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Final Report

FEASIBILITY OF LOW COST VENTILATION TECHNIQUES

By: TATSU HORI

Prepared for:

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

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WORK UNIT 1233A

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

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DETACHABLE ABSTRACT

The specific objective of the work project was to evaluate the use of a punkah to distribute air within a fallout shelter and to determine its flow characteristics. The punkah is an oscillating panel, with a series of simple one-way valves, that can be hung from a ceiling or in an open doorway. In the experiments, the punkah was used not only to distribute air within a room, but also to move air from one room to another. Punkahs were tried in various parts of the rooms that comprised the experimental shelter, and various paneling configurations for improving air delivery were investigated. Of special interest was the problem of ventilating a dead-end compartment, this being the most difficult type of room to ventilate because its only air inlet is a single inside doorway.

The internal heat load provided was all sensible heat. Dry-bulb temperature readings were taken at six room levels to evaluate the cooling effect of the punkah. The punkah was capable of ventilating a dead-end room and also of mixing the air within such a room sufficiently to maintain a climatic condition very near to that of the adjacent room.

Flow tests were made on the half-door sized punkah. For purposes of controlling flow and providing measurements of velocitv and pressure, tests were performed using a ducted housing. Performance curves for the punkah operating in four different modes were developed.

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INTRODUCTION

Under a recent OCD Shelter Ventilation Test Program, a thorough study was made of the ventilation requirements, principally as a function of geographical location, type of shelter, density of occupancy, and occupancy load. Once the ventilation requirements were known, the problem became one of delivering the required amount of air to the shelter and distributing it throughout the shelter so that the design climatic condition could be maintained.

Distribution of ventilating air within a fallout shelter is evaluated in terms of the ability of an air-moving or air-directing device to route the air to all rooms constituting the shelter and to all parts of those rooms so that the entire shelter environment is maintained at or below the design condition. In some shelters the location and number of the inlets and outlets may be so restricted that routing and distributing the air becomes a problem requiring careful planning. Among this type of shelters are large single rooms with inlets that are not well dispersed, those that have adjoining "dead-end" compartments with only a single connecting doorway, multiple room shelters, and corridor-type shelters.

There have been some general studies, by air-conditioning engineers, of air distribution within a room as a function of various air inlet and ducting configurations. In these studies, the principal concern has been comfort, as defined by small temperature variation and air movements in the accepted comfort region of 15 to 35 feet per minute. In a fallout shelter, however, optimum air-inlet configurations and ducting may not be built in. Ventilating systems must be of an emergency type, such as the recently developed ventilation kit (VK), which consists of a motor-driven or man-powered fan unit with its plastic tube ducting system; or the punkah, which is a simple hand-operated device.

Part One of this report presents an evaluation of the punkah as a means of distributing air within a fallout shelter, which is Part 6 of Task Order 64-201(25)65. (Parts 1 through 5 concerned the development of methods of distributing ventilating air within the shelter.) The evaluation provided herein includes the results of a series of qualitative and quantitative tests of punkah performance in the rooms of a simulated shelter on the SRI grounds. A specific aim of the study was investigation of the problem of delivering air into and distributing it within a "dead-end" room. It was hoped that much basic information would be gained from this investigation, leading to the development of techniques for delivering and routing ventilating air in confined shelter spaces of this type.

Part Two of this report presents the flow characteristics of the punkah that were determined in a series of tests using controlled air flow through a duct.

Part One

THE PUNKAH AS A MEANS OF DISTRIBUTING AIR WITHIN A FALLOUT SHELTER

I DESCRIPTION OF THE TEST

A. Test Site

The test site chosen was one of the wooden buildings (Bldg. 204B) on the Institute grounds. This building was originally built as a temporary hospital and was subsequently converted into apartments for Stanford University students. The floor plan is shown in Fig. I-1. The building has a gabled tarpaper roof, exterior walls of stucco and board, and a floor of asphalt tile over wood base. The linings of the interior walls are of sheetrock.

One of the apartments (Apt. 12) in this building was chosen for testing air distribution. This apartment consisted of three rooms plus auxiliary closets; the floor plan i shown in Fig. I-2. The rooms and windows were arranged in such a way that it was possible to study the air distribution in room A and room B using the air entering through either window W-3 or W-4. Windows W-1 and W-2 were boarded up with one-inch celotex sheets to form a windowless wall. The exhaust was located at the north wall, as shown in Fig. I-2, and the exhaust blower in the adjoining apartment.

Door D-5 of room A was boarded up with 1-inch celotex sheets, making room A an isolated room with only a single doorway (D-4) adjoining room B. The purpose of this "dead-end" room was to simulate many of the conditions that exist in present identified shelters.

Figure I-3 is a view of test room B looking east. Posts mounting heater wires occupy the room. Figure I-4 shows the north wall of the room where the exhaust duct is located, along with the power panel and the punkah drivers.

B. The Punkah

The punkah (shown in Fig. I-10) is essentially a panel hung by one edge and allowed to oscillate like a pendulum. It is equipped with a series of loosely hinged plastic sheet panels that act like a check valve, allowing air to travel in one direction only. Its construction and operation

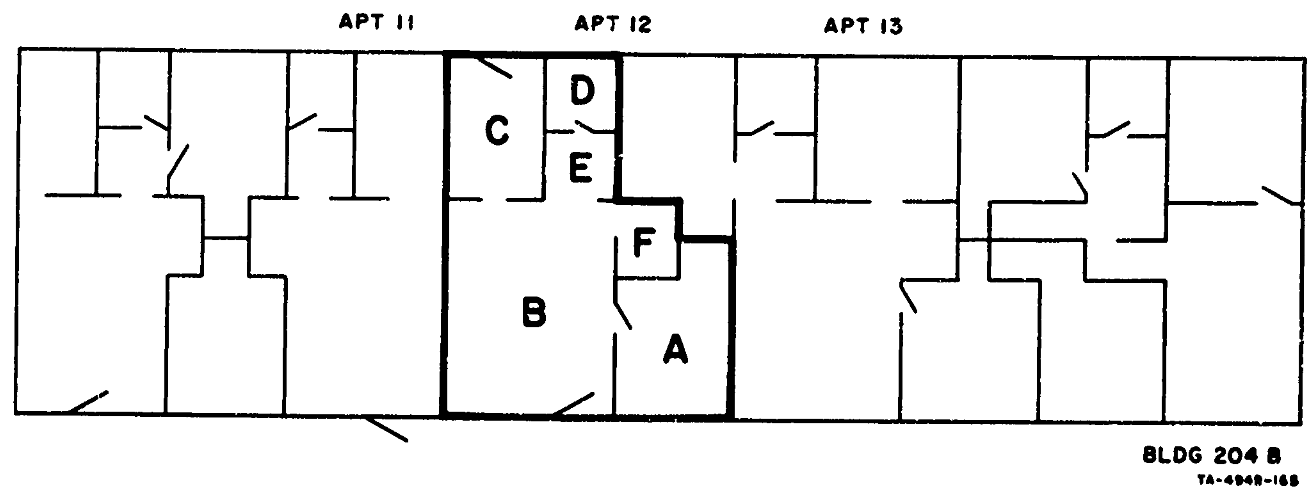

FIG. I-1 FLOOR PLAN OF BUILDING 204B, STANFORD RESEARCH INSTITUTE

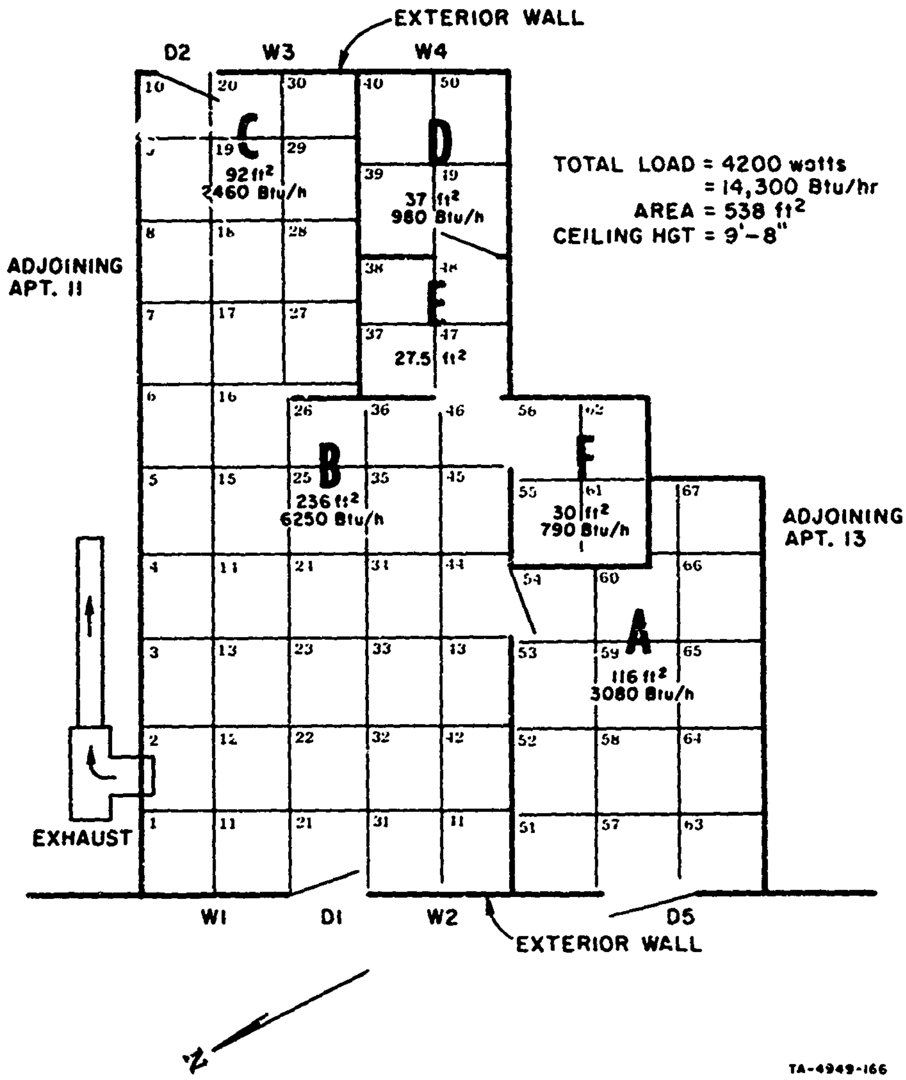

FIG. I-2 FLOOR PLAN OF APARTMENT 12, BUILDING 204B

FIG. I-3 TEST ROOM B WITH HEATER WIRES MOUNTED ON POSTS

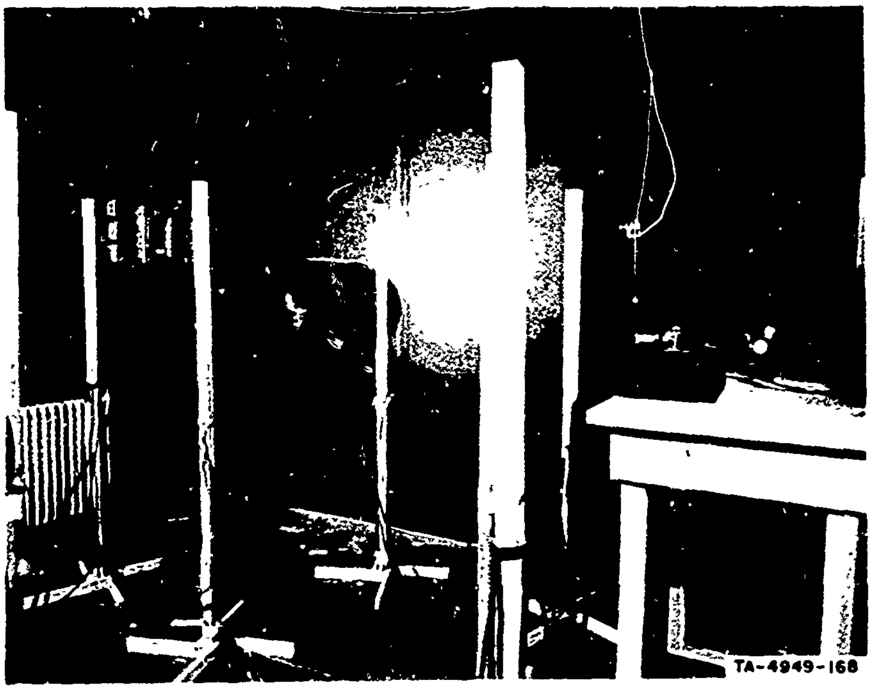

FIG. I-4 NORTH WALL OF TEST ROOM B, SHOWING EXHAUST DUCT are described in Refs. 1 and 2.* In Ref. 1, the punkah is described as a low-air-velocity (low-energy) air pump that delivers air over a large cross-sectional area. In this present project, the punkah was used both to mix the air and to move it between rooms.

The dimensions of the punkah were 27 X 36 inches. It was constructed so that it would fit in the doorway between rooms A and B, and its length was made about one-half the doorway height so that the other portion of the doorway could be used as an air inlet or outlet and as an entryway. The door punkah was used to pump air into dead-end room A, and other punkahs were located in different parts of the room to create various ventilation conditions for the air distribution study.

C. Simulated Occupancy Load

Electrical wires were used to generate the internal load. The wires, with a resistance of 7 ohms per foot, were distributed throughout the rooms and were supported on poles to a height of 30 inches so that heat could be generated at about the normal occupancy levels (see Fig. I-3). Since only sensible heat load is created with this arrangement, the change in dry-bulb (DB) temperature was the principal criterion in evaluating air distribution. In a 100-percent sensible heat process, the enthalpy char of 1 Btu per pound would require 1/.24 (1/specific heat) or approximately a 4-degree change in DB temperature. The experimental procedure was somewhat simplified by eliminating moisture generation and moisture change measurements.

The use of simocs (simulated occupants), which had been used in previous studies, was contemplated at the outset of this investigation. A simoc is essentially a cloth-covered, sheet-metal cylinder with a surface area equivalent to that of the average human body. It is equipped with an electrical heater, which simulates the total heat output of a single occupant. For moisture generation, water can be metered over the surface of a simoc in an amount relative to the magnitude of the DB temperature. Simocs were not used in this study for the following reasons:

(1) Recording the wet-bulb (WB) temperature would not provide additional information for determining air distribution.

(2) The volume of a simoc exceeds that of the average human body, even though the surface area is equivalent, and since these simocs would occupy excessive space in a room, it was felt that the air path might be adversely affected.

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*References are given at the end of this report.

D. Instrumentation

Instruments and gages used were:

(1) Dual-Channel dc Amplifier Recorder, Model 320; Sanborn

(2) Two stands mounting six temperature transducers each made up thermolinear thermistors, No. 44204, Yellow Springs Instrument Co., Yellow Springs, Ohio

(3) Bridge console for switching temperature transducers, (two sets six channels each); SRI

(4) Flowtronic Air Velocity Meter, Model 55B1; Flow Corp., Cambridge, Mass.

(5) Flex Tube Manometer, No. 27 F.W. Dwyer Mfg. Co., Michigan City, Indiana

(6) Fused Quartz Precision Pressure Gage; Texas Instruments Inc.

(7) Digital Voltmeter, Model 481: Nonlinear Systems Inc., Del Mar, Calif.

1. Temperature Transducers

It was not known initially how many temperature locations were required; therefore, a portable system was designed. Two 8-foot stands, each mounting six thermolinear transducers to measure the vertical temperature gradient at any station in the room, were set up for rooms A and B, respectively. Figure I-5 shows one of these stands in room A. The six thermistors were labeled as sensors a, b, c, d. e, and f, starting from the top of the stand. This identification was used in recording the vertical positions. Since the temperature readings of sensors a, b, c, and d varied only 0.5 degree or less throughout the test, only the b reading was recorded on the data sheet, as representative of all four readings. In determining the average temperature for a particular station, all six readings were used.

Cables from each of the two thermistor stands were connected to a console containing the bridge circuits, whose output was then recorded on a two-channel Sanborn recorder (Fig. I-6). Two sets of switches selected the particular sensors being recorded. Each channel recorded the six temperatures sensed by the six transducers. Bridge circuitry

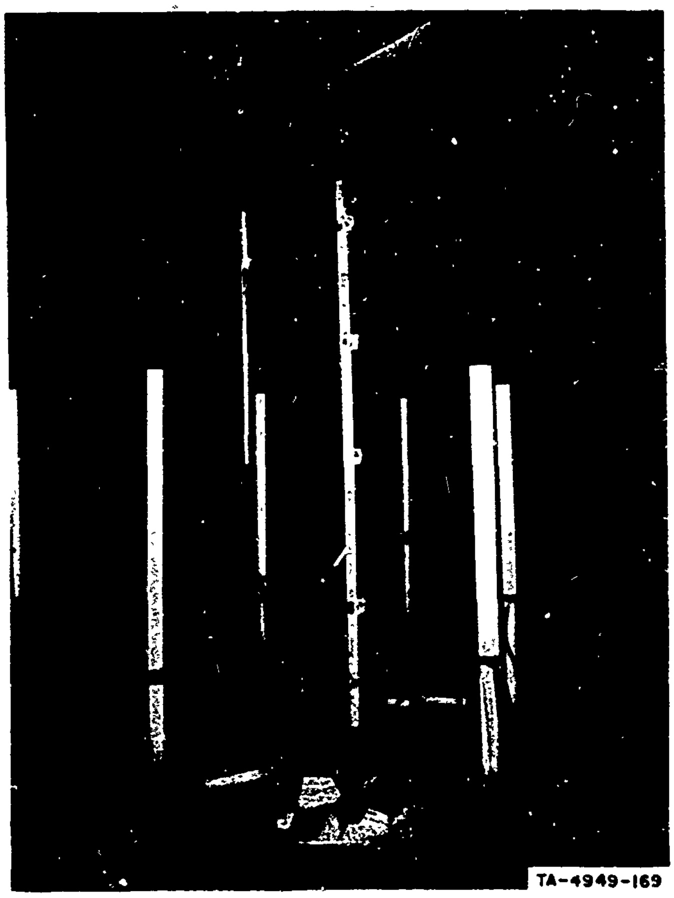

FIG. I-5 THERMOLINEAR TRANSDUCER STAND IN ROOM A

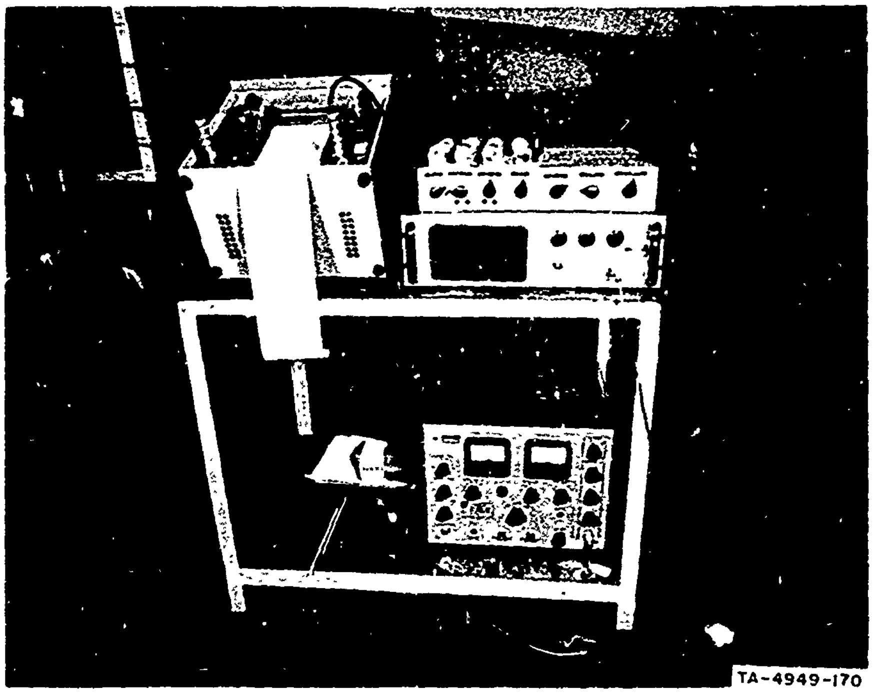

FIG. I-6 INSTRUMENT GROUP

for one channel is shown in Figure I-7. To realize the ± 0.2-percent accuracy of the thermistor bridge, the load resistance was required to be greater than 1MΩ. The Sanborn recorder has an input resistance of 500 kΩ, which was increased by using an emitter follower. To equalize the resulting base-to-emitter offset voltage, a second emitter follower of opposite polarity was cascaded. Also, to assure high input resistance and stable performance, high-beta silicon transistors were used.

Much of the temperature recording procedure required manual handling, but the portability of the stands and the rapid response of the thermistors made it quite simple to obtain groups of three-dimensional temperature readings. The thermistors were individually calibrated.

Station locations on the floor of the rooms were identified by grid numbers, shown in Fig. I-2. Temperatures at a few of the key stations were recorded, but when readings showed that the temperature variation throughout the room was small, only the temperatures at the geometric center were recorded; occasional temperature checks were then made on other parts of the room. Only the dry-bulb temperature was measured in the rooms; to determine the ambient and exhaust air temperatures, both the DB and WB (wet-bulb) temperatures were recorded (separate transducers).

2. Air-Flow Meter

A conventional exhaust blower was used for the primary ventilation system. Velocity was measured across the equal-area sections of the exhaust duct, and the flow rate was determined from the average velocity (see Fig. I-8).

The "Flowtronic" air-velocity meter was used to measure the air movements. The velocity meter reading was compared with the readings of the Fused Quartz Pressure Gage connected to the pitot tube at approximately 1300 feet per minute and was found to agree within 6 percent. The Flex Tube Manometer was also connected in parallel to the pitot tube as a rough check, but the readings in the low-pressure region were too fine to obtain an accurate reading.

In subsequent velocity measurements of room current and current created by the punkah, the Flowtronic meter was used. The zero calibration was checked periodically.

