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CONSULTING ENGINEERS

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FINAL REPORT

VENTILATION TESTS OF FALLOUT SHELTER SPACES

IN NEW YORK CITY AND VICINITY

Work Unit 1214B

February 1966

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FOREWORD

In order to determine and evaluate the physical environmental capabilities of typical shelter spaces in the various climatic regions of the United States, a series of experimental studies has been undertaken for the Department of Defense, Office of Civil Defense. The major objectives of the overall effort were to:

(a) evaluate parameters determining the nature of resultant environment in identified shelters in existing buildings;[*]

(b) determine minimum equipment requirements for environmental control in accordance with appropriate criteria; and

(c) gather and correlate experimental data in support of current or modified computational methods or for direct use as empirical information.

A majority of the experimental studies have been performed by three contractors: The University of Florida; the MRD Division of General American Transportation Corporation; and Guy B. Panero Inc.

This report summarizes the portion of the effort undertaken by the Special Projects Staff of Guy B. Panero Inc. This consisted of a series of ventilation tests conducted at eight distinct shelter facilities during the winter of 1963-1964 and the summer of 1964. These facilities are located in New York City and

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[*]Or other space having shelter potential within the framework of the National Fallout Shelter Survey.

surrounding suburban areas. Separate Interim Reports have been prepared which contain detailed information on the various tests performed at each site.

The first seven shelters were tested under Contract No. OCD-PS-64-66, which started on November 1, 1963, and terminated on August 31, 1964. Mr. F. C. Allen, Office of Civil Defense, Directorate of Research, served as the project monitor for this effort.

The work started under Contract No. OCD-PS-64-66 was extended under Subcontract No. B-64212(4949A-3)-US with the Stanford Research Institute. Under this subcontract ventilation tests were performed at the eighth shelter site and Interim Reports were prepared and completed for all the eight shelter tests. The work effort under this subcontract was coordinated by Mr. C. A. Grubb of the Stanford Research Institute.

GUY B. PANERO INC.

February 1966

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Current records indicate that approximately 130 million shelter spaces have been identified providing a protection factor of 40 or more and having a ventilation capacity of three cubic feet per minute of fresh air per shelter space, or comprising 500 cubic feet of shelter volume without ventilation. In addition, about 33 million additional spaces could be added to the inventory by providing fresh air circulation (Ref. 1).

Furnishing sufficient ventilation to control the chemical quality of the air within the shelter area is a fundamental habitability requirement. Although present N.F.S.S. criteria satisfied this need, it may not meet a minimum habitability requirement in terms of temperature and humidity. The O.C.D. environmental testing program is directed, to a large extent, toward the investigation of this aspect of shelter performance.

In November, 1963 (the start of our testing program) the study of the thermal behavior of shelter areas within the cores of high-rise buildings seemed appropriate in filling the "gap" in the existing program initiated by other testing groups under contract to the Office of Civil Defense. New York City accounts for a large portion of such identified shelter space. The N.F.S.S. statistics list 24,400,000 spaces (Ref. 2) in New York City, of which an estimated 80 per cent[*] are above ground. This percentage is somewhat higher than the national average of about 66 per cent because of the large number of high-rise structures in New York.

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[*]This estimate came from the New York City Civil Defense Office.

Therefore, from a cost-effectiveness viewpoint, it seemed desirable to concentrate our effort on testing shelter areas within high-rise buildings. Among the objectives of this part of the program were the following:

(a) to determine the confidence level, for normal occupancy with natural ventilation, at which the inside effective temperature would remain at 85°F or below during the summer months;

(b) to determine supplementary ventilation or cooling required for increased confidence (higher percentile levels); and

(c) to recommend procedures for optimizing natural (draft) air flow through the shelter area.

In commercial-type high-rise buildings the approximate ratio of core area to rentable floor area is about 1:10 and the normal occupancy density is about 100 square feet per person. One would expect, therefore, that the core area shelter could be occupied at the rate of one person per 10 square feet. In public housing high-rise structures, apartment occupancy regulations are such that the density in the core areas (hallways) would also not be less than one person per 10 square feet.

Within the rather limited summer period of 1964, three high-rise buildings were selected for testing:

(a) The 40 Wall Street Building-- a 70-story, commercial-type buildi y located in the financial district in downtown Manhattan. The 17th floor core area was tested from May 25 to June 12, 1964.

(b) Building No. 7 of the John Adams Houses, New York City
Housing Authority--a 21-story apartment building located
in the Bronx Borough of New York City. The central corridor
area of the 18th floor was tested from June 21 to June 26,
1964.

(c) The AMA (American Management Association) Building--a
23-story commercial-type structure located in midtown
Manhattan. The core area on the 13th floor was tested from
August 12 to August 28, 1964.

In addition to the above tests, two New York City Public Schools,
P.S. 21 and P.S. 115, were tested during the 1964 summer vacation period.
These schools are part of the 880 schools which comprise the New York
City Public School system.

(a) Public School 115--a 1300-pupil elementary school located in
the Bronx Borough of New York City. A sub-grade cafeteria
area and part of the second floor corridor area were tested
between July 6 and July 14, 1964.

(b) Public School 21--a 1100-pupil elementary school, also located
in the Bronx Borough of New York City. A basement area and
part of the third floor corridor area were tested during
July 17 and August 1, 1964.

Since many single-family homes have a significant amount of fall-
out radiation protection, especially in the underground basement areas,
a series of tests was conducted in the basement area of a suburban
house in Westchester County, New York, from September 9 through
September 24, 1964. An OCD pilot test survey of private homes is

presently in progress and monies have been included in the FY 1966 OCD budget requests for a full-scale survey effort in this direction (Ref. 3).

Two underground shelters were also included in our testing program:

(a) The New Canaan shelter, a high-grade privately owned suburban underground shelter with 328 square feet of floor area.

(b) The Vincentown shelter, a communal underground shelter with 1200 square feet of floor area, built and owned by a group of rural families.

Winter tests on the New Canaan shelter, a shelter with an efficient heat sink, were performed to investigate the lower range of the shelter's physical environment spectrum.

Summer tests were performed on the Vincentown shelter to ascertain the performance of a community shelter designed and built (during the Berlin Crisis of 1961) by a group of rural families. The construction work was done in six days at a total cash outlay of about $2300.

A number of inexpensive ventilation and heat dissipation devices were built by the Test Group, based on the designs and the work of Mr. Cresson Kearny, Senior Test Supervisor (now with Oak Ridge National Laboratories), in order to test their effect on improving shelter habitability. These included directional punkahs, manual valve-type air pumps, manual air pump and cooling coil mechanisms and a water-cooled heat exchanger.

2. TESTING PROGRAM

2.1 General

This section contains a synopsis of the various series of tests conducted at eight distinct shelter sites. Details of the work accomplished at each test site can be found in the individual Interim Reports as listed in Ref. 4 through Ref. 11.

Under the observations section of each test site summary, the estimated shelter performance for various occupancy loads has been related to outside air percentile summer design level conditions. These percentile summer design level conditions represent the combinations of wet and dry bulb temperatures, calculated independently, which would be exceeded for the respective per cent of the hours (2928) in the four summer months of June through September. For example, in a normal summer there should be 150 hours when the dry bulb temperature exceeds the 5 percentile dry bulb level, and 150 hours (not necessarily the same hours) when the wet bulb temperature exceeds the same percentile wet bulb level. Summer design level temperatures at the 1 percentile, $2\frac{1}{2}$ percentile, and 5 percentile levels are available from Ref. 12, Chap. 26. Wet bulb temperatures at the 10, 15 and 25 percentile levels can be found in Ref. 13 and the corresponding dry bulb temperatures may be estimated by extrapolation.

For the New York City, Upper Westchester County, and Vincentown, New Jersey areas, these percentile levels represent the following outside air conditions:

Outside Air Percentile Summer Design Level	Outside Air Temperatures (°F)		
	New York City	Upper Westchester County	Vincentown, N.J.
1 %	93 DB--77 WB	92½ DB--78 WB	94 DB--79 WB
2½ %	90 DB--76 WB	89 DB--77 WB	91 DB--78 WB
5 %	87 DB--75 WB	86½ DB--75 WB	89 DB--76 WB
10 %	83 DB--73 WB	82½ DB--73 WB	86 DB--75 WB
15 %	80 DB--72 WB	80 DB--72 WB	83 DB--74 WB
25 %	78 DB--70 WB	78 DB-- 70 WB	79 DB--72 WB

The preconditioned air used in forced ventilation tests in the P.S. 115 and P.S. 21 basement shelter areas was representative of a typical 10 percentile design level day in New York City. This 24-hour temperature cycle information (used to cut the cam in the pneumatic dry bulb controller in Test Vehicle No. 3) was obtained by ascertaining for each of the 24 hours in the day--that temperature which was equalled or exceeded for 10 per cent of the applicable hours from June through September from 1954 to 1963. Thus the controlled air supply represented a typical daily cycle of outside air temperatures to be anticipated for 10 per cent of the 122 summer days or about 12 days during an average year in New York City. Graphical plots of the 10 percentile daily cycle, as well as those for a typical 5 percentile and 1 percentile daily cycle, are included in Appendix D.

2.2 ABOVE-GROUND (HIGH-RISE) - BLDG. NO. 7, JOHN ADAMS HOUSES, NEW YORK CITY

2.2.1 Introduction

During the period between June 21 and June 26, 1964, natural venti-
lation tests and calibration tests of heat dissipation through boundary
surfaces were performed in an existing shelter area on the 18th floor of a
21-story apartment building (Bldg. No. 7, John Adams Houses), located in
Bronx County, New York (Ref. 4).

Aggregate simulated-occupant machines were used in the shelter area,
and the flow of outside air through this area was induced by opening win-
dows and/or stairwell doors.

The primary objects of the tests were:

> to ascertain the effect of natural ventilation (under varying
> outside air conditions) on the physical environment in the
> shelter;
>
> to ascertain the effect of solar radiation and heat transfer
> to or from the surrounding area on the shelter effective
> temperature; and further
>
> to obtain sufficient data to predict physical environmental
> conditions in the shelter at other occupancy levels and out-
> side weather conditions.

Due to the restrictions imposed on the length of the Test Group's
occupancy of the site, it was not possible to elongate the natural ven-
tilation tests, or to perform mechanical ventilation or "button-up"
tests.

2.2.2 Description

(a) Site

Building No. 7 is a 21-story apartment house located within the
John Adams Houses complex, a New York City Housing Authority project in
Bronx County (see Fig. No. 1). Construction was completed in 1964. The

JOHN ADAMS HOUSES

APARTMENT "G" OPEN WINDOWS

APARTMENT "C" OPEN WINDOWS

RECORDER ROOM

SHELTER AREA

SCALE 0 5 10 15 FEET
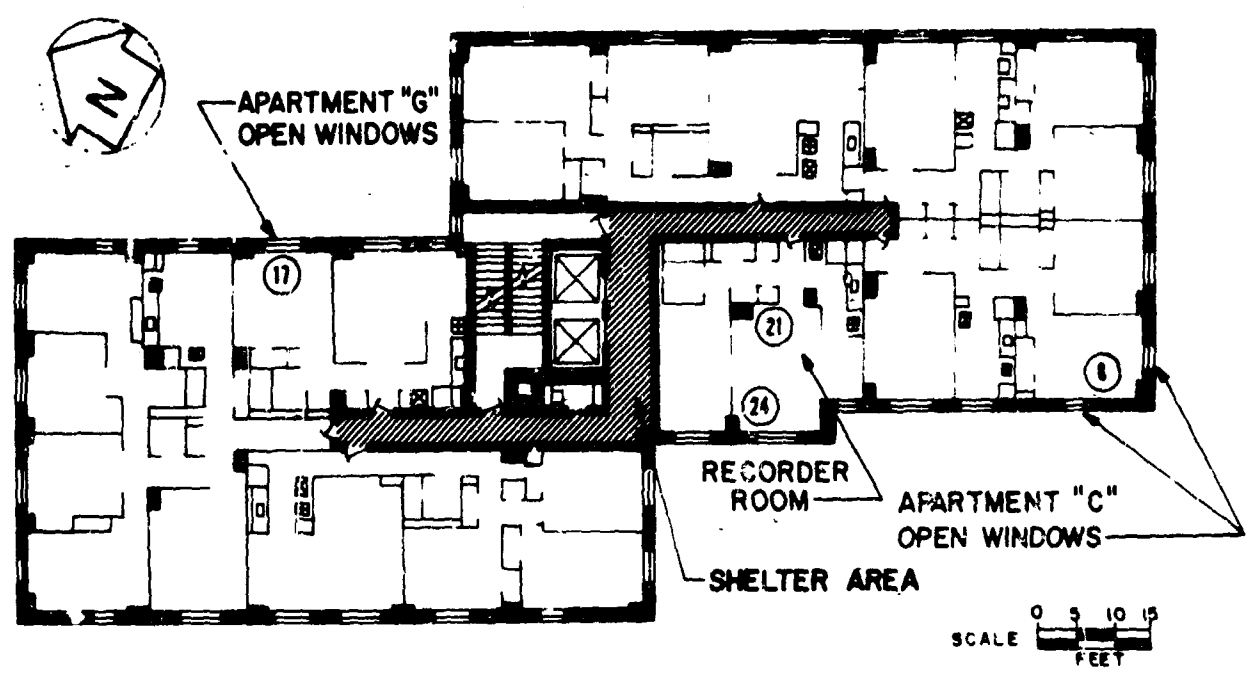
BUILDING #7 – 18TH FLOOR PLAN

EAST 156TH STREET

WESTCHESTER AVENUE

TINTON AVENUE

UNION AVENUE

EAST 152ND STREET

BUILDING #7

SCALE 0 100 200 FEET
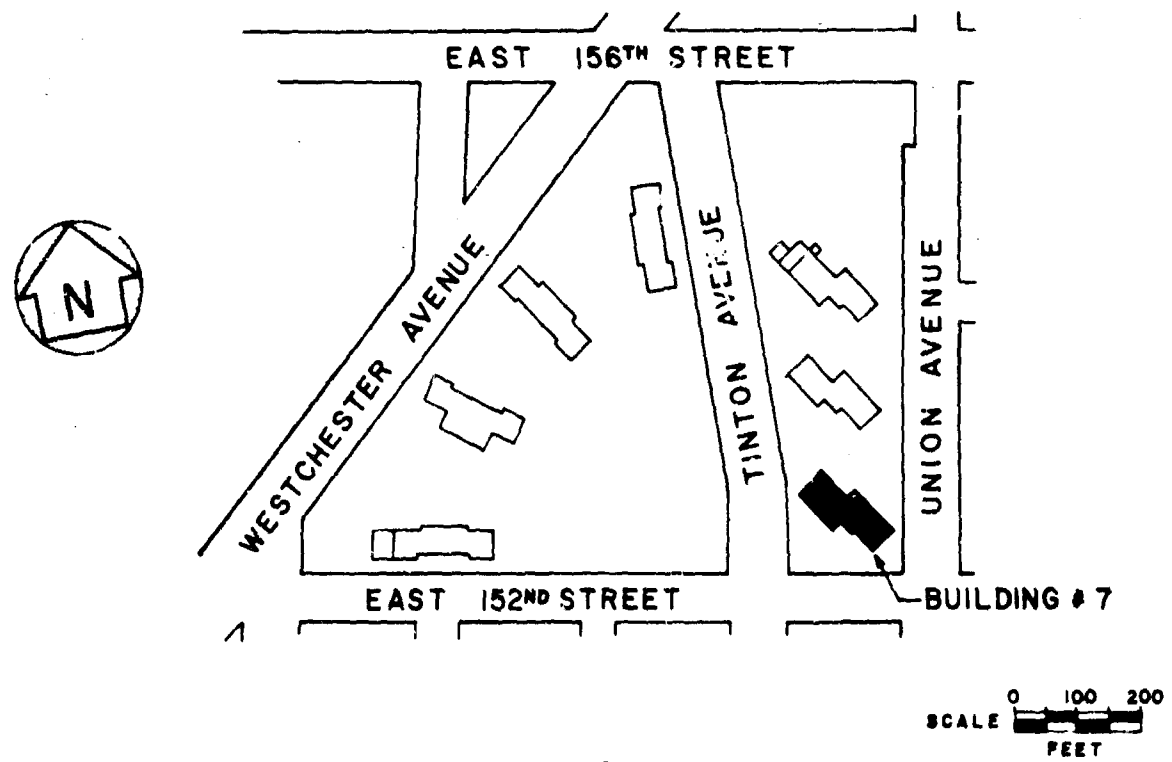
SITE PLAN

FIG. NO. 1

housing project is located on relatively open land, and the buildings rise high above the four- to six-story structures which surround them.

The shelter area is located in the public hallway of the 18th floor. Floor area is 400 sq. ft. and the ceiling height is 8'-0"; the protection factor category is 5.

(b) Equipment and Instrumentation

Shelter occupancy was simulated by two valve-type aggregate Simocs (see Fig. No. 2). A small electric pump was used to maintain water pressure at the Simocs and the quantity of water atomized within the shelter was measured by weighing the amount of water removed from a supply tank. Power input to each Simoc was checked hourly by measuring voltage and current with a voltmeter and a snap-on ammeter.

One 24-channel multipoint recorder was used to obtain hourly wet and dry bulb temperatures in the shelter area as well as the surrounding rooms. Outside air conditions were obtained with a portable psychrometer and windscope mounted on the roof, while a rotating-vane mechanical anemometer was used to measure air velocities in the shelter area and at the open windows.

(c) Test Performed

Because of time limitations imposed on the test site occupancy, it was decided to carry out only two natural ventilation tests-- crosswind and updraft--at this site. Each test was continued for 48 hours. Following these tests, a shelter calibration test was performed to ascertain the sensible heat transfer coefficient "U" for the shelter area.

The Calibration Test was carried out with two Simocs, each set at 11,600 BTU/hr. All doors and windows were closed and sealed. The test
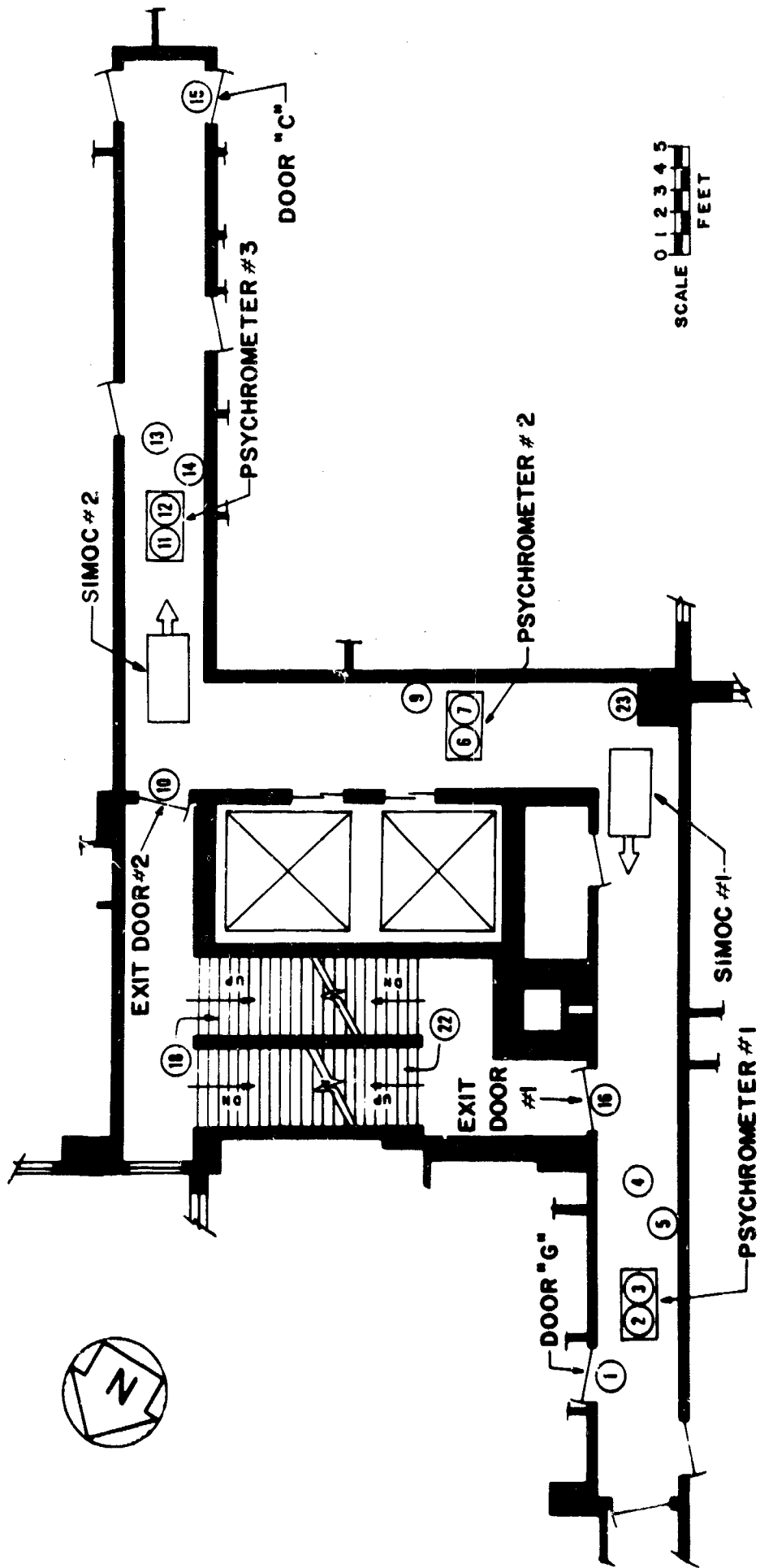
SHELTER PLAN
EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 2

was continued for 24 hours, in the last four hours of which the temperature difference between the outside air and the average shelter dry bulb temperature remained constant.

