
CONFIG.

The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level all others taken at 5 ft.

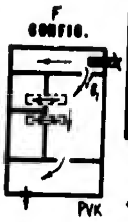
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 48(13:00) CONFIG. NO. F COND. MAX.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.2
AVG. E.T. OF ROOM 1 87.2 2 ___ 3 ___ 4 ___
(TRAVERSED ONLY ROOM 1)



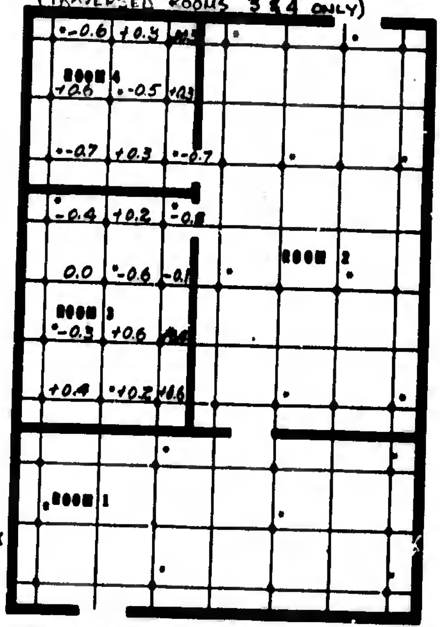
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.



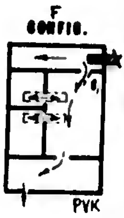
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 48(13:15) CONFIG. NO. F COND. MAX.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 87.1
AVG. E.T. OF ROOM 1 ___ 2 ___ 3 87.6 4 86.7
(TRAVERSED ROOMS 3 & 4 ONLY)



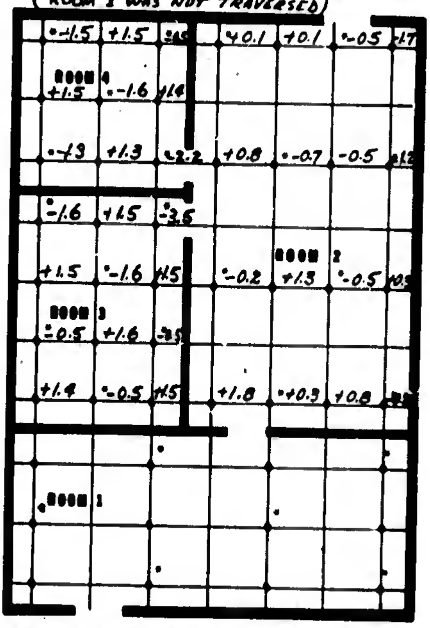
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.



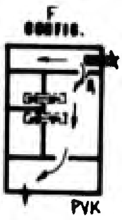
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 49(09:45) CONFIG. NO. F COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.9
AVG. E.T. OF ROOM 1 ___ 2 77.7 3 81.5 4 80.5
(ROOM 1 WAS NOT TRAVERSED)



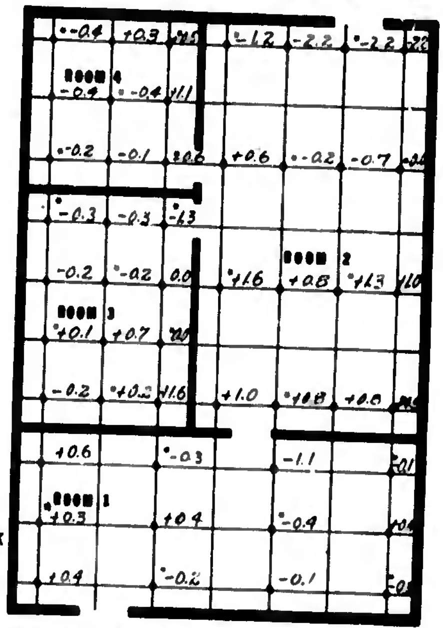
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.



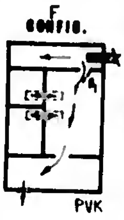
SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 49(15:15) CONFIG. NO. F COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.3
AVG. E.T. OF ROOM 1 80.6 2 78.2 3 80.2 4 78.7



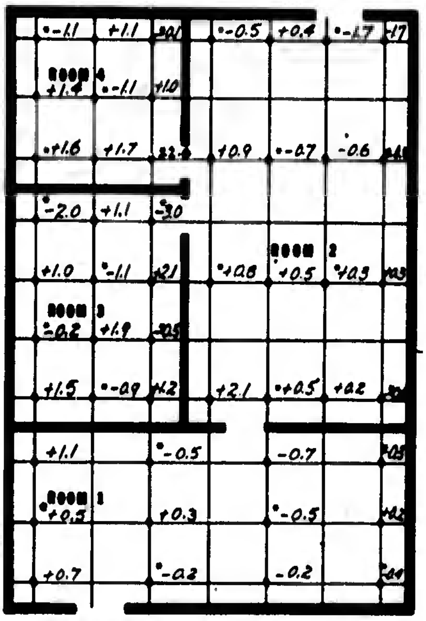
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

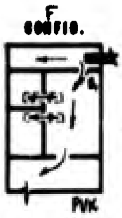
*Temperatures taken at 1 ft. level - all others taken at 5 ft.



SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 50(00:30) CONFIG. NO. F COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.4
AVG. E.T. OF ROOM 1 80.5 2 77.7 3 81.0 4 80.1



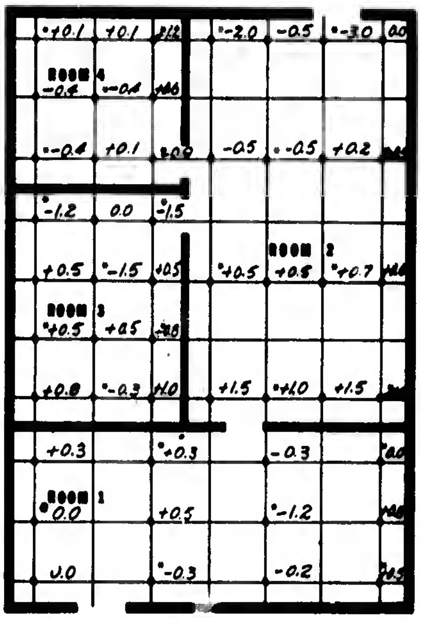


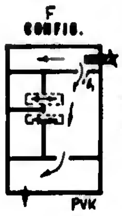
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 50(15:30) CONFIG. NO. F COND. MIN.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.5
AVG. E.T. OF ROOM 1 81.2 2 78.5 3 78.5 4 78.9



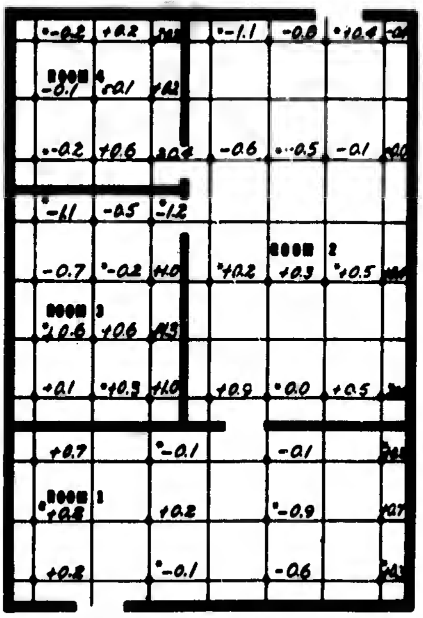


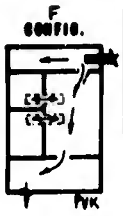
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 51 CONFIG. NO. F COND. AVE.
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.1
AVG. E.T. OF ROOM 1 84.1 2 82.6 3 83.2 4 82.3



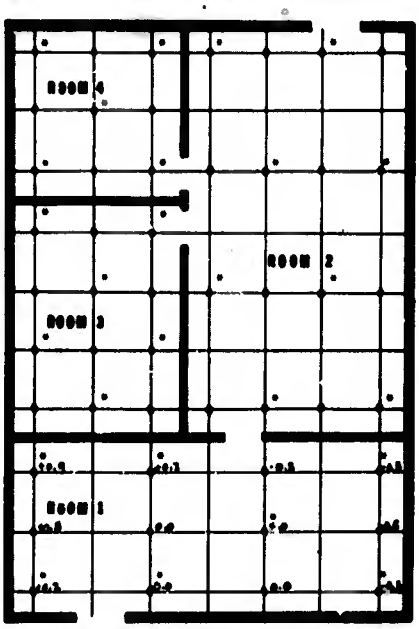


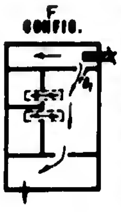
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 52 CONFIG. NO. F COND. AVG.
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. ______
AVG. E.T. OF ROOM 1 84 2 ____ 3 ____ 4 ____



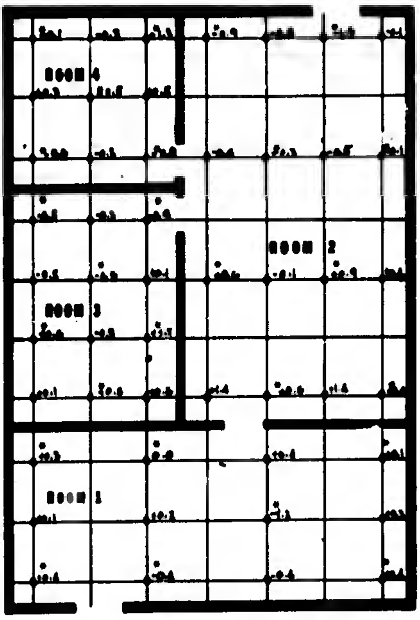


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 83 CONFIG. NO. F COND. ____
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. 83.4
AVG. E.T. OF ROOM 1 84.1 2 83.4 3 82.4 4 83.1

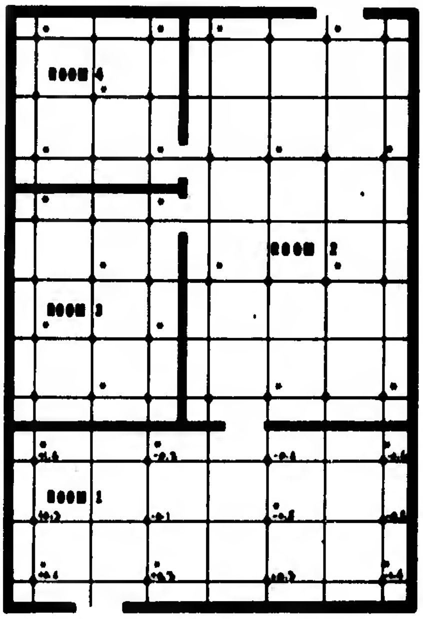


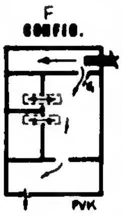
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 83(09:30) CONFIG. NO. F COND. ____
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. ____
AVG. E.T. OF ROOM 1 83.6 2 ____ 3 ____ 4 ____



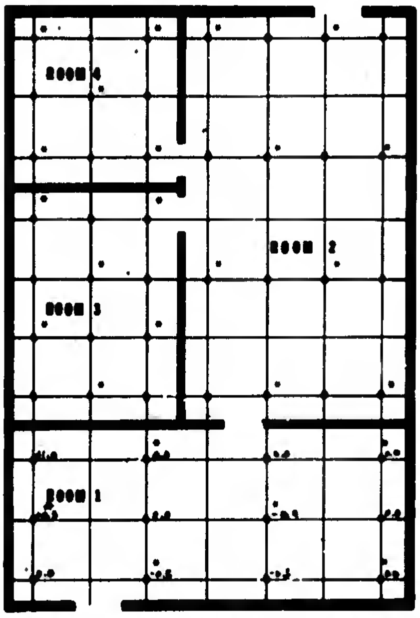


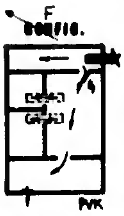
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 83(12:55) CONFIG. NO. F COND. ____
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. ____
AVG. E.T. OF ROOM 1 88 2 ____ 3 ____ 4 ____



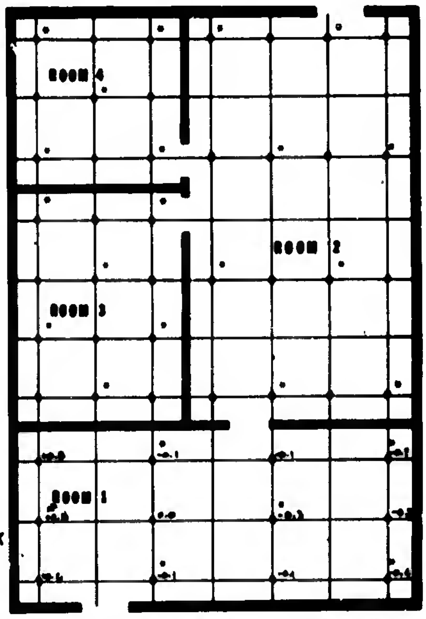


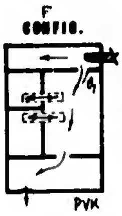
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 84(14:20) CONFIG. NO. F COND. MIN
VENTILATION RATE 18 CFM/OCC
OVERALL AVG. SHELTER E.T. ____
AVG. E.T. OF ROOM 1 84.3 2 ____ 3 ____ 4 ____





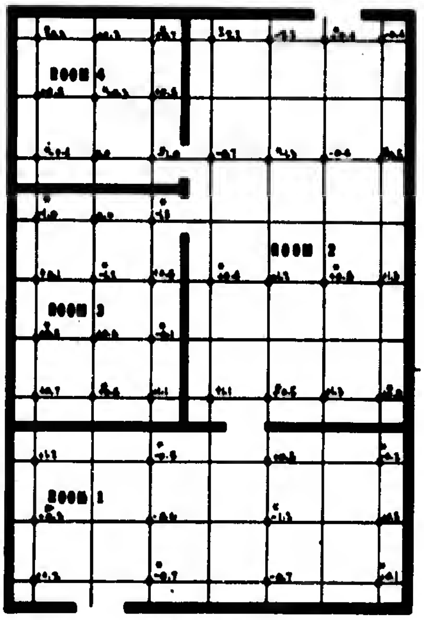
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

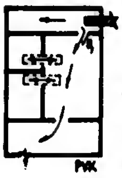
B.14

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 54 (12:30) CONFIG. NO. F COND. MIN
VENTILATION RATE 16 CFM/OCC
OVERALL AVG. SHELTER E.T. 79.7
AVG. E.T. OF ROOM 1 81.7 2 78.7 3 79.4 4 78.2



CONFIG.