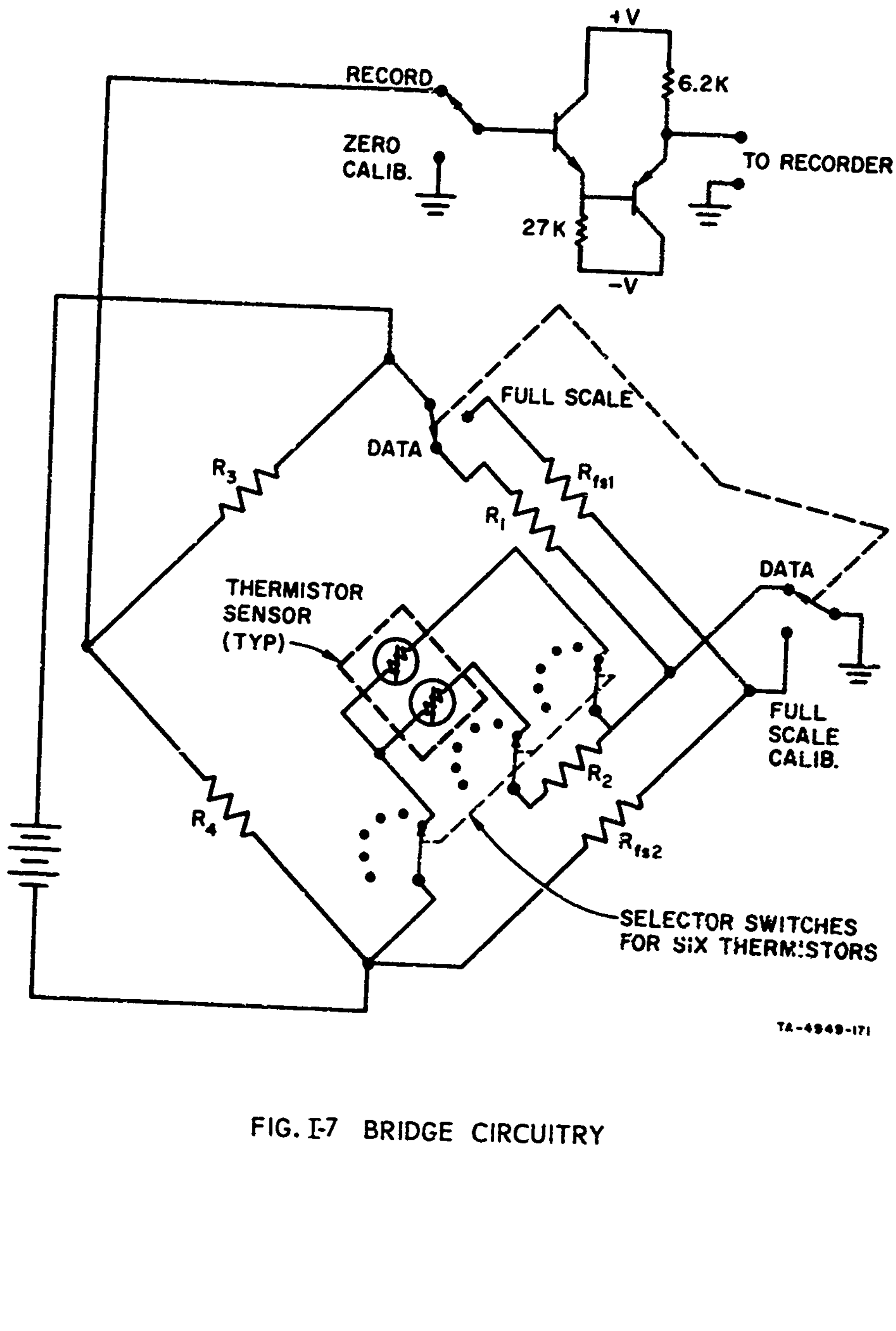

FIG. I-7 BRIDGE CIRCUITRY

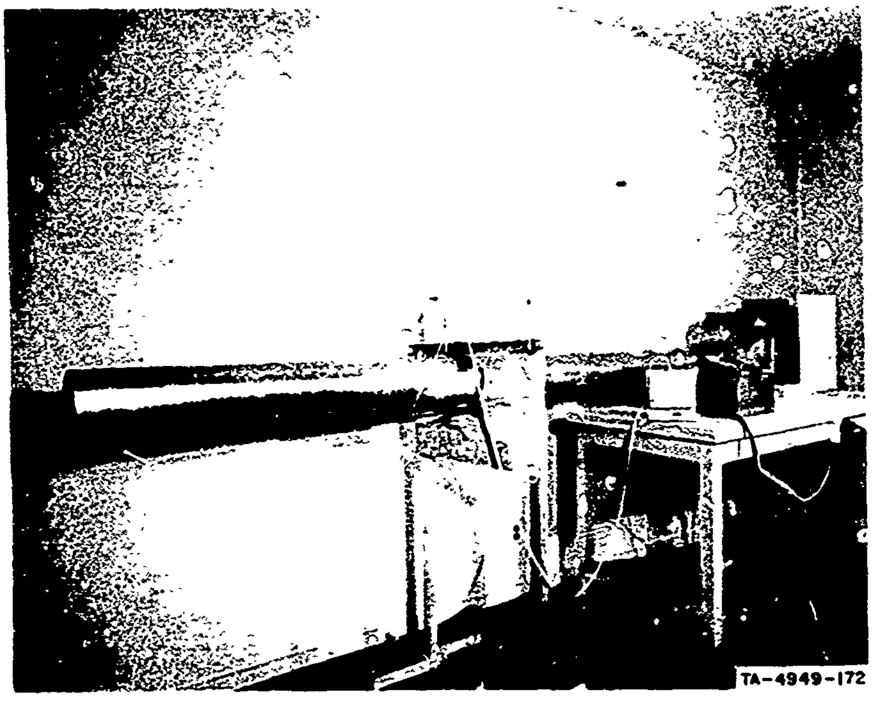

FIG. I-8 EXHAUST BLOWER

E. Smoke Tracing

Miniature smoke generators were obtained from a fireworks supply company. Smoke was generated for approximately 10 to 15 seconds each period. This appeared to be the ideal time duration for observation of smoke traces. Larger smoke bombs which generated smoke for longer periods were tried, but these proved unsatisfactory because of excessive smoke accumulation, dispersion of the downstream smoke, and general discomfort. By holding the smoke source at various parts of the room and in various positions near the punkah, the air motion and path could be readily observed. It was found that several local observations with a short-duration smoke generator provided far more information than large generators.

F. Test Procedures and Conditions

To evaluate the effectiveness of the punkah in distributing air within a shelter, a procedure was set up for measuring changes in the DB temperature as a function of time in several parts of the room under test. Temperatures were also measured at various horizontal levels to detect floor-to-ceiling gradient. Air currents were traced by means of smoke (see Sec. E), and air velocity was measured using a Flowtronic meter (see Sec. D-2).

Emphasis was placed on room A, since the only ventilating air into this dead-end room was through the common doorway between rooms A and B. The series of tests performed measured the ability of the punkah to ventilate room A following the conditioning of room B by means of the primary ventilation fan and punkahs.

1. Internal Load Stabilization

Prior to all tests, the electrical heaters simulating the internal load were turned on, and the interior temperature was allowed to reach equilibrium under a no-ventilation condition; i.e., the heat generated equaled the heat removed by conduction and infiltration. The inside temperature at stabilization was approximately 85°F. Heaters were left on for at least one day prior to the experiments. The adjoining rooms of the test area were heated to approximately the same temperatures, so that conductive losses were mainly through the floor, ceiling, and external walls. An internal load of 4200 watts (14,300 Btu per hour) was maintained throughout the series of tests. The distribution of the heat load was in proportion to the room area. The heat loads for each room are indicated in Fig. I-2.

2. Air-Flow Stabilization

The air exhaust was located on the north wall of room B. Air was admitted either through window W-3 or W-4. A flow rate of 5 ft^3/min per occupant was initially chosen, since the average ambient air temperature during the test period was on the order of 55°F. For a total space of 538 ft^2, with an allotment of 10 ft^2 per occupant, the air flow was adjusted to 271 ft^3/min. In the later tests, the flow was increased to 336 ft^3/min, which was the capacity of the blower (with 1/2 hp motor).

3. Room-Temperature Check

Prior to the start of each test, the uniformity of the temperature was checked in each room. At stabilization, it was found that the temperatures throughout all the rooms varied less than one degree. The temperature from ceiling to floor was also uniform. Only an overnight stabilization period was necessary prior to the tests.

Since the ventilating air was drawn in through an open window, the inlet air temperature was considered the same as the ambient air temperature. The experiments were performed during a period when the ambient temperature was relatively cool, averaging approximately 55°F, and when it was expected that the outside temperature would vary very little.

II TEST RESULTS

Only general observations of the test results are presented in this section. A summary of the test data is given in Table I-1, and details for the test series are presented in the Appendix.

Most of the tests were performed during the period when the ambient temperature ranged from 51°F to 64°F. With the exception of Test 11, the range of ambient temperature variation during the tests was less than 6 degrees. As mentioned in the previous section, the rooms were in thermal equilibrium at the start of each test. Each test was of comparatively short duration (a few hours), since the primary object was to observe the room condition maintained as a result of ventilating air being delivered or mixed by the punkah. Once ventilation was started, the time required to reach near steady-state condition was relatively short, since the temperature change was small and the walls of the rooms were of light 1/2-inch plaster board.

Three basic test configurations were used:

(1) Ventilation exhauster only

(2) Ventilation exhauster and pumping punkah between rooms A and B

(3) Ventilation exhauster, mixing punkah in room B, and pumping punkah between rooms A and B.

Within each of these configurations, variations of punkah location or the use of panel separators and air baffles were tried.

A. Test Summary

In Test 1, with only the ventilation exhauster operating, a distinct cool-air stratum formed below the 40-inch level. Above this level, the temperature gradient was very small, usually within 0.5 degree. The cool stratum close to the floor was not disturbed in Test 1, since no punkah or other mixing devices were in operation. The stratum was also preserved in test room A, although at a slightly higher temperature. Migration of cool air into room A was caused by a combination of convection and diffusion, due to the temperature differential.

Figure I-9 shows the various punkah arrangements used. In all but one test of the punkah used as an air pump between rooms A and B, the temperature of room A was kept within 1.5 degrees of the temperature of room B. The single exception was in Test 2, where a mixing punkah was also located in room A to agitate the air [see Figs. I-9(a) through I-9(c)]. In this case, the temperature of room A was 3.1 degrees higher than that of room B, indicating that random forced-mixing of the air in room A tended to impede the delivery of ventilating air into that room. The single pumping punkah in the doorway between the rooms was sufficient for the delivery of air as well as the mixing of air in room A. In all tests in which the punkah was used as an air mover, the vertical temperature gradient in room A seldom exceeded 1°F.

Smoke traces of air currents created by the punkah mounted in the doorway but without the use of separator panels showed considerable short-circuiting of the air (see Fig. I-10). In spite of this, the temperature of room A was maintained within 1.5 degrees of the room B temperature. When a horizontal panel was placed in the doorway, separating the top half from the bottom half, the smoke traces showed less short-circuiting [see Figs. I-11(a) and I-11(b)].

In the last series of tests (Tests 9-12), a punkah was mounted in a hole cut in the wall between rooms A and B (see Figs. I-12). The air inlet to room A was through the existing doorway, so that the inlet and outlet positions were separated. A study of the test results revealed that the doorway punkah, properly paneled, performed as well as the wall punkah.

The test series involving the mixing of air in room B showed that mixing lowered the average temperature of room B more than when the air was not stirred. The most effective type of mixing consisted of agitating the inlet air as soon as it entered the room. Test 12, in which the punkah was located in the main air stream at station 47, with window W-4 used as the inlet (see Fig. I-2), produced the best results. A second mixing punkah, installed at station 36, was also tried. The size of this punkah was identical to that of the door punkah (27 $\times$ 36 inches), but a 12-inch extension arm was added to increase the length of the swing arc (see Fig. I-13). This three-punkah configuration lowered the temperature of room B from 91°F to 82.9°F in three hours. With the wall punkah circulating air into room A, the temperature of room A dropped from 90.7°F to 84.3°F during the same period.

During Test 6, a 20-inch polyethylene plastic duct was connected to the lower portion of door D-4 to draw the air to the far part of room A. With this arrangement, the doorway punkah was able to deliver only a small

Table I-1

SUMMARY OF TEST DATA

(Average temperatures)

Test No.	Date and Time	Test Duration	Air Flow (ft^3/min)	Ambient Air (Inlet) (°F) DB* Start	End	WB* Start	End	Exhaust Air (°F) DB Start	End	WB Start	E
1	January 4 3:40 p.m.	1 hr 20 min	271	48	48	44	44	--	--	--	
2	January 5 1:30 p.m.	3 hr 15 min	271	54	48	45.5	43	--	--	--	
3	January 6 2:50 p.m.	1 hr	271	53	51	44	42	86	83	64	6
4	January 9 1:40 p.m.	1 hr	271	61	58	50	48	88	86.5	68	6
5	January 9 2:53 p.m.	2 hr	271	56.5	52	47.5	47	87.5	86	65	6
6	January 25 2:05 p.m.	3 hr 25 min	271	57	51	48	47	85.5	83.5		
7	January 26 1:55 p.m.	2 hr 50 min	271	55.5	56	54	54	86	85	66	6
8	January 27 9:00 a.m.	4 hr	271	60	64	55	60	87	89	67	7
9	February 17 9:10 a.m.	2 hr	271	56	62	50	56	86.5	85.5	67	6
9a	February 17 11:10 a.m.	2 hr	336	62	66	56	57	85.5	86	65	6
10	February 21 8:45 a.m.	1 hr 50 min	336	54	56	50	50	85	82.5	63	6
11	February 23 8:30 a.m.	1 hr 30 min	336	51	60	46	50		83		6
11a	February 23 10:10 a.m.	4 hr 10 min	336	60	64	50	51	83	93	60	6
12	February 24 10:35 a.m.	3 hr	336	58	58	49.5	50.5	88	83	63.5	6

*DB = Dry Bulb Temperature
WB = Wet Bulb Temperature

Table I-1

SUMMARY OF TEST DATA

(Average temperatures)

nlet)		Exhaust Air (°F)				Room A (Station 58) (°F) DB (average)		Room B (Station 23) (°F) DB (average)		
WB*		DB		WB						
rt	End	Start	End	Start	End	Start	End	Start	End	Remarks
	44	--	--	--	--	86	83	86	81	Ventilation fan only. No punkah.
5	43	--	--	--	--	87.5	86.8	87.5	83.7	Punkah in Room A only; punkah in doorway D-4 plus mixing punkahs in various locations of Room A.
	42	86	83	64	61.5	87	84.5	86.5	83	Punkah in doorway D-4 (no horizontal separator).
	48	88	86.5	68	65	88.5	88	89.5	87	Punkah in doorway D-4 with small horizontal separator.
5	47	87.5	86	65	65	87.5	87.5	87.5	87	Punkah in bottom half of doorway D-4.
	47	85.5	83.5			86.5	84.5	86	84.5	Punkah in doorway and mixing punkah in Room B.
	54	86	85	66	65.5	88.5	85.5	86.5	85	Punkah in doorway and with separator and mixing punkah in Room B.
	60	87	89	67	71	89.5	89	90	89	Punkah and baffles.
	56	86.5	85.5	67	65	87.7	86.3	87.8	84.8	Punkah at hole cut in wall.
	57	85.5	86	65	66	86.3	86	84.8	86	Punkah at hole cut in wall, increase ventilation rate.
	50	85	82.5	63	61.5	86.8	84.3	87	83.4	Punkah at hole cut in wall and PVK for circulation.
	50		83		60	87	84	87	83	Punkah at hole cut in wall and PVK for circulation.
	51	83	93	60	67	84	93	83	93	No fan or punkah; heat rise test.
5	50.5	88	83	63.5	62.5	90.7	84.3	91	82.9	Punkah in wall and two in Room B.