The first <u>Natural Ventilation Test</u> (Test A) was a crosswind test. Doors and two windows in each of Apartments "C" and "G" were opened so that air would sweep through the corridor shelter. All other doors and windows remained closed. The Simocs were set for a total occupancy of 60 people (150 per cent rated occupancy). In Test B, the second <u>Natural Ventilation Test</u> (updraft ventilation), Exit Door No. 1 was opened in addition, so that the air exited via the stairwell to the building roof. Simulated occupancy remained the same as in Test A.

2.2.3 <u>Observations</u>

1. In the crosswind ventilation test (Test A) the effective temperature (ET) in the shelter area increased during the night when the wind velocity (and consequently the air flow through the shelter) was at its lowest. This rise in ET occurred even though the outside air wet and dry bulb temperatures decreased. During the updraft test (Test B), the shelter ET was less dependent on the outside wind velocity than in Test A. The air flow caused by temperature differences, or "stack" effect, appeared to have the more significant effect on the shelter ET, particularly when wind velocities fell below 5 mph.

2. The average ceiling dry bulb temperature was approximately 3°F higher than at the breathing level. This is the equivalent of 1°F ET.

3. The value of "U" from the Calibration Test equalled 0.27. This was approximately that obtained by calculations from the ASHRAE Guide and Data Book.

4. This shelter should be considered as adiabatic, during the summer months, for purposes of calculating heat dissipation rates.

5. With an occupancy rate of 8.3 sq.ft. floor area per person, an effective temperature of $85^{o}F$ should not be exceeded in the shelter with a New York City 5 percentile outside air design level--except during periods of unusually calm wind conditions. This occupancy rate would permit the total building tenant population to be accommodated in the shelter spaces on the 4th to 19th floors, inclusive.

6. Forced ventilation is not considered a necessity in this building, as the occasions when outside air conditions would cause the shelter ET to rise above $85^{o}F$ are normally expected to prevail for only limited periods.

7. The most effective method of inducing natural ventilation in this type of building is to use crosswind ventilation on all floors that contain shelter areas, augmented by updraft ventilation on the lower floors.

8. The windows selected as air intakes should be those which face the summer prevailing wind direction (S to SW in New York City). Outlet windows should be located to allow the ventilating air to sweep through as much of the shelter area as possible.

9. In apartment buildings of this type, positive ventilation is normally provided by exhaust fans removing air from the toilets and public corridors (Ref. 15, Sec. 11). These systems could be easily modified in an emergency so that all positive ventilation passed through the shelter area. Then if electric power were available for the fans, approximately 900 cfm of outside air would be drawn

through each shelter area to assist ventilation during periods
of temporary calm winds during hot weather.

2.3 ABOVE-GROUND (HIGH-RISE) 40 WALL STREET BUILDING, NEW YORK CITY

2.3.1 Introduction

During the period between May 25 and June 12, 1964, natural venti-
lation tests and sensible heat dissipation rate tests were performed in
a shelter area located on the 17th floor of this 70-story office building
located in the lower Manhattan section of New York City (Ref. 5).

The primary objects of these tests were to study the ventilation
rates and physical environment obtainable in an occupied shelter, using
various modes of natural ventilation and under varying outside air con-
ditions; and further to determine the effect on shelter effective tem-
peratur ; of sensible heat transfer through shelter boundary surfaces.

Modes of natural ventilation studied included cross ventilation,
updraft ventilation and zero ventilation under closed shelter conditions.
Shelter occupancy was simulated using aggregate Simocs, and the flow of
outside air through the shelter was induced using combinations of open
windows and doors.

2.3.2 Description

(a) Site

The 40 Wall Street Building is a 70-story office building completed
in 1930. Construction is of brick and terra cotta over a structural steel
skeleton with 14-in. thick exterior walls.

The shelter proper is located in the central core of the 17th floor
(see Fig. No. 3). It consists of a central corridor 9 ft. wide and 112 ft.
long, to which are adjoined smaller passageways. The floor area com-
prises 1730 square feet and ceiling height varies between 8 ft. and $8\frac{1}{2}$ ft.,
giving as total shelter volume approximately 14,700 cu. ft. Interior
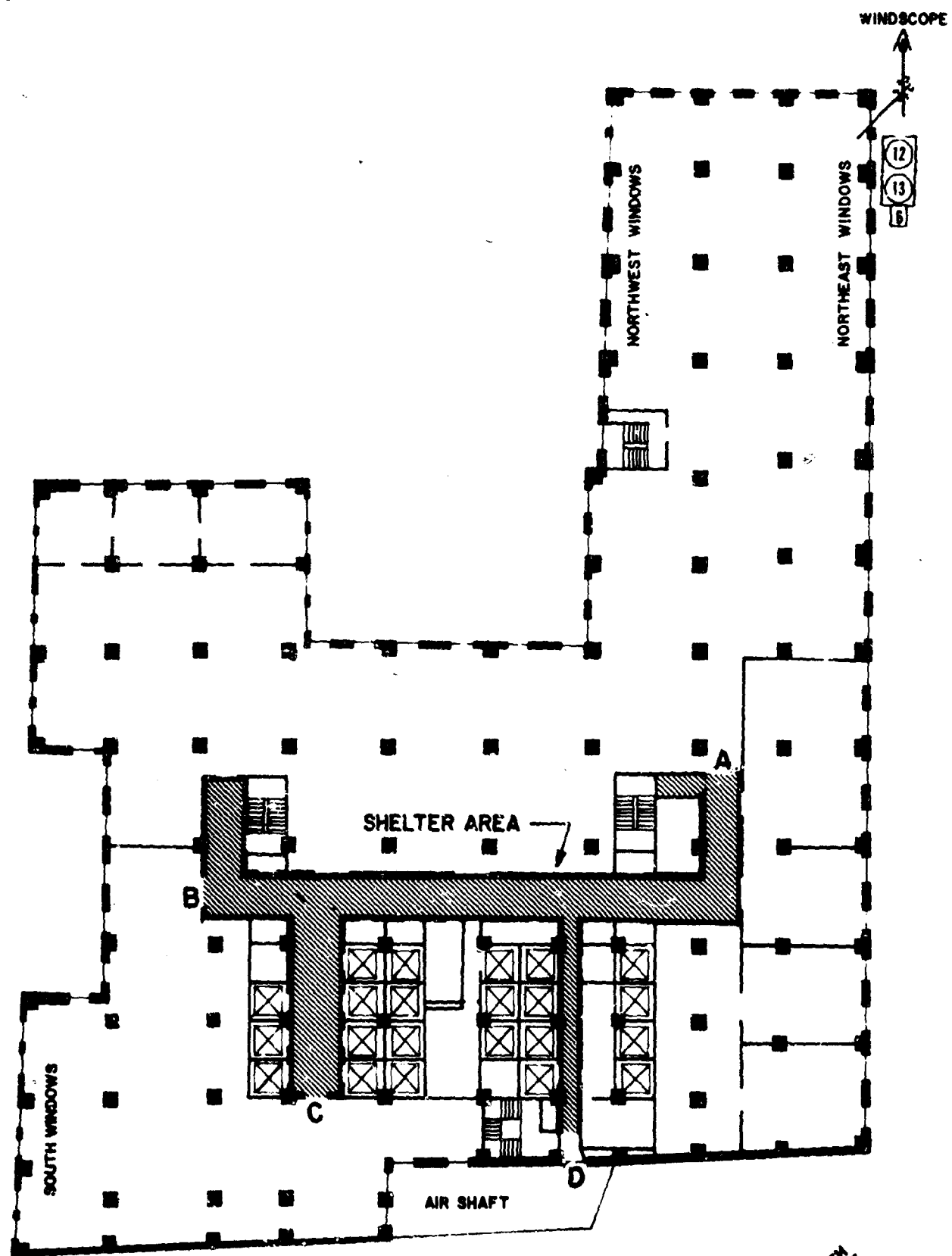
SEVENTEENTH FLOOR PLAN
FORTY WALL STREET BUILDING

FIG. NO. 3

partitions surrounding the designated shelter area are $4\frac{1}{2}$ in. thick, constructed of gypsum block with plaster facing. The floor slab is 9-in. reinforced concrete covered with 1/8-in. vinyl tile; the ceiling is composed of fiberboard acoustical tiles suspended from a 9-in. concrete slab.

The shelter area was identified in the National Fallout Shelter Survey (Phase 2) and assigned to protection factor category 4.

In the cross ventilation tests combinations of the double-hung 4 ft. by 5 ft. windows and the 3 ft. by 7 ft. doors into the shelter were opened to allow air to sweep through the shelter. The updraft tests used in addition the 15 ft. by 40 ft. airshaft to create a low resistance stack.

(b) Equipment and Instrumentation

In performing these tests shelter occupancy was simulated, using valve-type aggregate Simocs. A small electric pump was used to maintain water pressure at the Simocs, and the quantity of water atomized within the shelter was measured by weighing the amount of water removed from a supply tank. Total Simoc power consumption was measured using a kilowatt hour meter, and power input to each Simoc was checked by measuring voltage and current with a voltmeter and a snap-on ammeter.

Six motor ventilated psychrometers were installed in the shelter, as shown on Fig. No. 4. Their dry bulb and wet bulb temperatures, along with ten additional dry bulb temperatures, were measured using copper-constantan thermocouples and a Honeywell 24-point recording potentiometer.

Outside wind direction and velocity were monitored by a Taylor Windscope secured to a 10-ft. boom extending from the north corner of the 17th floor. Air velocities in the shelter were measured by a hand-held rotating vane mechanical anemometer.

SHELTER PLAN

EQUIPMENT AND
INSTRUMENTATION LAYOUT

LEGEND

SIMOC

PSYCHROMETER

THERMOCOUPLE

NORTH

FEET

DOOR A

DOOR B

DOOR C

DOOR D
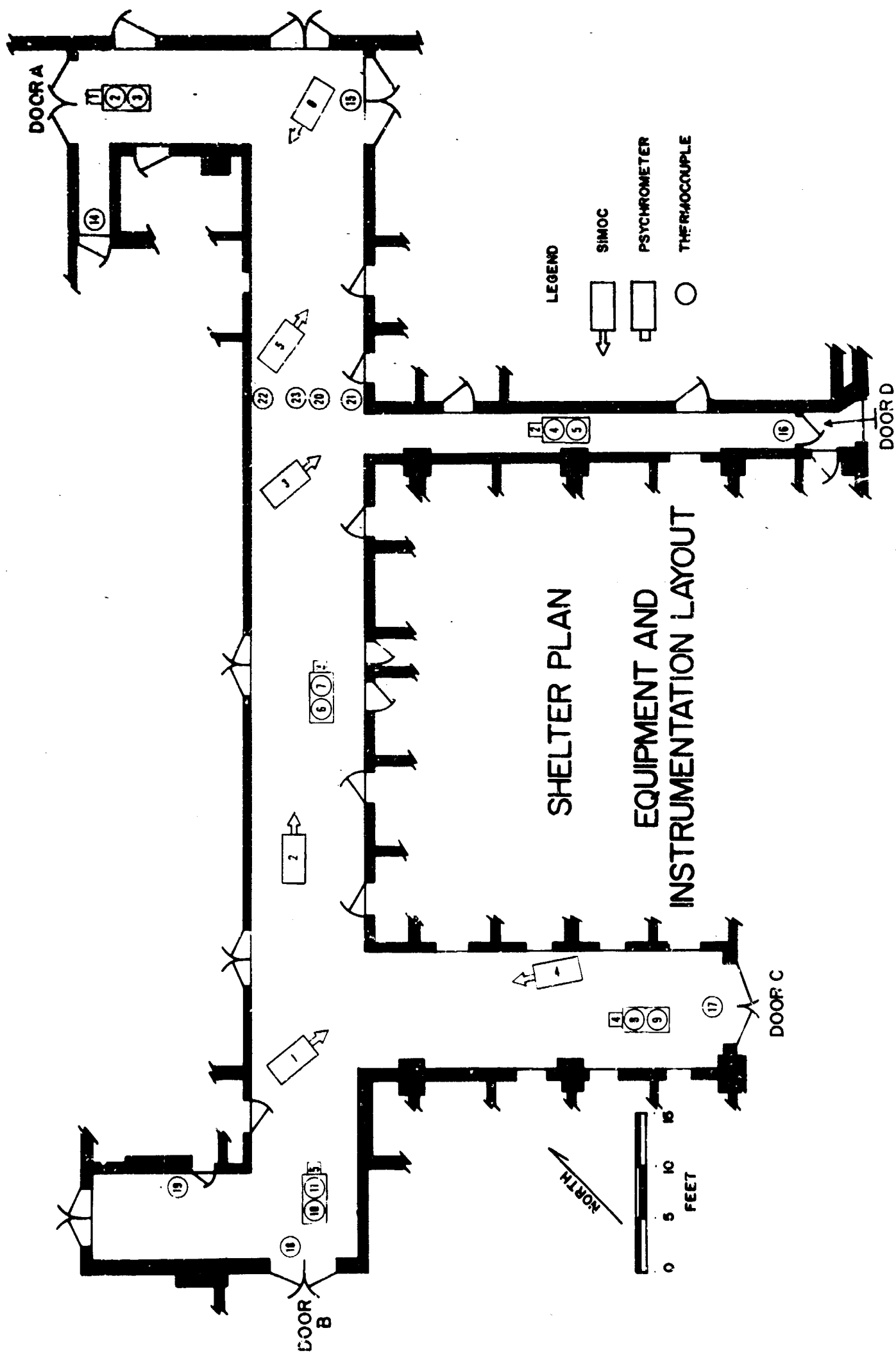
(c) Tests Performed

A list of the ventilation tests performed in this shelter is given below:

Test No.	Duration From	To	No. of Occupants	Ventilation Mode	Openings to Shelter
1	0800 5/25	-2200 5/25	180	Closed shelter	None
2	2300 5/25	-2200 5/27	180	Cross ventilation	2 windows NE 2 windows S 1/2 doors A-B
3	2300 5/27	-2200 5/29	180	Cross ventilation	6 windows NE 6 windows S Doors A-B
4	1300 6/1	--2000 6/3	180	Updraft ventilation	6 windows S Doors B-C-D
5	2100 6/3	--2000 6/5	180	Cross ventilation plus updraft	6 windows NE 6 windows S Doors A-B-C-D
6	1000 6/10	-1000 6/11	300	Cross ventilation plus updraft	6 windows NE 6 windows S Doors A-B-C-D
7	1100 6/11	-1100 6/12	300	Cross ventilation plus updraft	6 windows NW 6 windows S Doors A-B-C-D

In addition, a heat transmission test was conducted to determine the sensible heat transfer coefficient "U" for the shelter.

2.3.3 Observations

1. The closed shelter test demonstrated that it would be impossible to keep shelter openings closed for more than a few hours during summer conditions if the shelter is loaded to rated capacity. The shelter effective temperature (ET) climbed rapidly and stood above $85^{\circ}F$ at the end of three hours, stabilizing at $87^{\circ}F$ to $88^{\circ}F$.

2. In the two cross ventilation tests air flow averaging about 1500 cfm was established, about 8.3 cfm per occupant. No significant difference was noted in the ventilation rate between Tests 2 and 3; although the opening area in Test 3 was approximately double that in Test 2.

3. During the cross ventilation tests the ventilation remained quite constant, even during periods when the wind velocity was low. This fact indicates that sudden rises in shelter ET due to the wind falling off for short periods should not be a serious problem in this shelter.

4. A definite stagnant area was established in the hallway containing psychrometer No. 2 in those tests where Door D was closed. The ET here was some $7^{o}F$ to $8^{o}F$ higher than the average for the shelter.

5. When cross ventilation was combined with updraft, considerably higher ventilation rates--up to 6000 cfm--were obtained. However other heat producing equipment located at the base of the airshaft makes it impossible to determine what portion of the updraft was produced by the elevated temperatures in the shelter.

6. The heat transfer test indicates an average coefficient of heat transfer of 0.21 BTU/(hr)(sq.ft.)(^{o}F); the theoretical value determined by using building material design heat transmission coefficients is 0.24 BTU/(hr)(sq.ft.)(^{o}F).

7. Because of this low coefficient of heat transfer, duri. .m weather only a small fraction of the total heat input will be dissipated through shelter boundary surfaces; therefore this shelter should be considered as adiabatic during the summer months, for purposes of calculating heat dissipation rates.

8. With an occupancy rate of one person per 10 square feet of floor area, the shelter ET will not exceed 85°F using natural ventilation alone unless the outside air temperature rises above the 15 percentile summer design level or during unusually calm wind conditions. This level is attained for approximately 450 hours, or about 5 per cent of a normal year.

9. At the 5 percentile summer design level, the shelter effective temperature will not exceed 85°F, using natural ventilation alone, if the occupancy rate is reduced to one person per 16 square feet of floor area.

10. Assuming an occupancy load at or below one person per 10 square feet of floor area, mechanical ventilation equipment is not considered to be necessary for this shelter; the occasions when natural ventilation would result in uncomfortably high shelter effective temperatures are expected to prevail for only short periods.

2.4   ABOVE-GROUND (HIGH-RISE) AMA BUILDING, NEW YORK CITY

2.4.1   Introduction

From August 12 to August 28, 1964, natural ventilation tests and sensible heat transmission tests were performed in a shelter area located on the 13th floor of this 23-story office building located in the midtown section of New York City (Ref. 6).

The primary objects of these tests were to study the air flow rates and physical environment obtainable in an occupied shelter, using various modes of natural ventilation and varying outside air conditions; and further to ascertain the effect on shelter effective temperatures (ET) of sensible heat transfer through shelter boundary surfaces.

Modes of natural ventilation studied included cross ventilation, updraft ventilation, and air exchange between the core and surrounding office areas. Shelter occupancy was simulated using aggregate Simocs, and the flow of outside air through the shelter was induced using combinations of open windows and doors into the stairwell and into the shelter.

2.4.2   Description

(a)   Site

The American Management Association Building is a 23-floor structure located in midtown Manhattan. This building, completed in 1963, is of glass curtain wall construction with single-thickness, untinted glass accounting for approximately 65 per cent of the exterior wall area.

The tested shelter area is located in the central core of the 13th floor (see Fig. No. 5). Floor area comprises 1622 square feet and ceiling height is 9 ft.-6 in., giving as the total shelter volume 15,410 cu. ft.