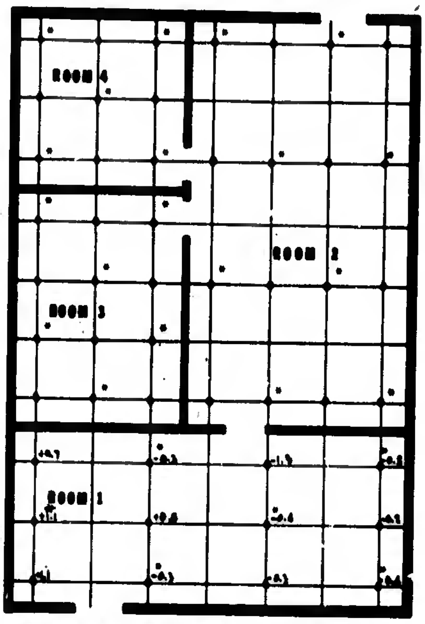


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

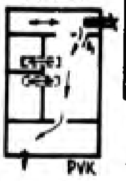
*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 55 (09:30) CONFIG. NO. F COND. MIN
VENTILATION RATE 12.5 CFM/OCC
OVERALL AVG. SHELTER E.T. ______
AVG. E.T. OF ROOM 1 84.4 2 ___ 3 ___ 4 ___



F
CONFIG.

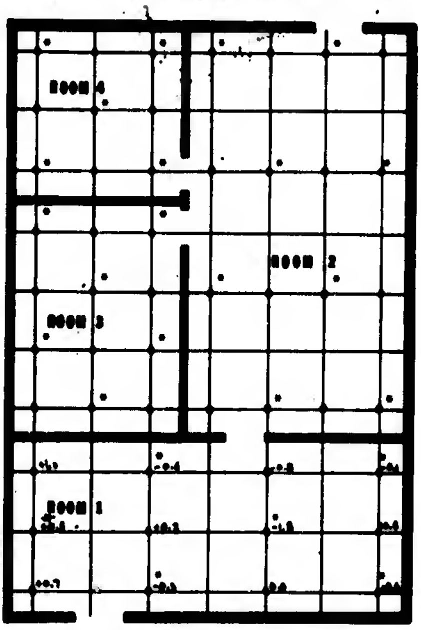


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 55 (12:30) CONFIG. NO. F COND. MIN
VENTILATION RATE 12.5 CFM/OCC
OVERALL AVG. SHELTER E.T. ______
AVG. E.T. OF ROOM 1 83.3 2 ___ 3 ___ 4 ___



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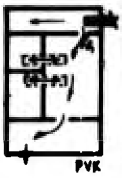
CONFIG.

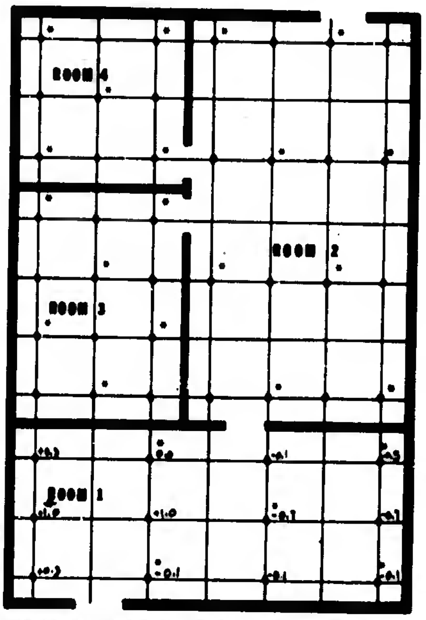


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

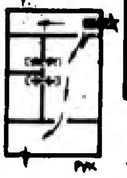
*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 56 (14:45) CONFIG. NO. F COND. AVG
VENTILATION RATE 12.5 CFM/OCC
OVERALL AVG. SHELTER E.T. ______
AVG. E.T. OF ROOM 1 86 2 ___ 3 ___ 4 ___



F
CONFIG.

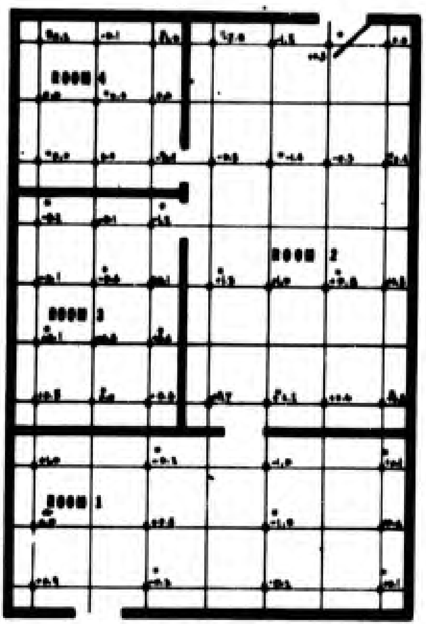


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 56 (09:00) CONFIG. NO. F COND. AVG
VENTILATION RATE 12.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 84.5
AVG. E.T. OF ROOM 1 86.0 2 83.5 3 86.1 4 83.0

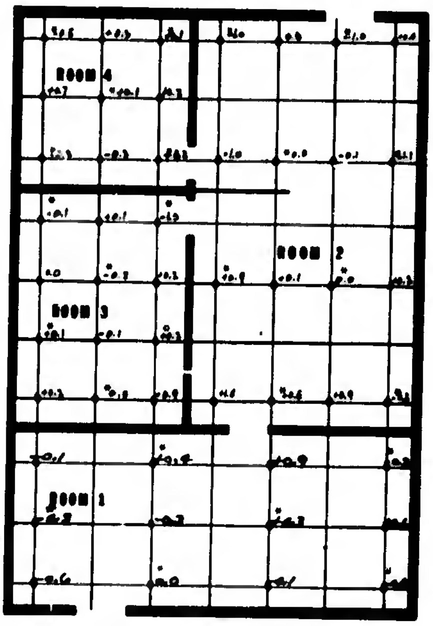


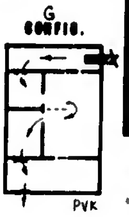
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 58(08:45) CONFIG. NO. G COND. MAX
VENTILATION RATE 12.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 86.1
AVG. E.T. OF ROOM 1 88.6 2 86.1 3 87.1 4 86.8



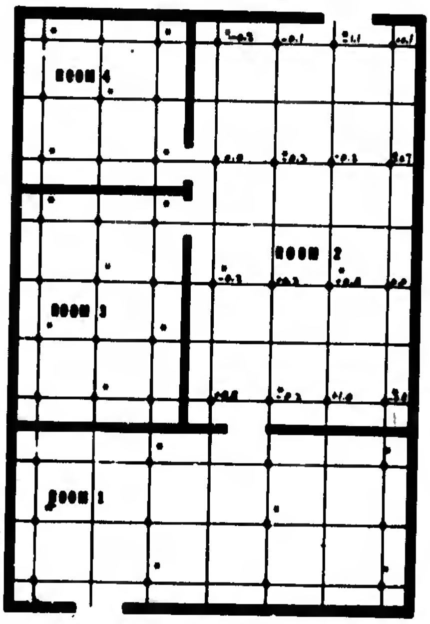


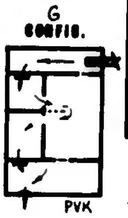
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 58 (11:10) CONFIG. NO. G COND. MAX
VENTILATION RATE 16.5 CFM/OCC
OVERALL AVG. SHELTER E.T.
AVG. E.T. OF ROOM 1 2 86.3 3 4



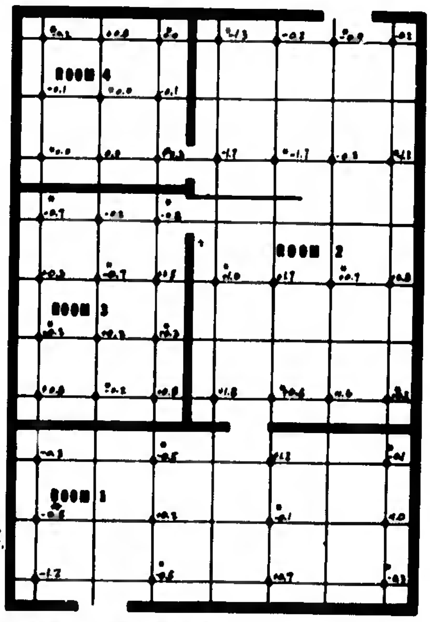


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER EFFECTIVE TEMPERATURE PATTERNS

TEST NO. 60(09:10) CONFIG. NO. G COND. [illegible] ONLY
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER E.T. 73.4
AVG. E.T. OF ROOM 1 76.3 2 72.2 3 73.7 4 70.2

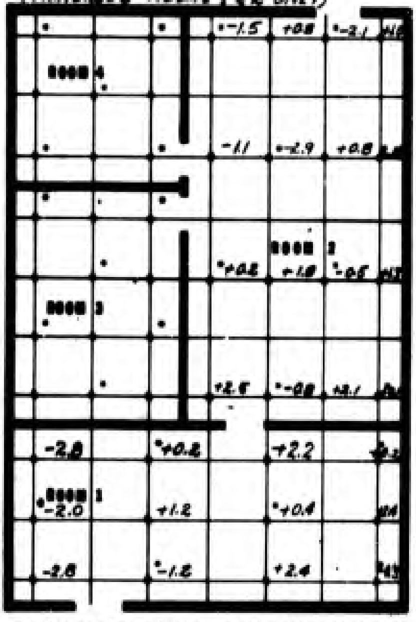


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

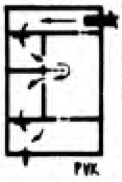
*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY BULB TEMPERATURE PATTERNS

TEST NO. 60 (13:10) CONFIG. NO. G COND. NOT
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER D.B 84.9
AVG. D.B. OF ROOM 1 88.8 2 81.0 3 – 4 –
(TRAVERSED ROOMS 1 & 2 ONLY)



G
CONFIG.

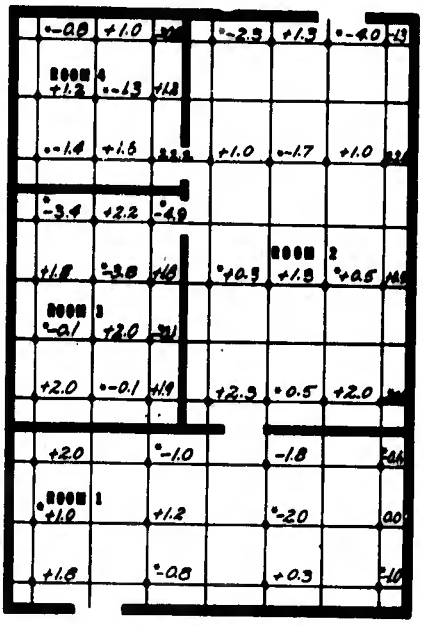


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY BULB TEMPERATURE PATTERNS

TEST NO. 61 (09:30) CONFIG. NO. F COND. NOT
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG SHELTER D.B 87.5
AVG. D.B. OF ROOM 1 90.0 2 85.5 3 89.0 4 86.3



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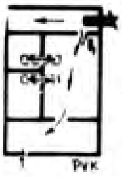
CONFIG.