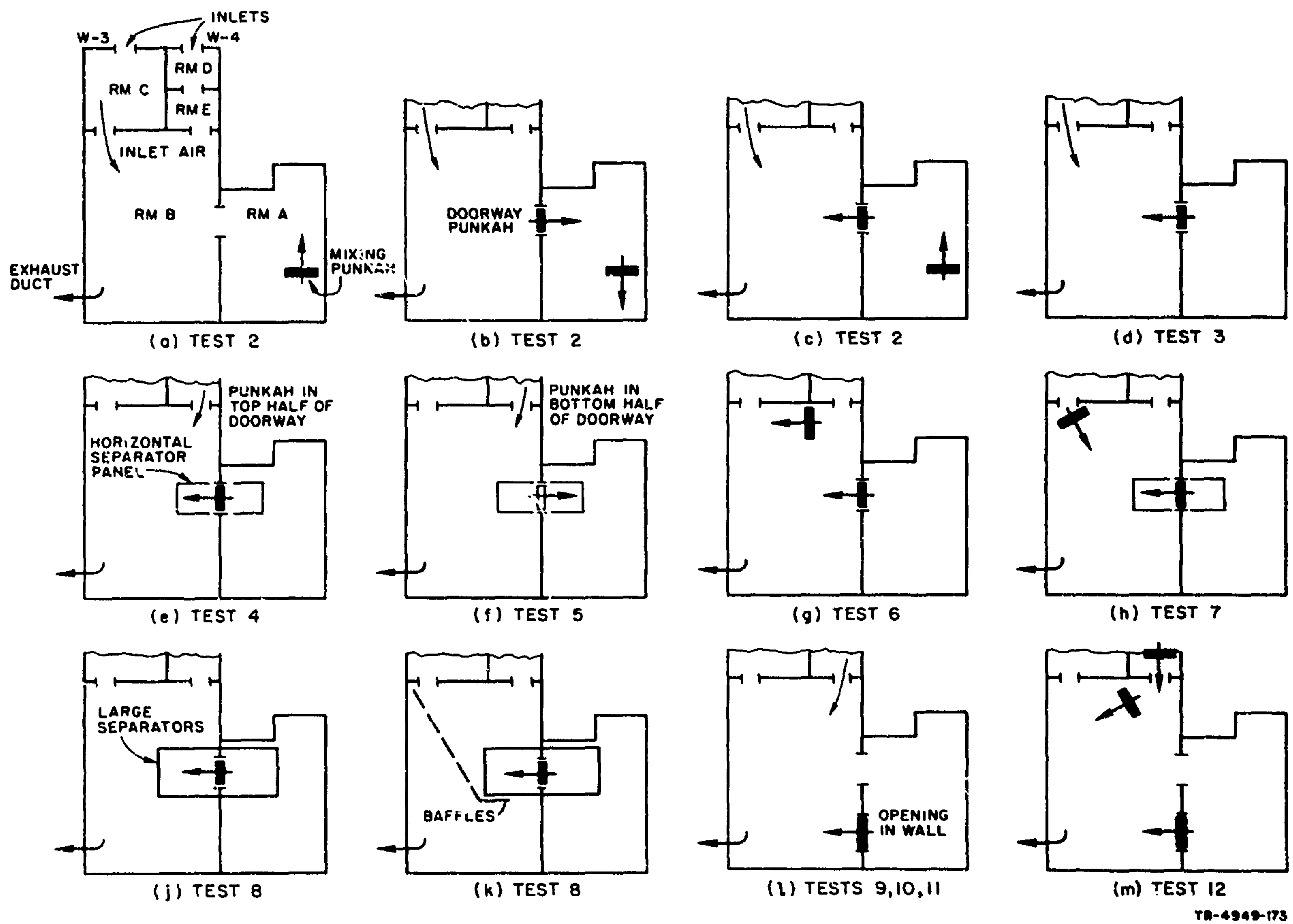

FIG. I-9 PUNKAH ARRANGEMENTS, ROOMS A AND B

FIG. I-10 SMOKE TRACE TEST WITH DOORWAY PUNKAH, SHOWING SHORT-CIRCUITING OF AIR

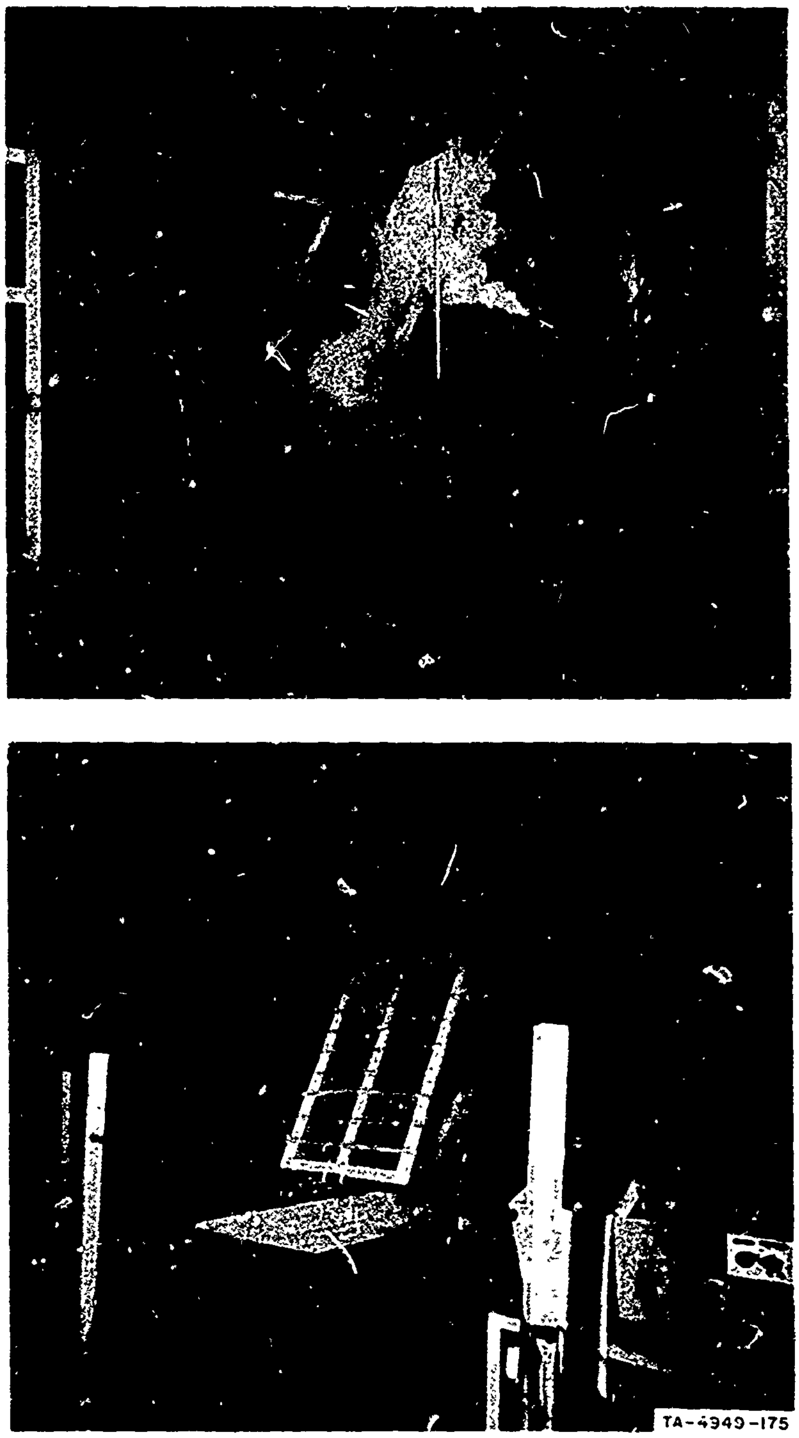

FIG. I-11 SMOKE TRACE TEST, SHOWING MINIMIZATION OF SHORT-CIRCUITING WITH ADDITION OF SEPARATOR PANEL IN DOORWAY

FIG. I-12 PUNKAH MOUNTED IN HOLE CUT IN WALL BETWEEN ROOMS A AND B

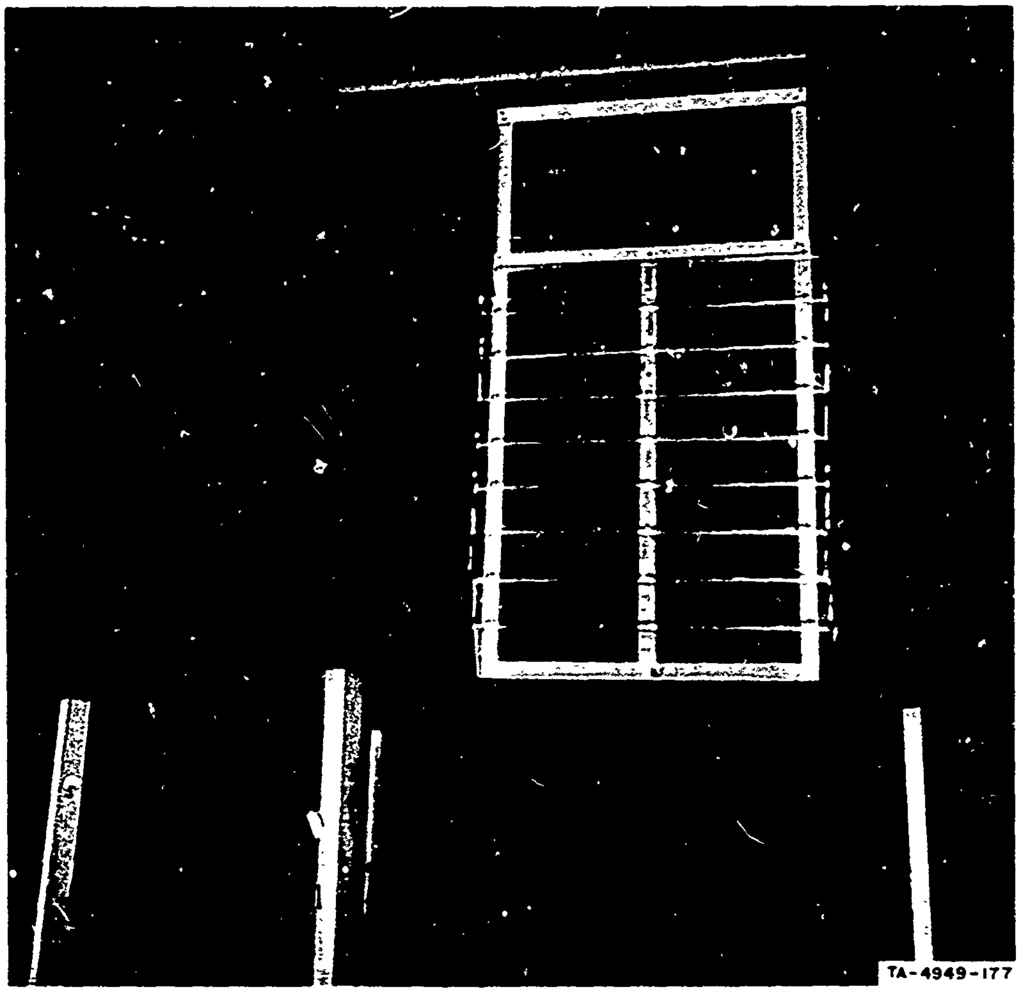

FIG. I-13 MIXING PUNKAH WITH EXTENSION ARM amount of air and only during a portion of its forward stroke. The collapsed (unsupported) ducting opened only momentarily during each pulse as a small quantity of air passed through. The collapsible plastic duct is not recommended for use with the punkah.

B. Analysis

1. Relationship of the Psychrometric Conditions of Rooms A and B

The psychrometric condition of room A is dependent upon the flow rate of the ventilating air and upon the psychrometric condition of the adjoining room B, since the latter is the source of all ventilating air into room A. (It is also dependent upon the room load and conduction losses, but these were more or less fixed during the test series.) The condition of room B is in turn dependent upon the flow rate and characteristics of the ambient air used for ventilation. It would be possible to maintain room A at an effective temperature one to two degrees higher than that of room B, provided sufficient quantity of air could be circulated.

It is seen that the condition of the inlet air to room A is the same as the air condition of room B, and also that the enthalpy change between the inlet and outlet air of room A must be kept small in order to maintain the condition of room A very close to that of room B. This means that a relatively large flow rate is required. In all cases, the effective temperature of room A will be greater than that of room B, assuming that both rooms have the same load density and conduction characteristics. Any method used to lower the effective temperature of room B will therefore lower that of room A.

2. Analysis of Heat Removal from Room A

The necessary high flow rate was obtained by using the punkah as a pumping device. Using the data of Test 10 as an example, we can see that the room conditions are practically stabilized after approximately 1-1/2 hours of ventilation. The stabilization time is relatively short, partly because the temperature drop is small. The pertinent data for room A in Test 10 are as follows:

Initial temperature	86.8°F (average)
Temperature after 1-1/2 hours	84.3°F (average)
Inlet temperature	83.4°F (average)
Ventilation rate	890 ft^3/min (punkah pump)

Room area	116 ft^2 (12 occupants)
Room load	3080 Btu/hr (267 Btu/hr-occupant all sensible heat)
Outside temperature at equilibrium	54°F DB, 50°F WB
Outside temperature at 1-1/2 hours	56°F DB, 50°F WB

Since no moisture is generated, the enthalpy gain of the ventilation air for room A is:

$$\Delta H = \frac{V}{v} c_p (t_{exh} - t_{in}) \quad , \Delta H = \frac{V}{v} \Delta h \qquad (1)$$

where

V = flow rate, cfh

v = specific volume, 15 ft^3/lb

c_p = 0.24 Btu/lb-°F

t_{exh} and t_{in} = exhaust and inlet temperatures

Δh = change in unit enthalpy;

$$\Delta H = \frac{890 \times 60}{15} \times 0.24\ (84.3 - 83.4) = 770 \text{ Btu/hr} \quad ; \qquad (2)$$

$$\Delta h = 0.22 \text{ Btu/lb.} \qquad (3)$$

(It can be seen that in a 100-percent sensible heat process, a change in h of 1 Btu/lb requires a DB temperature change of 4 degrees. This would be quite different from the process that occurs in an actual occupied shelter, as discussed in the next paragraph.)

The inlet temperature for all practical purposes was equal to the average temperature of room B (83.5°F, as recorded by station 23). The delivery of 890 ft^3/min by the punkah maintained the temperature of room A to within 0.8 degree of the room B temperature. The heat generated by the electrical heaters in room A was 3080 Btu/hr, but since the room was not adiabatic, only 770 Btu/hr had to be removed by ventilating air; the remainder was removed by conduction through the exterior wall, floor, and ceiling.

The initial condition at equilibrium was:

$$Q_e = Q_{c1} \quad , \tag{4}$$

where

Q_e = electrical heat load (100 percent sensible heat)

Q_{c1} = conduction loss at equilibrium condition.

In calculating the heat loss,

$$Q_{c1} = UA\ \Delta t_1 \qquad \text{at equilibrium} \quad , \tag{5}$$

where

U = conductivity coefficient calculated using composite wall sections

A = area of conductive surfaces (exterior wall, ceiling, and floor)

Δt_1 = temperature difference between room and outside at equilibrium.

$$Q_{c1} = 0.31 \times 319\ (86.8 - 54)$$

$$= 0.31 \times 319 \times 32.8 = 3240 \text{ Btu/hr} \quad . \tag{6}$$

This value is within 8 percent of the value for Q_e = 3080 Btu/hr. After steady state is reached in approximately 1-1/2 hours, the heat balance is:

$$Q_e = Q_{c2} + \Delta H \quad , \tag{7}$$

where

Q_{c2} = conduction rate at steady-state ventilation.

The reduction in conduction rate is:

$$Q_{c1} - Q_{c2} = UA\ (\Delta t_1 - \Delta t_2) \tag{8}$$

and

$$\Delta H = UA\ (\Delta t_1 - \Delta t_2)\ \text{[from Eqs. (4) and (7)]} \quad , \qquad (9)$$

where

Δt_2 = temperature difference between room A and outside at steady state.

Now,

$$\Delta t_1 = 32.8^\circ F$$

$$\Delta t_2 = 84.3 - 56 = 28.3^\circ F \quad ;$$

therefore,

$$\Delta H = UA \times 4.5 \quad ;$$

but

$$\Delta H = 770\ \text{Btu/hr} \quad \text{[from Eq. (2)]} \quad . \qquad (10)$$

Checking the value of UA × 4.5, we obtain

$$Q_{c1} - Q_{c2} = 0.31 \times 319 \times 4.5 = 445\ \text{Btu/hr} \quad . \qquad (11)$$

This value is substantially lower than the value of 770 Btu/hr for ΔH, the reason being that in Δt_2 above, the temperature of 84.3°F is obtained by averaging the temperature gradient of room A at steady state. Actually, during circulation the temperature of the air very close to the floor is 2 to 4 degrees cooler than the average temperature. This indicates that the conduction loss through the floor has been decreased, owing to a further reduction in Δt between the floor and the space below; i.e., Δt_2 is decreased and therefore [in Eq. (10) above] $(\Delta t_1 - \Delta t_2)$ would be greater than 4.5°F. This would bring the value closer to the ΔH of 770 Btu/hr.

In accepting the value of Q_e = 3080 Btu/hr and ΔH = 770 Btu/hr, it is seen that the conduction rate was reduced from the original equilibrium condition of 3080 Btu/hr by the amount of ΔH to 2310 Btu/hr after the ventilation condition reached a steady state.

Because of the high flow rate created by the punkah, room A was maintained at a temperature only slightly higher than that of room B. Because of the small temperature difference and the fact that the ventilating air followed a 100-percent sensible heat change (no moisture removed), very little heat was removed per pound of ventilating air. As seen above, the bulk of the heat (75 percent) was removed by conduction through the walls because of the low ambient temperature.

3. Analysis of Heat Removed from a Room with an Adiabatic Wall

In a room with an adiabatic wall, the ventilating air must remove the entire heat energy generated. That is,

$$Q_m = \frac{F \times 60}{v} \Delta h \quad , \qquad (12)$$

where

Q_m = metabolic heat generated = 400 Btu/hr-occupant

Δh = enthalpy gain of the ventilation air (Btu/lb)

F = ft^3/min-occupant.

Unlike the example of the previous paragraph, where only a sensible heat load of 267 Btu/hr-occupant was used, a load of 400 Btu/hr-occupant--a more conservative value based on the heat output of a sedentary adult--is used for the adiabatic example. The curves of Fig. I-14 will apply in this case (see Ref. 3). The outside dry-bulb temperature values of the curves refer now to the temperature of room B, and the abscissa, showing the values of the inside effective temperature, minus outside effective temperature, represents the difference in the effective temperatures of rooms A and B. As an example, if the dry-bulb temperature of room B is 87°F, then 50 ft^3/min per occupant is required to maintain room A at an effective temperature no greater than 2 degrees of the room B temperature.

Since the punkah in this case is capable of moving 890 ft^3/min, it should be capable of ventilating a space for 17 to 18 occupants while maintaining the above condition in a room with an adiabatic wall. At a space allowance of 10 ft^2/occupant, therefore, this represents a room of 170 to 180 ft^2. Should the effective temperature, which is higher by 2 degrees in the compartment room, exceed the limit of occupant tolerance, the occupant capacity must be reduced or the flow rate must be increased.

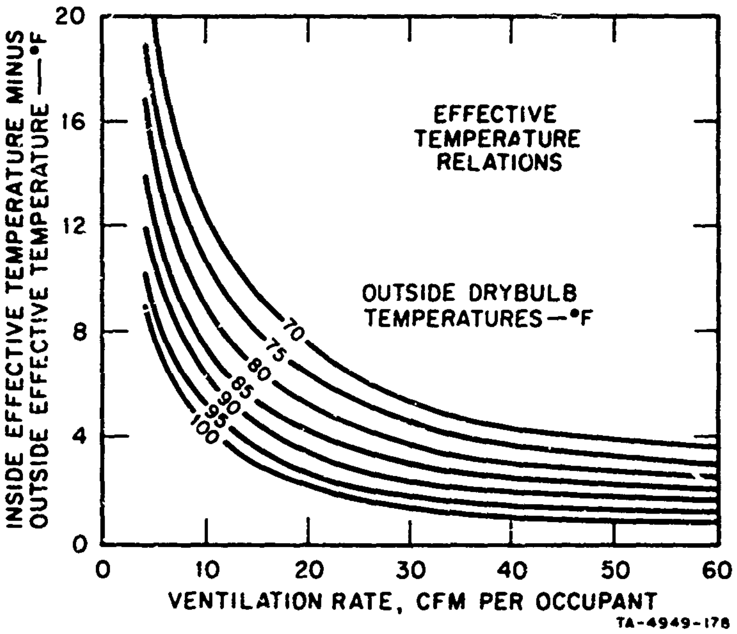

FIG. I-14 ANALYSIS OF VENTILATION REQUIREMENTS, BASED ON TOTAL HEAT LOAD OF 400 Btu/hr-occupant FOR ROOM WITH ADIABATIC WALL

The flow rate of 890 ft^3/min is based on the operation of an exhaust punkah located in the wall and separated from the inlet. However, a doorway punkah properly mounted with separator panels will perform almost as well. The punkah is discussed in detail in Sec. 5 below.

4. Effect of Mixing Ventilating and Room Air

An air exhauster on the north wall of room B was used to draw ventilating air through either window W-4 or W-3, whose openings were sufficiently large that the velocity and the pressure drop were minimal (see Fig. I-2). Since the normal flow of ventilating air had little effect in stirring the air, it was possible to study the effectiveness of other stirring or mixing devices.

Test 1 was conducted with only the ventilating exhauster operating. This condition will be considered first. The initial, intermediate, and final conditions of the vertical temperature gradient for three stations in Test 1 are illustrated in Fig. I-15. Station 16 is in the main stream of the ventilating air; station 23 is in the center of room B; and station 58 is in the center of room A. With only the primary ventilating system in operation, the vertical temperature gradient became pronounced as the condition at each station approached steady state. The data of Fig. I-15 show that the average temperature of room A was 2 degrees higher than that of room B; also, that the temperatures above the 42-inch level are constant. Since the vertical temperature gradient exists below this level, the temperatures are naturally comparatively cooler at the 12- and 18-inch levels. Now, from Ref. 4 shelter occupants spend five-sixths of their time in either a prone or sitting position; thus, they would occupy the lower level of the room most of the time. Under these conditions, it might be preferable to preserve the vertical temperature variation. However, it is not known whether the temperature gradient as found in Test 1 would exist under actual conditions of human occupancy; the configuration of the electrical heat generators used in the experiments is quite different from that of shelter occupants. Limited activities of actual occupants might tend to mix the air, and it would be necessary to make temperature measurements in an occupied shelter to determine actual vertical temperature variation.

When the punkah was used in the doorway to draw ventilating air from room B into room A, its action mixed the air in the general vicinity, minimizing the vertical gradient. Attempts were made to draw the cool air near the floor into room A, but the forced mixing by the punkah made the temperature of the inlet air to room A the same as the average temperature of the air in room B. Air deflectors 30 inches high were tried, but they did not help to direct the cool-air path into room A.

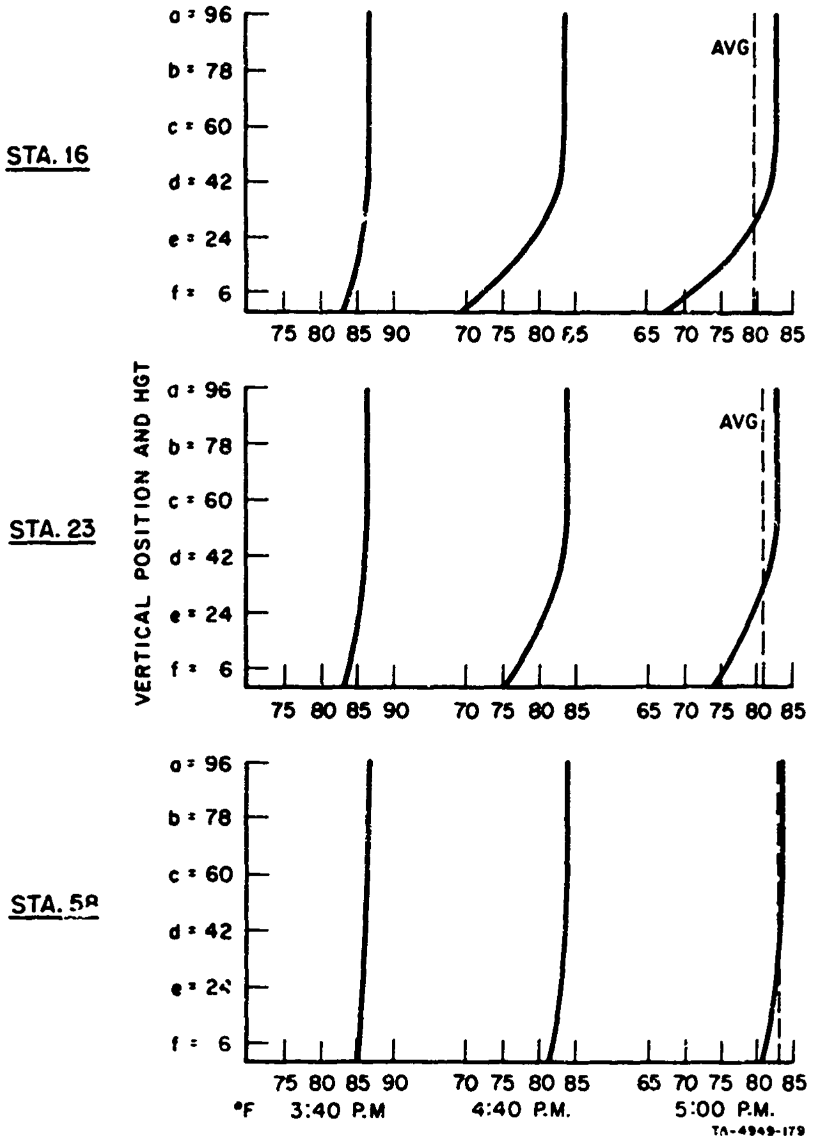

FIG. I-15 VERTICAL TEMPERATURE GRADIENT TEST 1 — VENTILATION FAN ONLY

It was also observed that the average temperature of room B at steady state was lower if the air was mixed. This result is illustrated by a comparison of Test 6, where a mixing punkah was used in room B, with Test 3, where no mixing punkah was used. In Test 6, the final average temperature of room A, ventilated by room B, was nearly the same as in Test 3, even though the ambient air temperature was higher throughout Test 6 (see Figs. A-1 and A-5). Comparison of Tests 7 and 5 gives a similar result (a mixing punkah was used in Test 7).

In Tests 9(a) through 12, the ventilation rate was increased from 271 ft^3/min to 336 ft^3/min. In previous tests, the decrease in the inside temperature was very slight, and it was therefore difficult to observe the changes. In Test 9(a), the change in the inside condition was negligible in spite of the increased air flow, partly because of the increase in ambient temperature and partly because no mixing punkah was used. In Tests 10 and 11, a PVK (packaged ventilation kit) was located in room E to study the effect of thoroughly mixing the inlet air from W-4. A comparison of Tests 3 and 10 shows that the average inside temperatures were nearly the same, even though the average ambient temperature for Test 10 was 59°F, as compared to 51°F for Test 3. Figure I-16 shows the vertical temperature gradient at near steady state for Stations 23 (room B) and 58 (room A) during Tests 3 and 10. The gradient at Station 49, included for reference, represents the cond tion at room D, in the main path of the ventilating air, prior to mixing.

The GATX report (Ref. 5) states that the less the shelter air is mixed, the lower the average effective temperature of the shelter will be. Mixing was defined as the mixing of fresh supply air with shelter air, or the mixing of air from one section of the shelter with air from another section. It was assumed, however, that there were no vertical variations in air temperature or humidity. This conclusion was derived from a computer analysis of air distribution in a shelter, using various combinations and quantitites of air inlets and outlets.