AMERICAN MANAGEMENT ASSOCIATION BUILDING

13TH FLOOR PLAN

OUTSIDE PSYCHROMETER

6 NORTH WINDOWS

6 SOUTH WINDOWS

DOOR "A"

DOOR "B"

DOOR "C"

SHELTER AREA

SCALE 0 5 10 FEET

N
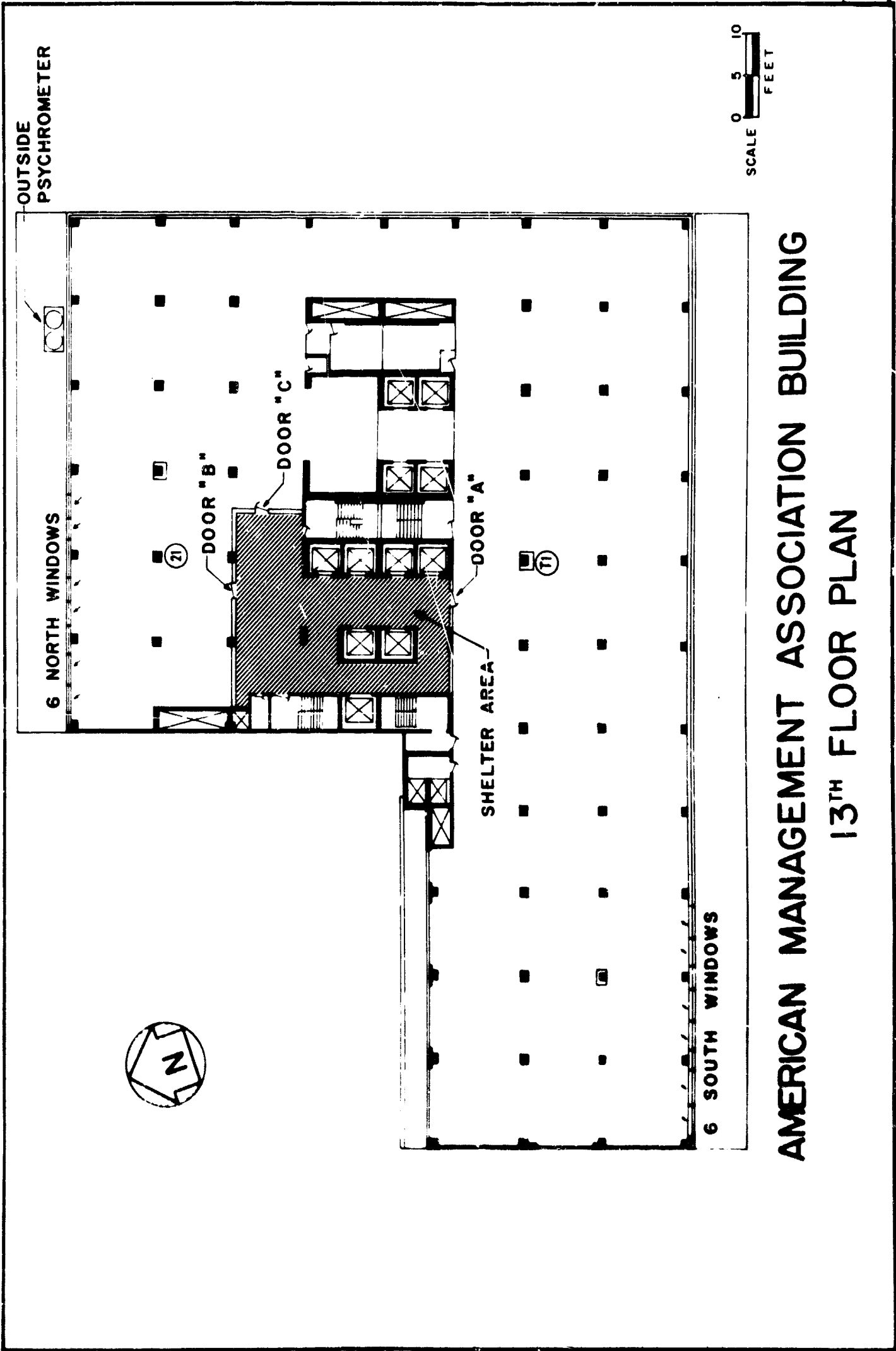
FIG. NO. 5

Walls adjacent to elevators and stairwells are 4 in. thick and con-
structed of hollow tile and plaster, while partition walls are composed
of two thicknesses of 3/4-in. gypsum board separated by a 3-1/2-in. air
space. Floor and ceiling are 5-1/2-in. reinforced concrete slabs, un-
finished on both floor and ceiling.

Since this building was only recently completed, it has not been
included in the National Fallout Shelter Survey. A preliminary estimate
gave a protection factor of 100 for the shelter area.

Natural ventilation of the shelter can be accomplished using either
cross currents of air through the shelter or thermal updraft through the
stairwells. On the 13th floor there are 74 projected steel sash, non-
weatherstripped windows, each 11.25 square feet, which can be opened.
In addition, the double stairwell on the east side of the shelter provides
a low-resistance stack which rises 100 ft. and exits through a hatch to
the roof or through two doors to the 23rd floor.

(b) Equipment and Instrumentation

Shelter occupancy was simulated using valve-type aggregate Simocs.
A small electric pump was used to maintain water pressure at the Simocs,
and the quantity of water atomized within the shelter was measured by
weighing the amount of water removed from a supply tank. Total Simoc
power consumption was measured using a kilowatt hour meter, and power
input to each Simoc was checked by measuring voltage and current with a
voltmeter and a snap-on ammeter.

Four motor ventilated psychrometers were installed in the shelter
as shown on Fig. No. 6. Their dry bulb and wet bulb temperatures, along
with sixteen additional dry bulb temperatures, were measured using copper-
constantan thermocouples and a Honeywell 24-point recording potentiometer.

SHELTER PLAN

EQUIPMENT AND INSTRUMENTATION LAYOUT
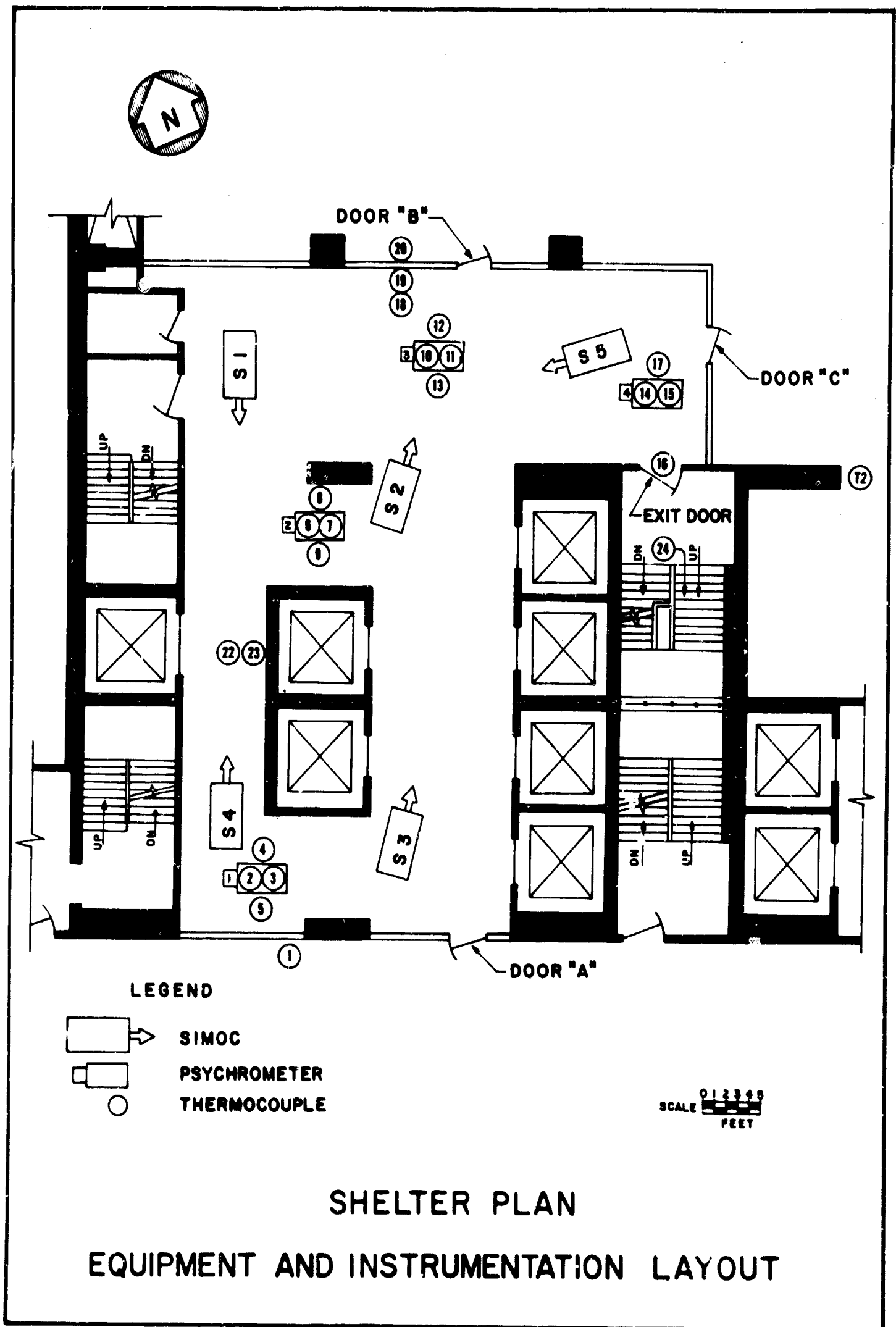
FIG. NO. 6

An additional psychrometer measuring outside air conditions was equipped with mercury-in-glass thermometers; thermometers were also used to measure T1 and T2.

(c) Tests Performed

The ventilation tests performed in this shelter are listed below:

Test No.	Duration From To	No. of Occupants	Ventilation Mode	Openings to Shelter
	August			
1	1900/18 - 1600/20	240	Cross Venti-lation	6 windows SW, 6 windows NW, Doors A-B
2	1700/20 - 1600/22	240	Updraft and Cross Venti-lation	6 windows SW, 6 windows NW, Doors A-B, Exit door, Hatch on 23rd floor
3	1800/23 - 2400/23	240	Air Exchange	Doors A-B
4	0100/24 - 0600/24	160	Air Exchange	Doors A-B
5	0700/24 - 2200/25	160	Air Exchange	Doors A-B-C

In the air exchange tests all outside windows were closed but doors from the shelter to the surrounding office space were left open. Temperature stratification in the shelter caused warmer air to flow out through the top of the doors and cooler air to flow in at the bottom, thus effecting an air exchange between the shelter and the surrounding building area.

In addition to the ventilation tests, a series of tests was conducted to determine the coefficient of sensible heat transfer for the shelter.

2.4.3 Observations

1. The cross ventilation test produced a good correlation between ventilation rate and wind velocity. Ventilation averaged about 1200 cfm, or about 5 cfm per person for the 240 simulated occupants.

2. During the updraft test ventilation was somewhat greater, averaging about 2000 cfm. As expected, the ventilation rate was greatest

during the night when the temperature difference between the shelter and the outside air was greatest; it approached the cross ventilation rate during the day when the outside temperatures were higher.

3. In the air exchange tests the expected air flow was established. Ventilation rate through the open doors ran between 1000 and 1500 cfm.

4. No stagnant spots were observed during any of the tests. Floor to ceiling dry bulb temperature gradient averaged $5^{O}F$ or less.

5. In the heat transmission test the coefficient of heat transfer, U, was determined to be 0.31 BTU/(hr)(sq.ft.)(^{O}F).

6. Since this low U factor means that during warm weather only a small fraction of the total heat input to the shelter will be dissipated through shelter boundary surfaces, this shelter should be considered as adiabatic, during the summer months, for purposes of calculating heat dissipation rates.

7. With an occupancy load of one person per 10 sq. ft. of floor area, the shelter ET would probably rise above $85^{O}F$ under New York City 5 percentile outside air summer design level conditions if natural ventilation alone is used. If the shelter occupancy load were reduced to one person per 20 sq. ft. of floor area, the shelter ET should not exceed $85^{O}F$ under the same outside air design level conditions, except during periods of unusually calm wind conditions.

8. If core areas are loaded with one person per 10 sq. ft. of floor area, natural ventilation alone should suffice to keep shelter

ET below 85°F at the 15 percentile summer design level. Thus, using natural ventilation, the ET should not exceed 85°F for more than 5 per cent of the normal year.

9. The entire building population cannot be sheltered in the core areas without increasing the shelter occupancy load above one person per 10 square feet of floor area.

2.5 BASEMENT AND ABOVE-GROUND, PUBLIC SCHOOL NO. 115, NEW YORK CITY

2.5.1 Introduction

A series of natural and forced ventilation tests was performed from July 6 through July 14, 1964, in the basement cafeteria and third-floor corridor shelter areas at Public School No. 115, East 183rd St. and Ryer Ave., Bronx County, N.Y. (Ref. 7). A calibration test of heat dissipation through boundary surfaces was also performed in each shelter area.

The primary objects of these tests were

> to ascertain the effect of natural ventilation (under varying outside air conditions) on the environment in the shelter;

> to ascertain the effect of solar radiation and heat transfer to and from the surrounding media on the shelter effective temperature (ET); and further

> to obtain sufficient data to predict physical environmental conditions in the shelter at various occupancy levels and outside weather conditions.

Occupancy of the 3480-square foot basement area and the 400-square foot above-ground core area was simulated by aggregate electro-mechanical "Simocs." Forced ventilation, at controlled temperatures, was supplied to the basement shelter from the mobile OCD shelter test vehicle. Updraft and crosswind ventilation was induced by opening windows and stairwell doors.

2.5.2 Description

(a) Site

Public School 115 is a four-story school built in 1938 and situated in a densely populated section of New York City. Total school population is approximately 1400 adults and children.

The basement shelter tested was in the school cafeteria, which has a floor area of 3480 sq. ft. The north shelter wall is buried to a height of 10 ft. The remainder of the north wall and the east wall are exposed. The latter is penetrated by ten 3 ft. x 8 ft. double-hung windows. All doors except A, B and C were sealed during the test period (see Figs. No. 7 and 9). The protection factor category is 4.

The above-ground shelter was in a section of the third-floor corridor. The corridor ceiling was 13 ft. high. Access to the shelter was from Stairwell IV. There is one $4\frac{1}{2}$ ft. x $9\frac{1}{2}$ ft. double-hung window in the shelter area (see Figs. No. 8 and 10). Protection factor category is 2.

(b) Equipment and instrumentation

Shelter occupancy was simulated in the basement shelter by six aggregate electro-mechanical Simocs (see Fig. No. 9). An electric pump was used to feed water to the Simocs. Power input to each Simoc and total moisture output were checked and adjusted hourly.

Two 24-channel multipoint recorders were used to record hourly the wet and dry bulb temperatures of the shelter area as well as the surrounding rooms and earth. Outside air conditions were obtained with a portable psychrometer and Windscope mounted on the roof.

Forced air was supplied to the shelter from the OCD test vehicle, which contained a 4400-cfm fan. Air temperature from this test vehicle was varied by an air washer and reheat coils, modulated by a temperature controller. Air flow rate in the supply duct was measured by a propeller-type anemometer.

PUBLIC SCHOOL № 115

PLOT PLAN

FIG. NO. 7

GYMNASIUM

CLASSROOM
325

ABOVE GROUND
SHELTER AREA

CORRIDOR

MILLINERY
ROOM
323

SCIENCE
ROOM
319

CLASSROOM
317

SCALE

FEET
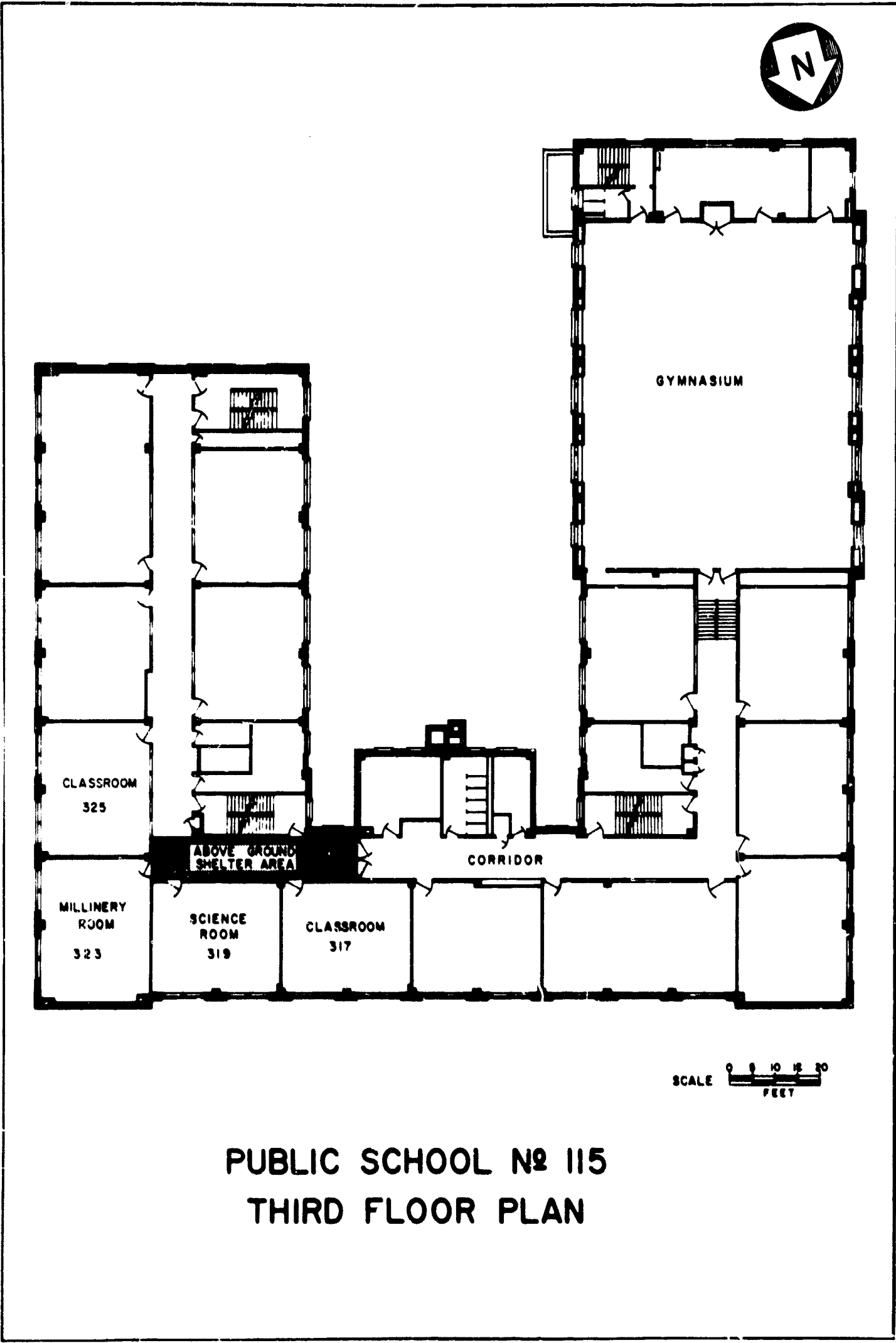
PUBLIC SCHOOL № 115
THIRD FLOOR PLAN

FIG. NO. 8
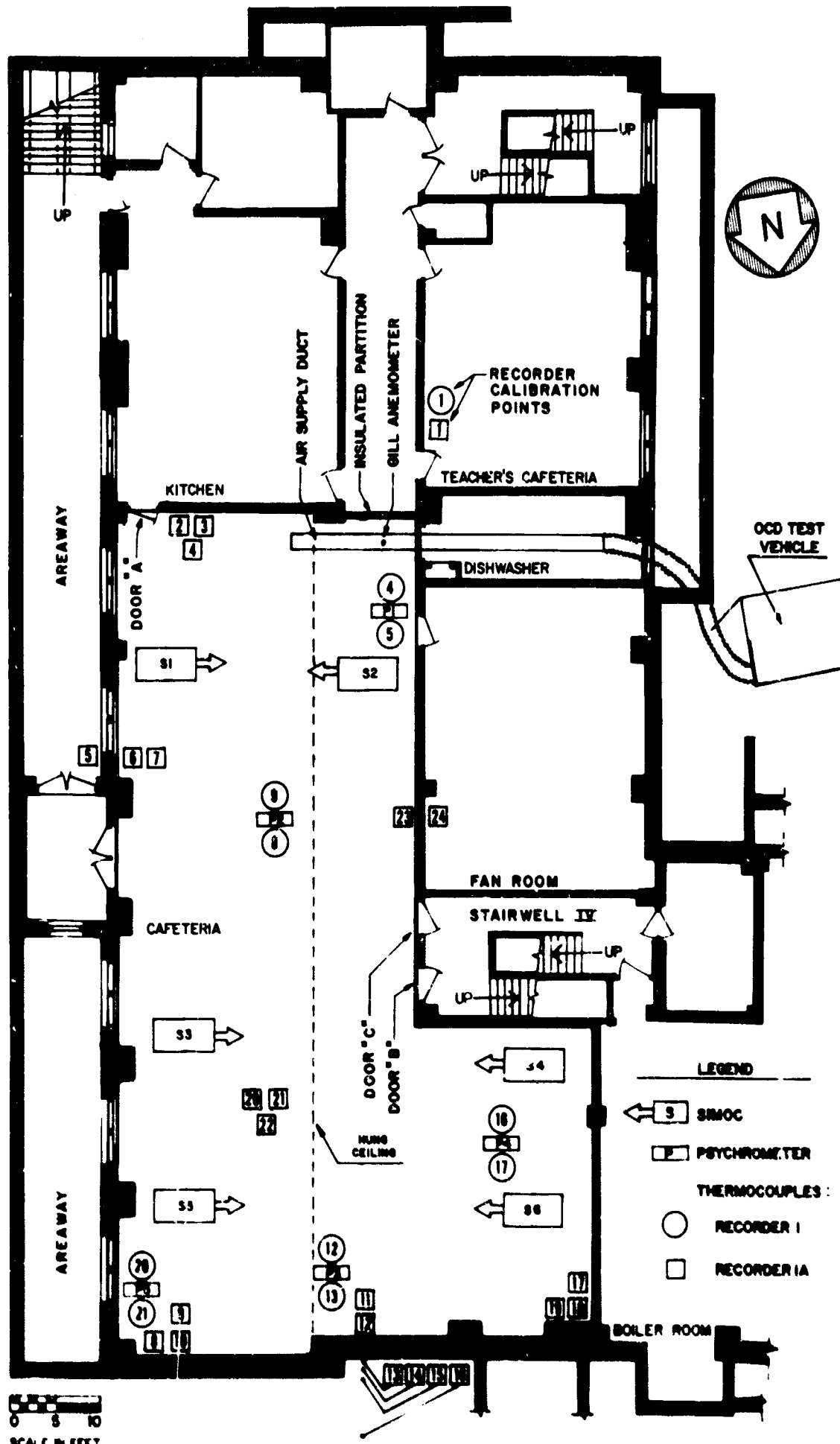
BASEMENT SHELTER AREA
EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 9