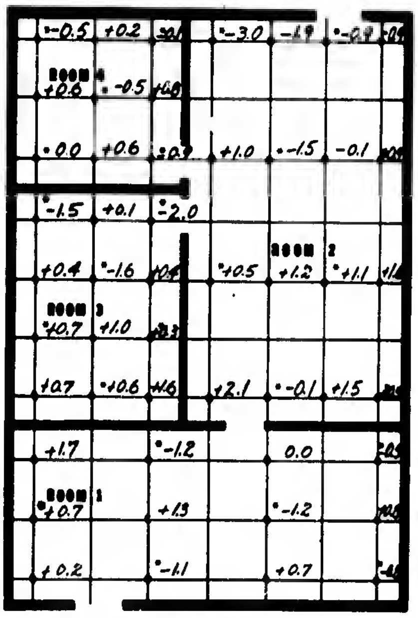


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

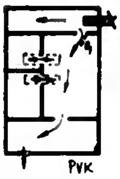
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY BULB TEMPERATURE PATTERNS

TEST NO. 61 (15:30) CONFIG. NO. F COND. NOT
VENTILATION RATE 13.5 CFM/OCC
OVERALL AVG. SHELTER D.B. 88.6
AVG. D.B. OF ROOM 1 91.8 2 88.0 3 87.5 4 86.0



F
CONFIG.

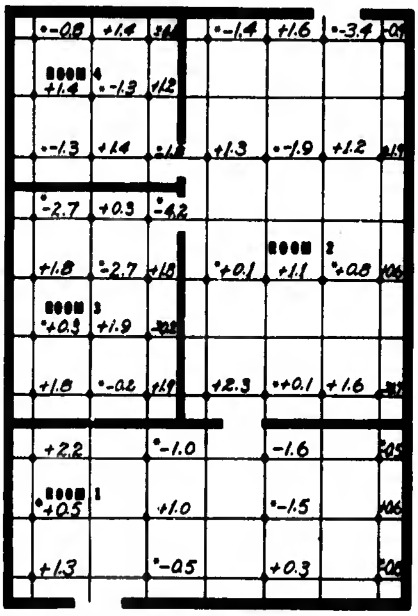


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

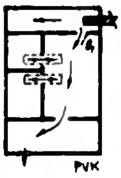
•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY BULB TEMPERATURE PATTERNS

TEST NO. 62 (08:30) CONFIG. NO. F COND. NOT
VENTILATION RATE 18.0 CFM/OCC
OVERALL AVG. SHELTER D.B. 87.9
AVG. D.B. OF ROOM 1 90.0 2 85.9 3 89.7 4 86.8



F
CONFIG.

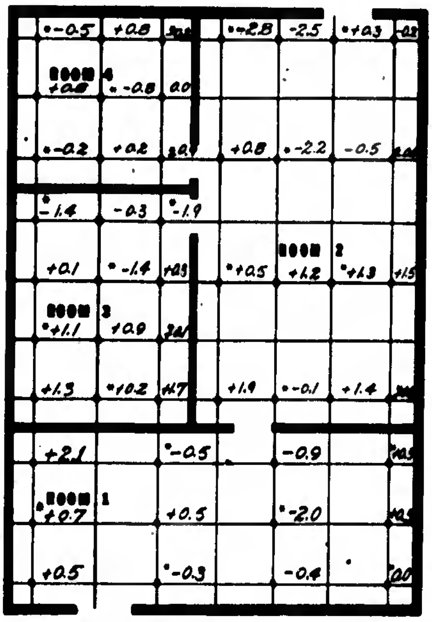


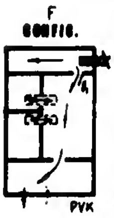
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

•Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY-BULB TEMPERATURE PATTERNS

TEST NO. 62(13:40) CONFIG. NO. F COND. NOT
VENTILATION RATE 18.0 CFM/OCC
OVERALL AVG. SHELTER D.B. 88.1
AVG. D.B. OF ROOM 1 90.5 2 86.7 3 88.9 4 86.0



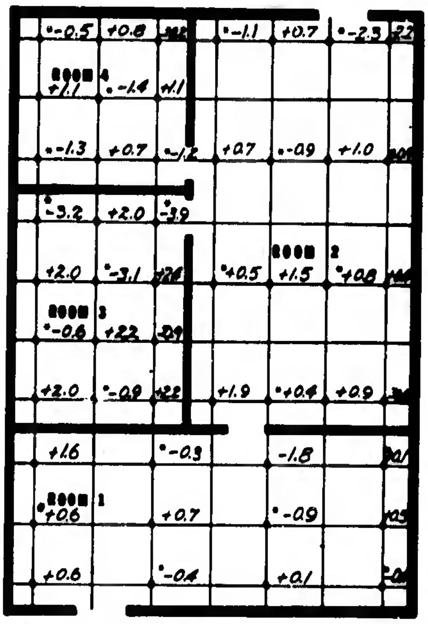


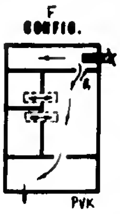
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY-BULB TEMPERATURE PATTERNS

TEST NO. 63(08:30) CONFIG. NO. F COND. NOT
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER D.B. 87.9
AVG. D.B. OF ROOM 1 89.4 2 86.1 3 90.0 4 87.3



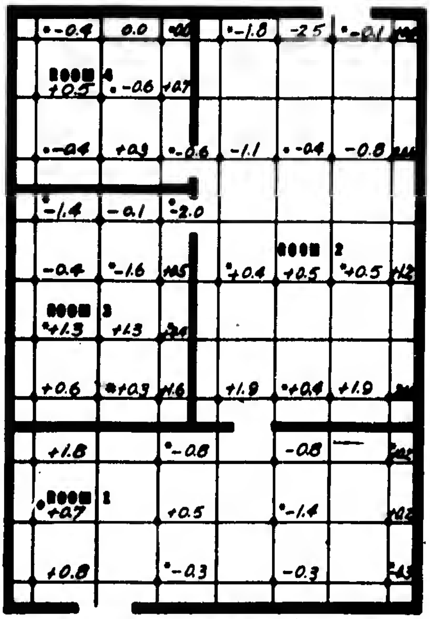


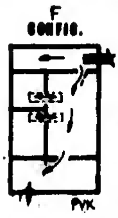
The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

SHELTER DRY-BULB TEMPERATURE PATTERNS

TEST NO. 63(13:15) CONFIG. NO. F COND. NOT
VENTILATION RATE 22.5 CFM/OCC
OVERALL AVG. SHELTER D.B. 88.1
AVG. D.B. OF ROOM 1 88.8 2 87.1 3 88.6 4 86.5



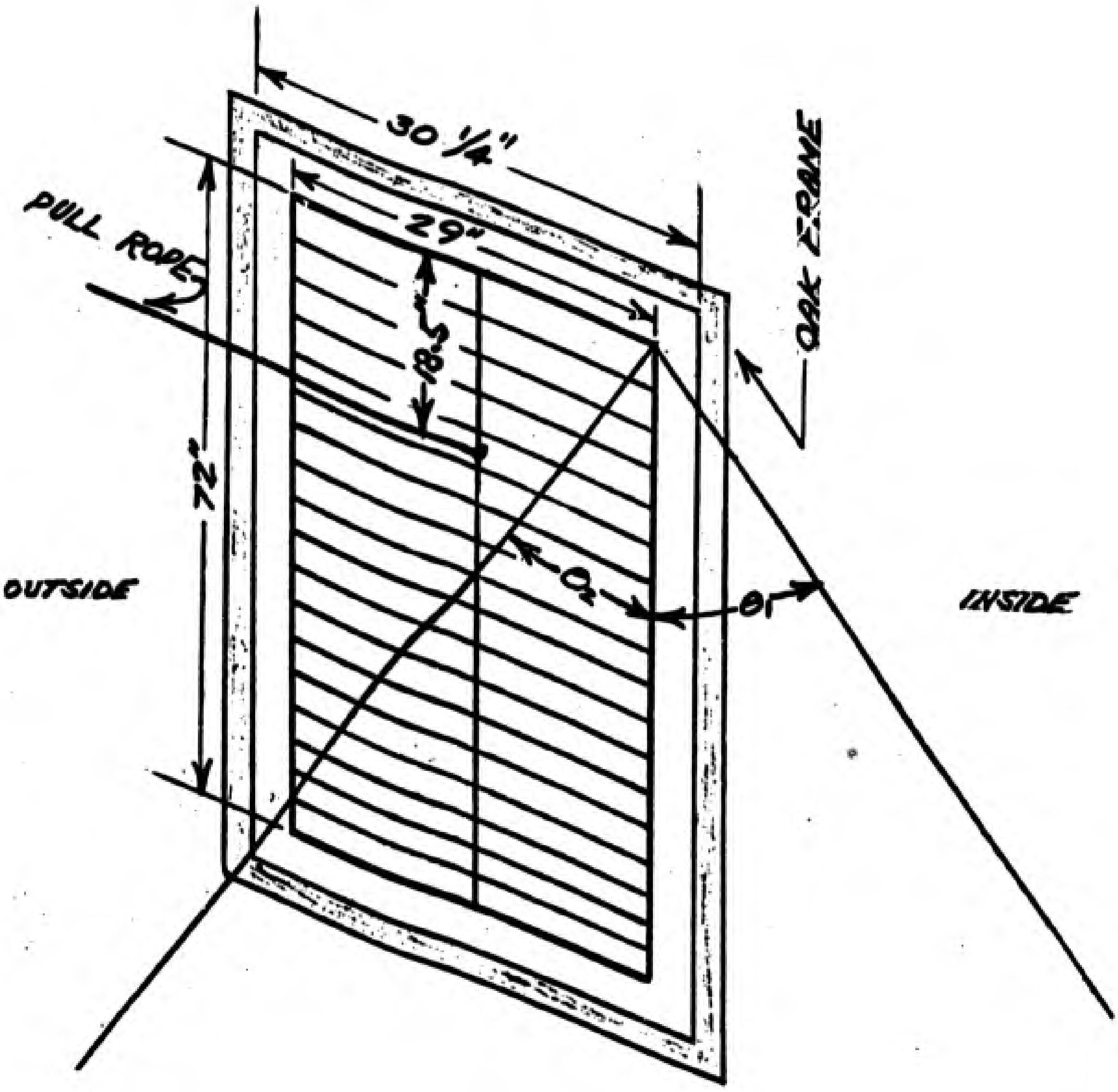


The plus or minus values shown are relative to absolute magnitude of the avg. E. T. for each room.

*Temperatures taken at 1 ft. level - all others taken at 5 ft.

APPENDIX C

PUNKAH DATA



Length of stroke and angles θ_1 and θ_2 determined by measurement.

$\theta_1 = 51°$

$\theta_2 = 64°$

Length of stroke = 31 inches

Figure C.1 Six foot full door punkah.

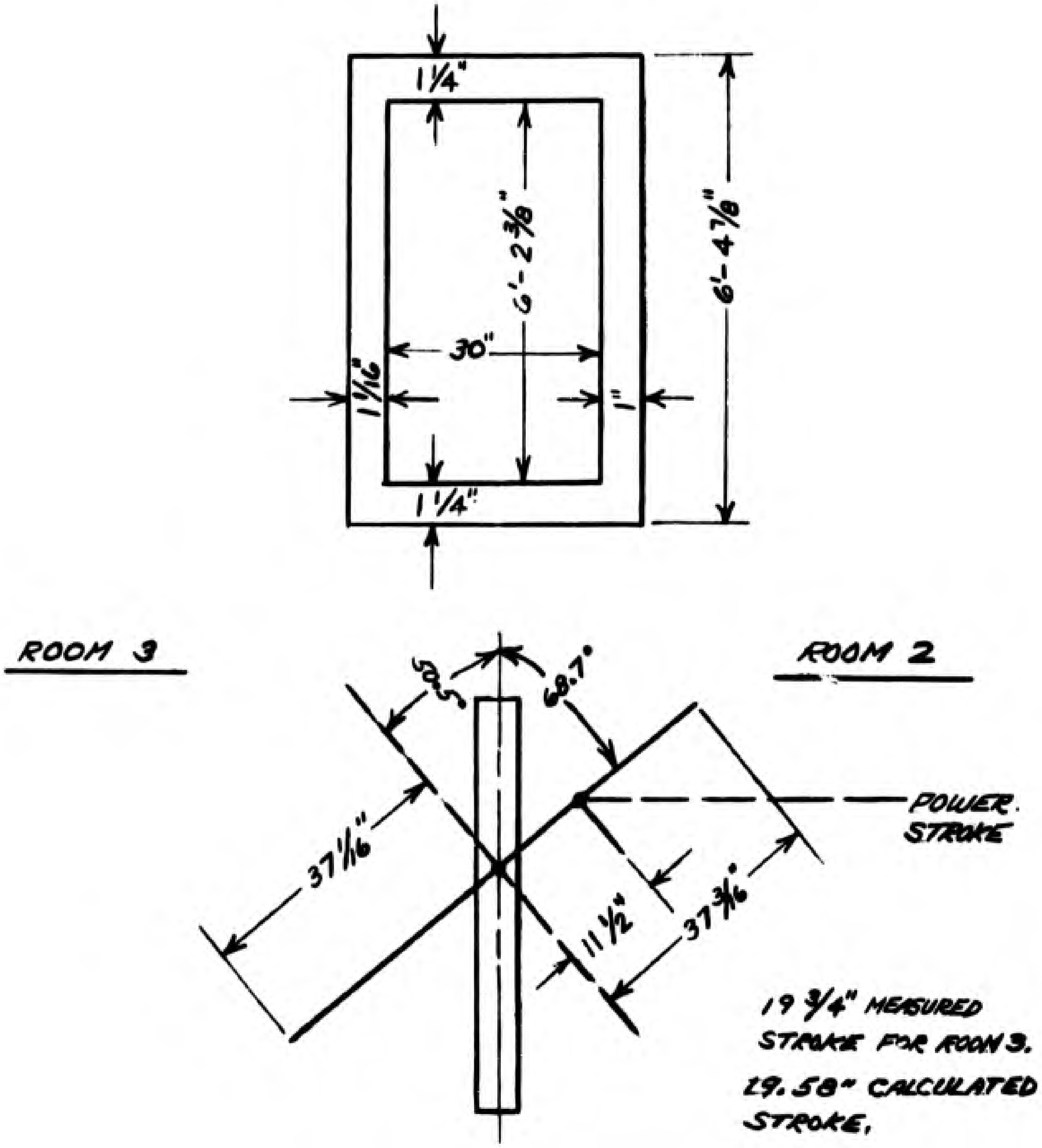


Figure C.2 Push-pull punkah - Rooms 2 and 3 - dimensions.