Portions of the above statement appear to contradict the results of our experiments, but it should be stated that ideal conditions are assumed for the analytical results (no vertical variations even without mixing). It was found from our tests that it is necessary to mix the ventilating air after its entry in order to minimize the vertical variation in room temperature. In other words, it was found to be impossible to obtain a uniform vertical temperature gradient without mixing. The GATX analysis also concludes that the "optimum ventilating system is one in which the supply air is admitted at one end of the shelter and exhausted at the other."[5] This statement defines a condition in which a

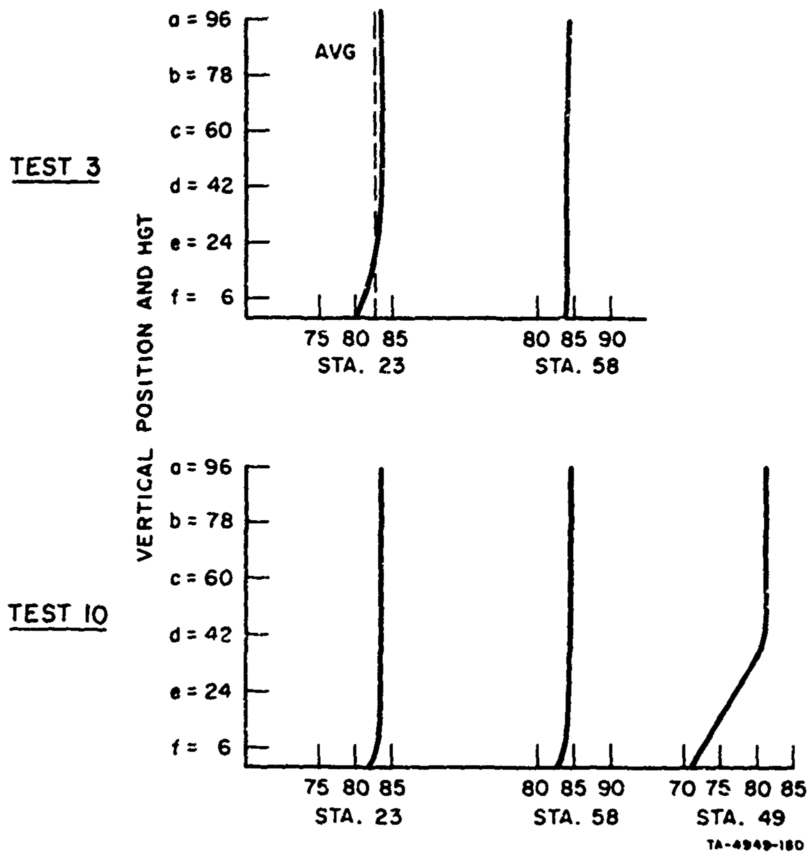

FIG. I-16 VERTICAL TEMPERATURE GRADIENT AT STEADY STATE — TESTS 3, AND 10 temperature gradient exists from the inlet to the outlet. In this respect our experiments agree, because the ventilating air was admitted at one end, mixed to minimize the vertical gradient, and exhausted at the opposite end.

5. Observations on Punkah Operation

a. General

The oscillating punkah is essentially an air mover and can be used for stirring or mixing air within a room or for pumping air from one space to another. Smoke-trace observations of the punkah in operation show that much of the action takes place in the generated space behind the punkah panel as it swings through its forward stroke. A slightly negative pressure is created behind the punkah, and the surrounding air immediately rushes in, continuing its forward motion and flow past the punkah. As the punkah finishes its stroke, the air continues to travel under the lower edge of the punkah. Figure I-17 shows air paths of an unconfined oscillating punkah operating within a room. Air mostly from region u and behind u follows the path shown. Some swirling of air occurs at the side of the punkah; but the air in regions v and w, immediately forward and in back of the upper portion of the punkah face, is relatively still; i.e., very little air is delivered through this section.

The flow rate of 890 ft^3/min, determined by measuring velocities of air at the separate inlet, was compared to the volume of the sector of air displaced by the punkah in one minute. For 30 oscillations per minute and an approximate 90-degree swing arc, calculations showed that the flow rate was very close to twice the displacement. The ratio would vary, depending upon the flow system characteristic (flow resistance), the rate of oscillation, and the maximum tangential tip speed of the punkah. It would appear that the volume of air generated by the punkah swing would not in itself be the primary criterion of the rate of flow.

In a punkah operation, it is desirable to have a relatively high tip speed. With a large amplitude of angular oscillation, this high velocity is generated. The behavior of a punkah is slightly different from that of a free-swinging compound pendulum, since there is a comparatively large air drag even on the punkah's return stroke.

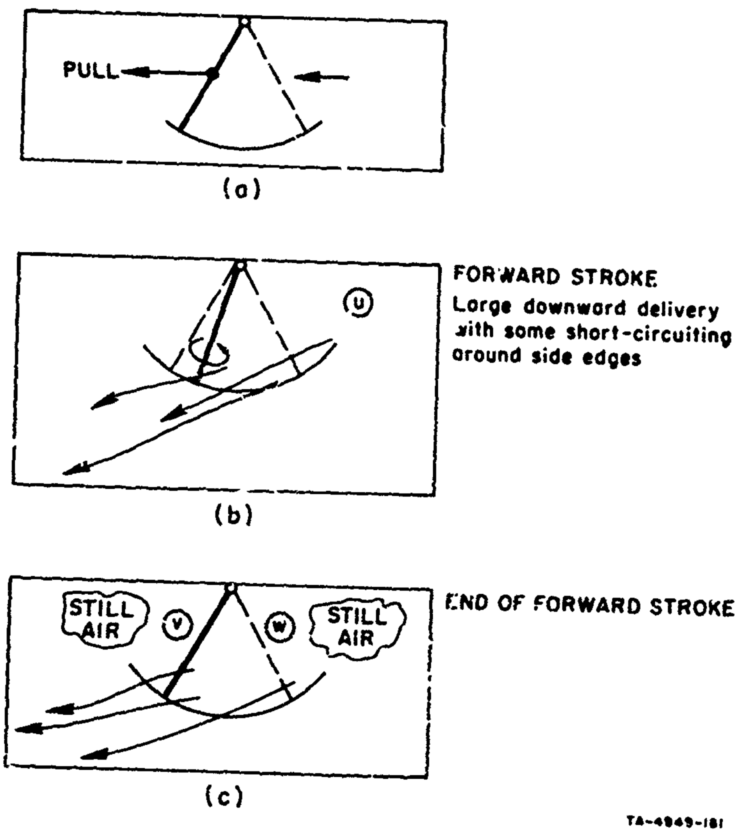

FIG. I-17 SMOKE TRACE TESTS OF AIR PATHS OF AN UNCONFINED OSCILLATING PUNKAH WITHIN A ROOM

Adding weights (approximately 2 lb) to the lower edge of the punkah improved its performance, so that it was able to overcome some of the drag that prevented full return on the backstroke. Since rotational inertia was increased, the period of oscillation was increased. The punkah used in these experiments operated at a rate of 30 strokes per minute, which is believed to be close to the maximum rate desirable for a manually operated device of this nature.

b. <u>The Punkah as an Air Mover Between Rooms</u>

Tests were conducted with the punkah installed in the single doorway between rooms A and B to simulate conditions in a compartment room in which it was not possible to cut a hole through the wall. The punkah was located in the upper portion of the doorway mainly because this arrangement would permit the lower half of the doorway to be used as an entryway. Ventilation conditions would be improved, however, if another access could be cut or broken and a punkah the full size of the doorway installed.

Figure I-18 shows air motion diagrams for the punkah mounted in the top half of the doorway, with the inlet air entering through the bottom half. During the forward stroke of the punkah (toward room B), air is drawn as explained above in Sec. 5-a. However, since the doorway is the only opening into room A, a slightly negative pressure is created in that room. This negative pressure causes air to be drawn in at the bottom of the doorway; but during the punkah's forward stroke, much of this air, which has started its forward travel, is reversed and is drawn back again. As the punkah finishes its forward stroke, the remainder of the air in forward motion continues its travel, since the path it now follows has cleared the low-pressure area. In this installation, much of the air pumped is short-circuited. (Figure I-10 shows the smoke path just prior to the finish of the forward stroke.)

Figure I-19 gives diagrams of the air paths when a short horizontal separator panel or baffle is added to the doorway configuration.* Inlet and outlet air are separated somewhat, but there is still some short-circuiting of paths x and y [Fig. I-19(b)]. When a longer panel is used,

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* It should be noted that the panels could increase storage problems as well as complicate instructions for the punkah installation. However, it may be possible to design the panels as walls for the storage closet containing the fallout shelter emergency equipment.

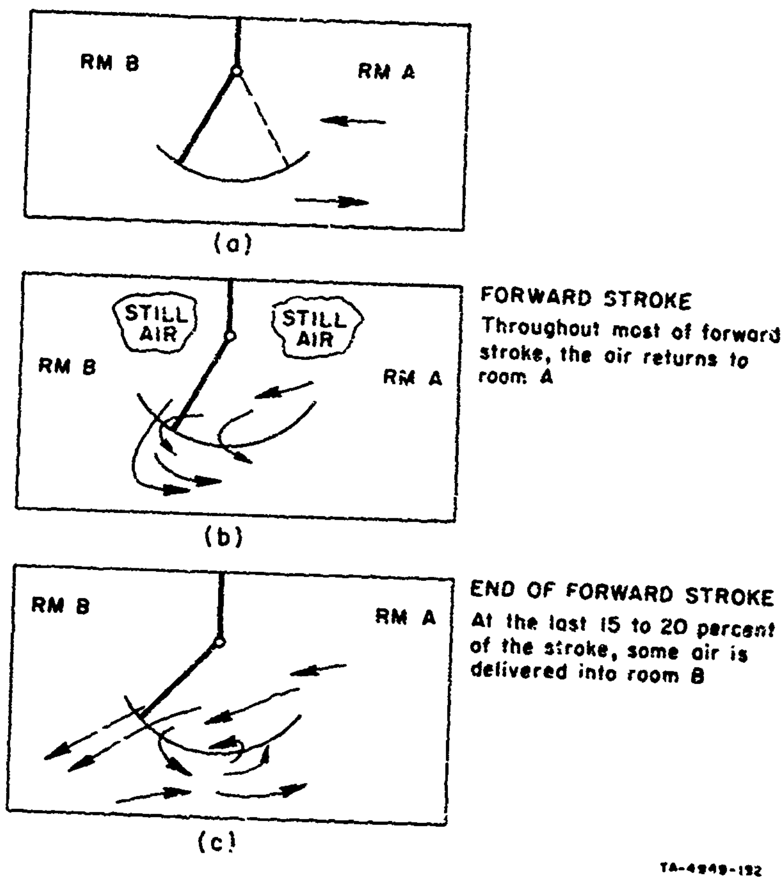


FIG. I-18 AIR MOTION DIAGRAMS FOR PUNKAH MOUNTED IN TOP HALF OF DOORWAY WITHOUT SEPARATOR (Air enters through bottom half of doorway.)

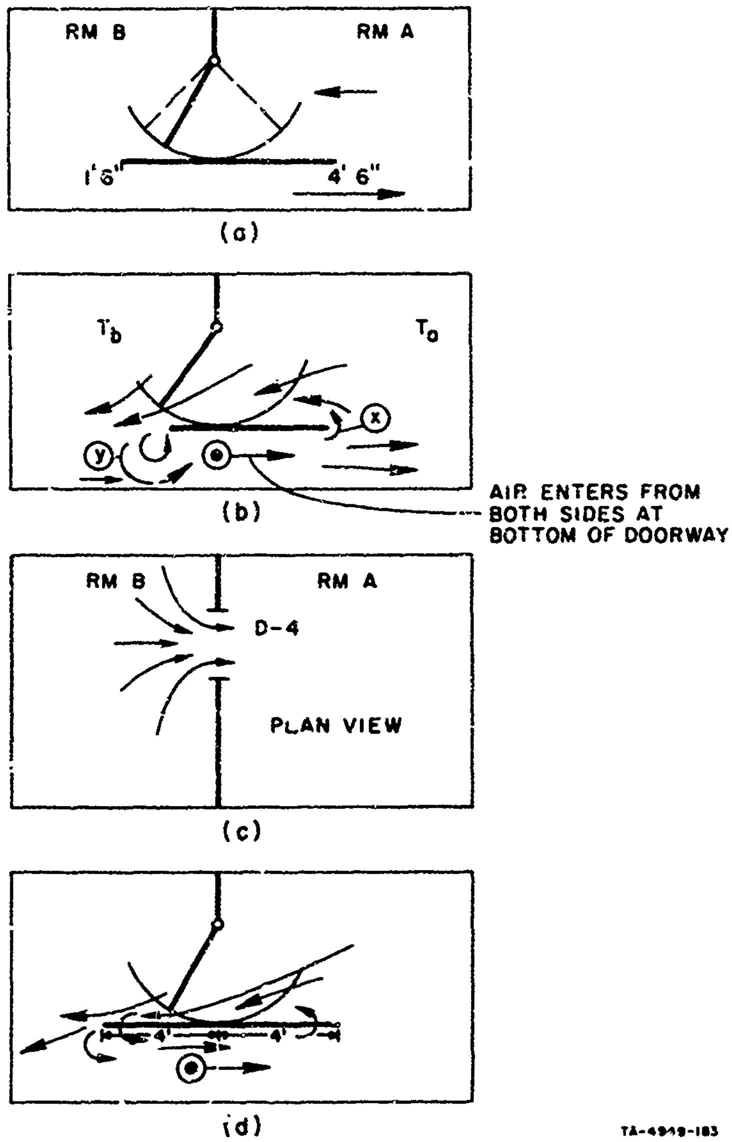


FIG. I-19 AIR MOTION PATHS FOR A PUNKAH MOUNTED IN DOORWAY WITH SEPARATOR the short-circuiting is decreased [see Fig. I-19(d) and also Figs. I-11(a) and (b)]. Adding side walls to the swinging punkah prevents short-circuiting from the side.

For tests 9 through 12, a hole was cut in the wall betweem rooms A and B, and a punkah the same size as the one mounted in the doorway was installed (see Fig. I-12). The air entered through the bottom half of the doorway between rooms A and B, the top half being boarded up. The flow was unidirectional, and therefore velocity measurements averaged over this area indicated the rate of flow of the ventilating air when no short-circuiting occurred between the inlet and outlet air. It was expected that the effective flow rate from the punkah operating in the hole in the wall would be greater than that from the punkah operating in the doorway, since some short-circuiting is always present in the latter situation; however, with proper paneling, the flow rate from the single-doorway punkah approached that from the wall punkah with separate air inlet and outlet.

The degree to which the doorway punkah short-circuits the air is measured by noting the difference in DB temperature of the inlet and outlet air in a sensible heat process. However, this measurement is difficult since short circuit mixing would render it impossible to separate the inlet and outlet air.

If a separate inlet and outlet were provided for room A, then the temperature of the inlet air would be equal to that of T_b (room B) and that of the outlet air equal to T_a. With the arrangement shown in Fig. I-19(b), however, the inlet air is mixed with the outlet air, owing to short-circuiting, and is therefore at a higher temperature than T_b; similarly, the outlet air is cooler than T_a. As a result, the temperature differential between the outlet and inlet air, in such a leaky system, is less than $T_a - T_b$. The heat removal is therefore less, even though the same quantity of air is apparently circulated. If the temperature differential can be measured, it would be proportional to the heat removed by the ventilating air (in a sensible heat process).

c. The Punkah as an Air Mixer

The velocity of the air moved by the punkah is very near that of the tip velocity of the punkah. When the punkah discharges air into the room, the air stream acts like a jet pump and moves the air surrounding it; thus, mixing occurs. Because of the relatively low velocity (energy content), the punkah would not have the mixing capabilities of high-velocity air driven by a fan at the same flow rate. However, the small punkah used in one-half of the doorway was sufficient to supply air to room A and also to mix the air. The same punkah would be capable of handling air in a room approximately 30 percent larger in area than room A. The punkah serves as a simple and inexpensive device, requiring minimum power per unit volume of ventilation air delivered.

III SUMMARY AND CONCLUSIONS

For evaluating the operation of the punkah, two adjoining rooms of an apartment complex were used as test rooms. Ambient air was drawn in from one end of room B (Fig. 2) and exhausted at the other end, using a centrifugal exhauster. The punkah was used both to mix air in room B and to ventilate room A, a dead-end compartment room with only a single doorway. Room A was used as the primary test room, and the main aim of the test was to maintain it at an effective temperature only slightly higher than that of room B. A large flow rate was therefore required.

It was assumed that the best means of ventilating room A was to mount a punkah in the upper half of the doorway between rooms A and B, allowing the remaining half for counterflow. Room loads were simulated by electrical heaters; only sensible heat was generated. The dry-bulb temperature difference between the inlet and outlet air, at a constant flow rate, was the only measurement of heat removed by the ventilating air. The dry-bulb measurement also clearly showed the vertical temperature gradients.

Since the air of room B was used to ventilate room A, the condition of room A depended on the condition of room B as well as on the effectiveness of the punkah. The average temperature of room B was slightly lower when the inlet air was mixed. When the mixing punkah was not used in room B, there was a distinct temperature stratification of air, with the largest temperature gradient present between the floor and the 40-inch level; above this height, the temperature was constant. With the stratified condition, the average temperature of the room was higher. An attempt was made to use the doorway punkah to draw the cooler air of the lower level into room A, but the motion of the exhaust and inlet air was sufficient to mix the air in the immediate vicinity of the doorway, so that the inlet air temperature was nearly that of the average temperature of room B.

If the doorway is the only opening to room A, the punkah mounted in it should be properly paneled to minimize short circuiting of the air. The addition of side panels along the two edges of the punkah further increases its effectiveness, but storage of these panels and instructions for installation might become a problem unless the panels are properly designed.

A 20-inch plastic ducting made of sheet plastic was tried as a means of directing air into room A, but the punkah was unable to deliver air continously because of the duct resistance.

If possible, a separate air access for room A should be cut or broken. A punkah the full size of the doorway could then be installed, which would improve ventilation.

The doorway punkah (punkah length equal to one-half the doorway height) is capable of delivering 890 ft^3/min when oscillated at 30 strokes per minute and an amplitude of 90 degrees of arc. The flow rate will vary somewhat, depending on the resonant frequency and tip velocity. Weight added to the extremity of the punkah improved its performance by overcoming damping forces; the period of oscillation was slightly reduced, but the amplitude was increased. A greater amplitude at the backstroke is needed to create a higher velocity, sustained for a longer period, in order to increase flow rate. In a punkah operation, the frequency of oscillation should be no higher than 30 per minute, to minimize the strain on a human operator.

If the ventilating air could remove all of the generated occupant load of 400 Btu/hr-occupant, the flow rate of 890 ft^3/min would be capable of ventilating a dead-end room area of approximately 170 to 180 ft^2 while maintaining that room at an effective temperature no greater than 2 degrees above the temperature of the adjoining room which supplies the air. The size of the room is determined on the basis of an adiabatic condition; therefore, an 890-ft^3/min flow rate could ventilate an even larger room if there were heat transmission losses. This condition assumes a punkah with proper paneling.

The smoke-trace tests proved to be very informative when combined with the dry-bulb temperature data. Care must be exercised in the interpretation of smoke traces when there is very low velocity, since smoke will diffuse to adjoining spaces of lesser concentration number, even in still air.

The punkah was generally proven to be a practical, inexpensive device for moving air within a shelter. Paneling is desirable, but excessive paneling should be avoided because it could take up valuable occupant space.

The summary and conclusions for Part Two are included separately at the end of Part Two.

Part Two

DETERMINATION OF PUNKAH FLOW CHARACTERISTICS

I DESCRIPTION OF THE TEST

In order to obtain punkah flow characteristics, air flow must be controlled so that flow resistance and velocities can be measured. Tests were conducted in a closed room measuring 17 X 28 feet. A rectangular duct (Figs. II-1 and II-2) served as a housing for the half-door size punkah, and also served to establish the flow system characteristic. The punkah was mounted at one end of the duct, and at the opposite end a pair of sliding doors were installed to vary the air flow, (see Figs. II-2, II-3 and II-4). Simultaneous recordings were made of the punkah displacement, forces to drive the punkah, the duct pressures, and the air velocities at the opening. The punkah was mounted in four different modes as shown in Fig. II-5.