ABOVE-GROUND SHELTER AREA

EQUIPMENT AND INSTRUMENTATION LAYOUT

NOTE: ● INDICATES MERCURY THERMOMETER
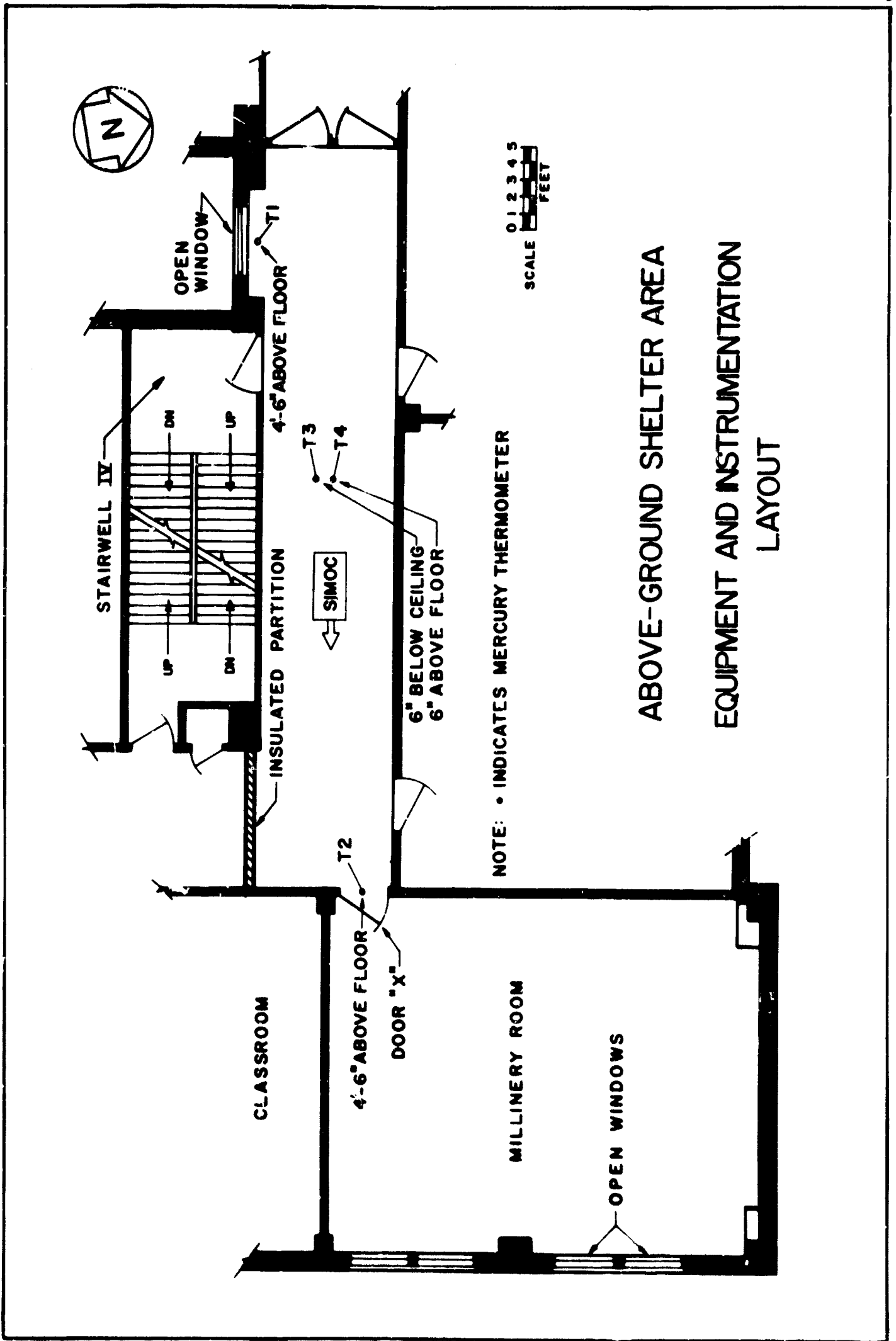
FIG. NO. 10

A single Simoc was used in the .<u>above-ground</u> shelter, with gravity

feed for the water supply. Sling psychrometers and mercury-in-glass

thermometers were used to obtain temperatures and relative humidities

in the corridor (see Fig. No. 10).

(c) <u>Tests Performed</u>

Test No.	Duration From To July	Type of Test	Shelter Population	
1	0400/6--0900/7	Natural Ventilation	290*	
2	1000/7--1000/9	Natural Ventilation	290*	
3	1100/9--1600/9	Forced Ventilation	290*	Basement
4	1700/9--0800/10	Forced Ventilation	290*	
A	0900/10-1500/11	Shelter Calibration	-	
5	1930/7--1730/9	Natural Ventilation	40	
6	1830/9--1530/11	Natural Ventilation	55	Above Ground
B	1100/13-1200/14	Shelter Calibration	-	

*These shelter populations are based on a shelter occupancy of one
person per 12 sq. ft. of cafeteria floor area--there were insufficient
Simocs available to test at the higher density of one person per
10 sq. ft. It is also assumed that the cafeteria would be modified for
radiation protection so that all the floor area (3480 sq. ft.)
would be available as shelter space.

The <u>Calibration Tests</u> were performed to obtain a "U" for the shelter

areas. As over half of the shelter wall surface in the basement was above

ground, two "U" values were required in this case--one for the outside air

and one for the surrounding earth. All doors and windows were closed and

sealed. Two tests were performed with different Simoc loading. Each test

was continued until the temperature difference between the average shelter

dry bulb and the earth or the outside air dry bulb stabilized. Two sim-

ilar tests were performed in the above-ground corridor shelter, but

here only one value for "U" was computed.

The first basement <u>Natural Ventilation Test</u> was performed to ascertain the air flow through the cafeteria when all the windows were open. Outside air entered at the bottom of each window and exited at the top, driven by temperature differential or "stack" effect. During this test all doors leading to the shelter area were closed. In the second basement test air entered the cafeteria via the kitchen window and door and was forced up the stairwell to the roof by "stack" effect. With this arrangement the kitchen could be used as a settling chamber for fallout particles, if this were considered necessary.

Two crosswind ventilation tests were carried out in the third-floor corridor shelter--with the corridor window and two Millinery Room windows open--in order to observe the effect of wind velocity and direction on the air flow through the shelter.

Also two <u>Forced Ventilation Tests</u> were performed in the basement shelter in which controlled air (representing a summer day in New York City which would be exceeded in temperature for approximately 12 days per annum) was supplied to the shelter. In the first test, the flow rate was 12 cfm/person and in the second test it was reduced to 6 cfm/person.

2.5.3 Observations

1. In the <u>basement</u> test, outside wind velocity and direction had little significance as the shelter windows were below grade. The air flow through the shelter was influenced primarily by the difference between the outside air and the average shelter dry bulb temperatures.

2. For the _above-ground_ test, the wind velocity and direction were much more effective in causing air to flow through the shelter.

3. Due to the high air flows and cool outside air temperatures, the effective temperature in both shelters remained below 85°F throughout the tests.

4. There was a 5°F temperature stratification between the shelter floor and ceiling in both shelters during the test period.

5. The values of Ue = 0.45 and Ua = 0.41 obtained from the Calibration Tests for the basement shelter appeared to be approximately right when applied to the shelter Heat Balance Calculations. They also agreed with the theoretical values obtained from ASHRAE for the building materials at the school.

6. The average calculated natural ventilation flow rate during the basement natural ventilation tests was 11-1/2 cfm/person. In the above-ground shelter, this value was 37-1/2 cfm/person.

7. During the summer months, approximately 40 per cent of the _basement_ shelter heat load will be dissipated through the walls, floor and ceiling to the outside air and surrounding media, for limited periods of occupancy. But the _above-ground_ shelter should be considered as adiabatic for purposes of calculating heat dissipation rates during the summer.

8. The most effective method of natural ventilation of the _basement_ shelter is by updraft from the east wall windows via the central stairwell to the roof. Under these conditions, the ASHRAE formula (Ref. 12, Ch. 24) for natural ventilation due to stack effect gives air flows comparable to the average test values if a Constant of Proportionality, K, equal to 6.3 is used.

9. In the _above-ground_ shelter, crosswind natural ventilation provides the most effective method of inducing air flow through the corridor. The windows selected as air intakes should be those which face the summer prevailing wind direction (S to SW in New York City).

10. With natural ventilation, the _basement_ shelter ET will not rise above 85^OF at rated occupancy (assumed to be one person/10 sq.ft. of floor area) unless the outside air temperature increases to the 12-1/2 percentile summer design level. This percentage is attained for approximately 325 hours in a normal year. At the 5 percentile summer design level, shelter occupancy would have to be reduced to 210 persons (one person per 16.6 sq.ft. of floor area) in order to maintain an ET below 85^OF under similar conditions.

11. In the _above-ground_ shelter--with the intake window wide open--the ET will remain below 85^OF at rated occupancy up to the one percentile summer design level (30 hours per year), except during unusually calm wind conditions.

12. Forced ventilation is not considered a necessity in this building, as the occasions when the outside air conditions would cause shelter effective temperatures to rise above 85^OF are normally expected to prevail for limited periods only.

13. While the school building population exceeds the National Fallout Shelter Survey designated capacity by approximately 300 adults and children, these _basement_ tests indicate that with natural ventilation only, it would be acceptable, from an environmental control stand- point, to rate the shelter area at one person/10 sq.ft. of floor area (cf., one person per 500 cubic feet in the N.F.S.S.). This rating would enable the total school population to be accommodated

in shelter areas and, in a ton, a number of occupants in the
less protected (lower protection factor) above-ground shelter areas
could be transferred to the basement.

2.6 BASEMENT AND ABOVE-GROUND, PUBLIC SCHOOL NO. 21, NEW YORK CITY

2.6.1 Introduction

A series of natural and forced ventilation tests was performed from July 17 through August 1, 1964, in the basement storage room and second-floor corridor shelter areas at Public School No. 21, 715 East 225th St., Bronx County, New York (Ref. 8). A calibration test of heat dissipation through boundary surfaces was also performed in each shelter area.

The primary objects of these tests were

> to ascertain the effect of natural ventilation (under varying outside air conditions) on the physical environment in the shelter;

> to ascertain the effect of solar radiation and heat transfer to and from the surrounding media on the shelter effective temperature (ET); and further

> to obtain sufficient data to predict physical environmental conditions in the shelter at various occupancy levels and outside weather conditions.

Occupancy of the 2550-sq.ft. basement area and the 1608-sq.ft. above-ground core area was simulated by aggregate electro-mechanical "Simocs." For ventilation, at controlled temperatures, was supplied to the basement shelter from the mobile OCD shelter test vehicle. For the second-floor corridor area, updraft and crosswind ventilation was introduced by opening windows and stairwell doors.

In addition, three tests were performed with plastic ducts, manually operated punkahs and air pumps to study the ability of this air moving and distribution equipment to improve the comfort level of the shelter occupants. These test results are discussed in the appendix.

2.6.2 Description

(a) Site

Public School 21 is a three-story L-shaped building with an older two-story wing connected to the north side. It is situated in a densely

f

populated section of New York City. Total school population is approximately 1100 adults and children.

The basement shelter tested was in the south wing storage room having a floor area of 2550 square feet (see Fig. No. 11). The rated occupancy was assumed to be one person/10 sq.ft. as it was considered that the existing mechanical ventilation system could be easily modified to provide 3 cfm/occupant in an emergency. Protection factor category is 5.

In order to separate the tested area from the boiler and fan rooms and to limit its area to the capacity of the available Simocs, an insulated partition was erected at the north end of the storage room. The shelter ceiling is 12 ft. high; the south wall is buried to a height of 5 ft., and the east and west walls to a height of 8-1/2 ft. There are no windows in this basement shelter area.

The above-ground shelter was in a section of the second-floor corridor and occupied a floor area of 1608 sq.ft. (see Fig. No. 12). Access to the shelter was from Stairwell No. 1. All doors not in use during the test period were closed and sealed. Protection factor category is 2.

(b) Equipment and Instrumentation

Shelter occupancy was simulated in the basement by six aggregate electro-mechanical Simocs (see Fig. No. 13). An electric pump was used to feed water to the Simocs. Power input and moisture output were checked and adjusted hourly.

Two 24-channel multipoint recorders were used to record hourly wet and dry bulb temperatures in the shelter area as well as in the surrounding rooms and earth. Outside air conditions were obtained with a portable psychrometer and Windscope on the school roof.

CONCRETE CURB AND FENCE

EAST 226th STREET

CONCRETE SIDEWALK ELEV. ± 0'-0"

PLAYGROUND
(ASPHALT PAVEMENT)
ELEV. – 2'-6"

GRASS AREA
ELEV. – 2'-6"

CONCRETE SIDEWALK ELEV. – 6'-0"

EAST 225th STREET

FIRST FLOOR
ELEV. + 4'-11"

CEMENT PAVEMENT
ELEV. – 2'-9"

OLD 2 STORY WING

NEW 3 STORY BUILDING

BASEMENT SHELTER
AREA BELOW
ELEV. –11'-0"

AREAWAY
ELEV. – 6'-6"

DN

CONCRETE YARD
ELEV. – 2'-10"

ASH HOIST

CONCRETE YARD
ELEV. – 2'-10"

UP

FENCE & RETAINING WALL

OCD TEST VEHICLE

PUBLIC SCHOOL Nº 21
PLOT PLAN

SCALE IN FEET
0 5 10 20 30

FIG. NO. 11
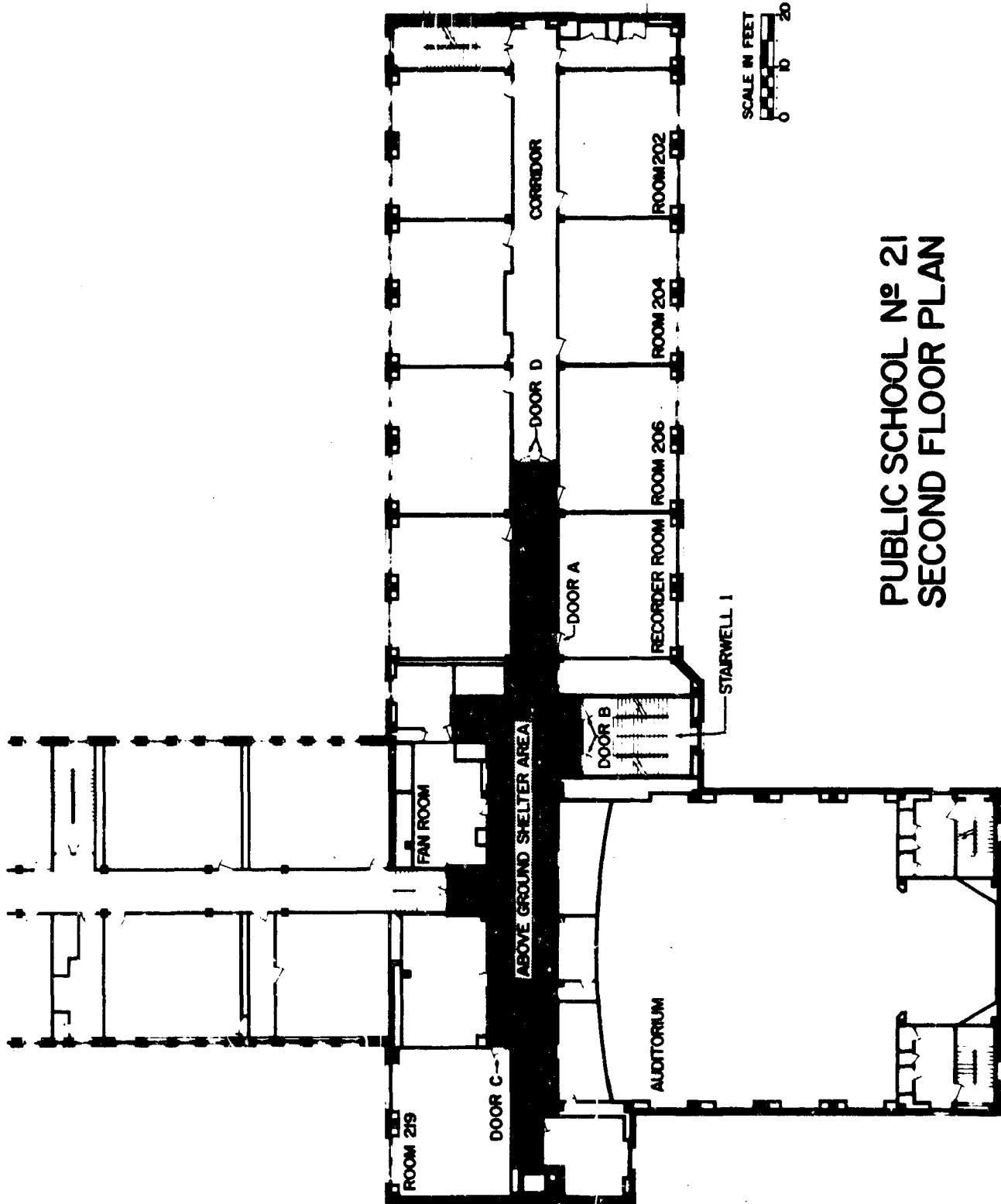
PUBLIC SCHOOL Nº 21
SECOND FLOOR PLAN

SCALE IN FEET

CORRIDOR

DOOR D

DOOR A

ROOM 202

ROOM 204

ROOM 206

RECORDER ROOM

STAIRWELL 1

DOOR B

FAN ROOM

ABOVE GROUND SHELTER AREA

AUDITORIUM

DOOR C

ROOM 219

FIG. NO. 12

Forced air was supplied to the shelter from the OCD test vehicle, which contained a 4400-cfm fan. Air temperature from this test vehicle was varied by an air washer and reheat coils, modulated by a temperature controller. Air flow rate in the supply duct was measured by a propeller type anemometer.

In the _above-ground_ shelter, four Simocs were used and water was fed to them from a graduated tank on the building roof. One 24-channel recorder was used, and the same type of measurements and observations were made as in the basement test (see Fig. No. 14).

(c) Tests Performed

Test No.	Duration From — To	Type of Test	Shelter Populations	
	July-August			
1	1600/17--1600/18	Natural Ventilation (Internal Circulation)	255*	Basement
2	1700/20--1500/23	Forced Ventilation (11 cfm/person)	255*	Basement
3	1600/23--1600/24	Forced Ventilation (6 cfm/person)	255*	Basement
A	1700/24--1600/25	Shelter Calibration (Three Levels)		Basement
4	1600/27--1600/29	Natural Ventilation (Crosswind)	160*	Above-Ground
5	1700/29--1600/31	Natural Ventilation (Updraft)	160*	Above-Ground
B	1800/31--1600/01	Shelter Calibration (Three Levels)	-	Above-Ground

*These shelter populations are based on an occupancy of one person per 10 sq.ft. of shelter floor area.