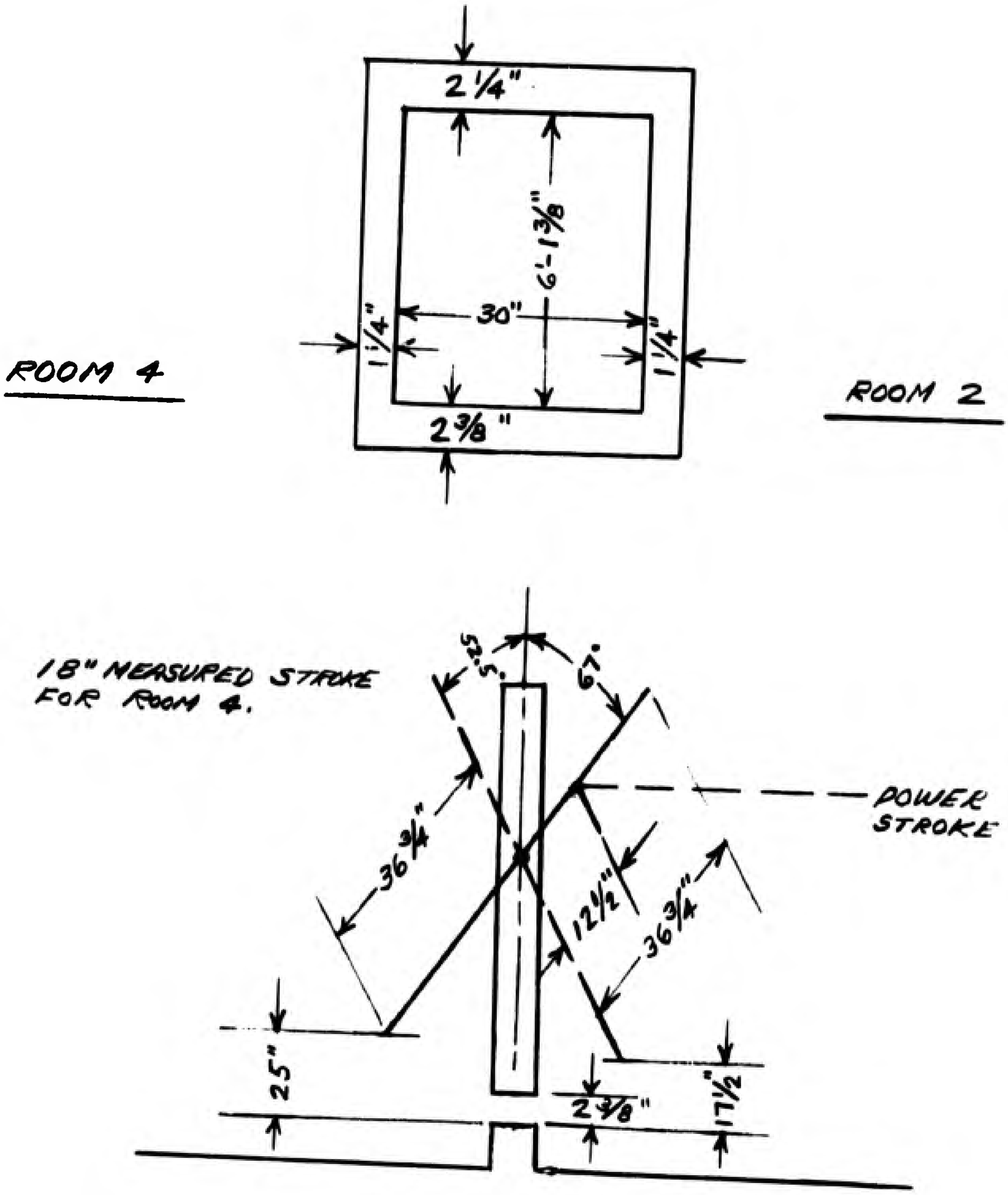


Figure C.3 Push-pull punkah - Rooms 2 and 4 - dimensions.

APPENDIX C

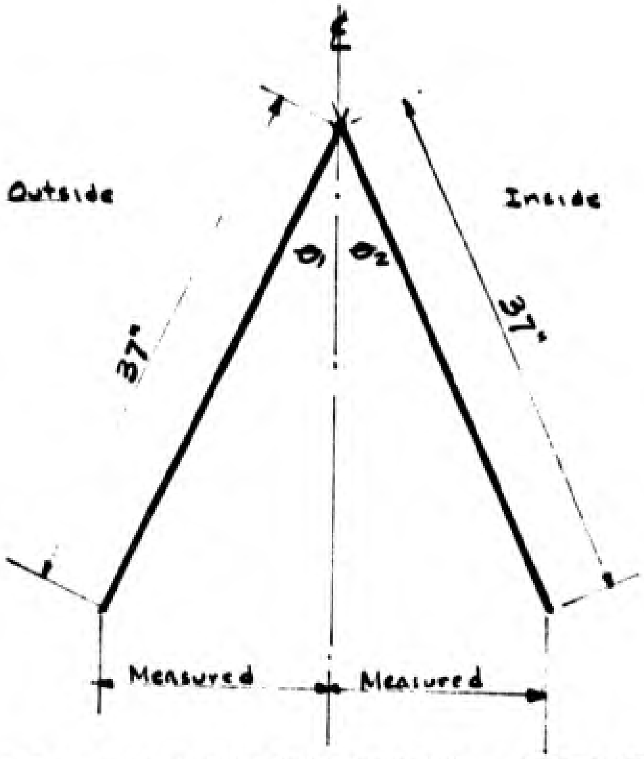


TABLE C.1 THREE FOOT DOOR PUNKAHS - ANGLES OF SWING

	Punkah High in Door 33 oscillations per minute		Punkah Low in Door 34 oscillations per minute	
Room	θ_1 Inside Swing	θ_2 Outside Swing	θ_1 Inside Swing	θ_2 Outside Swing
3	57°	61°	58°	60°
4	58°	61°	54°	58°

APPENDIX D

PROCEDURE FOR CALIBRATION OF CO_2 GAS ANALYZER FOR OTHER TRACER GASES

APPENDIX D

Procedure for Calibration of CO_2 Gas Analyzer for Other Tracer Gases

Appreciable CO_2 absorption by the wet SIMOCS undoubtedly has affected the air flow determinations obtained by the CO_2 tracer gas method. In order to use helium or argon, which is known to be less soluble in water than CO_2 (see Tables D.1 and D.2), the gas analyzer apparatus which was originally factory calibrated for CO_2, had to be recalibrated. The procedure described below illustrates the method used to calibrate the gas analyzer for the other two gases; helium and argon.

Procedure

(Refer to Figure D.1)

1. Fill 5 gallon jar with water and obtain tare weight.

2. Siphon off a nominal amount of water so that air can enter jar through Tube D. Equivalent volume of water removed equals equivalent volume of air entering.

3. Check manometer* reading so that atmospheric pressure exists in jar. Using Tube D, tracer gas is added to air sample trapped over the water in jar. In order to keep pressure as close to atmospheric as possible, and to determine the correct volume of tracer gas added to the air sample, water is siphoned off through Tube B until pressure is reduced to the initial atmospheric pressure in jar or very nearly so. Weights are now recorded and calculations made as shown hereinafter.

---

* Manometer used was 50" long, inclined, 4" water gage range, readable accuracy to 1/1000" water gage.

4. Mixture is then sampled to the gas analyzer through Tube A. Output of gas analyzer is recorded on an electronic recorder. Figure D.2 shows the apparatus used.

5. The millivolts output of the electronic recorder is plotted graphically against the percent tracer gas. Several points were obtained in this manner and plotted. The gas sample space in the jar was carefully purged with pure air between the individual sample readings. Appropriate calibration curves obtained are shown in Figures D.3, D.4 and D.5.

Sample Calculation - Tracer Gas Calibration Procedure

W = Initial weight of jar full of water.

W_1 = Weight of (jar and water) after air sample is admitted.

W_2 = Weight of (jar and water) after tracer gas is admitted and mixed with air sample in jar.

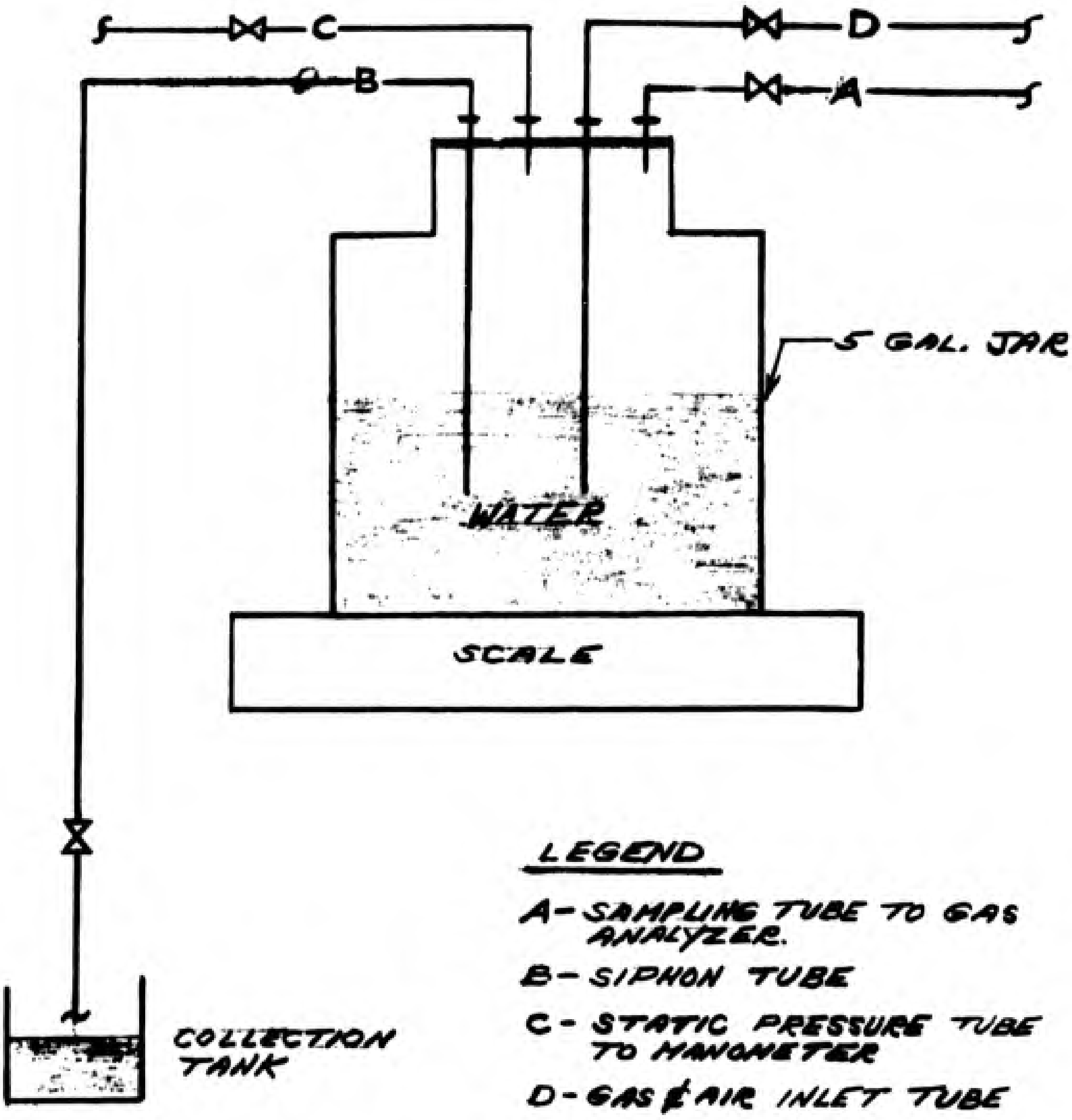
$$\% \text{ tracer gas} = 100 \frac{\frac{(W_1 - W_2)}{(62.4)}}{\frac{(W-W_1) + (W_1-W_2)}{62.4}}$$ which reduces to

$$\% \text{ tracer gas} = 100 \frac{(W_1-W_2)}{(W-W_2)}$$

APPENDIX D

APPARATUS FOR CALIBRATION OF CO_2 GAS ANALYZER

(FOR OTHER TRACER GASES)



LEGEND

A - SAMPLING TUBE TO GAS ANALYZER.
B - SIPHON TUBE
C - STATIC PRESSURE TUBE TO MANOMETER
D - GAS & AIR INLET TUBE

NOTES:

1. ALL TUBES EXTENDING INTO JAR ARE STAINLESS STEEL. MATERIAL FOR ALL OTHER PIPING RUNS IS POLYETHYLENE TUBING.
2. TUBES B AND D ARE SUBMERGED IN WATER AND ARE AT THE SAME LEVEL.