FIG. II-1 DUCT NETWORK FOR TESTS

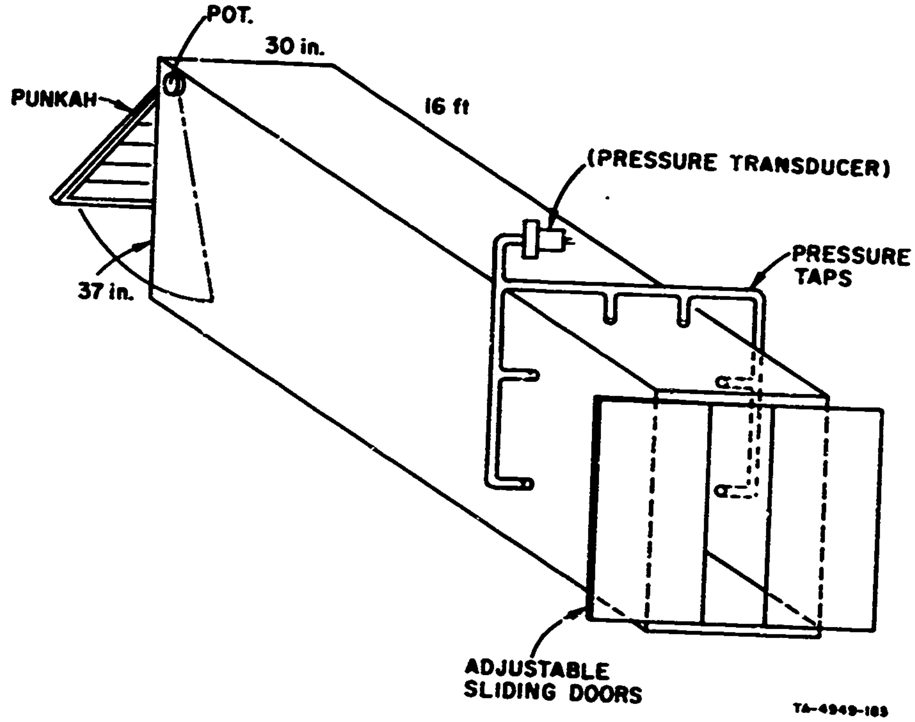


FIG. II-2 SKETCH OF DUCT NETWORK SHOWING PUNKAH, PRESSURE TAPS, AND DOORS

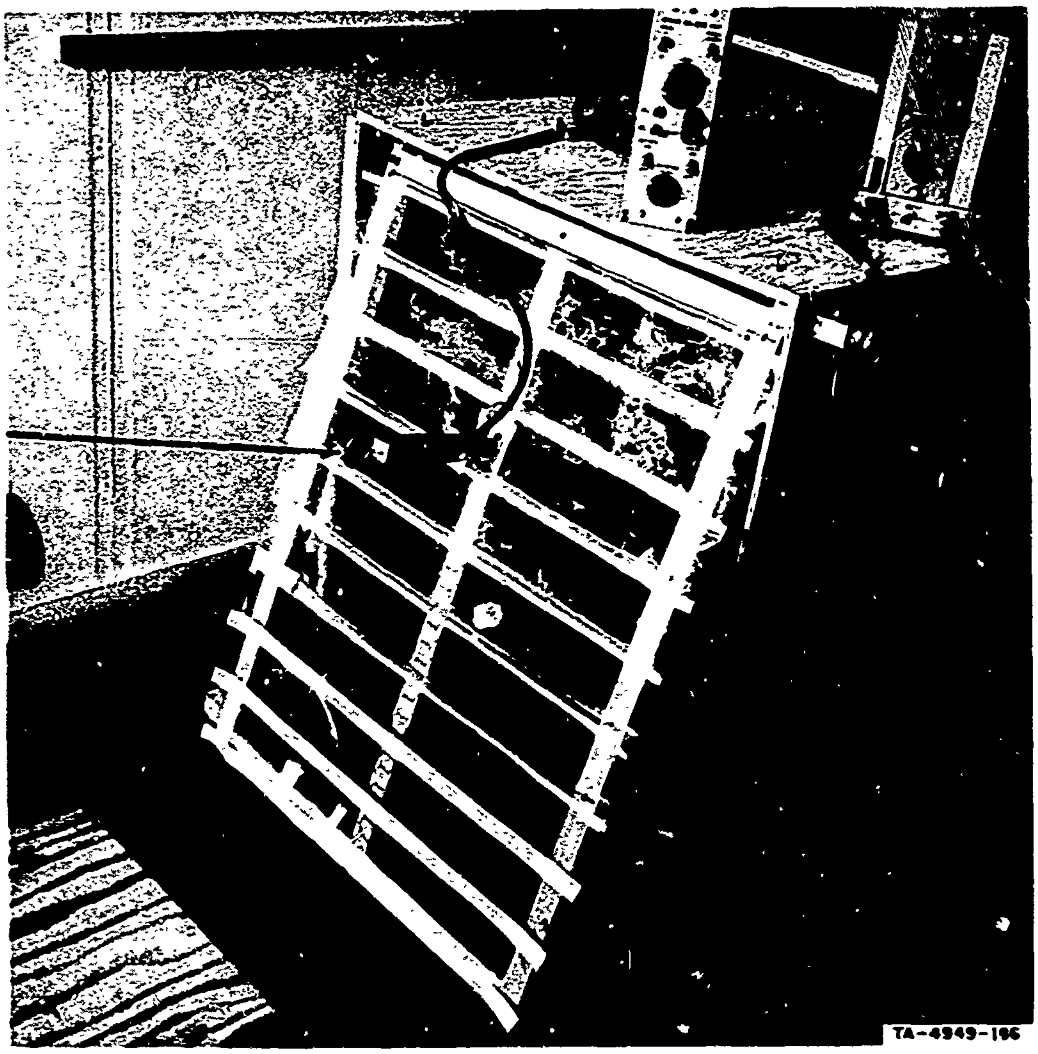


FIG. II-3 DUCT SHOWING PUNKAH INSTALLATION

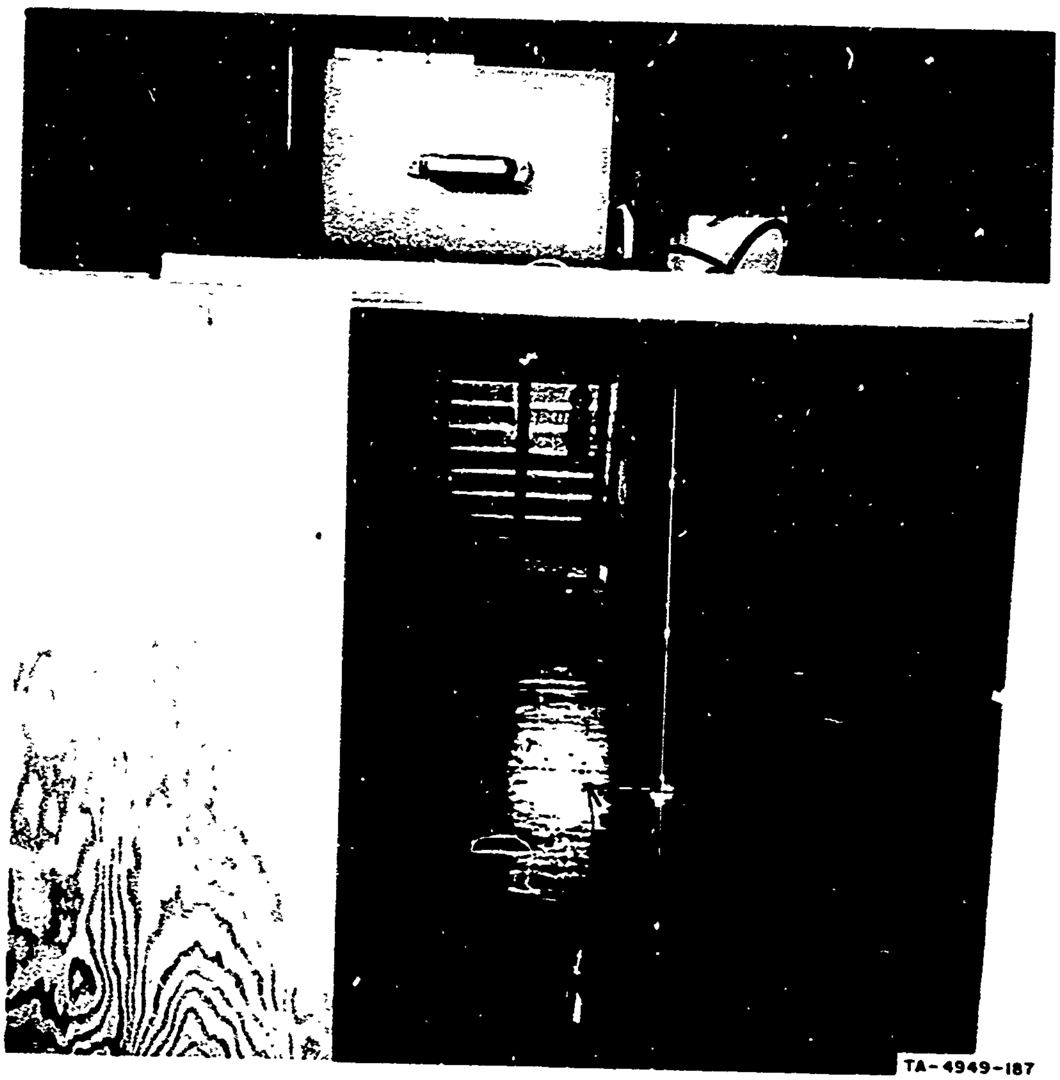


FIG. II-4 END VIEW OF DUCT

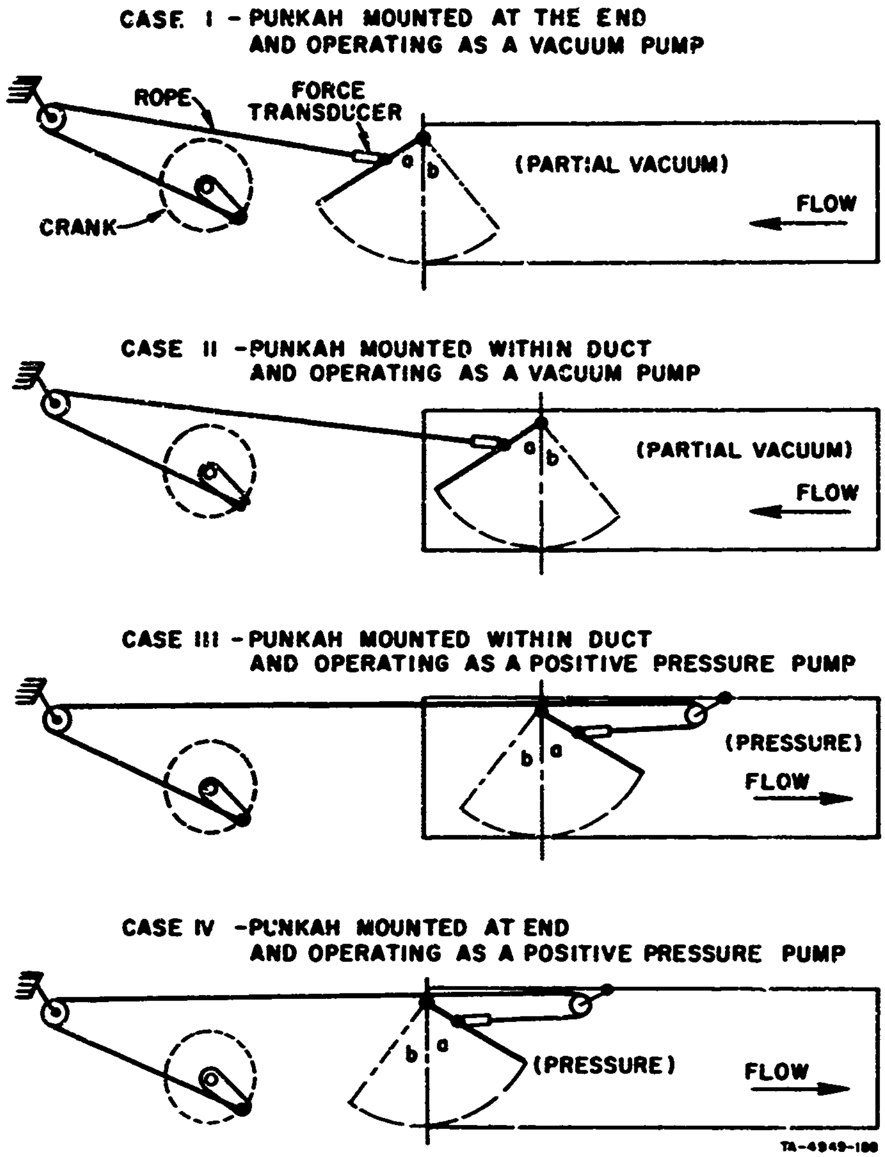


FIG. II-5 FOUR MODES OF PUNKAH OPERATION

II INSTRUMENTATION

The following instruments and gages were used (Fig. II-6):

(1) Dual-Channel dc Amplifier/Recorder, Model 320, Sanborn.

(2) Viscorder Model 906A, with amplifier and Timing Unit, Honeywell.

(3) Pressure Transducer ± 0.15 psi. Model PM5TC, Serial 11160, Statham Instruments, Inc., Los Angeles, Calif.

(4) Force Transducer 0-50 lbs. Model FT-1-1C, Dynisco, Inc., Cambridge, Mass.

(5) Constant Temperature Anemometer, Model 55A01, DISA Elektronik, Herlev, Denmark.

(6) Flowtronic Air Velocity Meter, Model 55B1, Flow Corporation, Cambridge, Mass.

(7) Digital Voltmeter, Model 481; Nonlinear Systems, Inc., Del Mar, Calif.

(8) Hook Gage No. 1420 (Micro-manometer) F.W. Dwyer Mfg. Co., Michigan City, Indiana.

(9) D.C. Amplifiers, Model 111 BF and 112A, Kintel.

(10) Bridge Balance Unit, Stanford Research Institute.

A. Force (Pull) to Drive the Punkah

The Dynisco transducer was mounted on the punkah and connected to the rope actuating the punkah, Fig. II-3. Thus it was possible to record the variation of the force over one cycle. The block diagrams of the instrument hook-up are shown in Fig. II-7.

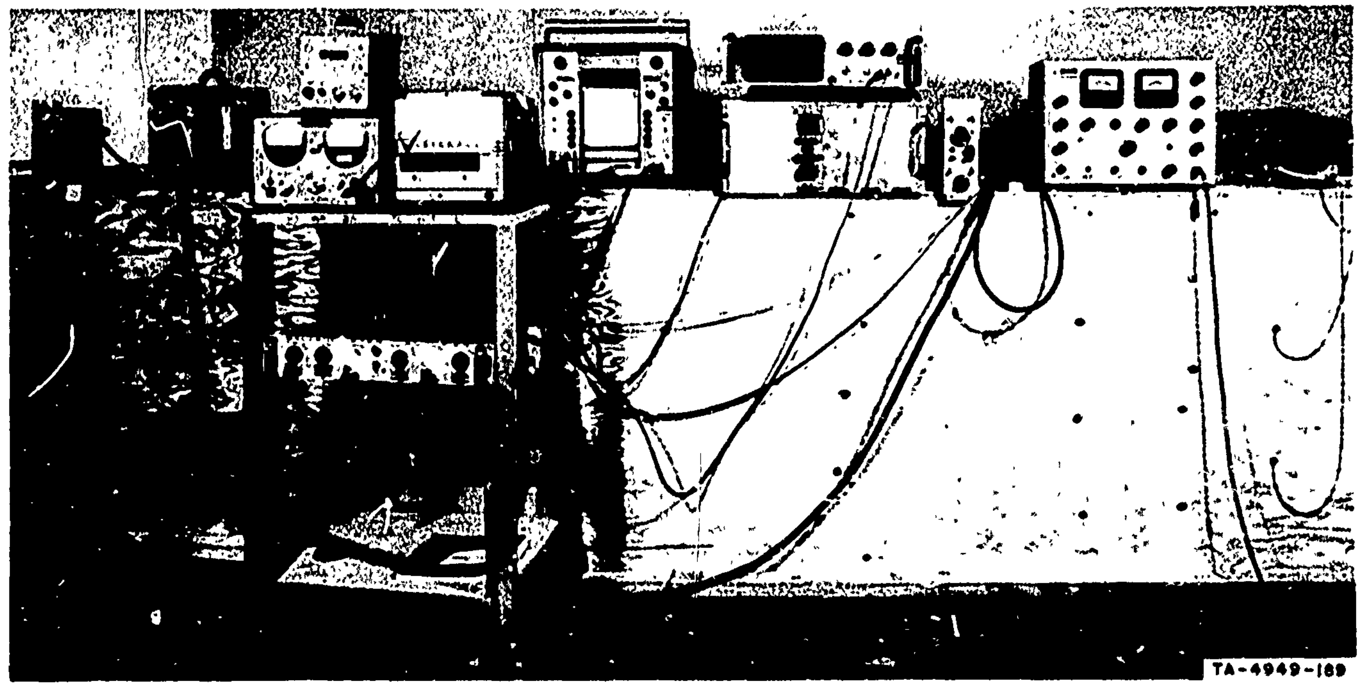


FIG. II-6 INSTRUMENTATION SET-UP

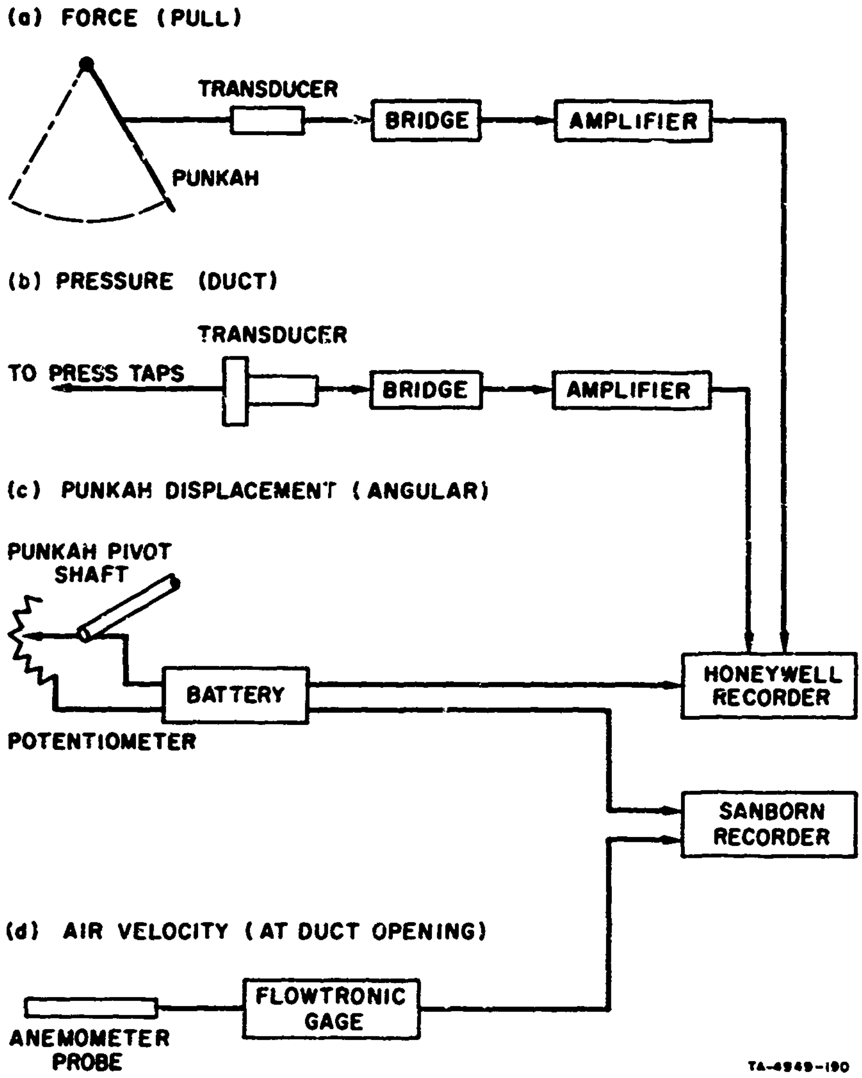


FIG. II-7 BLOCK DIAGRAM OF INSTRUMENT CONNECTIONS

B. Pressure in Duct

The changes of the static pressure of the duct system were recorded by the Statham pressure transducer as shown at the lower right of Fig. II-1. Pressure taps, connected in parallel, were located in six different positions on the duct.

C. Punkah Displacement

A potentiometer was coupled to the pivot shaft of the punkah. Using a voltage source of 1.5V, it was possible to record for change in the angular position of the punkah during oscillation.

D. Air Velocity

The Flowtronic Air Velocity Meter was the most feasible to use for measuring velocity at the duct opening. Velocity was recorded on the San-Born pen recorder through the wire anemometer transducer.

E. Calibration

The force transducer was calibrated using a Hunter dial spring gage. The transducer outputs were recorded on the Visicorder.

The pressure transducer was calibrated by loading it in parallel with the Precision Hook gage, which is equipped with a pair of micrometer coupled, sharp feeler points that indicate the water levels of two interconnected water compartments. The output voltages of the above transducers were tabulated to serve as basic reference values.

The possible indicator reading error of the Flowtronic velocity meter is ±5 percent + 10 ft/min. Since the output from the meter was not linear, a calibration curve, based on the indicated Flowtronic meter reading was made up. The recorded velocity curves were then replotted based on a linear scale. As mentioned in Sec. I D-2 of Part One, the measurements of the Flowtronic meter were compared to the measurements read by the pitot tube. The air velocity is expected to be within 15 percent in the 250 ft/min and above ranges. After directing considerable effort toward calibrating the DISA anemometer, it was concluded that use of the instrument would be too difficult. This highly sensitive anemometer was therefore not used.

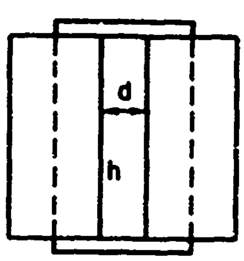
III TEST PROCEDURE

A motor connected to a speed reducer and crank mechanism drove the punkah at 30 oscillations per minute. The amplitude of swing was made close to 100°, which was observed as the approximate amplitude encountered in actual operation. In each of the four cases presented in Fig. II-5, it was difficult to adjust the punkah throw to exactly 100° since the return swing (free return of the punkah) varied slightly as the system characteristic was changed.

In each of the four cases the duct opening was varied by using the sliding doors. The following five different openings were used:

Table II-1

DATA RESULTING FROM VARIED DUCT OPENING



h = 35 in.

Opening	d	Area of Opening	Effective Area
A	29"	7.05 ft^2	6.70 ft^2
B	19.3	4.70	4.45
C	9.8	2.38	2.26
D	4.0	0.97	0.93
E	0	0	0

The measured parameters, force, pressure, displacement, and velocity were all recorded on a chart recorder. Force, pressure, and displacement were recorded simultaneously on the Visicorder, which uses a light-sensitive paper. The recorded chart could not be fixed permanently, and, therefore, pencil tracings had to be made over the lines produced by the light beams. It was necessary only to record through one or three cycles of the punkah for each case and door opening, (i.e., I-A, I-B, I-C...IV-D, IV-E).

For the velocity measurements, several readings were taken at each door opening, that is, the transducer was placed at several positions in the opening and averaged. Therefore, it was more advantageous to record the velocities on the two-channel Sanborn recorder which uses a hot pen producing a permanent record on the chart. The displacement was also recorded (on the second channel) so that a common reference was established between Visicorder and Sanborn chart records. The effective flow area was considered to be .95 of the area of the opening since the velocities were relatively low.