The _Calibration Tests_ were performed to obtain a "U" for the shelter areas. As over half of the shelter wall surface in the basement was above ground, two "U" values were required in this case--one for the outside air and one for the wall area in contact with the earth. All doors and windows
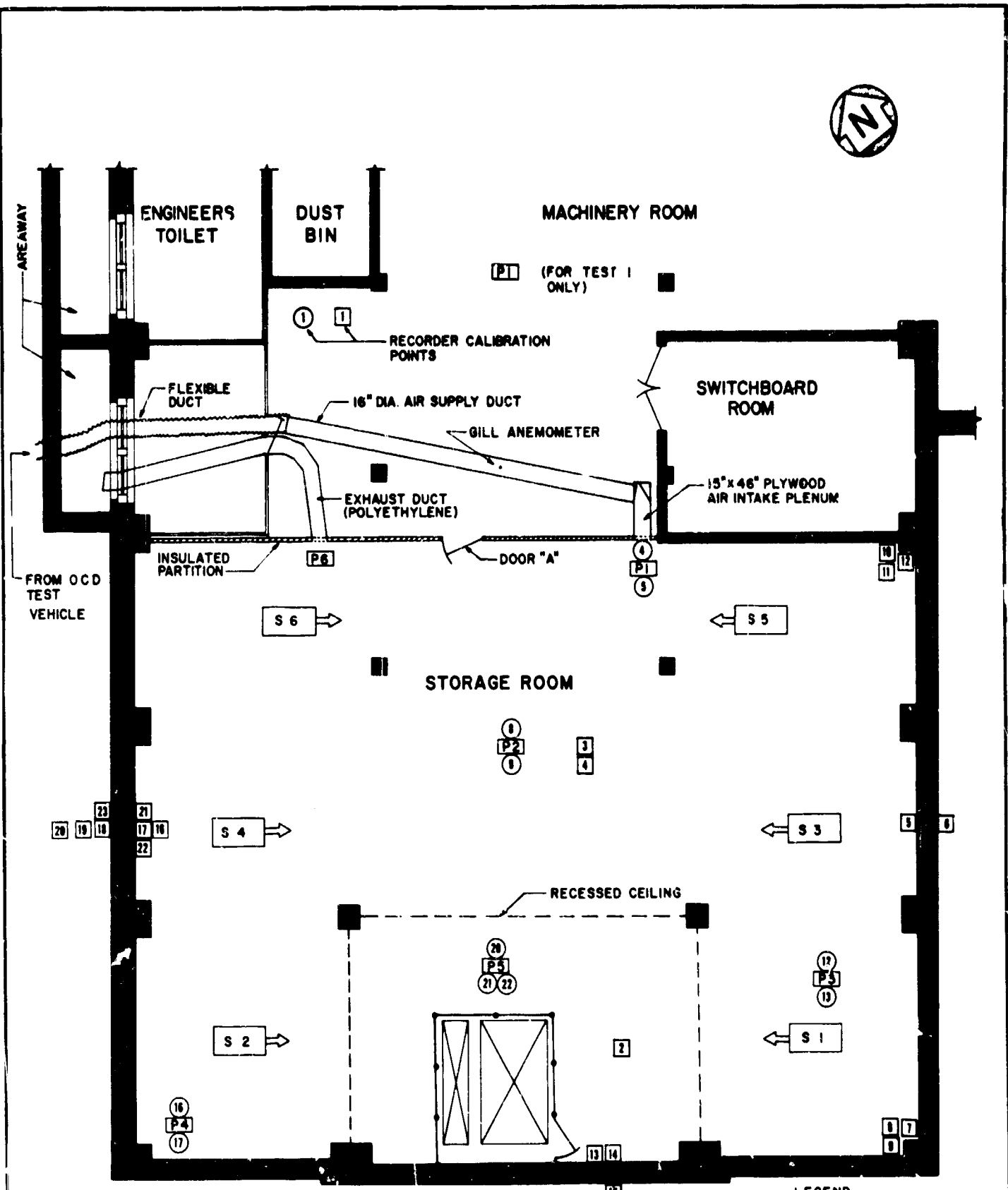
BASEMENT SHELTER

EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 13
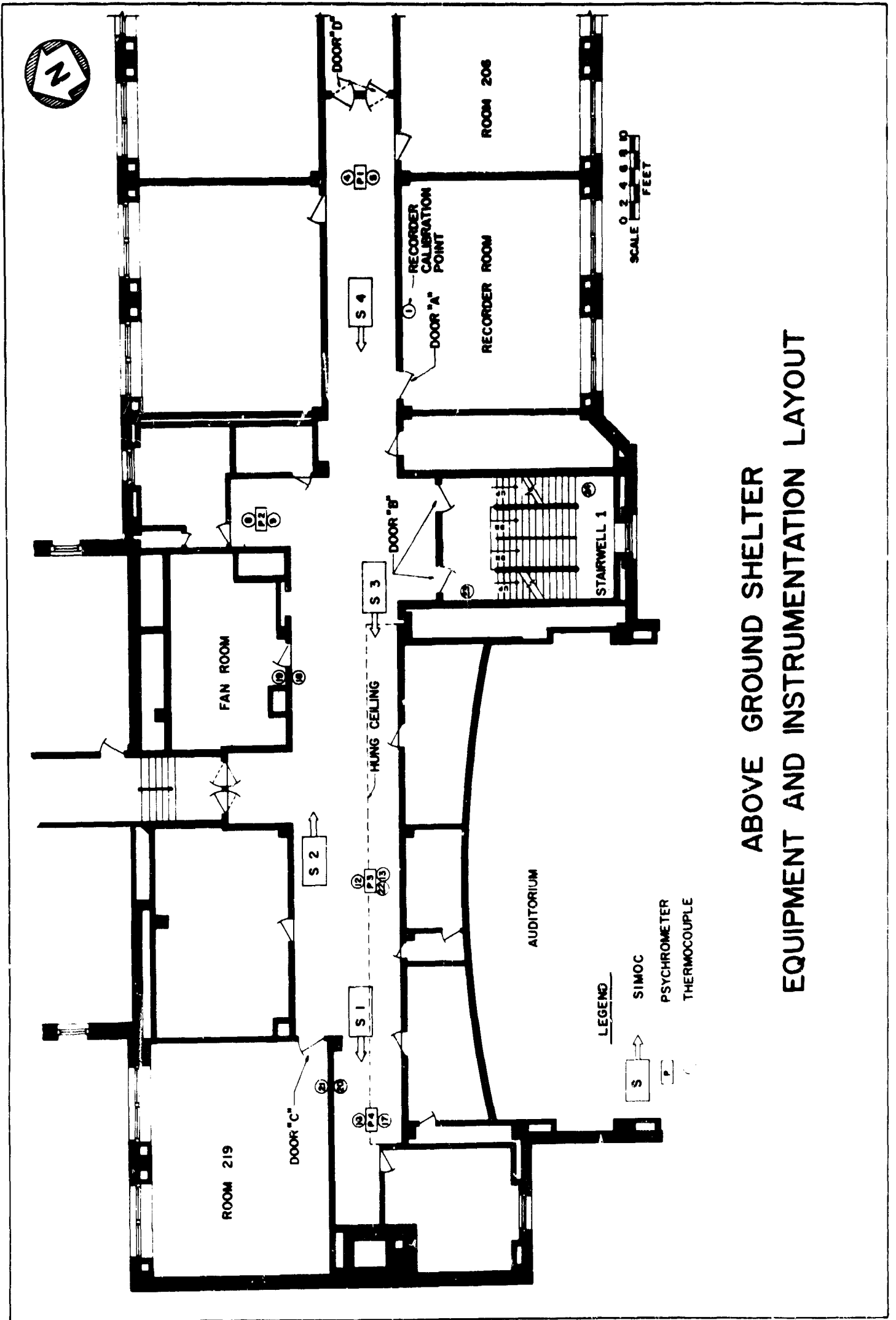
ABOVE GROUND SHELTER
EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 14

were closed and sealed. Three tests were performed with different Simoc loadings. Each test was continued until the temperature difference between the average shelter dry bulb and the earth or the outside air dry bulb stabilized. Three similar tests were performed in the above-ground corridor shelter, but here only one value of "U" was evaluated.

The first basement Natural Ventilation Test was performed as a modified "button-up" test; with all doors and windows in the school basement closed except for the door leading into the shelter area. Air flow was motivated by temperature stratification in the storage room, causing the warmer shelter air to flow out of the top half of the doorway, and inducing the cooler air in the Machinery Rooms to enter the shelter area via the bottom half. Shelter occupancy was set at 255 persons (one person/ 10 sq.ft. of floor area).

Two natural ventilation tests were performed in the second-floor corridor shelter. The first was a crosswind ventilation test with air flowing through the shelter from two windows in Room 202 and out of two open windows in Room 219. The second test was an updraft test, with the air from the shelter exiting via the stairwell to the building roof. In both cases, the shelter occupancy was simulated at 160 persons.

Also two Forced Ventilation Tests were performed in the basement shelter in which controlled air (representing a summer day in New York city, which would be exceeded in temperature for approximately 12 days per annum) was supplied to the shelter. In the first test, the flow rate was 11 cfm/person and in the second test the rate was reduced to 6 cfm/person. The Simoc setting remained at 255 persons.

2.6.3 Observations

1. There was a 10°F temperature stratification between the shelter floor and ceiling in the basement shelter during the test period. This value was only 2°F in the above-ground shelter tests.

2. In the first basement test (modified "button-up" test) the shelter ET rose rapidly above the 85°F ET level, and stabilized at approximately 89°F ET.

3. The values of Ue = 0.56 and Ua = 0.37 obtained from the Calibration Tests for the basement shelter appeared to be approximately right when applied to the Shelter Heat Balance Calculations. They also agreed with the theoretical values obtained from ASHRAE for the building materials at the school.

4. The average calculated natural ventilation flow during the above-ground crosswind and updraft ventilation tests was 14.7 cfm/person.

5. During the summer months, approximately 40 per cent of the basement shelter heat load will be dissipated through the walls, floor and ceiling to the outside air and surrounding media, for limited periods of occupancy. But the above-ground shelter should be considered as adiabatic for purposes of calculating heat dissipation rates during the summer.

6. In the above-ground shelter, crosswind and/or updraft natural ventilation provides a satisfactory method of inducing air flow through the corridor. The windows selected as air intakes should be those which face the summer prevailing wind direction (S to SW in New York City).

7. With the ventilating air inlet consisting of two half-open windows, the _above-ground_ shelter will remain below $85^{\circ}F$ ET at rated occupancy (assumed as 1 person/10 sq.ft. of floor area) during the 10 percentile design level outside air temperatures for New York City, except during unusually calm wind conditions. This design level is exceeded approximately 300 hours per annum.

8. In the windowless _basement_ shelter area, the ET will rise above $90^{\circ}F$ at rated occupancy and 3 cfm/person of outside air, if the temperature at the latter exceeds the 25 percentile design level for New York City (exceeded for approximately 750 hours per annum). In order to remain below $85^{\circ}F$ ET in the shelter at rated occupancy at the 5 percentile design level, a ventilation rate of 11 cfm/person would be required.

9. When air is naturally induced into the _basement_ shelter from the non-ventilated adjacent areas by temperature stratification of the shelter air, an average flow rate of 6.5 cfm per rated occupant results. This ventilation flow rate could probably be increased if the shelter door height was increased. This internal recircula- tion of air would be more applicable to shelters (above or below ground) with adjacent areas which would be unoccupied when the shelter was in use.

2.7 HOME BASEMENT, WESTCHESTER COUNTY, NEW YORK

2.7.1 Introduction

A series of ventilation tests, together with calibration tests of heat dissipation through boundary surfaces and a well-water coil dehumidification test, was performed from September 9 through September 24, 1964, in an existing basement shelter area at Building No. 2, the Lamb Estate, Croton-on-Hudson, Westchester County, New York (Ref. 9).

Occupancy of the 900-sq.ft. shelter floor area was simulated by aggregate electro-mechanical "Simocs." Uncontrolled ambient air was used in the forced ventilation test, and during the natural ventilation tests the flow of outside air through the shelter was induced by opening doors and boiler flue dampers.

The primary objects of the tests were

> to ascertain the effect of natural ventilation (under varying outside air conditions) on the physical environment in the shelter;

> to ascertain the effect of heat transfer to or from the surrounding media on the shelter effective temperature (ET);

> to obtain sufficient data to predict physical environmental conditions in the shelter at other occupancy levels and outside weather conditions; and further

> to check the performance of a manually-operated air pump and well-water coil unit when employed to lower the shelter ET.

2.7.2 Description

(a) Site

The building is an unattached, two-story, residential type house with a designated shelter area in the basement--assigned a protection factor in category J (see Fig. No. 15). It is located on rising ground overlooking the Hudson River, and was constructed in 1927. The building was unoccupied at the time of the test.

The basement exterior walls are constructed of 18-in. fieldstone laid up in mortar, with the upper 12 in. of these walls above grade. Floor and ceiling are of typical basement construction, with a ceiling height of 7'-6" and a floor area of 900 sq. ft.

There are five 2 ft. x $2\frac{1}{2}$ ft. projected windows--each having a 21-in. deep areaway. The basement has two doors--one leading to the garage and the other up to the main floor.

The building is heated by a one-pipe steam radiator system with an oil-fired boiler in the shelter area. This was not used during the test period.

(b) Equipment and Instrumentation

Three aggregate electro-mechanical Simocs were used during the test period (see Fig. No. 15). Water was fed by gravity from a graduated tank. Power to each Simoc and moisture output was checked and adjusted hourly.

Twenty-two thermocouples were used to record wet and dry bulb temperatures in the shelter area and also in the earth sink and adjacent rooms.

Outside wind was monitored by a Windscope mounted on the roof; the air flow through the shelter doors was checked by a mechanical anemometer.

A $1\frac{1}{2}$-hp centrifugal fan was used in the forced ventilation test. The air flow was measured in the supply duct with a thermal anemometer.

Manually-operated air pump and well-water coil unit:

The coil consists of a single row of eight vertical 3/4-in. O.D. copper tubes with aluminum extended surface fins. Each tube was connected to horizontal inlet and outlet headers at the bottom and top of the unit, respectively. The air pump consists of 24 3-in. plastic sheet

CROTON SHELTER

SHELTER PLAN
EQUIPMENT AND INSTRUMENTATION LAYOUT
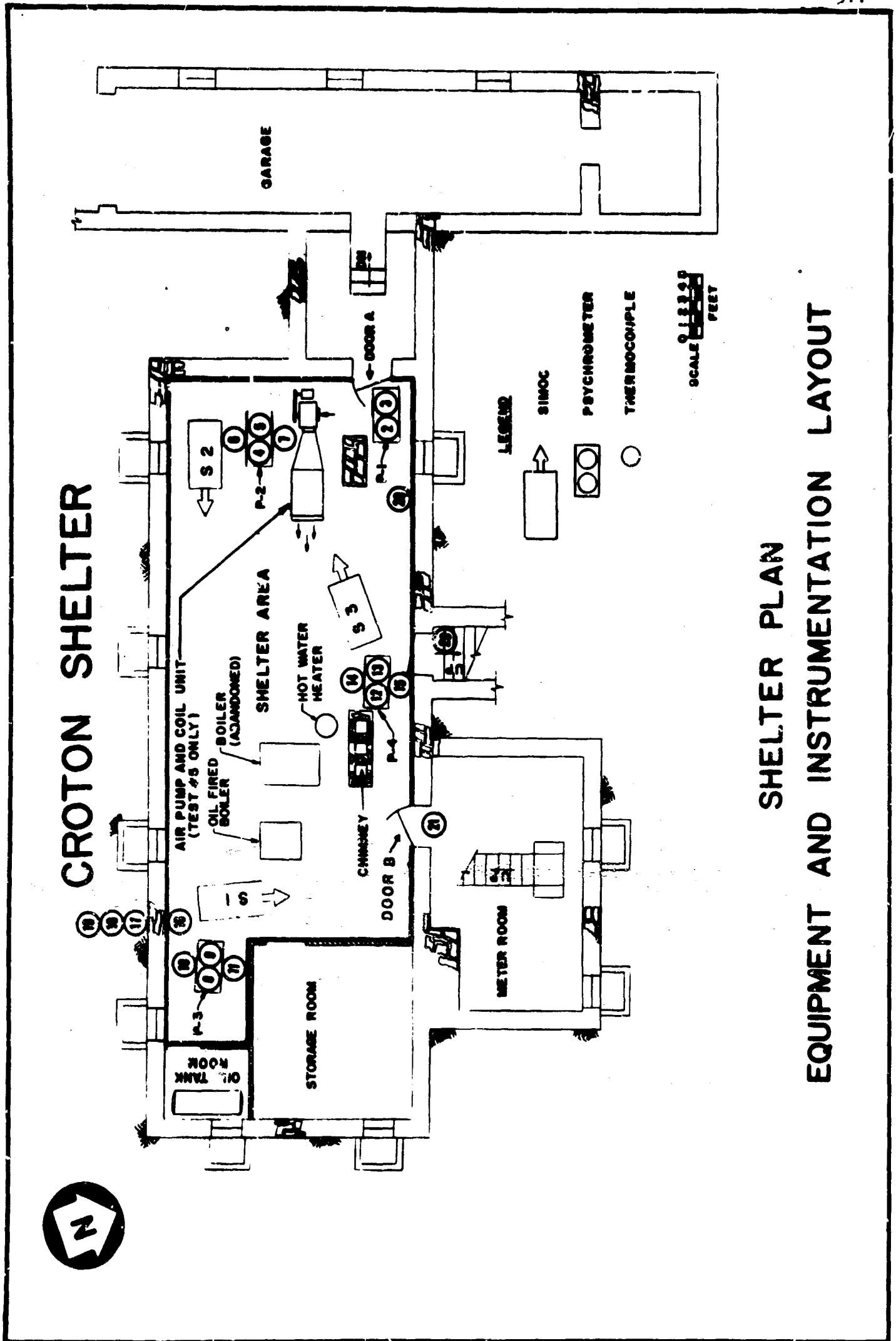
flap valves taped to a "chicken wire" network in a vertical frame which could slide back and forth in a plywood casing.

Overall dimensions: 6'-0" high x 2'-4" wide x 4'-0" deep.

Air flow through pump: 1500 cfm (2200 cfm maximum for a short time).

Assembly time: 22 man-hours.

Cost of materials: $130.

(c) Tests Performed

Test No.	From	To	Type of Test	Shelter Population
1A	September 1900/9--1000/10		Shelter Calibration	-
1B	1100/10-0900/11		Shelter Calibration	-
1C	1000/11-1800/11		Shelter Calibration	-
2	1500/14-0800/16		Natural Ventilation	135
3A	0900/16-1400/17		Natural Ventilation	135
3B	1500/17-2400/17		Natural Ventilation	90
4	1000/22-1900/22		Forced Ventilation	135
5	1100/24-1900/24		Air Pump and Coil Unit	Variable

The Calibration Tests were performed to obtain a 'U" for the shelter area. But, as nearly half of the shelter wall surface was above ground, two 'U" values were required, one for outside air and one for earth. All doors and windows were closed and sealed. Three tests were performed with different Simoc loadings. Each test was continued until the temperature difference between average shelter dry bulb and earth or the outside air dry bulb stabilized.

The Natural Ventilation Tests were performed with windows remaining sealed (assumed to be sandbagged). Simocs were set for 135 persons, 50 per cent above rated occupancy The first natural ventilation test was a

crosswind test with Doors A and B open. Updraft ventilation was used in the second natural ventilation test, with the boiler chimney stack employed as the air outlet. A <u>Forced Ventilation Test</u> was run to check the shelter air flow rates observed and calculated during the Natural Ventilation Tests.

The air pump and coil unit test was carried out in a "buttoned-up" shelter condition. Simocs were adjusted to stabilize the shelter ET at 85^OF. The unit was then operated at 1500 cfm with a centrifugal fan in lieu of manpower at an equivalent rate of 40 strokes per minute. Temperatures were taken to ascertain a shelter heat balance and water flow rates, and temperature drops through the coil were measured hourly. Test continued until shelter effective temperature was again stabilized at a low level.

2.7.3 Observations

1. During crosswind ventilation tests, the wind velocity and direction had greatest influence on shelter ET. The crosswind test resulted in a lower shelter ET than the updraft via boiler chimney test. With this updraft, the ET rose above 85^OF at rated occupancy, even though the outside air was more typical of October conditions.

2. There was a 6^OF temperature stratification between the shelter floor and ceiling.

3. The values of Ue = 0.47 and Ua = 0.39 obtained from the Calibration Test appeared to be approximately right when applied to the Shelter Heat Balance Calculations.

4. ASHRAE empirical formulae were not of use in calculating air flow through the shelter due to its high internal resistance.

5. The air pump and coil unit lowered the average shelter ET about $2^{\circ}F$ and removed 55 per cent of the heat input to the shelter. It also greatly decreased condensation on the floor and walls.

6. During the summer months, approximately 36 per cent of the shelter heat load will be dissipated through the walls, floor and ceiling to the outside air and surrounding media, for limited periods of occupancy.

7. Greater natural ventilation rates are obtainable with the two shelter access doors open than with one door and the boiler flue damper open.

8. With natural ventilation, the shelter ET will not rise above $85^{\circ}F$ at rated occupancy[*] unless the outside air temperature increases to the 15 per cent summer design level or during unusually calm wind conditions. This percentage is attained for approximately 450 hours per annum, or 5 per cent of the hours in a normal year.

9. At the 5 per cent summer design level, the acceptable shelter occupancy level would have to be reduced to 57 persons (one person/ 15.8 sq.ft.) in order to maintain an ET below $85^{\circ}F$ with natural ventilation.