Figure D.1 Apparatus for calibration of CO_2 gas analyzer.

APPENDIX D

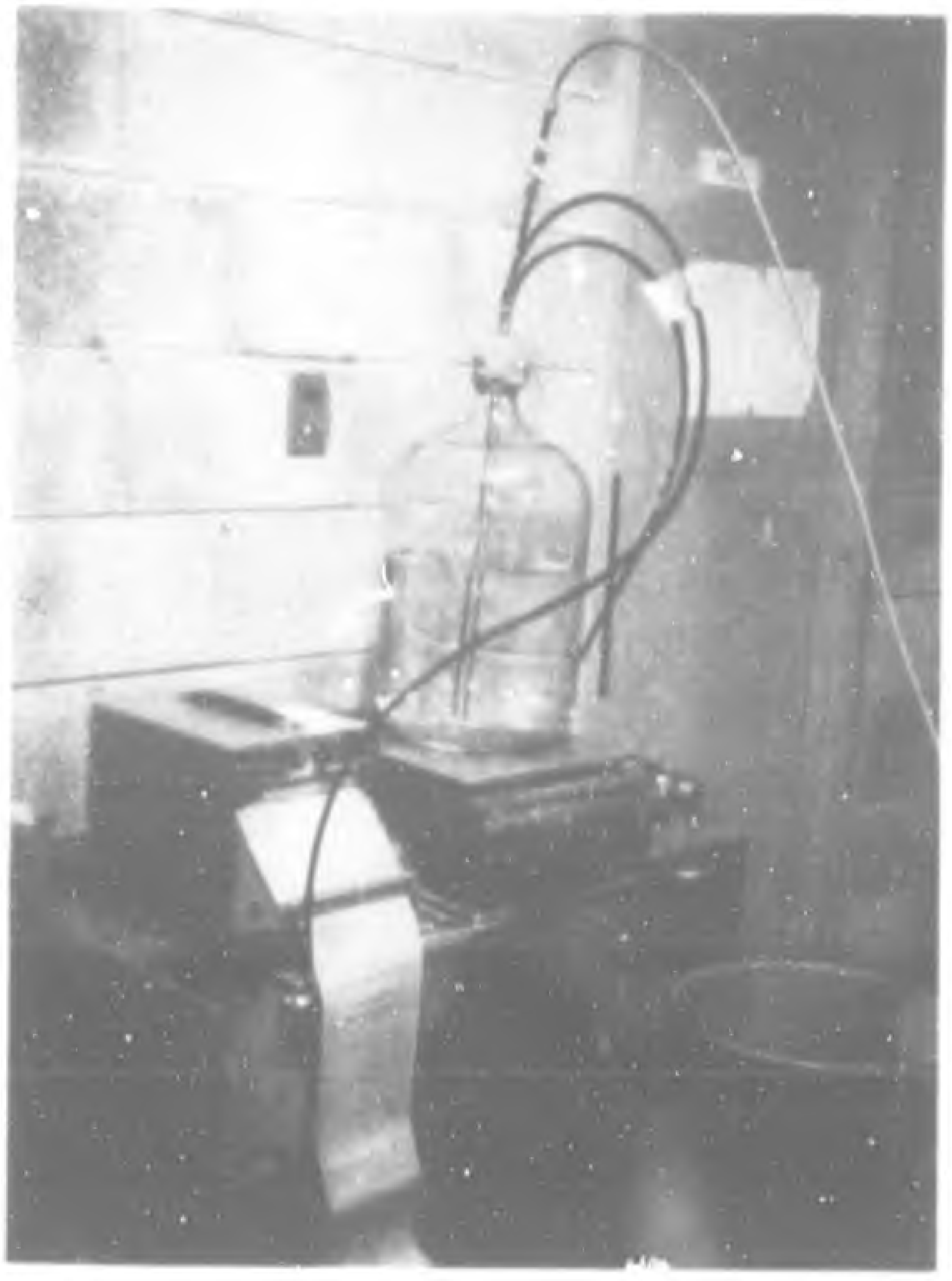


Figure D.2 Apparatus used to calibrate CO_2 gas analyzer for Helium and Argon.

APPENDIX D

Information on the Properties of Various Gases

Table D.1*

Solubilities of Gases in Water

Gas	By Volume at Atmospheric Pressure and 68° F	K x 10 $^{-7}$
Argon		2.58 @20°C
Carbon Dioxide	0.96	0.108 "
Helium		10.9 "

The above values represent Henry's Law Constant K, i.e.,

$$K = \frac{P}{X}$$

where P = partial pressure mm. of Hg.
X = mole fraction

For a given value of P, K varies inversely as X. If the mole fraction is relatively large, then the K value is relatively small, which indicates that the gas is more soluble in water. A higher value of K indicates less solubility in water. The above table shows that helium is the least soluble in water, whereas carbon dioxide is highly soluble.

* Abstracted from "Handbook of Chemistry and Physics", published by the Chemical Rubber Publishing Company of Cleveland, Ohio.

Table D.2

Thermal Conductivities of Various Gases

Gas	Mol. Wt.	Density	k
Air	29	0.075	0.0140 @32°F
Argon	40	0.1037	0.00915 "
Carbon Dioxide	44	0.1142	0.0084 "
Helium	4	0.0103	0.0818 "

It should be noted that helium has the largest "k" value, whereas CO_2 has the lowest "k" value.

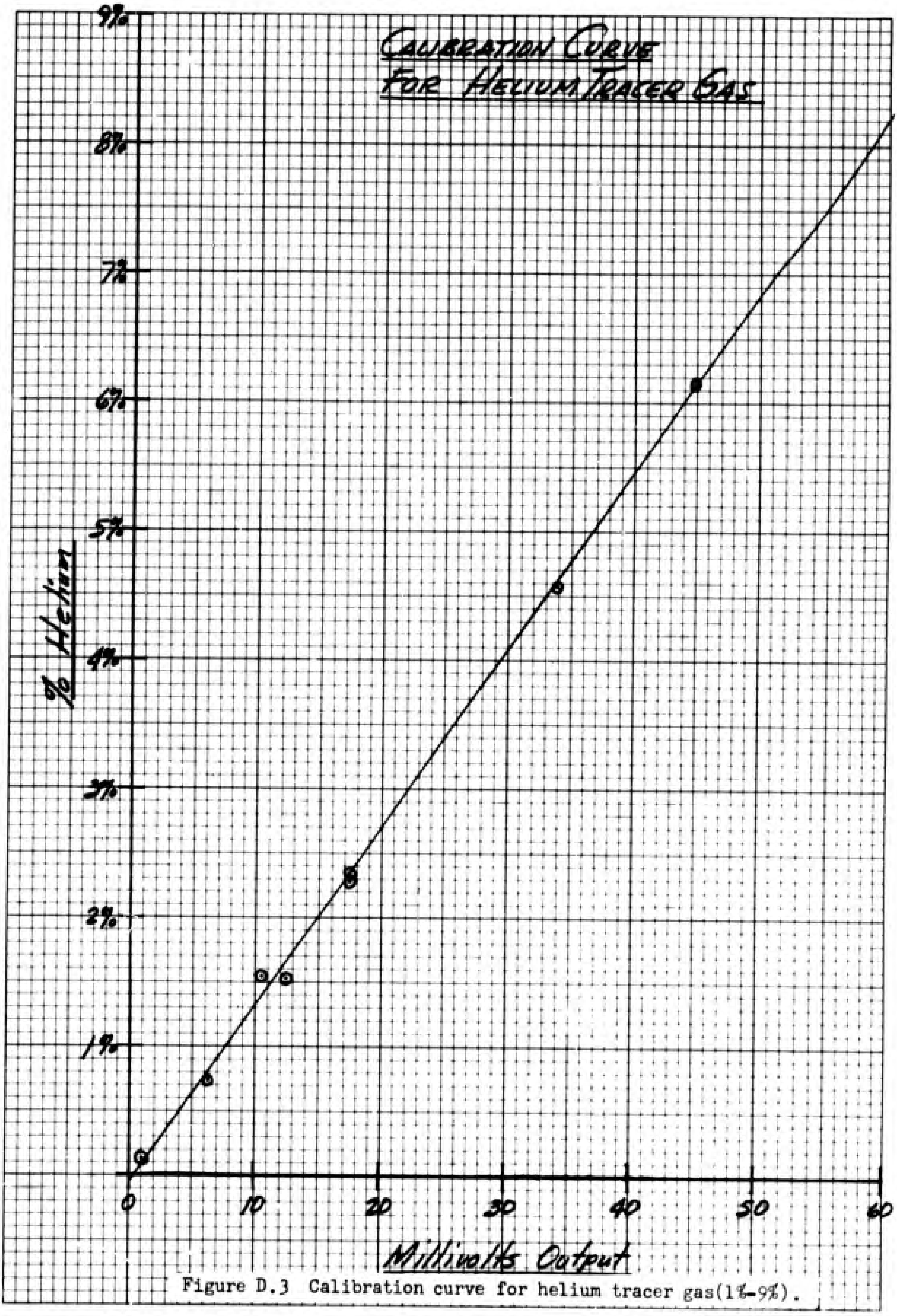


Figure D.3 Calibration curve for helium tracer gas(1%-9%).

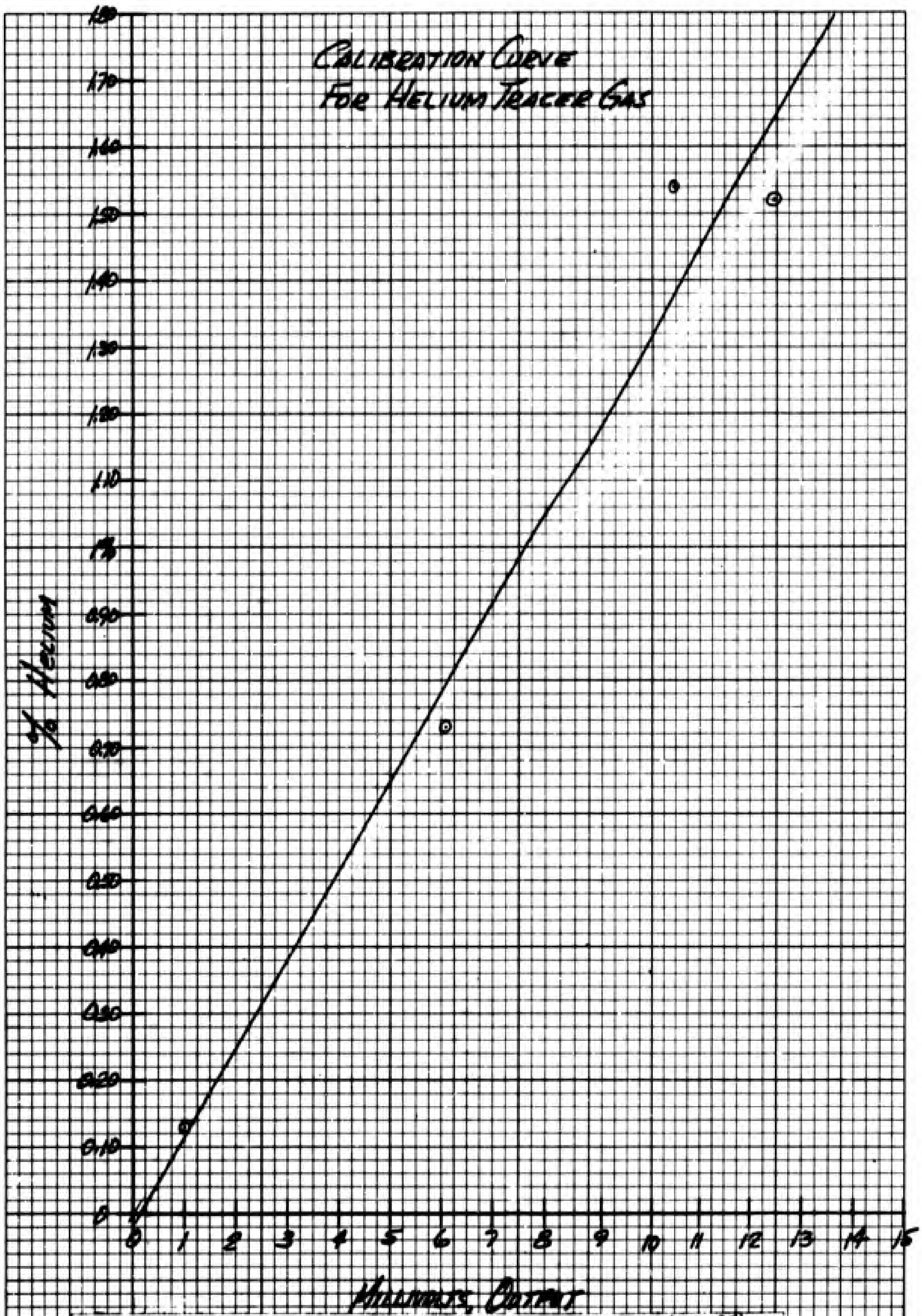


Figure D.4 Calibration curve for helium tracer gas (0-1.8%).