IV REDUCTION OF TEST DATA

A. Force, Pressure, and Velocity

The peak and the average values of each measured parameter were determined. For determining the average values, the area (with a planimeter) of the recorded curves above the zero line over the length of one cycle of punkah oscillation were measured, and the area was divided by the base length.

The force transducer mounted at the punkah recorded only the forces transmitted from the rope to the punkah. The transducer was thus mounted in order to eliminate recording the friction forces of the several pulleys that were needed between the punkah and the driver in the test setup.

In the velocity measurements, readings were obtained at several points at the duct opening for each setting. In order to average these readings, an average curve for one cycle was determined by selecting a near average curve by inspection and by tracing this curve on paper. This curve was then fitted over each of the curves recorded in the same run to observe how close to average the selected curve was. That is, in fitting the traced curve over several of the other curves on the chart, some would have a slightly larger or smaller area in comparison. In most comparisons the areas were nearly equal. It would have been too tedious to have first measured the areas of each curve recorded and then average, since at least four cycles were recorded at each point of the opening. The recorded curves for Case III are shown in Figs. II-9 and II-10.

In the velocity curves, the displacement of the curve is nonlinear since the output from the Flowtronic meter is nonlinear. From the average curve selected, the curve was replotted to a linear scale prior to measuring the area.

B. Power Required

The value of the power required for the oscillating punkah can be determined by the product of the total energy input per cycle and the frequency,

$$P = Ef = \frac{E}{T}, \quad (1)$$

where P = power required

T = period of oscillation

and

$$P = \frac{1}{T}\int_0^T F(t)\ v(t)\ dt, \quad (2)$$

where F(t) = instantaneous forces (from recording)

v(t) = instantaneous velocity

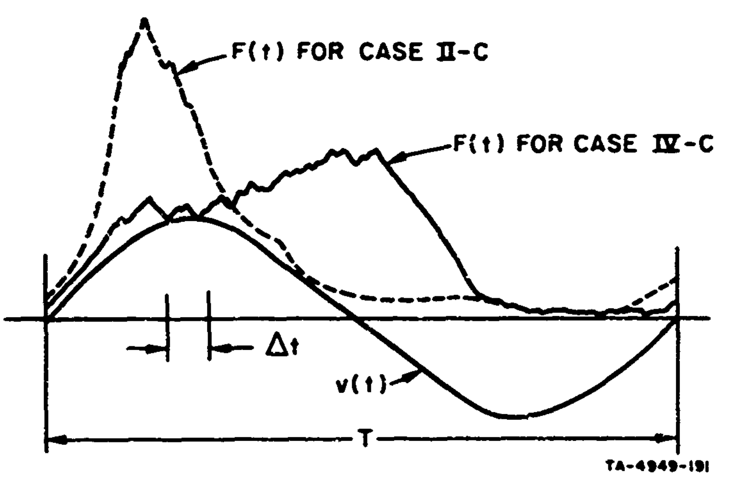
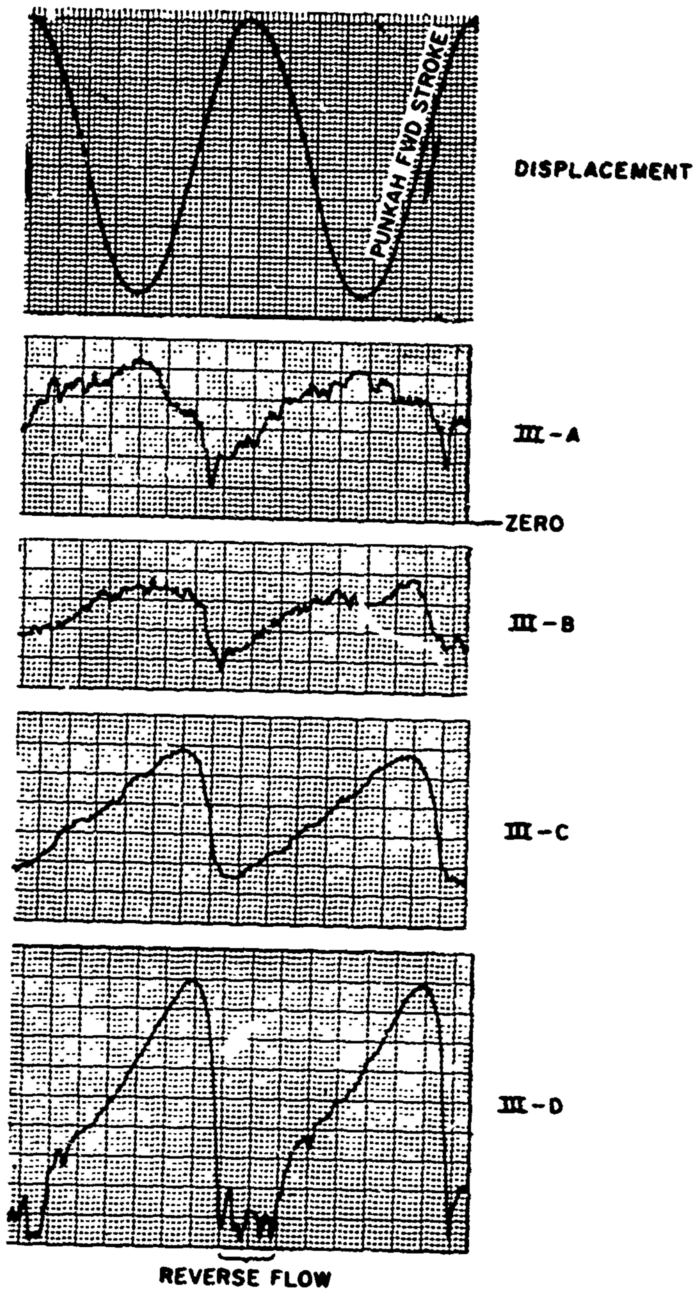


FIG. II-8 IN PHASE FORCE AND VELOCITY FUNCTIONS

The velocity is the velocity of the point of application of force on the punkah. The velocity curve was plotted as a derivative of the displacement curve, and its maximum amplitude was determined from the peripheral velocity of the crank mechanism driving the punkah. That is,



1. Read from right to left
2. Vertical scale of velocity not linear

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FIG. II-9 EXAMPLES OF VELOCITY DATA FROM CHART RECORDINGS, CASE III

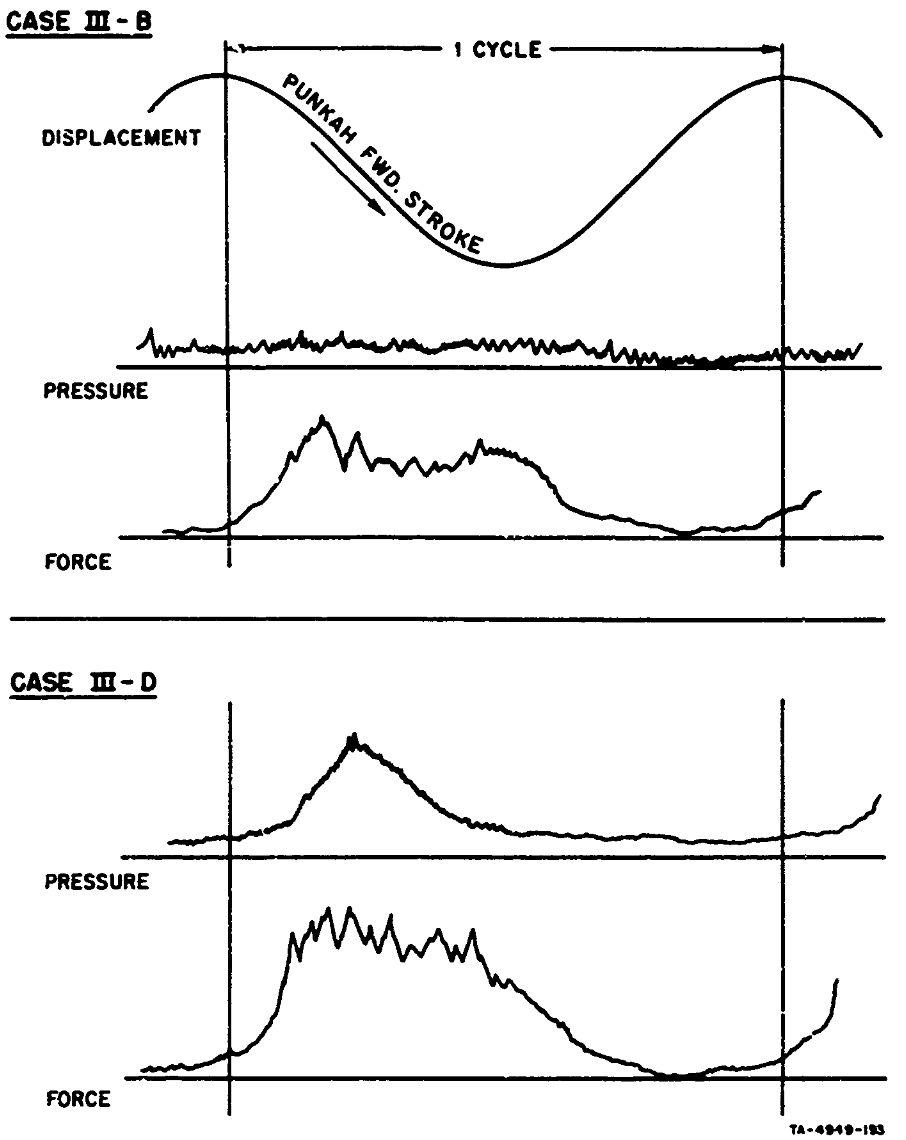

FIG. II-10 EXAMPLES OF PRESSURE AND FORCE RECORDS, CASE III

$$v_{max} = \text{(circumference of crank circle)} \times \text{(rpm)} \qquad (3)$$

From the velocity and force curves plotted in phase (as shown in Fig. II-8), the power was determined graphically by summing the increment as follows:

$$P = \frac{1}{n} \sum_{i=1}^{n} F_i \, v_i \qquad (4)$$

The value of n was 15 plus or minus depending upon the length of one cycle on the chart. By this method, the resultant energy is obtained, that is, a summation of the energy input during the forward actuation of the punkah as well as the energy supplied by the punkah during its return stroke to pull the rope are considered. (The latter is indicated by the negative portion of the velocity curve.)

The output power was obtained as a product of flow and average pressure.

V TEST RESULTS AND DISCUSSION

The average values of force, pressure, and velocity for each test are shown in Table II-2. Air flow, also shown, is the product of the average velocity and effective area. Also presented are maximum values of the parameters, which are measurements of the maximum point of the curves recorded, and are of short duration. Nevertheless, they give indication of the maximum magnitude attained. The power and efficiency values are given in Table II-3.

The above results were plotted to define the performance curves for Cases I, II, III, and IV and are shown in Figs. II-11 through II-14.

In the experiments reported in Part One, the flow generated by the punkah mounted on the doorway of the dead-end room and drawing air out of the room was approximately 890 CFM (facility for accurate velocity measurements was not available at that time). This application resembled closest that of Case I. If we apply the delivery rate of 890 CFM to Case I, the operational static negative pressure of .03 inch of water, is read from the curve, Fig. II-11. Other values are given on Table II-4 for operation in the region of .03 to .04 inches of water.

The following observations are made from the four performance curves:

(1) In the operational ranges of .03 and .04 inch of water static head, the enclosed duct system (Cases II and III) produce a higher flow rate, and operate at higher efficiencies.

(2) The punkah operating as a vacuum pump has a slightly higher flow rate (than pressure operated) at the above operational pressure (i.e., II is higher than III, I is higher than IV).

(3) The pressure systems operate at a higher efficiency requiring less power than the corresponding vacuum system.

(4) The pressure system produces a higher flow rate at low static head (free air delivery).

(5) Punkahs mounted within the duct (Cases II and III) can operate against a higher static head at no flow. (This condition is not apt to be encountered in punkah operation in a shelter.)

Table II-2

TEST RESULTS

	Average Values					Maximum Values		
	Force (lbs)	Pressure (in. H_2O)	Velocity (fpm)	Effective Area (ft^2)	Flow (cfm)	Force (lbs)	Pressure (in. H_2O)	Velocity (fpm)
Case I								
A	1.8	-.016	175	6.70	1,170	13.5	.05	300
B	1.6	-.02	270	4.45	1,200	12.5	.08	450
C	2.0	-.035	345	2.26	780	13.5	.10	720
D	2.9	-.055	390	0.93	360	15.5	.22	1,300
E	4.5	-.085	<15	appr. 0	—	17.5	.5	—
Case II								
A	1.9	-.018	220		1,470	12	.05	300
B	1.9	-.025	245		1,090	12.5	.09	450
C	2.7	-.045	350		790	12.5	.11	700
D	3.5	-.06	455		420	15.5	.21	1,300
E	6.0	-.11	<15		—	19	.43	—
Case III								
A	1.8	.01	250		1,670	4	.05	400
B	1.8	.02	295		1,310	4.1	.05	500
C	2.0	.035	330		750	6	.10	700
D	2.9	.06	425		395	7.5	.20	1,300
E	4.1	.11	—		—	12.5	.35	—
Case IV								
A	3.0	.01	270		1,800	10	.05	400
B	3.3	.02	305		1,360	10	.06	500
C	2.7	.03	335		760	6.5	.10	750
D	3.0	.05	395		365	7.5	.20	1,300
E	4.0	.08	—		—	11.5	.60	—

Table II-3

POWER AND EFFICIENCY

	Air Power Output (Flow X Avg. Press.) (ft-lbs/min)	Power Input to Punkah		Efficiency (percent)
		(ft-lbs/min)	(hp)	
Case I				
A	97	260	.008	37%
B	125	282	.009	44
C	142	320	.010	44
D	103	390	.012	26
E	0	670	.020	--
Case II				
A	139	295	.009	47
B	142	295	.009	48
C	185	335	.010	55
D	130	415	.013	31
E	0	570	.017	--
Case III				
A	87	138	.004	64
B	135	173	.005	78
C	136	202	.006	67
D	122	217	.007	56
E	0	365	.011	--
Case IV				
A	94	153	.005	62
B	141	185	.006	76
C	118	(135)*	.004	(86)*
D	95	250	.008	38
E	0	264	.008	--

* These points do not fall along the curve of Case IV, Fig. II-14.

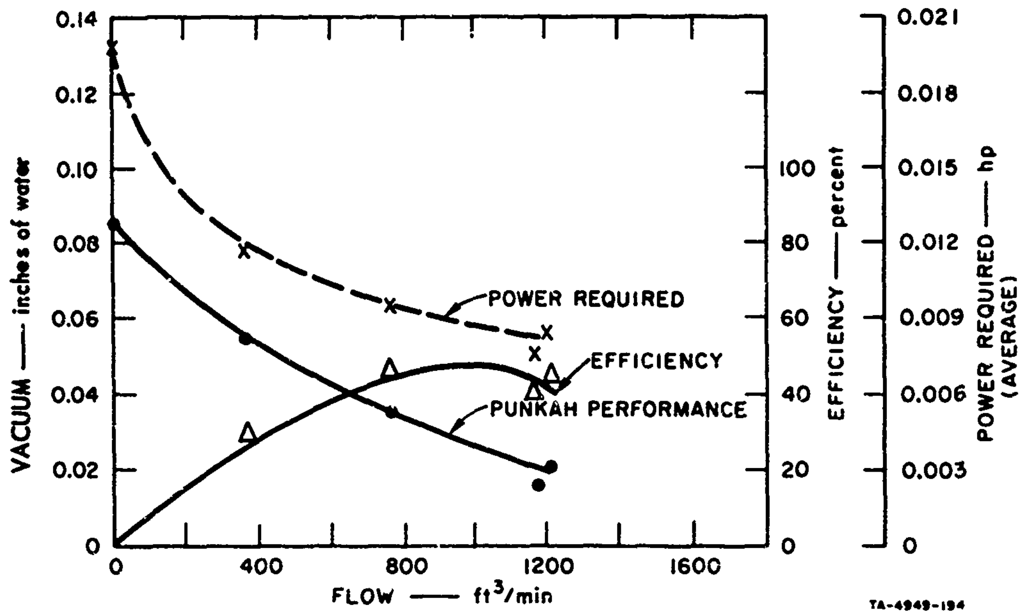

FIG. II-11 PUNKAH PERFORMANCE CURVES, CASE I

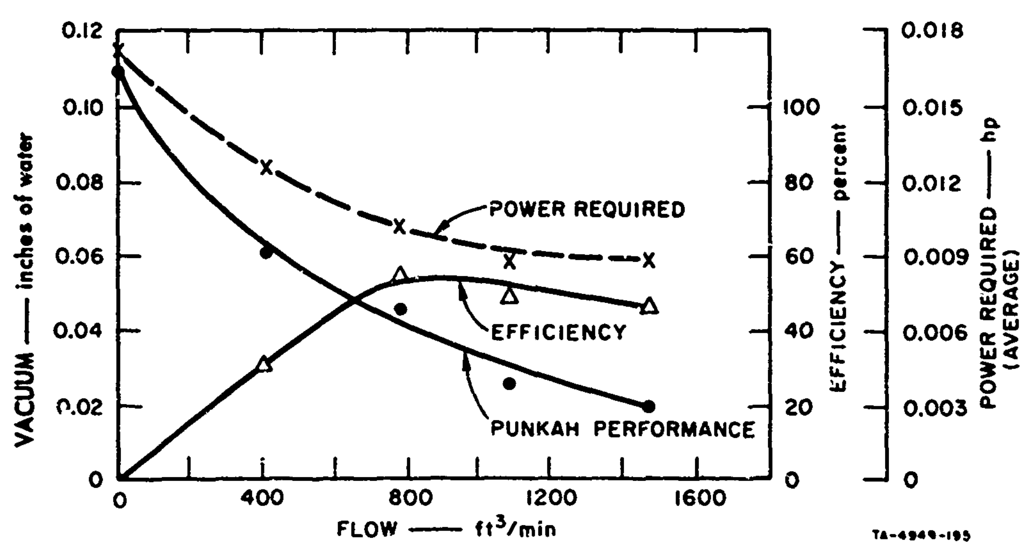

FIG. II-12 PUNKAH PERFORMANCE CURVES, CASE II

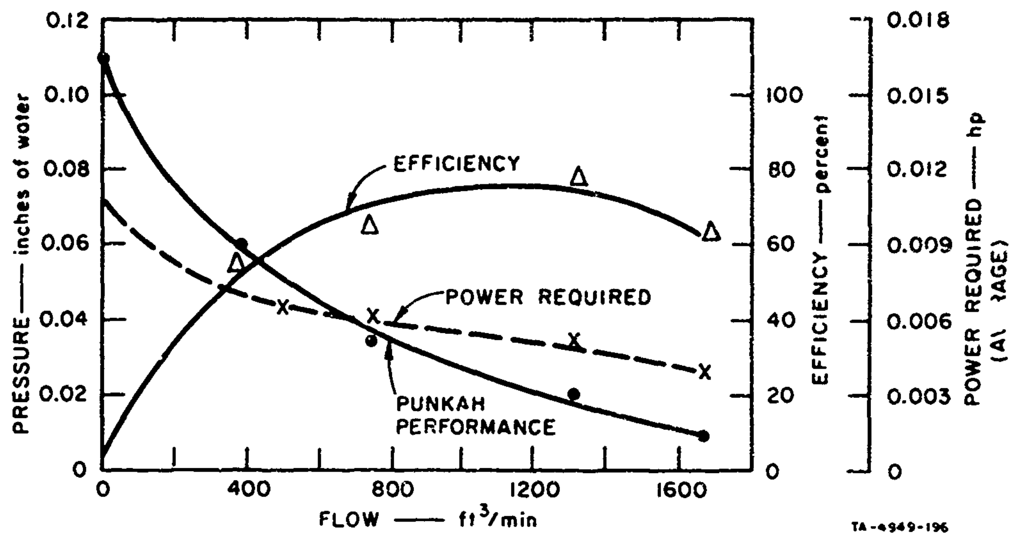

FIG. II-13 PUNKAH PERFORMANCE CURVES, CASE III

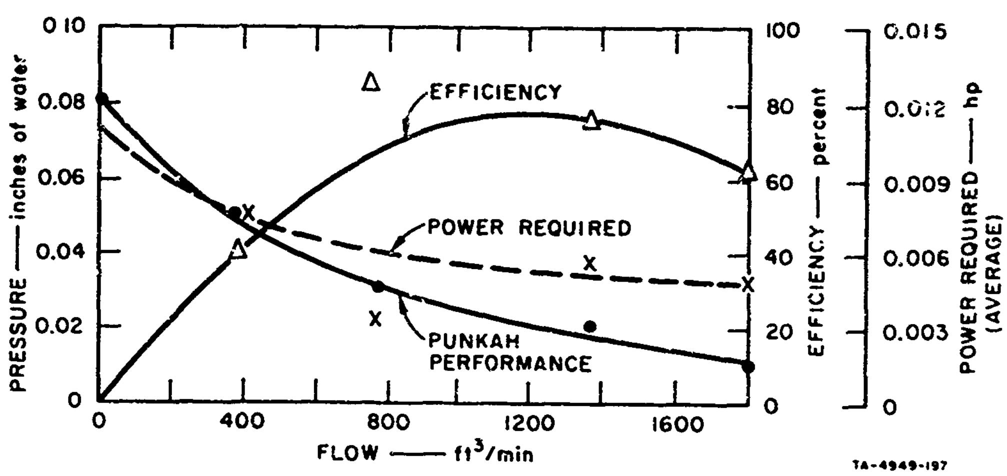

FIG. II-14 PUNKAH PERFORMANCE CURVES, CASE IV

Table II-4

TEST RESULTS FOR OPERATION IN .03 TO .04 INCHES OF WATER

	Delivery (CFM)		Power (ft-lb/min)		Efficiency (percent)	
Static Pressure, Inch of Water →	.03	.04	.03	.04	.03	.04
Case I (vacuum)	890	650	310	335	47	40
Case II (vacuum)	1060	830	310	330	52	54
Case III (pressure)	930	680	190	210	75	68
Case IV (pressure)	770	510	190	220	50	66

Note: The above values are based upon the punkah operating with equal displacement and frequency (as near as can be controlled).