10. From the above data, mechanical forced ventilation is not considered to be necessary for this type of shelter, as the occasions when outside air conditions would cause uncomfortably high shelter effective temperatures are expected to prevail for only limited time periods.

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[*]Rated occupancy is defined as one person per 10 sq.ft. of shelter floor area, and for purposes of this report is equal to a total of 90 persons. In the National Fallout Shelter Survey Phase 2, a capacity of 61 persons was assigned to the central area of the basement with a Protection Factor in category No. 3.

2.8 UNDERGROUND SHELTER, NEW CANAAN, CONNECTICUT

2.8.1 Introduction

A series of natural ventilation, forced ventilation and button·up tests was conducted in an underground shelter area in New Canaan, Connecticut, from February 8 through February 17, 1964 (Ref. 10).

Occupancy of the 328-sq.ft. shelter floor area was simulated by aggregate valve-type "Simocs." Uncontrolled ambient air was used during the forced ventilation tests, and the existing inlet and outlet openings were used to induce air flow for the natural ventilation tests.

The primary objects of the test were to obtain data on the lower limits of shelter effective temperatures (ET) under varying amounts of outside air ventilation and varying occupancy loads; investigate some method of increasing the shelter ETs; and further, ascertain the heat transfer characteristics of the shelter surfaces and the surrounding soil.

2.8.2 Description

(a) Site

The shelter is located in a sparsely populated residential section of New Canaan, Connecticut. The shelter construction consists of 9-in. thick reinforced concrete walls, roof and floor slabs (see Figs. No. 16 and 17); it is completely buried under 39 inches of earth and has a protection factor of over 1000 (Category 8). This shelter is also designed to withstand blast overpressure greater than 30 psi, and is equipped with blast detectors and valves in its 6-in. diameter intake and exhaust openings. Shelter equipment consists of a 375-cfm electric-manual blower, a water well and pump, and an aut   c start, 5-kw engine generator set. The engine generator set and its starting equipment is located above grade. The shelter consists of a 6 ft. x 10 ft. filter room and a 32 ft. x 8 ft.

NEW CANAAN SHELTER

SHELTER PLAN
EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 16

SECTION "A-A"

NOTE: ALL THERMOCOUPLES ARE LOCATED IN THE PLANE OF SECTION "A-A" (SEE FIG.1)

SECTION "B-B"
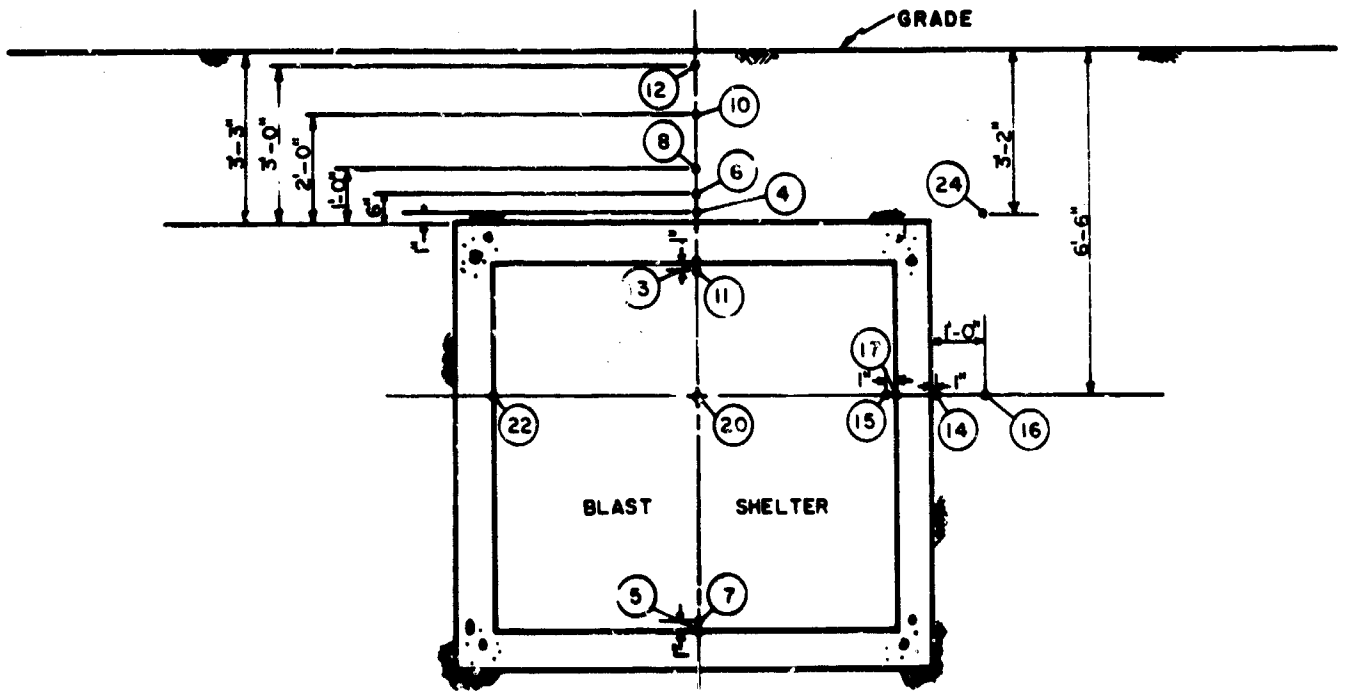
NOTE: ALL THERMOCOUPLES ARE LOCATED IN THE PLANE OF SECTION "B-B" (SEE FIG.1)

SHELTER ELEVATIONS
INSTRUMENTATION

FIG. NO. 17

main room, and has a total floor area of 328 sq.ft. The filter room

has provisions for adding CBR filters to the forced ventilation system.

(b) Equipment and Instrumentation

Thermocouple locations (f r earth, shelter surfaces, shelter air and

ambient air temperatures) are as shown on Figs. No. 16 and 17. Instrumen-

tation and measurements of Simoc electric power and water consumption,

air flow rates and outside air conditions are described in detail in Ref. 10.

An aggregate valve-type Simoc was used to simulate the shelter occupant

load. For the purposes of these tests, rated shelter occupancy was set

at 30 persons. Soil sample analysis indicated a soil conductivity value

of 19 BTU/(hr)(in.)(sq.ft.)($^\circ$F).

(c) Tests Performed

A total of twelve tests were performed in the New Canaan Shelter

as indicated below:

Test No.	Description	CFM Average	Occu- pants	Average CFM per Occupant	Duration From	To
					February	
1	Forced Ventilation	332	18*	18.4	1700/8---	1500/9
2	Forced Ventilation	289	33*	8.8	1600/9---	1500/10
3	Forced Ventilation	89	18*	4.9	1600/10---	1500/11
4	Forced Ventilation	98	33*	3.0	1700/11---	1500/12
5	Natural Ventilation	31	32**	0.97	2000/12---	1500/13
6	Button-up	0	15	0.	1800/13---	1500/14
7	Button-up	0	30	0.	1730/14---	0900/15
8	Button-up (partially insulated)	0	30	0.	1615/15---	1400/16
9A	Button-up (Main Room fully insulated)	0	21	0.	2300/16---	0600/17
9B	Button-up (Main Room fully insulated)	0	10.5	0.	0624/17---	0900/17
9C	Natural Ventilation (Main Room fully insulated)	(Not measured)	10.5	-	1000/17---	1130/17
9D	Natural Ventilation (Main Room fully insulated)	(Not measured)	21	-	1200/17---	1400/.)

*Includes motorized blower load equivalent to total metabolic heat load
of three occupants.

**Includes Test Operator at 800 BTU/hr.

The first seven tests were conducted to ascertain the range of shelter ETs likely to be encountered in an uninsulated shelter under a variety of ventilation air flow rates and shelter occupancy conditions. Tests 8, 9A, 9B, 9C and 9D were performed to determine the effects of a radiant reflective type of insulation, when applied to part of or all of the shelter surfaces, upon the shelter ET. Sensible heat balance calculations were used to determine the heat loss through the shelter surfaces. During Natural Ventilation Test 5, a 6-1/2 ft. high x 12-in. square stack was periodically attached to the shelter inlet air pipe to determine its effect on the natural ventilation flow rate.

2.8.3 Observations

1. The New Canaan shelter has an efficient heat sink. Under normal winter conditions (25°F dry bulb (DB) average air temperature), the percentage of the total shelter heat load absorbed via the shelter surfaces and the surrounding soil ranged from about 20 per cent with a forced air ventilation rate of 9 cfm/occupant to about 80 per cent with a natural ventilation rate of 1 cfm/occupant.

2. Low shelter ETs were encountered at a shelter occupancy loading of 1 person/10 sq.ft. of floor area. The average shelter ET ranged from 43.9^{o}F for Test 1 (18.4 cfm/occupant) to 59.3^{o}F for Test 5 (1 cfm/occupant).

3. The application of radiant reflective type of insulating paper to the shelter surfaces proved effective in substantially increasing the shelter ET and the shelter DB temperature. For similar test conditions with insulation (Test 9D) and without insulation (Test 5), this type of insulating material increased the shelter ET 11°F and the shelter DB temperature 13°F.

4. The periodic attachment of a 6-1/2 ft. x 12 in. square stack to the inlet air pipe increased the natural ventilation air flow rate from 28 cfm to 33 cfm.

5. The test results suggest that an undercrowded, underground shelter with an efficient heat sink may present habitability problems for shelter occupants during the winter months because of lower shelter ETs. Occupants may shut off ventilation air (either forced or natural) in an effort to keep warm and thus inadvertently subject themselves to carbon dioxide toxicity. Some countermeasures against the danger of CO_2 toxicity should be taken, such as:

a) providing suitably printed shelter instruction warning shelter occupants of the hazards if ventilation air is shut off;

b) stocking CO_2 absorption agents in the shelter; and

c) supplying the shelter with a CO_2 concentration level detector. It should also be remembered that carbon monoxide is another possible hazard due to outside fires or due to occupants smoking within the shelter. Therefore, a CO detection system might also be considered a shelter requirement.

6. Application of thermal or radiant reflective type of insulation materials on the shelter surfaces is one method of increasing shelter ETs without reducing minimum shelter ventilation. Although there are other ways of increasing the shelter temperatures (e.g., electric heaters), the use of the insulating material will also maintain the heat sink for possible extended closure or natural ventilation periods. The insulation material could be applied by occupants if low shelter temperatures required it and, if at a later time shelter

temperatures rose too high, then a portion of the insulation could
be removed from the shelter surfaces. This would expose part of the
preserved heat sink and help to maintain tolerable shelter tempera-
tures, even when ventilating the shelter with the minimum cfm required
to prevent CO_2 toxicity.

7. For underground shelters with forced ventilation systems, it may
be possible to increase (or maintain) the effectiveness of the heat
sink on a continuous basis by the addition of an indoor-outdoor thermo-
static controller such that forced air would circulate through the
shelter space whenever the outdoor temperature fell below the soil
temperature. This would also serve to exercise the ventilating
system.

2.9 UNDERGROUND SHELTER, VINCENTOWN, NEW JERSEY

2.9.1 Introduction

A series of natural ventilation and forced ventilation tests, together with a water-cooled heat exchanger test and a manual piston-type air pump test, were conducted from August 9 through August 21, 1964, in an underground shelter at Vincentown, New Jersey (Ref. 11).

Aggregate simulated occupant machines (Simocs) were used to provide shelter occupancy loads in this 1200-sq.ft. shelter area. Uncontrolled ambient air was used for all forced ventilation tests.

The main purposes of the tests were to determine the effects of natural ventilation on the physical environment in the shelter; to determine the effect of heat transfer to or from the surrounding soil on the physical environment in the shelter; to obtain sufficient data to predict physical environmental conditions in the shelter at various occupancy levels and outside weather conditions; to ascertain the performance of a water-cooled heat exchanger when used to lower the shelter effective temperature (ET); and further to measure the performance of a manually-operated, piston-type air pump.

2.9.2 Description

(a) Site

The Vincentown shelter, located 20 miles east of the Philadelphia-Camden area, is an underground shelter with approximately 1200 square feet of net floor area. As shown on Fig. 18, this shelter consists of 18 6 ft. by 10 ft. rooms opening into a 36-in. wide central corridor. Two access corridors, each an extension of the central corridor, are provided in the shelter. The south access corridor leads to the basement of the nearby Frazier home; the north access corridor exits to grade via a

VINCENTOWN SHELTER

SHELTER PLAN

SECTION "A-A"

NOTES

1. ALL WALLS ARE OF HOLLOW CONCRETE BLOCK 8" THICK, WITH 3/8" CEMENT MORTAR FACING ON BOTH SIDES.

2. CEILING IS OF REINFORCED CONCRETE SLAB 9" THICK.

3. FLOOR IS OF POURED CONCRETE 4" THICK, OVER 6" CLEAN GRAVEL FILL
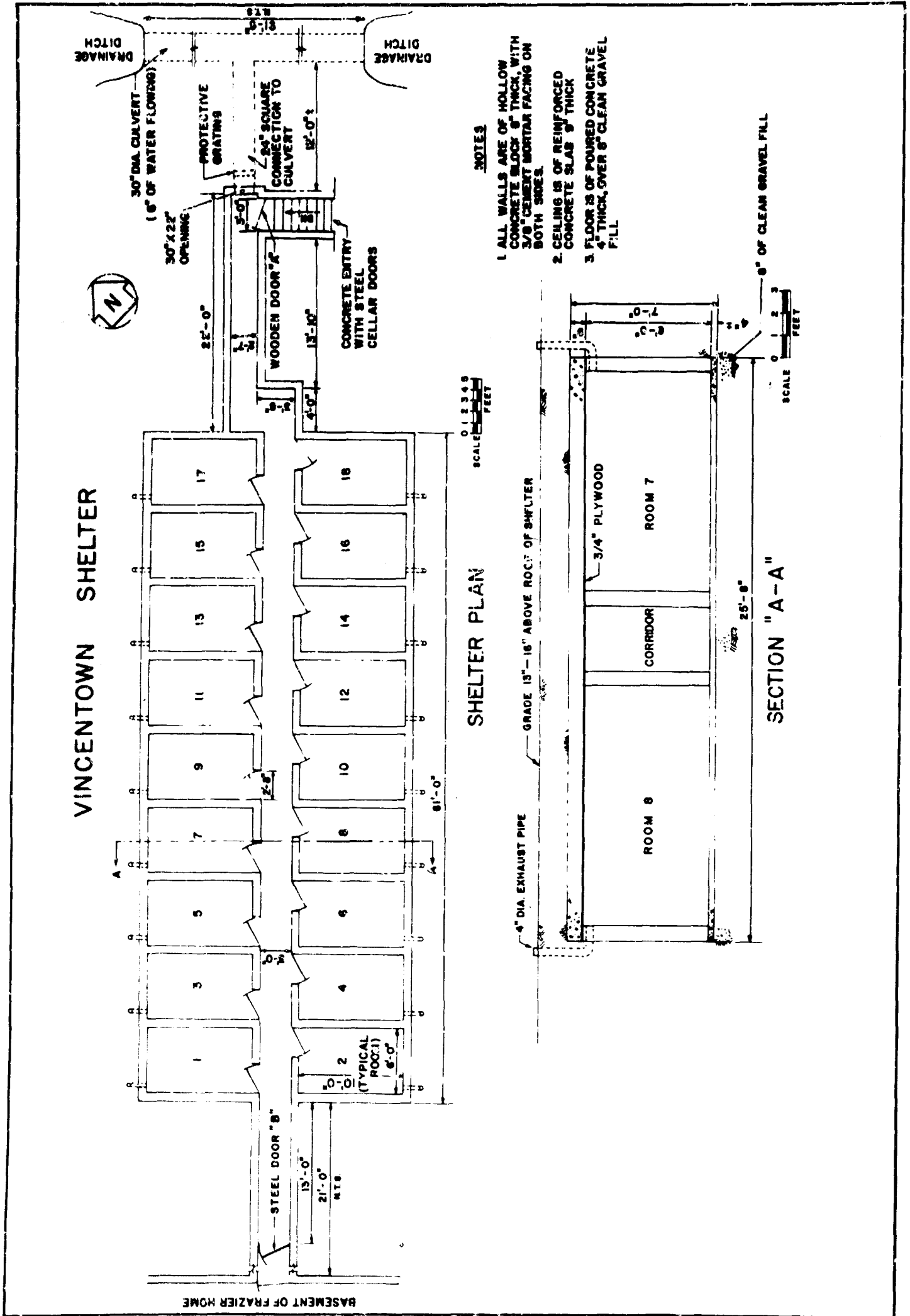
FIG. NO. 18

concrete stairwell. The shelter gross floor area (including the access corridor) is 1373 square feet.

The shelter floor is 4-in. thick concrete poured on top of an 8-in. bed of gravel; shelter walls and interior partitions are made of 8-in. hollow core cinder block (cores not backfilled); the shelter ceiling is 9-in. thick reinforced concrete and the original ceiling plywood forms (now in various stages of decay) are still in place. Soil analysis indicates that the dry, sandy soil surrounding the shelter has a thermal conductivity, K, of 8 (BTU)(in.)/(hr.)(sq.ft.)(^{o}F). The top of the shelter roof slab is covered by 13 to 16 in. of soil with sporadic grass growth. The shelter has a protection factor of over 1000 (category 8).

The shelter has no forced ventilation system. Natural ventilation air normally enters via the 30 in. x 22 in. opening (which leads to a 30-in. diameter irrigation water culvert) near the concrete stairwell at the north access corridor; ventilation air exhausts via 4-in. diameter pipes located in each of the 18 6 ft. x 10 ft. rooms. Water is not available within the shelter but at least 6 in. of water normally flows in the 30-in. diameter irrigation water culvert, 12 ft. north of the north access corridor exit.

This shelter was designed and constructed in six working days by a group of rural families during the Berlin Crisis of 1961. The total cash cost of shelter construction amounted to $2300. or approximately $2/sq.ft. of net shelter floor area.

(b) Equipment and Instrumentation

Aggregate valve-type Simocs were employed to simulate shelter occupancy loads. A variety of temperature (soil, shelter surface and shelter air) points, air flow rates, Simoc electric power and water

consumption data were recorded hourly as described in Ref. 11 and as shown on Fig. No. 19. A portion of this instrumentation was utilized for the water-cooled heat exchanger test conducted in shelter Room No. 3 toward the end of Ventilation Test No. 5. Frequent air flow rate measurements were taken to determine the performance of a manually-operated air pump for a variety of shelter air inlet and exhaust openings.

(c) Tests Performed

Two natural ventilation tests (Nos. 1 and 2) were performed at an occupancy density of one person per 10 sq.ft. of net floor area, each test utilizing a different shelter air inlet opening. Three forced air ventilation tests (Nos. 3, 4 and 5) were conducted under various air flow rates and occupancy load conditions. All tests used outside air; ambient weather conditions during August 1964 were abnormally cool and most of the outside air conditions during the test runs approximated October-November conditions. A summary of the test runs is listed below:

Test No.	Description	CFM Average	Shelter Load* (Occupants)	CFM/ Occupant	Duration From To August
1	Natural Ventilation (inlet Air via Culvert Opening; All Doors Closed)	200	117	1.7	1300/9--1100/10
2	Natural Ventilation (inlet Air via Door A Opening; All Other Doors and Culvert Closed)	200	118	1.7	1200/10-1300/11
3	Forced Ventilation	693	117	5.9	1500/11-1200/13
4	Forced Ventilation	1310	118	11.1	1300/13-1200/16
5	Forced Ventilation**	1323	168	7.9	1300/16-2100/20

*Includes instrument load of 380 watts, equivalent to approximately the total metabolic heat load (400 BTU/person) of three occupants.