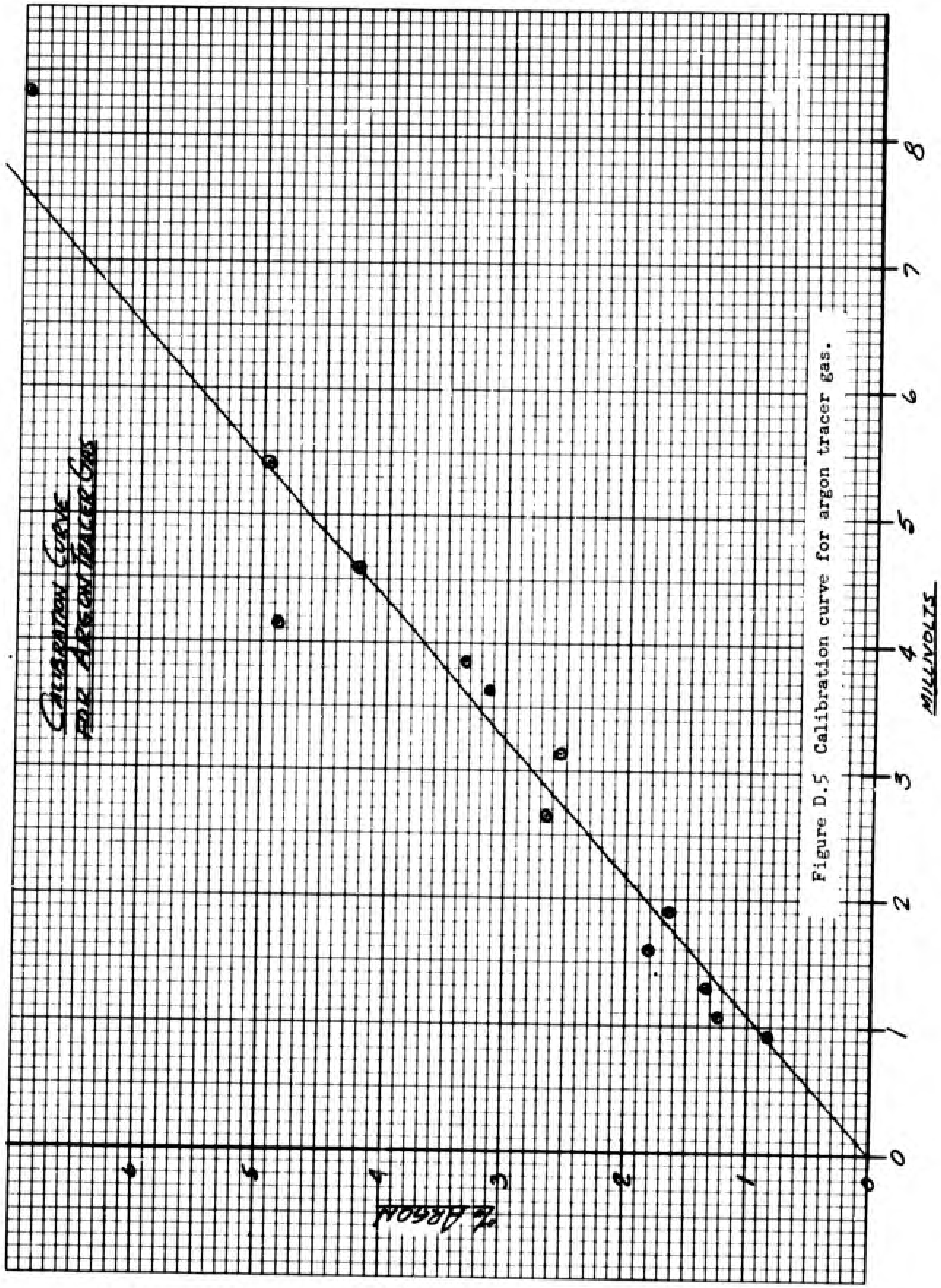


Figure D.5 Calibration curve for argon tracer gas.

APPENDIX E

LOCATION DIAGRAM OF THERMOCOUPLES AND HUMIDITY SENSOR HEAD

APPENDIX E

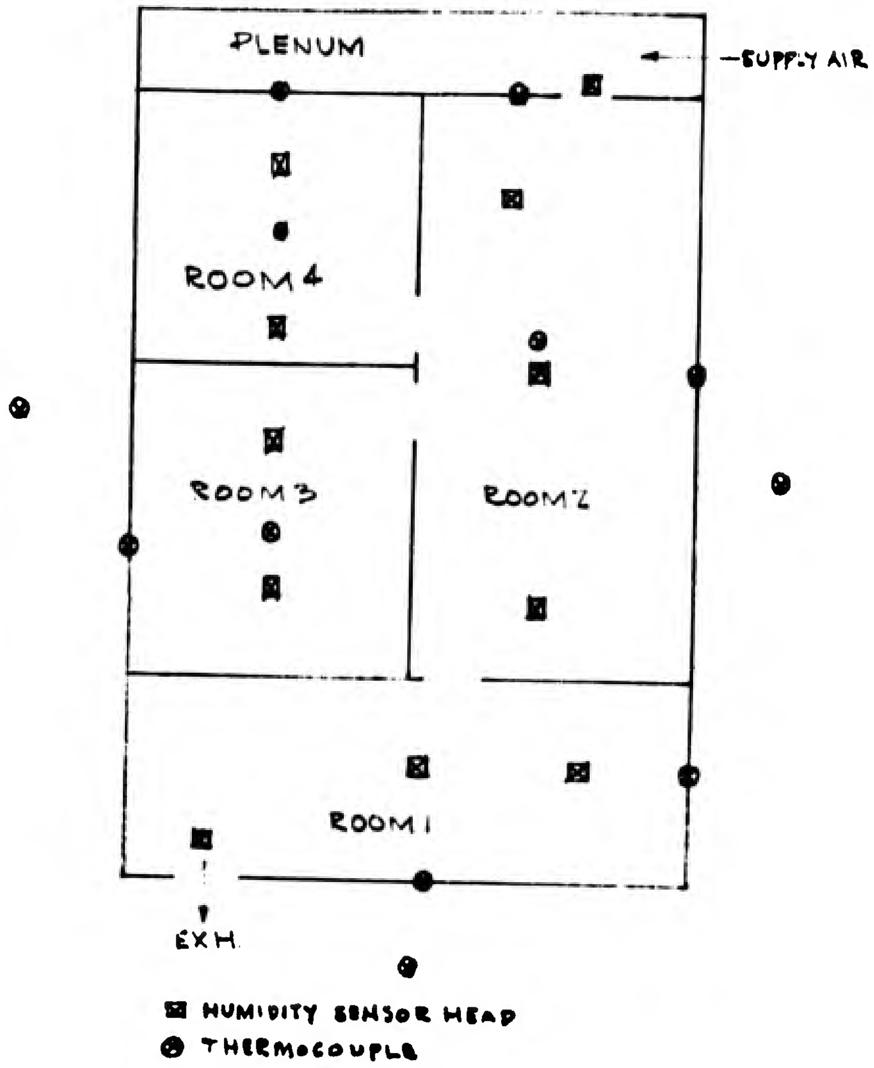


Figure E.1 Location diagram of thermocouples and humidity sensor heads.

APPENDIX F

CORRIDOR TEST SHELTER

APPENDIX F

CORRIDOR TEST SHELTER

F.01 A series of tests were conducted with the shelter arranged as shown in Figure F.1. The test shelter was a 6-room "adiabatic" mock-up shelter with 98 individual "Simocs" based on a loading ratio of 10 sq. ft. of shelter area per person (excluding corridor).

An adiabatic shelter was obtained in the sense that the DB temperatures are maintained essentially the same on the outside and inside to eliminate or nearly eliminate heat losses through the shelter boundaries. Thus, we know that essentially the only heat exchange which takes place in the shelter is between the Simocs and the ventilation air.

F.02 Conditioned air was supplied to the shelter from the Environmental Control and Instrumentation Trailer at varying flow and temperature conditions, similar to the Multi-room shelter test series described herein.

TABLE F.1

CONDITIONED AIR

"Condition" refers to MIN, AVG or MAX, steady state condition based on empirical diurnal variations representing a one percent summer design day. The various conditions are as follows:

	DB	WB	DP	Percent RH
MIN	76	73.1	72	88
AVG	84.6	75.5	72	66
MAX	93	77.6	72	51

F.03 PVK in Supply Configurations. The PVK was sealed in the door between the corridor and the plenum. A 20' diameter polyethylene duct was attached to the PVK shroud and extended through the corridor with 8' and 10' diameter branch ducts into each of the six shelter rooms as shown in Figure F.2. The branch ducts were each 10" long. A photograph of this test is included in Figure F.3.

F.04 Punkah in Exhaust Configuration. A six foot (full door size) punkah was mounted in the doorway at the end of the corridor as shown in Figure F.1 as the main air exhaust device for the shelter. The punkah was operated at a rate of 26 oscillations per minute. The punkah air delivery rate used in the tests was limited by the trailer capacity, about 28 cfm per occupant. To insure compatibility of the rate of air delivery of the punkah and the trailer, manometer readings to ascertain balance in the pressure levels in the test rooms and the plenum were taken at various times, especially just prior to scheduled temperature reading traverses. It was noted that the flexible ceiling of the test shelter pulsated with the pumping action of the punkah. However, this is considered to have little, if any, effect on temperatures recorded in the various rooms.

F.05 Table F-2 presents effective temperature conditions observed within the shelter rooms during the test for varying air supply quantities and conditions.

F.06 Auxiliary Devices for Side Rooms. To investigate beneficial effects of auxiliary devices in supplying air to the side rooms, punkahs and/or baffles were placed in the corridor doorways of certain shelter rooms. Punkahs used were the 3' type, or half door size, and were located essentially to accommodate previously placed motors and device mechanisms. Plywood "scoop" baffles were installed in the corridor doorways to the side rooms. The baffle consisted of a 3' x 4' plywood upright, fixed to the door jambs and extending at an angle into the corridor; see Figure F.4. Table F.3 shows representative figures for tests at maximum conditions.

F.07 Results.

a. The 6' full door punkah provides a more effective means of delivering air to the shelter than the PVK.

b. Punkahs are required to assure adequate distribution of available air to rooms not in the direct air flow path from supply to exhaust.

c. Results of "scoop" baffle tests were inconclusive with the indication being that they are ineffective.