In the curves for Case IV, one of the points turned out to be off the lines that would make a smooth curve for "efficiency" and "power required." Although a smooth curve is not always the result, in this case, the required power appeared relatively low, making the efficiency at 760 CFM as high as 86 percent. This value is not out of line, but the point when plotted did not fall along the curve determined by the other values. Therefore, in fitting the power and efficiency curves, these points were not considered.

The power required for Cases I and II are shown to be relatively high. The maximum forces in Table II-2 for these cases also indicate that high peaks were encountered. In checking the recorded charts, it was observed that the high forces occurred in the regions of the higher punkah velocities (see Fig. II-8). That is, the high force was in phase with the forward velocity of the punkah thereby showing a high power input. A portion of this may be due to the drive system with its connecting rope which was shorter than that used in Cases III and IV. The longer rope used for Cases III and IV (see sketches of Fig. II-5) may have acted as a buffer to momentarily store the peak forces and release them over a longer period of time. (The transducer recorded only the forces transmitted from the rope to the punkah.) It should be noted that the average forces are roughly comparable for all cases (Table II-2).

In Case IV the average forces are relatively high, yet the power required was relatively low. The forces recorded in this case showed that a portion of the forces occurred during the return stroke (as shown in Fig. II-8), that is, the punkah was returning energy to the drive. Therefore, the resultant power input was not as high as would be expected by observing only the forces. The punkah displacement was quite high on the forward stroke in Case IV. In reference to Fig. II-5, the angle "a" was always greater than angle "b". In Case IV, angle "a" was considerably greater.

The input power of the punkah is high at zero flow. The punkah can be classified more as a positive displacement pump. In the centrifugal fan, as a comparison, the power required is low at cut-off and rises with increase of flow.

The efficiency (ratio of power output to power input) in this case is very sensitive to the pressure, since power output is dependent on the pressure. The accurate determination of pressure is very difficult from the chart curves, especially in the A and B door opening condition where the magnitude is very small. An example is shown of the pressure curve for III-B in Fig. II-10.

Although the presentation of pressure data in thousandths of an inch of water may appear very fine, it should be noted that the highly sensitive Statham transducer was calibrated with a water manometer having micrometer adjustment hook gages. Generally, the average measurements from the recorded curves (see Sec. IV) were used, and values of the parameters were calculated by using the constant determined from the calibration curve.

Possible error sources are more apt to occur as a result of drift in amplifier and/or recorder, which may affect readings of very small magnitudes.

VI SUMMARY AND CONCLUSIONS

The punkah was operated in four different modes:

Case I: Operation as a vacuum pump; mounted at end of duct
Case II: Operation as a vacuum pump; mounted within the duct
Case III: Operation as a pressure pump; mounted within the duct
Case IV: Operation as a pressure pump; mounted at end of duct

Performance curves were made up from the test data. From the approximate flow rate of 890 CFM determined in the tests of Part I, the approximate operational pressure head was estimated at .03 inch of water. In this region of operation:

(1) The enclosed duct systems (Cases II and III) produce a higher flow rate, and operate at higher efficiencies.

(2) The vacuum operation produces a slightly higher flow rate than the corresponding pressure operations.

(3) The pressure systems operate at a higher efficiency than the corresponding vacuum system.

(4) Pressure systems produce a larger free-air delivery rate.

The maximum delivery rate obtained was 1800 CFM at free discharge in Case IV. The maximum average static head developed was .11 inch of water with peaks of .6 inch of water observed. The maximum average power required tabulated was 670 ft-lbs/min which corresponds to 0.02 horsepower. The maximum average pulling force was 6 lbs. Also recorded was a maximum instantaneous peak force of 19 lbs.

The preceding information was obtained from the study of test results of the half-door length punkah. It should be noted, however, that certain measurements such as the pressure measurements were difficult to accurately determine from the chart records in the low-pressure region. The static head in this region, it is estimated, can be off by 25 percent to 30 percent, thereby affecting the efficiency value.

Because the punkah is a pulsating pump, power input was determined by averaging the summation of the increment products of the force function and the velocity function of the driver. The force functions for vacuum and pressure operation differed considerably. One reason for this may be attributed to the different lengths of the connecting rope and the pulley system used for the pressure and vacuum systems. It would be recommended to study further the reasons for the difference in the force functions.

In the actual operation of the punkah, the primary concern would be the magnitude of flow that can be generated. Power required and efficiency should be considered if their values are out of line. The foregoing is based on the assumption that there would be available a number of shelter occupants for punkah operation, and, therefore, the requirement of a slightly higher power would be a trade-off for a higher rate of air delivery.

The summary and conclusions for Part One are given separately at the end of Part One.

FUTURE WORK

The tests outlined in Part One and Part Two of this report, involving the punkah, were initial tests performed at SRI. Studies of the test data show that further tests are needed in order to obtain more positive information on the punkah and its application. Several of the results are marginal due to the delicate nature of the measurements that were made.

From the review of the tests, it is recommended that a future program should include tests and test procedures as follows:

(1) Perform tests using the same rope and pulley system for both pressure and vacuum condition of punkah operation so that total power input can be measured at the driver end and compared.

(2) Investigate the reason for the large difference between the force curve functions of the punkah operating in the pressure and vacuum conditions.

(3) Perform tests with a more carefully controlled forward and return displacement of the punkah swing.

(4) Perform tests with punkah operating at resonant frequency rather than operate all tests at equal periods and near resonance.

(5) Study the comparisons between the power input functions of the crank mechanism and that of the human driver.

(6) Perform studies of the full-door size punkah.

(7) Determine the approximate static pressure head encountered in pumping against various sizes of rooms.

The series of tests performed using the punkah has enabled us to develop and apply various special instrumentation techniques. The greater portion of the project effort was expended in the preparation, calibration, and application of special instrumentation. Punkah performance tests that were conducted in Part Two must be considered as preliminary. Improved testing and measurement techniques will be applied to future tests.

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2. C. H. Kearny, "Mechanized Durability Tests of a Six-Foot Punkah Pump," ORNL-TM-1155, Oak Ridge National Laboratory (July 1965).

3. G. Engholm, "Phsiological and Meteorological Aspects of Shelter Ventilation," Report for the Scientific Working Party of the NATO Civil Defense Committee, General American Transportation Corp., Niles, Illinois (29 June 1965).

4. J. A. Hammes and R. T. Osborne, "Shelter Occupancy Studies at the University of Georgia, 1962-1963," Final Report, Civil Defense Research Psychological Laboratories, University of Georgia, Athens, Georgia (31 December 1963), pp. 68-70.

5. G. J. Ducar, R. J. Baschiere, and G. Engholm, "Analysis of Ventilation Air Distribution Requirements for Survival Shelters," GATC Interim Report MRD 1195-70-1, Prepared for OCD under Contract OCD-OS-62-134 (April 1963).

Appendix

TEST RESULTS

Appendix

TEST RESULTS

In all tests, the electrical heaters creating a load of 14,300 Btu per hour were left on continually. Stations 58 and 23 of rooms A and B, respectively, were the geometrical centers of these rooms. Temperature measurements of other stations were also made in order to check the uniformity of the temperature distribution in the rooms. The results of the tests and brief discussions of each are given.

Tests 1 through 8 were performed to study the ability of the doorway punkah to deliver air from an outside room (room B) into a compartment room (room A) having only the inter-room doorway and no windows.

Arrangements of punkahs for distribution of air within room A were also studied. In Tests 9 through 12, an opening was cut in the wall between rooms A and B and an exhaust punkah was mounted there [see Figs. I-9(ℓ) and I-12]. Ventilating air from room A was drawn in through doorway D-4 between the rooms. Ventilation with this punkah arrangement was expected to be equal to or better than that with the punkah mounted in the top half of the doorway with separator and side panels.

Test 1:

This initial test was performed to study the changes in the temperatures of rooms A and B produced by the ventilation exhaust blower only. The exhauster was located on the north wall of room B, and a window on the far side served as the inlet. Since the exhaust blower had little effect in stirring the air, the effectiveness of other stirring devices could be studied.

The duration of this test was 1-1/2 hours. Due to the relatively cool outdoor dry-bulb temperature and some infiltration, there existed a temperature gradient of up to 3 degrees from floor to ceiling at the time of stabilization; however, throughout the two test rooms, the temperatures at the common levels were uniform within 1 degree.

Test results showed an immediate stratification of the temperatures in room B, especially pronounced at stations in the main stream (stations 16, 14, and 5). After a half hour, stratification was noticeable in room A, although it was not as pronounced. Results at the end of the test showed that although test room A responded to the temperature changes of of room B, there still existed a finite differential in the average temperatures of the two rooms when the punkah was not used. Data show that temperatures at the same levels were uniform in room A. The primary stream of air was from the inlet (W-3) to the exhaust, with secondary flows into room A. The flow into room A was caused by a combination of convection and diffusion as a result of the temperature difference. Smoke traces showed distinct flow patterns into room A; however, smoke traces in this particular case were not truly indicative of air flow, since much of the smoke movement could have been caused by diffusion as a result of differences in the concentrations of smoke generated in the test room. Careful studies should be made of temperatures together with velocities and smoke patterns to arrive at a sensible conclusion on air movements within a room.

Stratification of temperature creates a cooler environment at the lower levels (under 2 feet); however, a relatively low-velocity condition must be maintained. In Test 1, the only circulation was created by the exhaust blower; currents measured throughout the rooms did not exceed 30 ft/min. Although the heaters created small convection currents, stratification was quite distinct. Because of the cool stratum created, shelters ventilated in this manner might appear to be more habitable, especially since the occupants are either sitting or lying down most of the time. However, some activity takes place in shelters, and this is quite likely to result in some air mixing that would tend to break up the stratum. It was mentioned in Ref. 4 that the occupants spend approximately one-half of their shelter time lying down, one-third sitting down, and one-sixth standing. This indicates that the environment surrounding most occupants is below the 30-inch level. It will therefore be significant to study the temperature gradient in shelters with live occupants. If a cooler stratum can be maintained in spite of occupant movements, it might be best to keep any mechanical mixing to a minimum.

Test 2:

Test 2 involved the use of punkahs in different locations and arrangements in room A. The various arrangements are shown in Figs. I-9(a), (b), and (c). The purpose of this test was to study the effect of air mixing in room A.

The results showed that practically no temperature reduction took place in room A in spite of a temperature reduction in the adjacent room B. In arrangements I-9(b) and I-9(c), a punkah was located in the doorway, pumping into as well as out of the room. Evidently the second punkah, used to stir the air within test room A, impeded air entry into room A. Smoke tests showed considerable short circuiting of air when the punkah was operated in this manner. The punkah mounted in the doorway covered one-half the area. The same size punkah was used for mixing air in room A.

Later tests showed that the punkah located in the doorway was very effective when paneling was installed, maintaining the temperature of room A very close to that of room B. This indicates that a mixing punkah in room A was not needed.

Test 3 (Fig. A-1):

Temperature measurements of the centers of rooms A and B were compared while a punkah was operated on the top half of the doorway between the rooms. The punkah was installed to pump the air out of room A through the upper half of the door. Test results show that the average temperature of room A followed that of room B within 1-1/2 degrees, in spite of the short-circuiting across the punkah. This result is compared to that of Test 2, where a second, mixing punkah within room A impeded the flow of air into the room. The ambient temperature remained almost constant throughout the test.

Test 4:

A horizontal separator was placed between the upper and lower half of the doorway in which the punkah was mounted [Fig. I-9(c)]. Study of the data indicates that the temperature of room A did not change, although this condition alone is not indicative of poor circulation. Smoke tests showed good circulation with less short-circuiting than in Test 3. The data also show that the temperature at station 23 in room B dropped to 87°F from the initial condition of 89.5°F. The temperature of room A, which is dependent upon that of room B, did not fall below 88°F. This was due to the fact that the ambient temperature was higher than in previous tests.

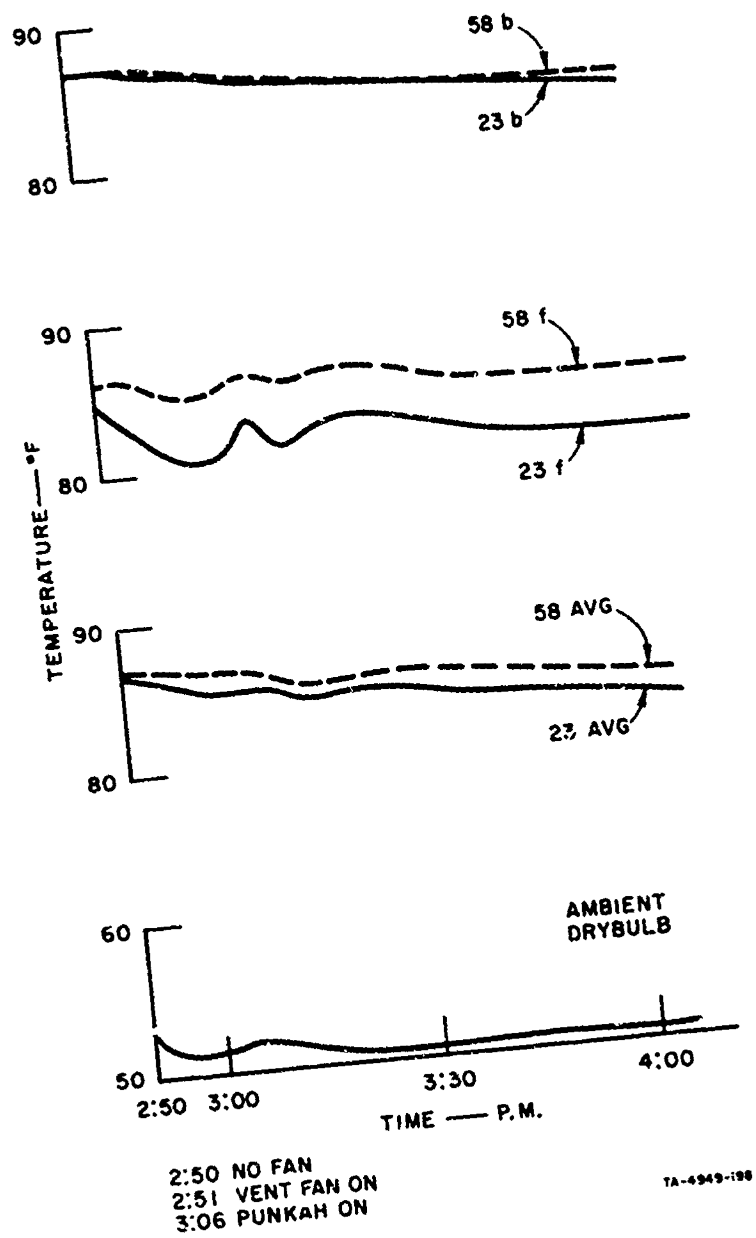


FIG. A-1 TEST 3 — TEMPERATURE AT STATIONS 58 (Room A) AND 23 (Room B)
(Punkah arrangement shown in Fig. 9(d); window W-3 open)

Test 5 (Fig. A-2):

The punkah was mounted at the bottom half of the doorway, and a horizontal panel was installed above it [Fig. I-9(f)]. For some reason, the temperature in room B in the vicinity of the doorway did not drop; therefore, the temperature of room A remained virtually unchanged. The data show that use of the doorway punkah reduced the temperature gradient of room B so that the differential between the temperatures at the ceiling and floor was in the region of 3 degrees, compared to approximately 10 degrees in Test 1, where no punkah was used.

Test 6 (Fig. A-3):

This series of tests was performed with a mixing punkah suspended over station 36 in room B [Fig. I-9(g)]. The pumping punkah in the doorway was also in operation. Temperatures were taken of all six levels in various parts of the room to observe the mixing effect of the punkah. The main stream at stations 13 and 18 showed stratification, as expected.

Temperature distribution was observed to be almost uniform throughout the room, with vertical gradients of about 2 degrees from floor to ceiling. The average temperature at station 58 in room A was well in line with the average temperature of room B, as recorded at station 23. For a more thorough mixing of the air in room B, two mixing punkahs would be needed. The punkah was the same size as that used in doorway D-4, but the arm was extended 1-1/2 ft so that the swing arc was greater.

Towards the end of the test, a 20-inch polyethylene tubular duct was mounted in the intake portion of the doorway. An 8-foot length of the duct was extended into room A but was left unsupported. The pumping action of the punkah in the top half of the doorway caused some air to enter room A through the duct, but the punkah was not able to sustain inflation of the duct. A small quantity of air was delivered in pulses as it responded to the action of the punkah, and the duct opened only momentarily as the air passed. A punkah mounted in the doorway in this manner is not able to overcome the resistance of the collapsible plastic duct. The temperature at station 58, level f, showed a sharp gradient because the outlet of the duct was directed to the thermistor detecting this level. Because of the small delivery rate through the duct, the air at the inlet was not completely disturbed, and a portion of the cooler air was drawn in.

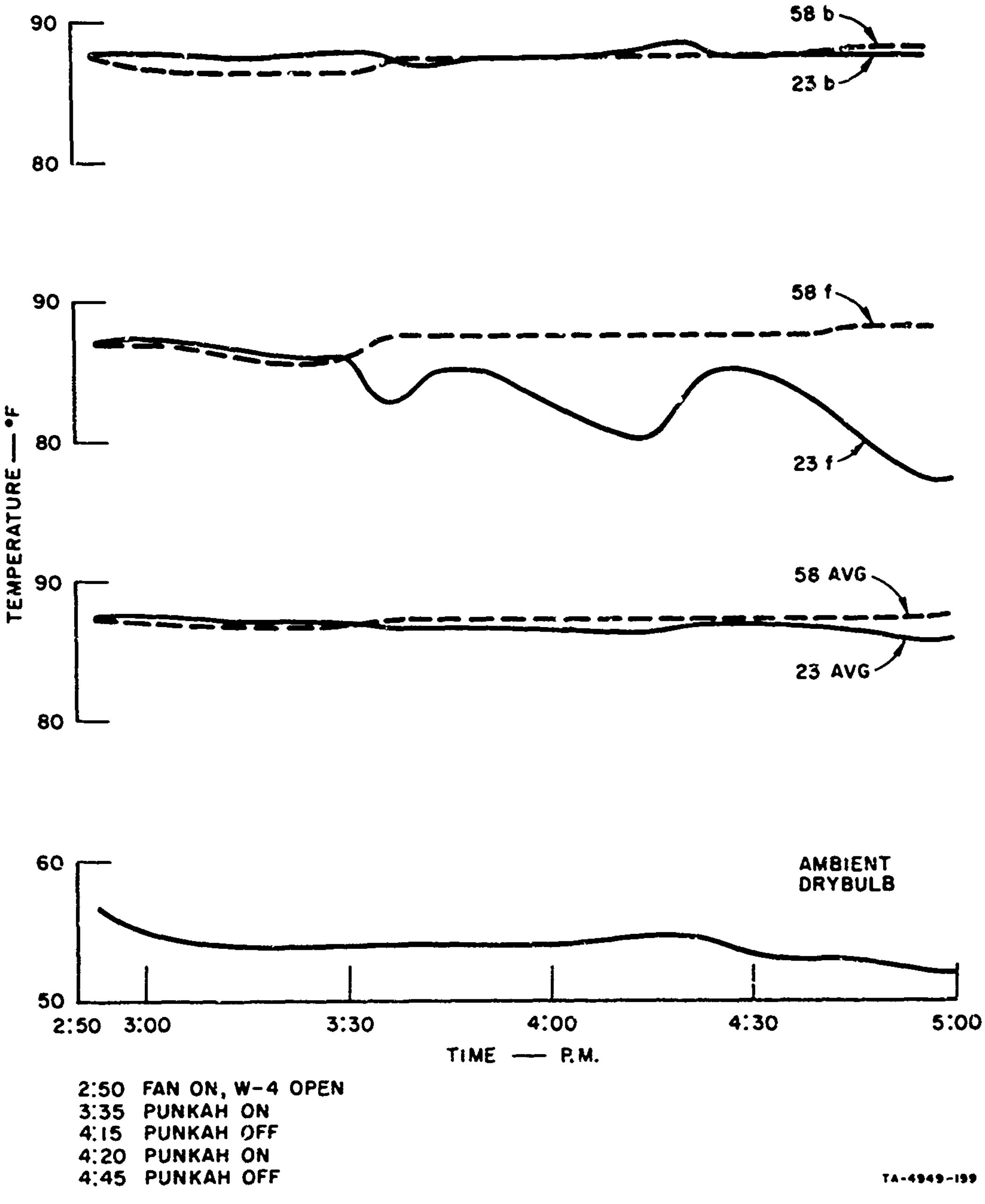
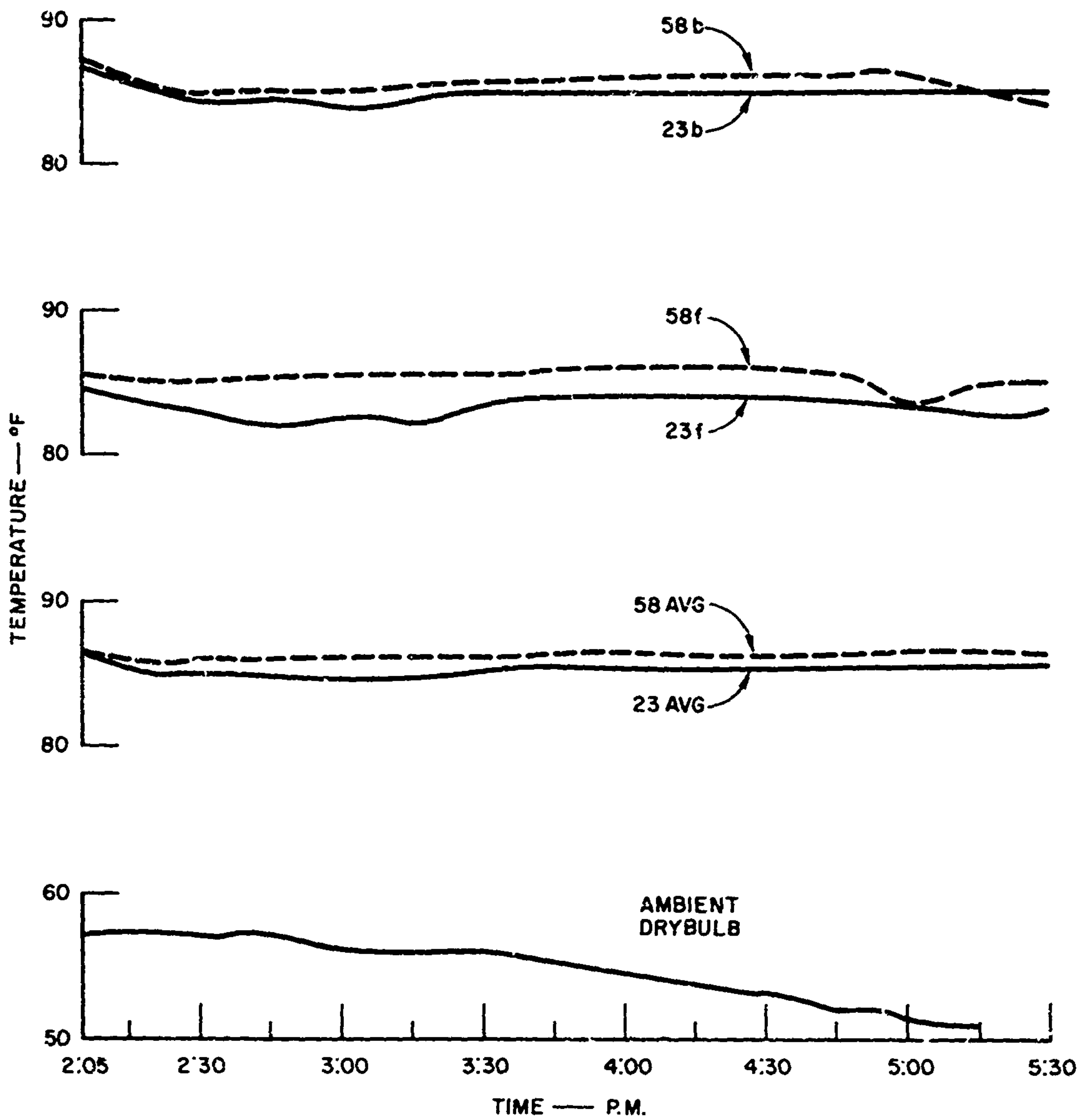


FIG. A-2 TEST 5 — TEMPERATURE AT STATIONS 58 AND 23



2:05 STILL AIR
2:15 FAN AND PUNKAH ON; W-3 OPEN
3:05 6FT. SEPARATOR PLACED IN DOORWAY UNDER PUNKAH
4:40 ADD 20 INCH DUCT AT DOORWAY TO ROOM A
4:52 W-3 CLOSED, W-4 OPEN
5:13 STOP PUNKAH AND ADD DIAGONAL DEFLECTOR TO DOORWAY.