**Water heat exchanger test performed in Room No. 3 from 1440 to 1550 on 8/20.

The piston-type air pump tests were conducted after the termination of Test No. 5 on August 21. The CFM output of a manually-operated, piston-type

VINCENTOWN SHELTER
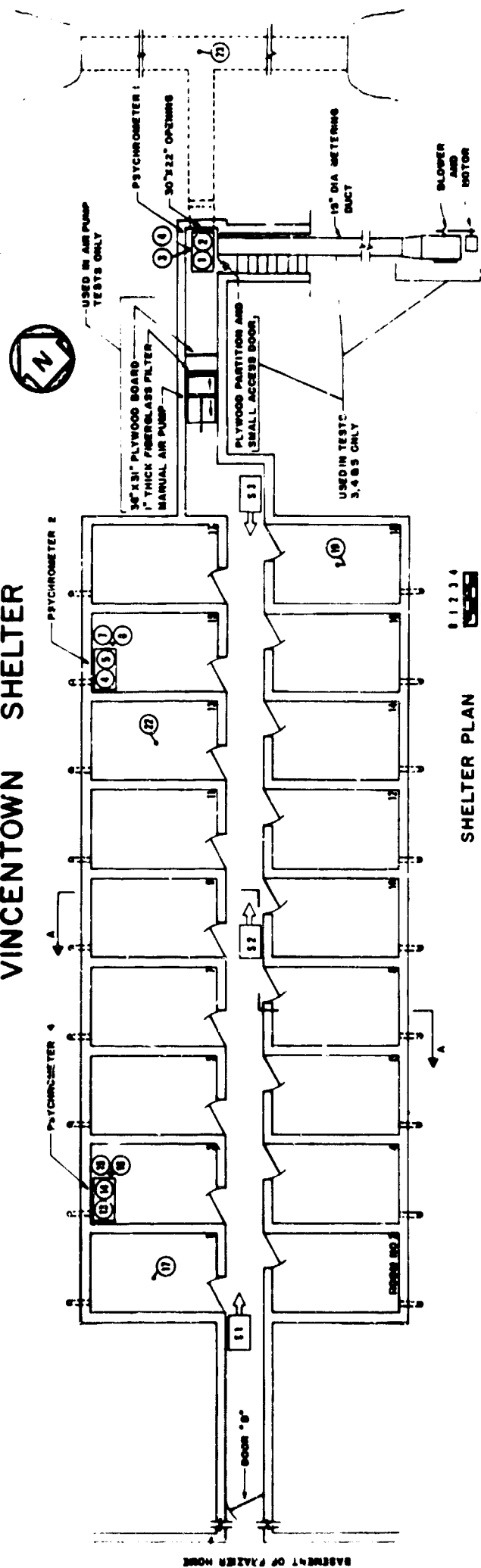
SHELTER PLAN
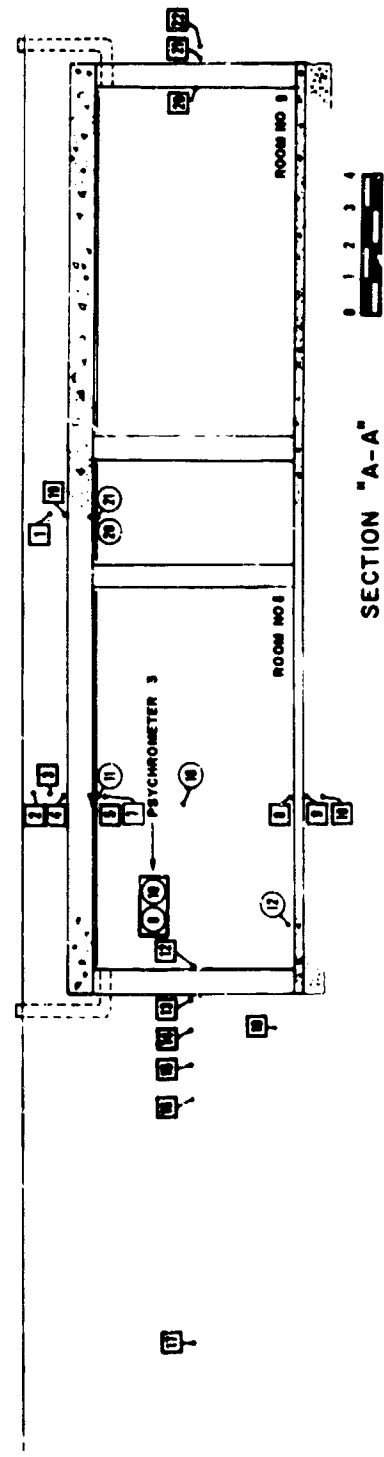
SECTION "A-A"

EQUIPMENT AND INSTRUMENTATION LAYOUT

FIG. NO. 19

air pump with a 1-in. thick fiberglass filter was measured for three

conditions of shelter resistance to air flow:

Pump Test	Shelter Conditions (see Fig. No. 18)
A	Minimum resistance (Doors A, B, doors in Frazier basement, 30 in. x 22 in. opening to culvert and 18 - 4-in. diameter exhaust pipes all open; 36 in. x 31 in. plywood partition in corridor on pump inlet)
B	Maximum resistance (same as Test A, except that Door B was closed)
C	Less than maximum resistance (same as Test B except that 36 in. x 31 in. partition was removed)

2.9.3 Observations

1. This shelter has a relatively poor heat sink. The percentage of
   the shelter's internal heat load that was transferred to the surround-
   ing soil varied from a maximum of 30 per cent (Test 2, Natural Venti-
   lation, minimum air flow rate of 1.7 cfm/person) to a minimum of
   14 per cent (Test 4, maximum forced air flow rate of 11.1 cfm/person).

2. The inefficient heat sink was due to poor soil conductivity and
   construction features peculiar to this shelter. These construction
   features are: the location of the shelter floor above the water table;
   the unfilled core spaces in the concrete block walls; and the plywood
   forms (in various stages of decay) on the shelter ceiling.

3. The average natural ventilation flow rate of the shelter was 200 cfm.
   The average natural ventilation flow rate for Test 2 was the same as
   for Test 1, even though larger area air inlets were used in Test 2
   and even though higher wind velocities prevailed during Test 2.

4. The natural ventilation rate apparently was limited by the large
   number of internal shelter partitions and the size of the air exhaust
   pipes. Wind velocities had small effect on the natural ventilation
   rate because the inlet air openings were located at or below grade.

5. With an occupancy density of one person per 10 sq.ft. of floor area
    and a natural ventilation flow rate of 200 cfm, the shelter ET rose
    above 85°F, even though abnormally cool summer weather prevailed
    during Natural Ventilation Tests 1 and 2.

6. Using a coefficient of heat transfer, U = 0.18, and a natural ven-
    tilation flow rate of 200 cfm, the predicted shelter capabilities are
    as follows:

Shelter Eff. Temp. (°F)	Outside Air Temperature (°F)	Outside Air Percentile Design Level	Shelter Occupancy (Persons)
85	89 DB--76 WB	5	45
85	86 DB--75 WB	10	48
85	83 DB--74 WB	15	52
85	79 DB--72 WB	25	60
85	<79 DB-<72 WB	>25	117*

*Rated occupancy corresponding to one person/10 sq.ft. of floor area.

7. An unconventional manual piston-type pump, similar to the one tested
    can be used to supply 1275 cfm of air using the existing shelter
    inlet and exhaust openings at a cost of about 35¢/occupant (for
    rated occupancy of 117 persons).

8. Calculations indicate that at the 5 percentile summer design level,
    1275 cfm of forced ventilation will limit the shelter ET to 85°F
    at rated occupancy.

9. Test results indicate that the ET of rooms nearest the inlet air
    (i.e. Room No. 15) averaged about 5°F lower than the ETs of rooms
    farthest from the inlet air (i.e., Room No. 3)

10. The results of the water-cooled heat exchanger test illustrate the advantages of having a supply of cool water with which to maintain tolerable shelter environmental conditions. 0.032 gpm/occupant of $60^{\circ}F$ water removed 2600 BTU/hr from Room No. 3, while reducing its ET from $85.5^{\circ}F$ to $82.5^{\circ}F$. Additional air circulation, provided by a directional punkah, increased the heat removal rate to 3300 BTU/hr and decreased the ET another $1.2^{\circ}F$.

11. The use of a water-cooled heat exchanger in conjunction with a forced air system would further improve this shelter's habitability performance. A $68^{\circ}F$ water supply is available in the culvert 12 ft. north of the shelter.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 High-Rise Buildings and Other Above-Ground Spaces

A total of five above-ground shelters were tested, of which three (Building No. 7 of John Adams Houses, the 40 Wall St. Building, and the AMA Building) were in high-rise buildings; the other two (Public School 115 and Public School 21) were in, respectively, four- and three-story structures. In all cases only the central core areas, specifically the public corridors, were tested. This does not represent all of the identified shelter space on the tested floors but is the area with the highest protection factor.

It would be advantageous if the entire floor population could be housed in the core area without exceeding the shelter's rated capacity of one person per 10 sq. ft. of floor area. In Building 7 this is feasible. Housing Authority regulations limit tenant population in this building to 37 persons per floor. Since hallway area is 400 sq. ft. per floor, there is a slight surplus of space. In office buildings there are no corresponding regulations on building population. However, standard estimates, confirmed by the superintendents of the tested buildings, place occupancy at about one person per 100 sq.ft. of office area. Thus, if all occupants are to be sheltered in the core area, keeping within the rated capacity, the ratio of office area to core area must not exceed 10:1. Although in commercial-type high-rise buildings the approximate ratio of core area to rentable floor area is generally at this level, this was not the case in the two office buildings tested. In the AMA Building the ratio was 14:1, while in the 40 Wall St. Building it was 12.6:1. This means that in these buildings either overcrowding must be tolerated or some of the occupants must be sheltered in lower quality areas.

To test the effect of overcrowding, some tests were run with densities as high as one person per 6 sq.ft. of floor area in the 40 Wall St. Building. In this case, during days typical of a 25 per cent New York City summer design day (but with rather high winds), the shelter effective temperature (ET) did not exceed $80^{O}F$. In a similar test in the AMA Building, with shelter density at one person per 6-2/3 sq.ft. of floor area, the ET did not exceed $85^{O}F$. Thus, from a thermal standpoint alone, some summer overload capability does exist in this type of shelter, even when natural ventilation is used.

In general the analysis of a particular shelter for predicting the temperature resulting from a given occupancy load and given ventilating air conditions must include the sensible heat transfer ed through shelter boundary surfaces. However, in all five above-ground shelters the coefficients of heat transmission (ranging from 0.21 BTU/(hr)(sq.ft.)(^{O}F) in the 40 Wall St. Building to 0.31 BTU/(hr)(sq.ft.)(^{O}F) in the AMA Building) and the surface area per occupant were so low that during the summer months the shelter should be considered as <u>adiabatic</u>. This means that as a vehicle for disposing of the heat and moisture generated in the shelter, only the ventilating air should be considered. Boundary heat losses, in the tests generally less than 10 per cent of the total heat input, provide at best a small safety factor.

This being the case, the only variable remaining to specify the shelter temperature (under given occupancy and outside air conditions) is the quantity of ventilating air. To study the ventilation which might be obtained, the test program considered three general modes of natural ventilation:

(a) cross ventilation,

(b) updraft (stack effect), and

(c) closed shelter and closed building operation.

Where possible the results obtained were compared with the formulas given in Chap. 24 of Ref. 12, for predicting the ventilation due to wind forces and temperature difference forces, to test whether these formulas give an accurate prediction of shelter ventilation.

In most tests the ventilation rate could not be measured directly since the instantaneous rate varied rapidly. Since the Simocs vaporize a known quantity of water vapor into the shelter air, the conservation of water mass could be used to compute an approximate average ventilation rate.

In the cross ventilation tests, ventilation openings varied from 8 sq. ft. to 67 sq. ft. at both inlet and outlet; winds encountered averaged about 5 mph, with a maximum of about 15 mph. Ventilation rates ranged from a low of about 4 cfm per person (in an overload test in the AMA Building) to a high approaching 50 cfm per person (in the Public School 115 shelter).

Generally the formulas given in Ref. 12 gave reasonably accurate results when the effectiveness of the wind was taken to be 0.2 to 0.25. This is the value typical of diagonal winds. In the two tests where large discrepancies resulted, the formula predicted ventilation rates higher than were obtained. But in these tests the wind fluctuated rapidly in velocity and direction, and it seems reasonable that such winds would be less effective than a more steady wind.

Two factors present in this formula were not investigated in the test program. First, it predicts that ventilation will increase linearly

with the area of ventilation openings, and second, it assumes that internal resistance is negligible. Obviously, beyond some point the opening of more windows will not measurably increase the ventilation rate, and if the shelter has high resistance or is disadvantageously placed, the ventilation can be a great deal less than that predicted. Thus some caution must be exercised in applying the formula, but in the range considered in the tests it yielded reasonably accurate results.

Therefore, if data on the winds at the shelter site are available, the cross ventilation rate can be predicted fairly accurately. Usually the wind data available have been recorded at an observatory more or less remote from the shelter location. During the test series the wind data recorded at the test site were compared with those reported by the weather bureau. It was determined that in direction they generally agreed, but there was less correlation between the respective velocities, although at the test site the velocity tended to average lower than at the observatory.

In the updraft tests stairwells, and in the 40 Wall St. Building, an airshaft were used as low resistance stacks. In addition, in one test conducted in the basement shelter of Public School 115, the temperature difference between the bottom and the top openings of 8-ft. high windows provided the driving force. In every case more ventilation was obtained when updraft was used, either alone or in conjunction with cross ventilation, than when cross ventilation alone was used. The increase was least in Building No. 7 where a relatively small, 16.5 sq.ft. stack opening and a 34-ft. high stack were used; it amounted to approximately 100 per cent in the AMA Building and the 40 Wall St. Building where the stack opening was 21 sq.ft. and the height 60-100 ft. Since none of the tests

were conducted in weather as severe as, say, the 5 percent summer design level, no data could be taken on the effectiveness of updraft ventilation under such conditions. However, since the metabolic sensible heat ratio decreases with higher dry bulb temperature, thus reducing the dry bulb temperature differential between the shelter and outside air, it can be postulated that updraft will not be effective under severe outside air conditions. Evidence of this was observed, for example, in Test 2 in the AMA Building, which used both updraft and cross ventilation. Here, during the night, when the dry bulb temperature was low, the ventilation rate was almost double that obtained with cross ventilation alone, while during the day the increase was only about 25 per cent. This means that updraft ventilation is least available when it is needed most. Probably the most effective application of updraft ventilation, aside from augmenting cross ventilation, will be to make habitable with moderate outside air conditions an overcrowded shelter or one with poor provision for cross ventilation.

Unfortunately the formula given in Ref. 12 for predicting updraft ventilation proved far less satisfactory than the corresponding formula for cross ventilation. This is due primarily to its failure to include the air resistance in the shelter and in the stack. Generally the observed ventilation was only about 30 per cent to 50 per cent of the predicted rate. However, in two cases, the upstairs shelter of Public School 21 and the basement shelter of Public School 115, good agreement between observed and predicted flows was obtained. In Public School 21, where a 25-ft. high stairwell was used as the stack, the constant of proportionality was determined empirically to be 8.3. In the basement shelter of P.S. 115, two updraft tests were conducted. In the first test, air exhausted at the top of the 8-ft. windows; here a constant of 7.6 gave

accurate results. In the second test, an 85-ft. stairwell leading to the
roof was used as the stack. The constant of proportionality was determined
to be 6.3. These were, however, the only cases where the formula did seem
to be accurate; generally more experience with this formula seems to be
necessary before it can be used to predict ventilation in fallout shelters.

In the closed shelter studies it was determined that if the shelter
itself were sealed, the low coefficients of sensible heat transmission
and the small air volume per person meant that the ET would rise within
three or four hours to above $85^{O}F$. However, studies in the AMA Building
and the basement shelter of P.S. 21 showed that if the shelter were left
open and all outside windows and other openings shut, the shelter might
remain habitable for a period of hours, or even days. A mechanism of
air exchange was created by the dry bulb temperature difference between
the shelter and the surrounding area, with cooler air flowing in at the
bottom of each shelter opening and hotter air exhausting at the top.
In the AMA Building, with a temperature differential of $8^{O}F$, a total of
about 1240 cfm was observed to be flowing through three 7 ft. x 3 ft.
doors. In P.S. 21, with a $10^{O}F$ temperature differential, about 1650 cfm
was flowing through one 7 ft. x 3 ft. door, and one 4 ft. x 2.5 ft. open-
ing at the bottom of the shelter wall. If a simplified model of the
openings is used, which assumes half the opening height used for inlet
and half for outlet and also assumes a linear distribution of air velocity
with respect to opening height (this agrees fairly well with velocity
measurements taken with an anemometer), the effective opening can be taken
as half the actual area and the "stack height" as half the opening height.
Using these values, the updraft formula of Ref. 12 can be applied, which
agrees with the flow in the AMA Building if a constant of 6.4 is used,

but in the case of P.S. 21 gives a flow of only half the observed rate even if the constant of proportionality is taken as 9.4, the maximum value.

As a means of comparing the various above-ground shelters and to give a first approximation to the maximum summer conditions under which the shelters will remain habitable, the New York City percentile summer design level conditions have been determined under which the shelter ET should not exceed 85°F, assuming natural ventilation only, when the shelter load is one person per 10 sq.ft. of floor area. As recommended above, an adiabatic shelter model has been used, and the ventilation openings assumed are those actually present during the tests. Because under severe summer conditions updraft will probably not be effective, only cross ventilation is considered. As recommended in Ref. 12, winds of approximately half the average summer velocity, or about 5 mph, have been assumed; either calm or high velocity winds could materially alter the shelter ET.

The results of this calculation are given in the following table:

| Shelter | Assumed Ventilation | | % Level for 85°F |
	CFM	CFM Per Person	
Building No. 7 John Adams Houses	880	22.0	2.5
40 Wall St. Bldg.	750	9.7	15.0
AMA Building	1160	7.2	25.0
P.S. 21	1940	12.5	10.0
P.S. 115	1740	43.5	1.0

In the case of the AMA Building this simple model probably gives an unduly pessimistic rating. For at the 25% summer design level the dry bulb

temperature, 78°F, is so low that some boundary heat transmission will
occur, especially in this building which, because of its glass wall con-
struction, had the highest coefficient of heat transmission of any build-
ing tested. Further, the amount of ventilation which this shelter receives
could easily be increased. Fig. No. 5 shows the opening to the east of
the shelter through which about 85 per cent of the air entering the build-
ing short circuited around the shelter. If this path were closed off
the rating could probably be increased to the 15 per cent or 10 per cent
design level.

The above example illustrates how judicious use of building geometry
can increase the amount of ventilation which a shelter receives. Every
effort should be made to insure that when cross ventilation is used, the
only path available to the air inside the building passes through the
shelter.

Another area for discretion is the choice of ventilation openings.
The increased ventilation obtained in Test No. 7 performed in the 40 Wall
St. Building over that in Test No. 6 shows the advantage of opening win-
dows facing directly into the wind direction. For most cities the
direction of the prevailing summer wind is available (Ref. 12 or 13,
for example); shelter openings could be planned to favor winds from
this direction to ensure efficient cross ventilation. When building
interfaces provide natural funnels for air current, windows at the end
rather than at the sides of such a funnel should be opened.

Should radioactive particle ingress prove to be a problem, control
of ventilation openings can help to reduce the fraction reaching the
shelter. In many above-ground shelters there are outer rooms available--

offices, class rooms, apartments--which can be used as settling chambers. In the absence of these the openings could be chosen to maximize path length from the inlet openings to the shelter area. However, until experimental evidence on particle ingress is available, it is difficult to assess how much of a problem this will be.

When using updraft ventilation, too, a judicious selection of openings will maximize the amount of ventilation received. Openings to the stack should be large and the stack should be as tall as possible. It 's not known what the effect would be of multiple use of a stack by shelters on adjacent floors, but in the 40 Wall St. Building, where heat producing equipment was located in the air shaft, five stories below the shelter, more updraft was obtained with this additional heat input than without it.

However, it is probable that updraft using a stack will not be available to the upper floors of a building, since not only do they lack stack height but part of the air rising from below might exhaust through these shelters, in effect ventilating the occupants with hot, humid air from other shelters.

Even when the use of some sort of stack is not possible, shelters can make some use of updraft merely by opening windows at the top as well as at the bottom. The natural temperature stratification will cause hot air to flow out at the top and cooler air to flow in at the bottom, as was demonstrated in Test No. 1 in the P.S. 115 basement shelter.

3.2 Below-Ground Spaces

3.2.1 Heat Transfer to Soil

Heat balance calculations based on test data for below-ground spaces indicate that for high shelter ventilation rates per occupant the heat transferred to the surrounding soil is a small percentage of the total shelter heat load (simulated occupants plus instrumentation) even though the shelters' soil conductivities may be quite different. For example, the New Canaan underground shelter has an efficient heat sink with a soil conductivity of 19 BTU(in.)/(hr.)(sq.ft.)(^{O}F) and the Vincentown underground shelter has a poor heat sink with a soil conductivity of 8 BTU(in.)/(hr.)(sq.ft.) (^{O}F). At a ventilation rate of 8.9 cfm/occupant, approximately 20 per cent of the total New Canaan shelter heat load was transferred to the surrounding soil; at a ventilation rate of 11 cfm/occupant approximately 14 per cent of the Vincentown shelter heat load was transferred to the surrounding soil. At these high ventilation rates, a large part of the shelter's total head load is removed by the ventilating air and the heat sink plays a minor role in heat dissipation.

However, soil conductivity apparently has a pronounced effect on the percentage of heat transferred through the shelter surfaces to the surrounding media in underground shelters for low ventilation rates or under button-up conditions. The New Canaan shelter's efficient heat sink absorbed over 80 per cent of the total shelter heat load at a natural flow rate of 0.9 cfm/occupant, whereas the Vincentown shelter's relatively poor heat sink could only absorb 30 per cent of the total shelter heat load at a natural flow rate of 1.7 cfm/occupant. It should be noted that part of the inefficiency of the Vincentown heat sink should be attributed to certain construction features (e.g., the location

of the shelter floor above the ground water table, the unfilled core
spaces in the concrete block walls, and the plywood forms on the shelter
ceiling) which hindered heat transfer to the soil.