APPENDIX F

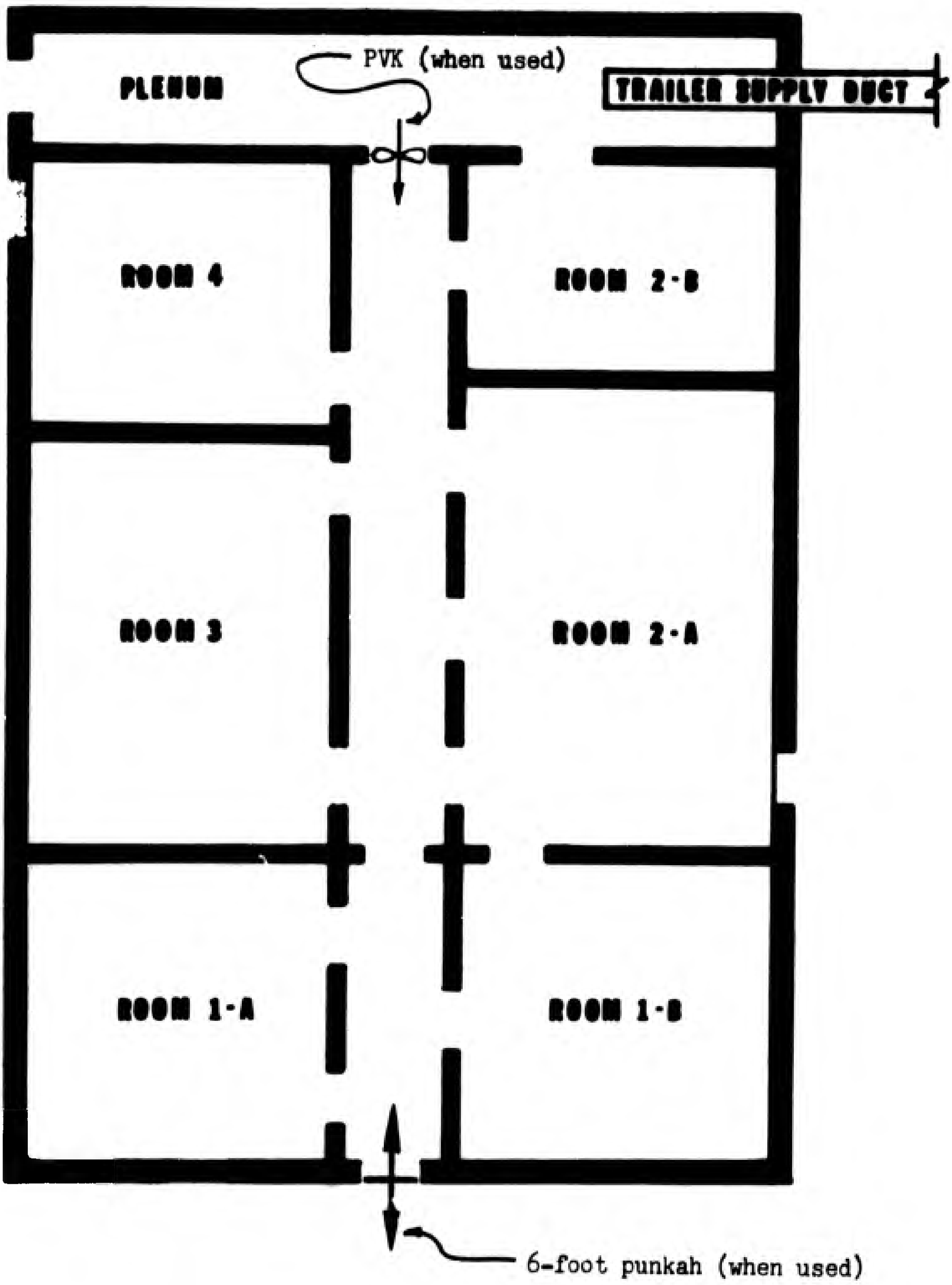
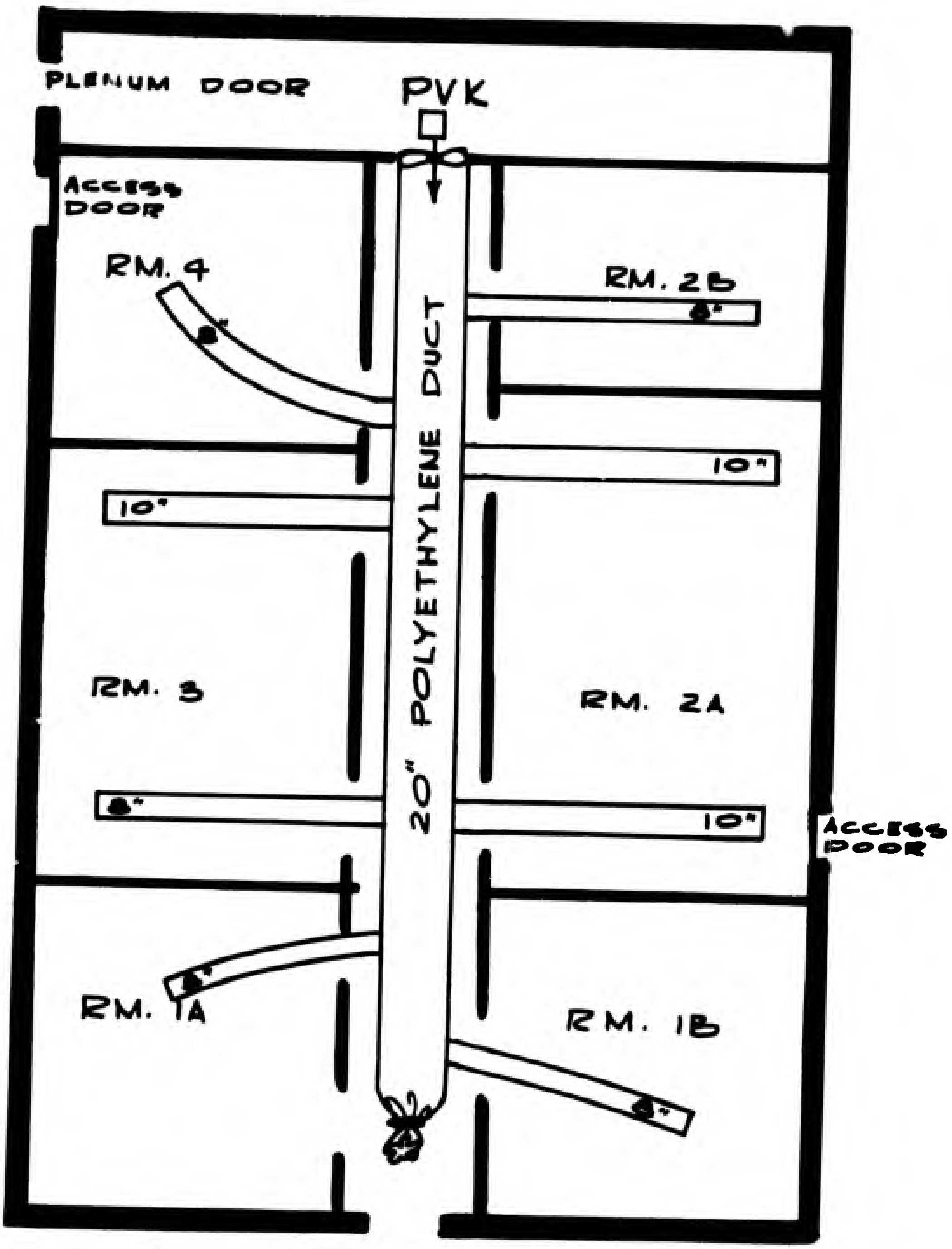


Figure F.1 Corridor Type Test Shelter

APPENDIX F



NOTE: ALL BRANCH DUCTS ARE 10'-0" LONG.

Figure F.2 Plastic Duct System

Figure F.3 Plastic supply duct in central corridor. Branch ducts extend into siderooms from main trunk.

Figure F.4 "Scoop" baffles in shelter corridor. Air flow is from front to back of picture. Three foot punkahs are used in corridor ceiling to mix stratified air.

TABLE F-2

Corridor Type Shelter

Effective Temperatures

	PVK - Plastic Duct Air Supply							6' Punkah - Exhaust		
	Minimum Conditions			Average Conditions			Max Cond	Min Cond	Avg Cond	Max Cond
Room	22.5 cfm	18 cfm	13.5 cfm	22.5 cfm	18 cfm	13.5 cfm	22.5 cfm	27 to 28 cfm		
1A	80.1	84.4	82.5	83.4	83.8	84.9	86.0	81.0	82.4	84.9
1B	81.5	81.6	83.9	83.7	84.0	85.9	86.1	83.0	83.9	86.5
2A	79.0	80.6	82.3	83.0	82.8	85.6	85.7	80.5	80.9	83.9
2B	81.8	81.2	85.0	84.1	84.0	86.9	87.5	78.0	80.5	84.9
3	78.0	80.3	80.9	82.0	82.5	84.0	85.3	80.3	81.3	84.0
4	81.2	80.7	83.4	84.2	84.6	85.9	86.6	81.4	83.5	84.0

APPENDIX F

TABLE F-3

Corridor Type Shelter
Punkahs and Baffles at Side Rooms

Effective Temperatures
(Maximum Conditions-PVK Exhaust)

	13.5 cfm		18 cfm		22.5 cfm		
Room	No Provisions	With Punkahs	No Provisions	With Punkahs	No Provisions	With Punkahs	With Baffles
1A	89.5	87.9	88.7	87.1	88.4	86.7	86.0**
1B*	89.2	88.4	88.0	86.7	88.1	86.7	87.0**
2A	87.5	86.0	86.6	85.1	87.1	84.8	80.3
2B	86.7**	86.6	86.1	86.1	86.7	86.4	85.4
3*	87.1	86.0	86.4	85.0	87.1	84.9	85.1
4*	88.0	85.0	88.2	84.5	87.9	84.5	85.5**

* 3' punkahs operating in upper portion of corridor doorway

** baffles in corridor doorway.

APPENDIX G

INDEX TO TEST NUMBERS AND SHELTER CONFIGURATION

APPENDIX G

TABLE G.1

INDEX TO TEST NUMBERS AND SHELTER CONFIGURATION
(ALL TESTS WITH EXHAUST CONFIGURATION ONLY)

TEST NUMBER	SHELTER VENT. RATE CFM/OCCUPANT	AIR SUPPLY CONDITION	LOCATION OF PUNKAH	TRAVERSE		REMARKS BAFFLE AND PUNKAH ARRANGEMENT
				VELOCITY	PSYCHOMETRIC	
1	13.5	Minimum	None		x	
2	13.5	Minimum	Low		x	
3	13.5	Average	None	x	x	
4	13.5	Average	Low	x		
5	13.5	Average	Low	x		
6	13.5	Maximum	None			Install Bfl. B_1
7	13.5	Maximum	None	x	x	Remove B_1
8	13.5	Maximum	Low	x	x	Install B_1
9	13.5	Maximum	None			"
10	13.5	Maximum	High	x		"
11	13.5	Maximum	None			"
12	13.5	Maximum	High			"
13	13.5	Maximum	High	x	x	"
14	13.5	Maximum	None			B_1, Side Bfls. Rooms 3 & 4
15	13.5	Maximum	Low	x	x	B_1, Side Bfls. Rooms 3 & 4
16	13.5	Average	None			B_1, Side Bfls. Rooms 3 & 4
17	13.5	Average	Low		x	Install B_1
18	- -	Not Cond.	None			B_1, Horiz. Bfls. Rooms 3 & 4 ($\frac{1}{2}$ hr.)
19	- -	Not Cond.	None			6' Punkah
20	- -	Not Cond.	None			6' Punkah
21	- -	Not Cond.	None			6' Punkah
22	- -	Not Cond.	None			6' Punkah w/Bfls.
23	- -	Not Cond.	None			6' Punkah w/Bfls.
24	41.0	Average	None	x	x	6' Punkah w/Bfls.
25	41.0	Average	Push/Pull	x	x	6' Punkah
26	41.0	Average	Push/Pull	x	x	6' Punkah, CO_2 Test, Room 3
27	41.0	Minimum	Push/Pull	x	x	6' Punkah, w/Bfl-Plenum
28	40.0	Maximum	Push/Pull		x	6' Punkah, B_1, CO_2 Test, Rms. 3 & 4 6' Punkah, B_1, CO_2 Test, Rms. 3 & 4

TABLE G.1 (continued)

TEST NUMBER	SHELTER VENT. RATE CFM/OCCUPANT	AIR SUPPLY CONDITION	LOCATION OF PUNKAH	TRAVERSE		REMARKS BAFFLE AND PUNKAH ARRANGEMENT
				VELOCITY	PSYCHOMETRIC	
29	41.0	Maximum	Push/Pull	x	x	6' Punkah, B_1, CO_2 Test, Rms. 3 & 4 + Parallel Airflow
30	26.6	Maximum	Push/Pull	x	x	6' Punkah, No Bfls.
31	27.0	Maximum	Push/Pull	x	x	6' Punkah, No Bfls.
32	- -	Not Cond.	None			6' Punkah, Bfls. Outside Door
33	13.5	Average	None	x		PVK Exhaust, B_1
34A	13.5	Average	Push/Pull	x	x	" "
34B	13.5	Average	Push/Pull	x	x	Remove B_1, CO_2 Test, Rms. 3 & 4
35	13.5	Average	Push/Pull		x	Remove B_1, CO_2 Test, Rms. 3 & 4
36	13.5	Maximum	Push/Pull		x	B_1, 3'x7' Side Bfls, Inside & Outside Rms. 3 & 4
37	13.5	Maximum	Push/Pull	x	x	B_1, Horiz. Bfls, Inside & Outside Rms. 3 & 4
38	13.5	Minimum	Push/Pull		x	"
39	13.5	Minimum	Push/Pull			"
40	18.0	Minimum	Push/Pull	x	x	"
41	18.0	Average	Push/Pull		x	"
42	18.0	Average	Push/Pull		x	Remove B_1, Horiz. Bfls. Inside & Outside Rms. 3 & 4
43	18.0	Maximum	Push/Pull		x	B_1, Horiz. Bfls, Inside & Outside Rms. 3 & 4
44	22.5	Minimum	Push/Pull	x	x	"
45	22.5	Average	Push/Pull		x	"
46	22.5	Average	Push/Pull	x	x	B_1, Horiz. Bfls, Inside & Outside Rms. 3 & 4 + Cross Bfls.