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FIG. A-3 TEST 6 — TEMPERATURES AT STATIONS 58 AND 23
[Punkah arrangement shown in Fig. 9(g)]

Test 7 (Fig. A-4):

This test was similar to Test 6, but the mixing punkah in room B was placed in a different position [see Fig. I-9(ℓ)]; it was suspended from the ceiling over station 15. This arrangement proved more effective than that of Test 6, in which the punkah was located over station 32. At station 15, the punkah was able to mix the incoming air from window W-3 as it entered room B. Test results show that although the ambient temperature was much higher than during Test 6, the temperatures at stations 23 and 58 were lowered to almost the same temperature as in Test 6. Circulation of air into room A was good.

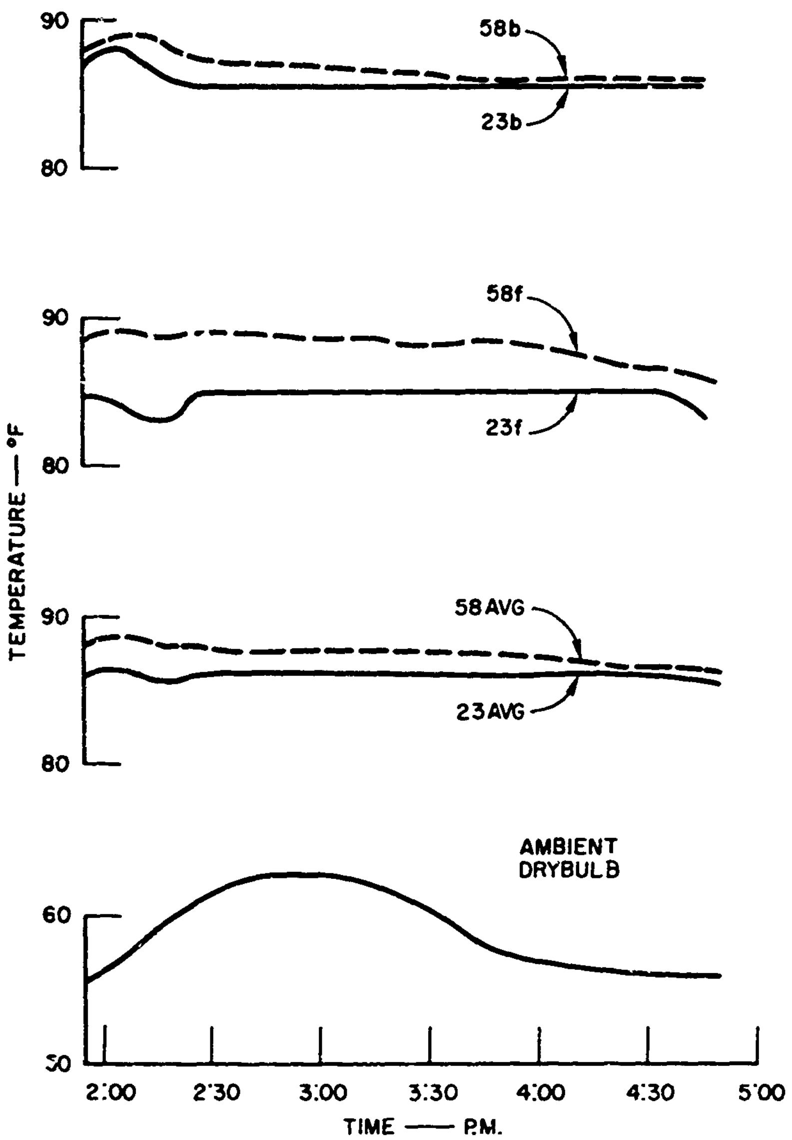
In both Tests 6 and 7, a large plywood separator sheet was placed in the doorway, separating the bottom portion from the upper portion where the pumping punkah was in operation (Fig. I-13).

During the test, baffles made up of sheet plastic mounted on a frame were placed in various positions to act as air deflectors. These had very little effect in changing the temperature distribution. Such baffles cannot channel the air as can enclosed ducting.

Test 8:

During this test, the ambient dry-bulb temperature was high, relative to the temperature during other tests. Ambient temperature at the beginning of the test was 60°F, rising to 64°F by the end of the test. Since air was delivered at the same rate as in all former tests, the temperatures of rooms B and A were held almost constant, dropping less than 1 degree. Observation of the results of Test 11(a) show that a similar ventilating air temperature (ambient temperature) prevailed. Under a no-ventilation condition during Test 11(a), the temperature in the rooms rose to 93°F. In Test 8, the temperature in both rooms was held to 89°F as a result of the ventilation.

At 11:00 A.M., a velocity reading was taken at various portions of the open doorway when only the mixing punkah was operating in room B. The punkah was removed from the doorway. Velocity measurements showed that some air entered room A at the bottom of the doorway and exited at the top. Over a very narrow section at the very top and bottom of the doorway, the velocity was recorded in the region of 50 ft/min. In the center portion there was little movement, and readings of approximately 10 ft/min were recorded. The average velocity was estimated to be 25 ft/min, indicating that the flow through one-half the door area was on



2:03 FAN ON
2:25 START PUNKAH
3:00 PUNKAH AT STAT 16 DISCONNECTED
3:40 DEFLECTORS ARRANGED DIAGONALLY ACROSS ROOM STATIONS #6 TO #33
4:10 ROOM B SMOKE TEST; NO SHORT CIRCUIT

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FIG. A-4 TEST 7 — TEMPERATURES AT STATIONS 58 AND 23
[Punkah arrangement shown in Fig. 9(h)]

the order of 200 ft^3/min. Since some short-circuiting occurs, the effective flow would be less. Therefore, the flow rate without the punkah is insufficient in this case, where the entry and exit temperature differential is small.

The velocity distribution across the inlet was not measured during punkah operation in the doorway, since some short-circuiting took place and the results would not be reliable. Velocity readings were recorded in Test 9, where the punkah was mounted at another part of the wall.

At 11:40 A.M., the air was drawn in through window W-4, and only the doorway punkah, mounted at the top and pumping outward, was put into operation. It was thought that the cooler air in the airstream directly from W-4 could be drawn into room A through the lower portion of the door. Temperatures measured at the 6-inch level at station 46 indicated stratification of cool air (77.5°F); however, only 4 feet away at station 45, a temperature of 85°F was recorded at the 6-inch level. This temperature difference was caused by the mixing of air, due to the punkah action. When side panels were installed (in addition to the horizontal separator), the temperature at the 6-inch level of station 45 dropped to 80°F, showing that without the side panels some of the exhaust air from room A moved out by the punkah (at the upper portion of the doorway) tended to short circuit around the horizontal separator to the lower half of the doorway. Smoke trace tests confirmed this. Even though the lower-level temperature at station 45 was relatively low, temperature readings taken at nine positions of the inlet area (bottom half of doorway) showed an average of 87.5°F, with only one position giving a low reading of 85.5°F. This result indicated that even though some air stratification existed, an increased motion of air, due to punkah action, caused air mixing so that the air temperature measured across the large entry area was almost uniform.

Test 9:

For the first two hours of Test 9, the primary ventilation rate (271 ft^3/min) was the same as for all former tests. The ambient temperature increased from 56°F to 62°F within this period. The average temperature at station 58 dropped from 87.7°F to 86.3°F. The average temperature of the inlet air to room A was 85.7°F, according to the reading taken at 10:55 A.M. The temperature differential between the inlet and outlet air of room A was 0.6°F. The top half of the doorway was boarded up so that the inlet air entered through the lower half. Velocity measurements were taken at the centers of nine equal-area segments, and the average was found to be 114 ft/min. For the 7.9 ft^2 opening, the flow rate was therefore 890 ft^3/min.

The 84.8°F temperature at station 23 was lower than that recorded on other tests when the ambient temperature was as high as 62°F. The reason is that the punkah in this test was no longer located in the doorway. On former tests, the doorway punkah helped mix the exhaust air from room A with that of room B.

Test results for the first two hours show that mounting the punkah in such a position that the inlet and exhaust areas were separated, produced no noticeable difference in ventilation of room A. The benefit of this arrangement would most likely be noticeable in a room larger than A.

From 11:00 A.M. on, the ventilation rate was increased to 336 ft^3/min, the maximum capacity of the exhauster at the fixed motor speed. Temperatures measured over the next two hours showed a rise due to a further increase of the ambient temperature. The temperature of room A followed that of room B very closely, indicating good pumping action of the punkah.

<u>Tests 10 and 11 (Fig. A-5)</u>:

Tests 10 and 11 were performed with the wall punkah mounted as in Test 9, and with the PVK operating in room B at station 46. The PVK was used for mixing the air in room B, and the air stream was directed diagonally toward station 1. Generally, these tests were similar to Tests 6 and 7, in which a punkah was used to stir the air in room B, but in this case mixing was more vigorous.

The test results show that the improved mixing of the inlet air by the PVK lowered the average temperature of room B slightly more than in the other tests. The inlet-air temperature average was comparable to that of Tests 6 and 7. The temperature change in room A was a good response to the room B temperature change, which was produced by the punkah operation. In Test 10, the temperature of room A averaged 84.3°F after approximately 2 hours. The average temperature of the inlet air to room A was 83.4°F at 10:23 A.M., indicating a 0.9°F differential between inlet and outlet temperature.

In Test 11a, operation of the ventilation fan and punkah was stopped so that the temperature rise within the test rooms--the result of the continued internal load and the rising ambient temperature--could be observed. In four hours, the ambient temperature rose from 60°F to 64°F; the interior temperature rose from 83°F to 93°F over the same period.

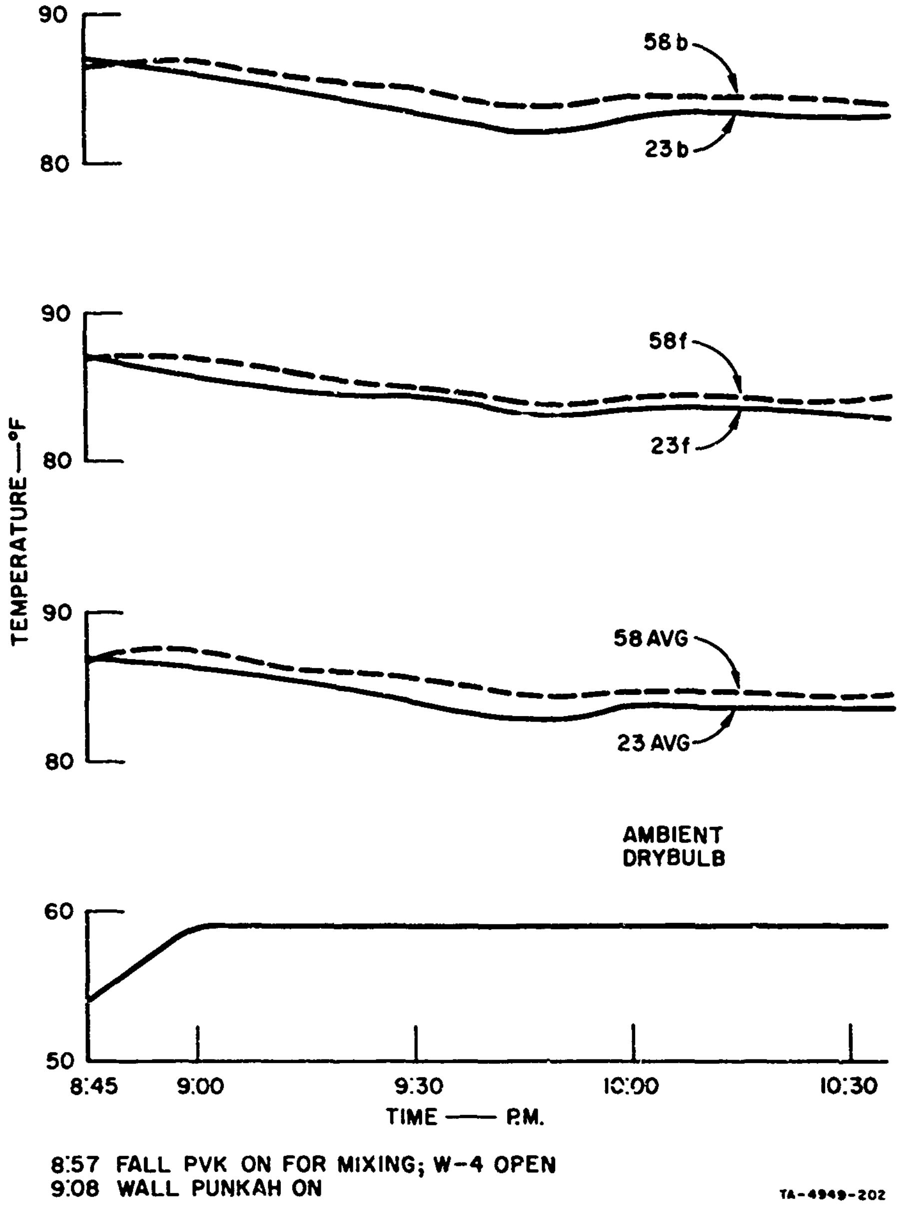

FIG. A-5 TEST 10 — TEMPERATURES AT STATIONS 58 AND 23
[Punkah arrangement shown in Fig. 9(1); window W-4 open]

Test 12 (Fig. A-6):

This test was similar to Tests 10 and 11. Two stirring punkahs were used in room B, and the pumping punkah on the wall betw. 'n rooms A and B was also in operation [see Fig. 9(m)]. One punkah was located over station 47 and the second over station 36. The day was overcast, and the ambient temperature remained constant from 10:30 A.M. through 1:30 P.M. The initial stabilization temperature was relatively high at 91°F. In three hours of operation, the temperature at station 23 had dropped to 82.6°F and the temperature at station 58 to 84.3°F. The results of Tests 10, 11, and 12 show that stirring the air quite vigorously at the ventilating air inlet lowered the average temperature of the room.

One explanation might be as follows: If the cool air is not mixed upon entering the room, it starts to cool the walls, ceiling, and floors in the vicinity of the inlet, and thus the potential of the ventilating air for cooling the room air is decreased. If the cool ventilating air is mixed as soon as it enters, then it is the immediate room air which first gives up heat to the cooling air. The ventilating air, now slightly warmer, absorbs less heat from the surfaces in the immediate area of the inlet, and thus more heat can be removed from the shelter air.

The above was apparent in Test 10, when the temperature at station 49 was measured. The temperature was very cool at this station, which was located in a direct line with the ventilating air flow. Thus, much of the ventilating air was used to cool the surfaces of rooms D and E.

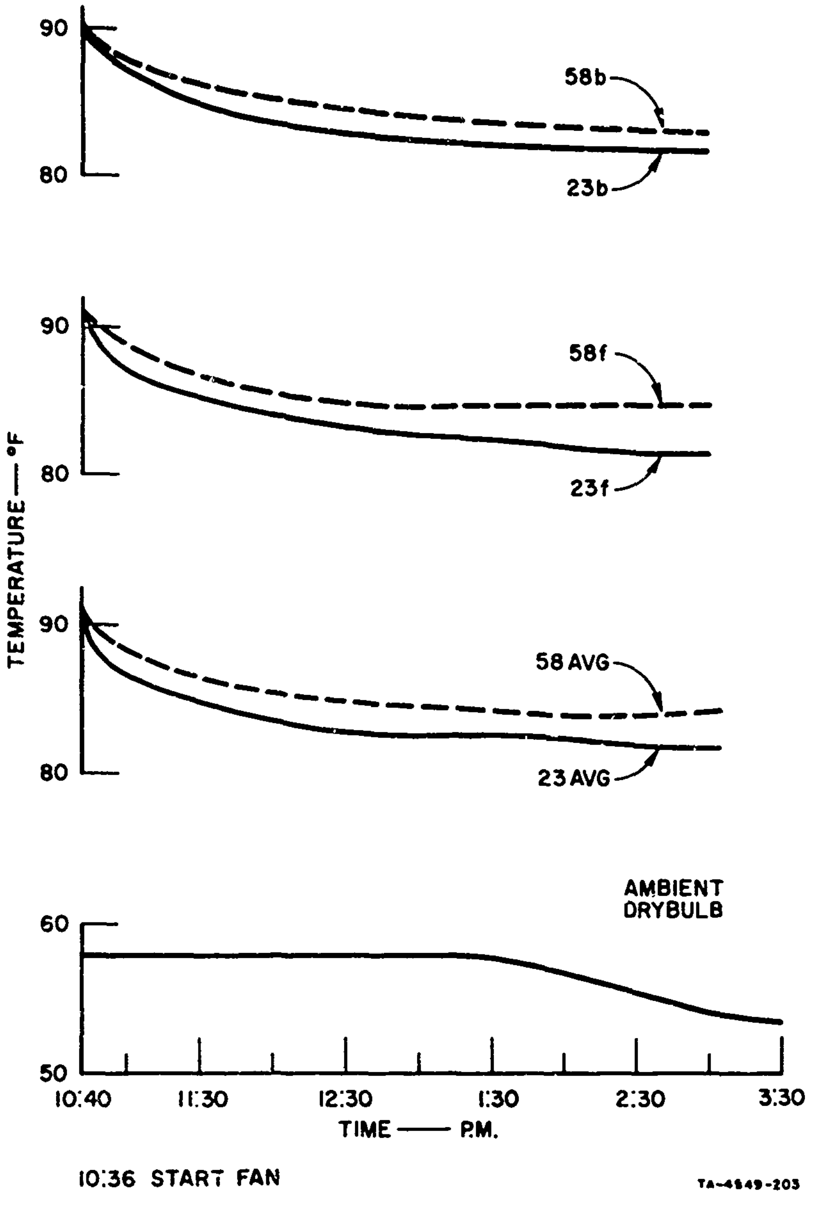

FIG. A-6 TEST 12 — TEMPERATURES AT STATIONS 58 AND 23
[Punkah arrangement shown in Fig. 9(m); window W-4 open]

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13 ABSTRACT

The specific objective of the work project was to evaluate the use of a punkah to distribute air within a fallout shelter and to determine its flow characteristics. The punkah is an oscillating panel, with a series of simple one-way valves, that can be hung from a ceiling or in an open doorway. In the experiments, the punkah was used not only to distribute air within a room, but also to move air from one room to another. Punkahs were tried in various parts of the rooms that comprised the experimental shelter, and various paneling configurations for improving the air delivery were investigated. Of special interest was the problem of ventilating a dead-end compartment, this being the most difficult type of room to ventilate because its only air inlet is a single inside doorway.

The internal heat load provided was all sensible heat. Dry-bulb temperature readings were taken at six room levels to evaluate the cooling effect of the punkah. The punkah was capable of ventilating a dead-end room and also of mixing the air within such a room sufficiently to maintain a climatic condition very near to that of the adjacent room.

Flow tests were made on the half-door sized punkah. For purposes of controlling flow and providing measurements of velocity and pressure, tests were performed using a ducted housing. Performance curves for the punkah operating in four different modes were developed.

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