TABLE G.1 (continued)

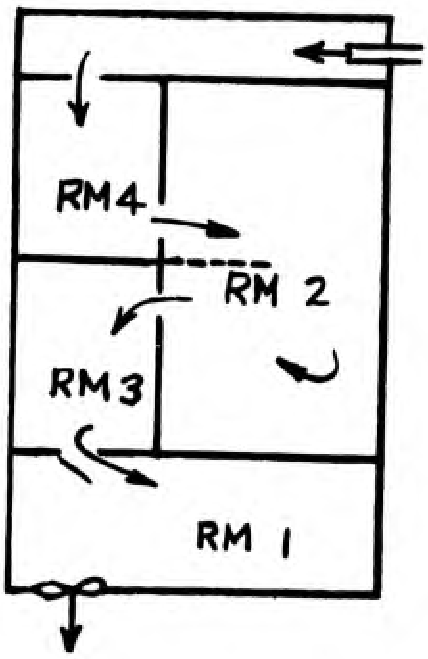
TEST NUMBER	SHELTER VENT. RATE CFM/OCCUPANT	AIR SUPPLY CONDITION	LOCATION OF PUNKAH	TRAVERSE		REMARKS BAFFLE AND PUNKAH ARRANGEMENT
				VELOCITY	PSYCHOMETRIC	
47	22.5	Maximum	Push/Pull		x	B_1, Horiz. Bfls, Inside & Outside Rms. 3 & 4 + Cross Bfls.
48	22.5	Maximum	High		x	"
49	22.5	Minimum	High	x	x	Horiz. Bfls, Inside & Outside Rms. 3 & 4
50	22.5	Minimum	High	x	x	B_1, Horiz. Bfls, Inside & Outside Rms. 3 & 4
51	22.5	Average	High		x	"
52	18.0	Average	High	x	x	B_1, Horiz. Bfls, Cross Bfls.
53	18.0	Maximum	High		x	B_1, Horiz. Bfls, Cross Bfls. + HE & CO_2 Tests
54	18.0	Minimum	High	x	x	Same as 53 w/o HE Test
55	13.5	Minimum	High/Low	x	x	B_1, Horiz. & X Bfls, CO_2 Test
56	13.5	Average	High		x	"
57	13.5	Maximum	High			"
58	13.5	Maximum	None	x	x	Series Air Flow
59	13.5	Minimum	None	x	x	"
60	13.5	Dry Heat	None		x	"
61	13.5	Dry Heat	None	x	x	B_1, 1/2 Size Punkahs w/horiz. Bfls. in/out Rms. 3 & 4
62	18.0	Dry Heat	None		x	"
63	22.5	Dry Heat	None		x	"

APPENDIX H

SERIES AIR FLOW CALCULATIONS

APPENDIX H

SERIES AIR FLOW CALCULATIONS



RESPONSE @ AVERAGE SUPPLY CONDITIONS - 13.5 CFM/OCC. OR 1512 CFM TOTAL

Path:

Room 4 = 1512/13 = 116 cfm/occ.

Room 2 = 1512/45 = 33.6 cfm/occ.

Room 3 = 1512/19 = 79.6 cfm/occ.

Room 1 = 1512/35 = 43.2 cfm/occ.

$$ta = \frac{1.08gtv+1000}{1.08g+10}$$ Shelter Dry Bulb*

$$Wa = \frac{Wv+10ta-600}{4700g}$$ Shelter Specific Humidity*

*Extracted from Chapter 30, ASHRAE Guide and Data Book 1964, Applications, Equations (5) and (6).

APPENDIX H

Room 4

$$ta = \frac{1.08x116x84.6+1000}{1.08x116+10} = 85.7$$

$$Wa = .017+\frac{10(85.7)-600}{4700x116} = .017$$

$$twb = 75.8$$

$$ET = \underline{80^{\circ}}$$

Room 2

$$ta = \frac{1.08x33.6x85.7+1000}{1.08x33.6+10} = 88.8$$

$$Wa = .017+\frac{10(88.8)-600}{4700x33.6} = .019$$

$$twb = 78.7$$

$$ET = \underline{82.5^{\circ}}$$

Room 3

$$ta = \frac{1.08x79.6x88.8+1000}{1.08x79.6+10} = 90^{\circ}$$

$$Wa = .019+\frac{10(90)-600}{4700x79.6} = .020$$

$$twb = 80^{\circ}$$

$$ET = \underline{84^{\circ}}$$

Room 1

$$ta = \frac{1.08x43.2x90+1000}{1.08x43.2+10} = 91.8$$

$$Wa = .020+\frac{10(91.8)-600}{4700x43.2} = .0215$$

$$twb = 82^{\circ}$$

$$ET = \underline{85.3^{\circ}}$$

APPENDIX H

RESPONSE @ AVERAGE SUPPLY CONDITIONS - 13.5 CFM/OCC. OR 1512 CFM TOTAL

Path:

Room 2 = 1512/45 = 33.6 cfm/occ.

Room 1 = 1512/35 = 43.2 cfm/occ.

Room 3 = 1512/19 = 79.6 cfm/occ.

Room 4 = 1512/13 = 116 cfm/occ.

Room 2

$$ta = \frac{1.08 \times 33.6 \times 84.6 + 1000}{1.08 \times 33.6 + 10} = 87.9$$

$$Wa = .017 + \frac{10(87.9) - 600}{4700 \times 33.6} = .019$$

$$twb = 78.5$$

$$ET = \underline{82.1^{\circ}}$$

Room 1

$$ta = \frac{1.08 \times 43.2 \times 87.9 + 1000}{1.08 \times 43.2 + 10} = 90^{\circ}$$

$$Wa = .019 + \frac{10(90) - 600}{4700 \times 43.2} = .0204$$

$$twb = 80.4^{\circ}$$

$$ET = \underline{84^{\circ}}$$

Room 3

$$ta = \frac{1.08 \times 79.6 \times 90 + 1000}{1.08 \times 79.6 + 10} = 91^{\circ}$$

$$Wa = \frac{.0204+10(91)-600}{4700x79.6} = .0212$$

$twb = 81.4^{\circ}$

$ET = \underline{85^{\circ}}$

Room 4

$$ta = \frac{1.08x116x91+1000}{1.08x116+10} = 91.9$$

$$Wa = \frac{.0212+10(91.9)-600}{4700x116} = .0218$$

$twb = 82.2$

$ET = 85.5$

RESPONSE @ MAXIMUM SUPPLY CONDITION - 13.5 CFM/OCC.

Path:

Room 2 = 1512/45 = 33.6 cfm/occ.

Room 1 = 1512/35 = 43.2 cfm/occ.

Room 3 = 1512/19 = 79.6 cfm/occ.

Room 4 = 1512/13 = 116 cfm/occ.

Room 2

$$ta = \frac{1.08x33.6x93+1000}{1.08x33.6+10} = 94.5$$

$$Wa = \frac{.017+10(94.5)-600}{4700x33.6} = .0191$$

$twb = 80.2$

$ET = \underline{85.4}$

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Room 1

$$ta = \frac{1.08x43.2x94.5+1000}{1.08x43.2+10} = 95.5^{\circ}$$

$$Wa = \frac{.0191+10(95.5)-600}{4700x43.2} = .0208$$

$$twb = 82^{\circ}$$

$$ET = \underline{86.5}$$

Room 3

$$ta = \frac{1.08x79.6x95.5+1000}{1.08x79.6+10} = 96^{\circ}$$

$$Wa = .0208+\frac{10(96)-600}{4700x79.6} = .0218$$

$$twb = 83.2^{\circ}$$

$$ET = \underline{87.2^{\circ}}$$

Room 4

$$ta = \frac{1.08x116x96+1000}{1.08x116+10} = 96.3^{\circ}$$

$$Wa = .0218+\frac{10(96.3)-600}{4700x116} = .0218$$

$$twb = 83.3^{\circ}$$

$$ET = \underline{87.5^{\circ}}$$

RESPONSE @ MAXIMUM SUPPLY CONDITION - 13.5 CFM/OCC. PATH (Theoretical Check Against Actual Test Data)

Path:

Room 4 = 1512/13 = 116 cfm/occ.

APPENDIX H

Room 2 = 1512/45 = 33.6 cfm/occ.

Room 3 = 1512/19 = 79.6 cfm/occ.

Room 1 = 1512/35 = 43.2 cfm/occ.

Room 4

$$ta = \frac{1.08x116x93+1000}{1.08x116+10} = 93.5^{\circ}$$

$$Wa = .017+\frac{10(93.5)-600}{4700x116} = .017$$

$$twb = 77.8^{\circ}$$

$$ET = \underline{83.9^{\circ}}$$

ROOM 2

$$ta = \frac{1.08x33.6x93.5+1000}{1.08x33.6+10} = 95^{\circ}$$

$$Wa = .017+\frac{10(95)-600}{4700x33.6} = .0192$$

$$twb = 80.5$$

$$ET = \underline{85.5^{\circ}}$$

Room 3

$$ta = \frac{1.08x79.6x95+1000}{1.08x79.6+10} = 95.5$$

$$Wa = .0192+\frac{10(95.5)-600}{4700x79.6} = .0201$$

$$twb = 81.5^{\circ}$$

$$ET = \underline{86.2^{\circ}}$$

APPENDIX H

Room 1

$$ta = \frac{1.08x43.2x95.5+1000}{1.08x43.2+10} = 96.3$$

$$Wa = .0201+\frac{10(96.3)-600}{4700x43.2} = .0219$$

twb = 83.3

$ET \underline{= 87.5^{\circ}}$

RESPONSE @ MAXIMUM SUPPLY CONDITION - 13.5 CFM/OCC.

Path:

Room 4 = 1512/13 = 116 cfm/occ.

Room 3 = 1512/19 = 79.6 cfm/occ.

Room 1 = 1512/35 = 43.2 cfm/occ.

Room 2 = 1512/45 = 33.6 cfm/occ.

Room 4

$$ta = \frac{1.08x116x93+1000}{1.08x116+10} = 93.5^{\circ}$$

$$Wa = .017+\frac{10(93.5)-600}{4700x116} = .017$$

twb = 77.8°

ET = 83.9°

Room 3

$$ta = \frac{1.08x79.6x93.5+1000}{1.08x79.6+10} = 94.2^{\circ}$$

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$$Wa = .017+\frac{10(94.2)-600}{4700x79.6} = .0179$$

$$twb = 79^{o}$$

$$ET = \underline{84.9^{o}}$$

Room 1

$$ta = \frac{1.08x43.2x94.2+1000}{1.08x43.2+10} = 95.2$$

$$Wa = .0179+\frac{10(95.2)-600}{4700x43.2} = .0196$$

$$twb = 80.9^{o}$$

$$ET = \underline{85.9^{o}}$$

Room 2

$$ta = \frac{1.08x33.6x95.2+1000}{1.08x33.6+10} = 96.2^{o}$$

$$Wa = .0196+\frac{10(96.2)-600}{4700x33.6} = .0219$$

$$twb = 83.4^{o}$$

$$\underline{ET = 87.5^{o}}$$

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$$Wa = .017+\frac{10(94.2)-600}{4700x79.6} = .0179$$

twb = 79°

ET = $\underline{84.9°}$

Room 1

$$ta = \frac{1.08x43.2x94.2+1000}{1.08x43.2+10} = 95.2$$

$$Wa = .0179+\frac{10(95.2)-600}{4700x43.2} = .0196$$

twb = 80.9°

ET = $\underline{85.9°}$

Room 2

$$ta = \frac{1.08x33.6x95.2+1000}{1.08x33.6+10} = 96.2°$$

$$Wa = .0196+\frac{10(96.2)-600}{4700x33.6} = .0219$$

twb = 83.4°

ET = $\underline{87.5°}$

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13. ABSTRACT

Ventilation studies for determining the effectiveness of manual air moving devices were conducted in the multi-room adiabatic mock-up shelter at the Protective Structures Development Center.

The air moving devices used in the study were adapted from the Oriental Punkah, a device used to fan a room. They are low in cost, of simple construction, rugged and durable, can be stored indefinitely under most conditions, and are capable of circulating relatively large volumes of air at extremely low power requirements.

Observations of the air distribution and velocity patterns within all shelter rooms for various configurations and ventilation rates indicates that punkahs exert a significant influence.

Punkahs provide an inexpensive, simple, durable, and efficient method of improving the ventilation and habitability of fallout shelter spaces.

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Security Classification

END