Although circumstances precluded the obtaining of soil conductivity
data for the other partially-buried, below-ground spaces (home basement,
Westchester; P.S. 115 basement cafeteria; and P.S. 21 basement), the
approximate percentage of the total shelter heat load transferred to
the surrounding soil during high ventilation flow rates is indicated
below:

Shelter	% of Total Sur- face Area Adja- cent to Soil	Ventilation Rate (CFM/Occupant)	% of Total Shelter Heat Load Trans- ferred to Soil
Home Basement, Westchester	58	7.0	20.2
P.S. 115 - Basement Cafeteria	40	9.5	20.2
P.S. 21 - Basement	48	6.6	21.8

While soil conductivity is an important factor in maintaining tol-
erable environmental conditions in below-ground shelters (without bona
fide internal heat dissipation equipment) under low ventilation flow con-
ditions or button-up periods, the quality of soil conductivity exerts a
minor influence upon heat transfer to the surrounding soil for below-
ground shelters with high ventilation rates.

The calculated heat flux, based on the below-ground shelter test
data, was found to be 25 to 60 per cent higher than the recommended
ASHRAE (Ref. 12, Chap. 25, Table 5) values of below-grade heat losses
for basement walls and floors.

3.2.2 Natural Ventilation

The natural ventilation tests performed during summer weather on below-ground shelters indicate the following levels of confidence with rated shelter occupancy loads (assumed as one person/10 sq.ft. of floor area):

Shelter	Occupants	Natural Vent. (CFM)	Outside Air Percentile Summer Design Level	Hours per Normal Year
Home Basement Westchester	90	630	15%	450
P.S. 115 Basement Cafeteria	348	1400	12-1/2%	375
P.S. 21 Basement	255	1685*	12-1/2%	375
Vincentown	117	200	>25%	>750

*This "natural" ventilation flow was induced from non-ventilated adjacent areas by temperature stratification of shelter air. This was a hypothetical case, because these adjacent areas would be used by shelter occupants.

Air flow through a shelter can be produced by two natural effects. First, air flow is caused by outside wind forces and is dependent on wind speed and direction. Second, the difference in temperature between the column of air in the outlet "stack" and the outside air induces an air flow through the shelter which is a function of the temperature difference, the height and resistance to flow of the stack, and the effectiveness of the inlet and outlet openings. Both effects are also dependent on the area of the inlet and outlet openings and the resistance to flow through the shelter. Air flow due to wind forces was considered negligible for those below-ground shelters whose air intakes were either at or below grade.

As expected, the below-ground shelters with the largest air openings, the Westchester home basement (two 3 ft. x 6 ft. doors) and the P.S. 115 basement cafeteria (3 ft. x 8 ft. windows and a large stairwell)

could maintain a shelter effective temperature (ET) of 85°F or less under rated occupancy loads when naturally ventilated with outside air at 15 percentile and 12-1/2 percentile summer design level conditions, respectively. The basement area tested at P.S. 21 has no window openings, and the test conditions used to induce flow by temperature stratification are hypothetical. Calculations indicate that if 3 cfm per person of forced ventilation were provided in this basement area, the shelter ET would rise above 90°F at rated occupancy if the outside air conditions exceeded the 25 percentile summer design level. The Vincentown shelter has a low natural ventilation flow rate because of the small exhaust openings (18 4-in. diameter pipes) and the high resistance to flow in the shelter. Although the New Canaan shelter also has a low natural ventilation flow rate, it has forced ventilation equipment capable of supplying over 11 cfm/person at rated occupancy.

If 15 percentile summer design level conditions are an acceptable level of confidence for below-ground spaces, then additional ventilation and/or cooling is not required for the home basement (Westchester) and the P.S. 115 basement cafeteria. Additional ventilation and/or cooling would be required for the P.S. 21 basement and the Vincentown shelter.

The table below lists the additional ventilation required by the below-ground shelters at rated occupancy with outside air at the 5 percentile summer design level conditions.

Shelter	Rated * Occupancy	Shelter Eff. Temp. (^{o}F)	Natural Ventilation CFM	Natural Ventilation Occupants	Total CFM required to Support Rated Occupancy*
Home Basement Westchester	90	85	630	57	990
P.S. 115 Basement Cafeteria	348	85	1400	210	2320
P.S. 21 Basement	255	85	1685**	154	2750
Vincentown	117	85	200	45	1275

*Assumed as 1 person/10 sq.ft. of shelter floor area.
**Hypothetical test conditions.

The inclusion of large area intake and outlet openings and low shelter resistance into the design of below-ground shelters would not only increase the natural ventilation flow rate but also enhance the performance of future installations of manual or power-driven ventilation equipment.

3.2.3 Winter Conditions

The New Canaan shelter test results suggest that undercrowded underground shelters (located in the northeast part of the country) with efficient heat sinks may present habitability problems for shelter occupants during the winter months because of low shelter effective temperatures. Occupants may shut off ventilation air in an effort to keep warm and inadvertently subject themselves to carbon dioxide toxicity.

Some measures should be considered to lessen the possibility of CO_2 toxicity, such as: (a) providing suitably printed shelter instructions warning shelter occupants of the hazards if ventilation air is shut off; (b) stocking CO_2 absorption agents in the shelter; and (c) supplying the shelter with a CO_2 concentration level detector.

It should also be remembered that carbon monoxide is another possible hazard due to outside fires or due to occupants smoking within the shelter.

Therefore, a CO detection system might also be considered a shelter requirement.

Application of thermal or radiant reflective type of insulation materials on the shelter surfaces is one method of increasing shelter ETs without reducing minimum shelter ventilation. Although there are other ways of increasing the shelter temperatures (e.g., electric heaters), the use of the insulating material will also maintain the heat sink for possible extended closure or natural ventilation periods. The insulation material could be applied by occupants if low shelter temperatures required it; and, if at a later time shelter temperatures rose too high, then a portion of the insulation could be removed from the shelter surfaces. This would expose part of the preserved heat sink and help to maintain tolerable shelter temperatures, even when ventilating the shelter with the minimum cfm required to prevent CO_2 toxicity.

For underground shelters with forced ventilation systems, it may be possible to increase (or maintain) the effectiveness of the heat sink on a continuous basis by the addition of an indoor-outdoor thermostatic controller such that forced air would circulate through the shelter space whenever the outdoor temperature fell below the soil temperature. This would also serve to exercise the ventilating system.

3.3 Manual Ventilating and Cooling Devices and Other Means of Improving Shelter Habitability

Although above-ground shelters will derive sufficient ventilation during most of the year using natural ventilation alone, below-ground shelters may need supplementary ventilation equipment. Furthermore, even in above-ground shelters stagnant areas may exist, such as the one noted in the 40 Wall St. Building, where the ET was $7^{\circ}F$ to $8^{\circ}F$ higher

than the shelter average. And in most of the tested shelters a dry bulb temperature difference of $4^{\circ}F$ to $8^{\circ}F$ existed between the floor and the ceiling; this would be significant if tiered bunking were used. To correct these inhomogeneities, some means of distributing air within the shelter would be desirable.

On a cost-effectiveness basis simple, manually-operated pumps and other devices may be the best means of providing the additional ventilation or air distribution. To study the capabilities of such devices, a number of tests were conducted, as described in appendices A, B and C, of piston pumps, lightweight polytheylene ducts, and directional punkahs. An additional test of a piston pump combined with a well-water fin coil unit is described in Ref. 9, and a test of a simple water-cooled heat exchanger is described in Ref. 11. Many of these devices were the invention of Cresson H. Kearny, now with Oak Ridge National Laboratory. A more recent development, producing what may be the most effective air pump in a shelter with low resistance, involves suspending a large directional punkah in the shelter doorway, surrounded by a plywood or fabric housing. In a test at the Protective Structures Development Center, Fort Belvoir, Virginia, a pump of this type delivered 5000 cfm to a shelter without a filter, and with a 1-in. fiberglass filter, pumped 3500 cfm into the same shelter (Ref. 14).

All of the pumps tested had in common the feature of being able to move large volumes of air with a very low expenditure of energy--in the case of the directional punkah the work rate was only 0.0067-hp to pump more than 2400 cfm. Operating several punkahs simultaneously, it becomes feasible to distribute air to all parts of the shelter and to fan bodies of occupants at the same time.

Either the directional punkahs or the plastic duct system would also be useful to distribute air to all parts of the shelter in those shelters where a mechanical blower is envisioned. In a dual-purpose shelter area the plastic ducts have an advantage over regular ductwork in that they may be strung on a supporting wire and stored folded, unobtrusively, against one wall of the shelter, to be extended along the supporting wire only when actually needed.

When the piston pump is combined with a water-cooled fin coil, the ventilating air can be cooled as well. Although more work is needed on the most effective arrangement of such a pump and coil unit, the initial test described in Ref. 9 showed that, with a water flow rate of 39 lbs. per minute and a water temperature rise of $10^{\circ}F$, 23,400 BTU/hr or half the heat input to the shelter was removed by the coil unit.

In the test of the simple heat exchanger described in Ref. 11, with a water flow rate of 3 lbs. per minute and a temperature rise of 15^{C}, approximately 2600 BTU/hr were removed from the shelter air. When a punkah was used to blow the air against the exchanger, this was raised to 3300 BTU/hr.

Thus, in shelters where well water is available, the environmental problem is greatly alleviated. Although more developmental work is required to determine the optimum equipment for utilizing this water, some form of heat exchanger used in conjunction with a manual pump seems to be very effective as a means for improving shelter habitability at low cost.

In shelter areas where the ventilation air enters at one end of the shelter and sweeps through the length of the shelter to exit at

the far end, a substantial ET gradient will occur. In the Vincentown
underground shelter, which is subdivided into individual cells, the
cells farthest from the air inlet averaged 5°F higher in ET than
the cells nearest the air inlet opening; the 40 Wall Street above-
ground shelter averaged a 3° to 6°F rise in ET between inlet and outlet
areas. The use of electro-mechanical Simocs probably has distorted
this effective temperature gradient between inlet and outlet areas to
a certain degree. Even though the ET gradients might decrease under
live occupancy conditions, shelter managers should recognize the need
for rotating occupants within the shelter area in order to improve
shelter habitability.

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6. APPENDICES

APPENDIX A. PLASTIC DUCT TEST

A test was made in the basement shelter of Public School 21 to evaluate the practicality of using large diameter, thin-walled polyethylene tubing in conjunction with a mechanical blower to provide an inexpensive and unobtrusive emergency ventilation system.

The types of duct tested and their respective costs, based on the New York City price for polyethylene tubing of 50¢ a pound (polyethylene is commonly sold by weight), were:

(1) 3 ft. diameter tube with 4 mil. walls; cost 9¢ per ft.; weight 0.18 lbs. per ft.
(2) 2 ft. diameter tube with 3 mil. walls; cost 4½¢ per ft.; weight 0.09 lbs. per ft.
(3) 1 ft. diameter tube with 1.25 mil. walls; cost 1¢ per ft.; weight 0.02 lbs. per ft.

Experimental intersections of these 3 ft., 2 ft., and 1 ft. diameter ducts were formed using cutting patterns and duct tape. In practice it was found that the 45° bends gave no better performance than the 90° bends while being considerably harder to make. Hence for these tests only 90° intersections were used.

For the main test the arrangement of ducts shown on Figure A1 was constructed and laid on the floor of the shelter. When the blower was turned on it was discovered that if the tubes continued full diameter to their open ends, severe fluttering resulted. This was easily eliminated by partially constricting the ends to increase the positive pressure inside. It was also found that at velocities exceeding 400 fpm pronounced vibration occurred in the main, 3 ft. diameter tube. However, another investigator* has routinely used a 6 mil. 2 ft. diameter tube at velocities up to 2,000 fpm with no reported trouble, so the vibration problem may be inherent only in the thinner and larger tubing.

On Figure A1 are indicated the velocities and volumetric flow rates measured inside and at the ends of the ducts. For this test a reasonably even distribution pattern was obtained immediately, but should adjustments be necessary, they are easily effected by greater or lesser constriction of the several tube ends.

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*B.A. Libovicz et al., "Summer Ventilation Test of 200-Occupant Basement Shelter in Milwaukee, Wisconsin," GATC Interim Report NRD 1105-54-2, Contract OCD-OS-62-134, Niles, Ill., April 1964.

Subsequent to this test one section of duct was suspended on loops connected to a wire stretched taut near the ceiling (see Figure A2). Since even the largest duct weighs only 0.18 lbs. per ft., support strength is an insignificant problem. To conserve space and to avoid puncturing the fragile plastic, ceiling suspension is probably the best way of mounting these ducts.

However, because of their bulkiness and fragility, some difficulty was experienced in hanging the ducts, even in an empty shelter with good illumination. To avoid the possibly hazardous complications of assembling and hanging these ducts during an emergency situation in a crowded shelter, it would probably be best to prefabricate the duct system, hang it from the supporting wire, and then store it folded flat (accordion fashion) in a box attached to the wall at one end of the wire.

BASEMENT SHELTER

POLYETHYLENE DUCT AIR DISTRIBUTION SYSTEM

FIG. A1

PLASTIC DUCT SUSPENDED FROM WIRE
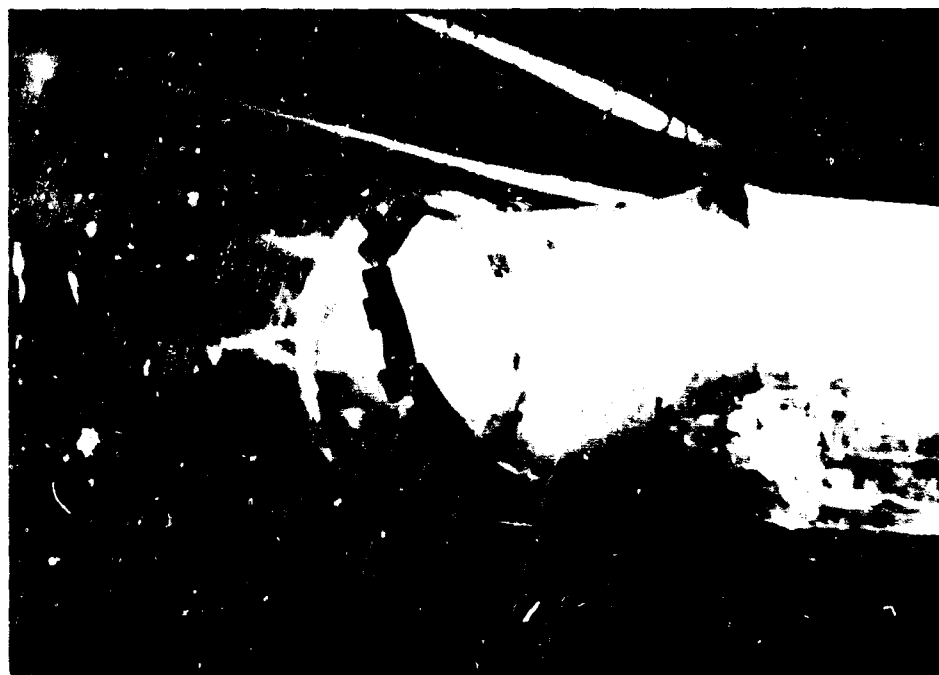
INTERSECTION IN SUSPENDED DUCT SYSTEM

FIG. A2

APPENDIX B. DIRECTIONAL PUNKAH TEST

At the conclusion of the regular test series a test was made of the feasibility of using directional punkahs to distribute air and to fan shelter occupants in lieu of or as an adjunct to a conventional air distribution system.

The directional punkah was invented by Mr. Cresson H. Kearny, now with Oak Ridge National Laboratory. As illustrated on Figure B1, it is composed of a rectangular steel or wooden frame (in this model 36 in. by 28 in. strung with mesh or parallel wires. To these wires are fastened polyethylene flaps so mounted as to form a network of one-way air valves. (The principle is not unlike a simple hearth bellows which uses a single leather flap valve.) The punkah is suspended by hinges from a ceiling, pipe, etc. and is driven like a compound pendulum by a cord pull which passes over a pulley and is pulled with a vertical motion. During the power stroke the valves close, pushing air ahead of the punkah, while during the recovery stroke they open, offering little resistance and thus creating no counter flow of air.

A preliminary test was made of the air-moving capacity of a single steel frame punkah, operating alone. With a swing of 120° and a 1.8 second period this punkah moved a measured average of 2400 cfm through a 31 sq. ft. vertical plane area set 3 ft. in front of the punkah. Air velocity in this plane averaged 80 fpm with the maximum being 225 fpm. Additional air was distributed at either side of this plane area, but at velocities below 30 fpm and hence not suitable for fanning shelter occupants.

The power required to operate this punkah was later measured using a camera exposing 80 frames per second and a spring gauge connected in the pull rope. It was determined to be 0.0067 H.P.

For the main test of air distribution thirteen directional punkahs--12 crudely built 36 in. by 30 in. wooden frame punkahs and the more efficient steel frame punkah tested above--were hung at an average height of about 8 ft. above the floor near the shelter walls, arranged to move air in a clockwise direction as shown on Figure B2. The punkahs were ganged to permit operation by five persons. (More efficient ganging could have reduced the number of operators to four or fewer.)

During punkah operation air flow measurements were taken at various locations in the shelter at a height of 4 ft. above the floor. These measurements are given on

Figure B2. They indicate velocities exceeding 50 fpm over roughly 1/3 to 1/2 the floor area of this shelter. Had additional punkahs been installed in the center of the shelter, air velocities exceeding 50 fpm could easily have been achieved throughout the entire shelter.

A more careful traverse was made at section A-A (see Figure B2) to determine the volumetric distribution rate. Through a plane area 12' wide and 9' high (over which the minimum velocity exceeded 30 fpm) approximately 5,000 cfm were observed to be moving. Additional air was moved to either side of this area, but at velocities below 30 fpm and hence not suitable for fanning shelter occupants. Since twelve of the thirteen punkahs used in this test were crudely built and relatively inefficient, this figure probably represents the minimum ventilation rate obtainable with this arrangement. Indeed, Figure 2 shows that the highest velocity obtained, by a considerable margin, was located in fromt of the more efficient steel frame punkah.

Conclusions: This test indicates that directional punkahs, even when crudely built, can be used to distribute large volumes of ventilating air at velocities high enough to fan shelter occupants' bodies. The effort required to operate the punkahs is minimal and by ganging them together few people are needed to work the punkahs. Floor area requirements are essentially zero, and by using a pulley and a vertical stroke even the operator requires no extra space.
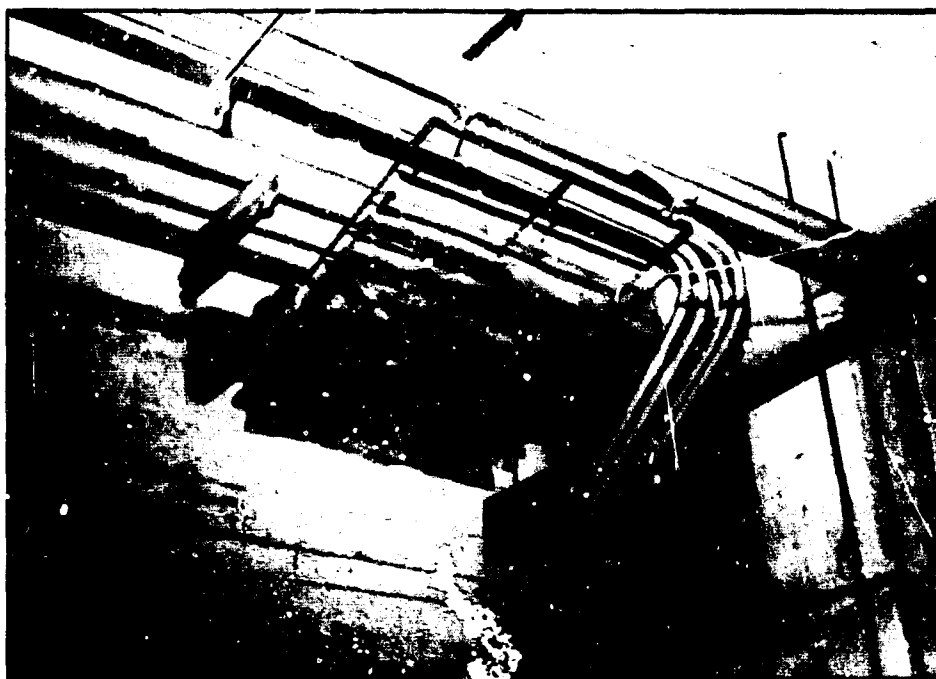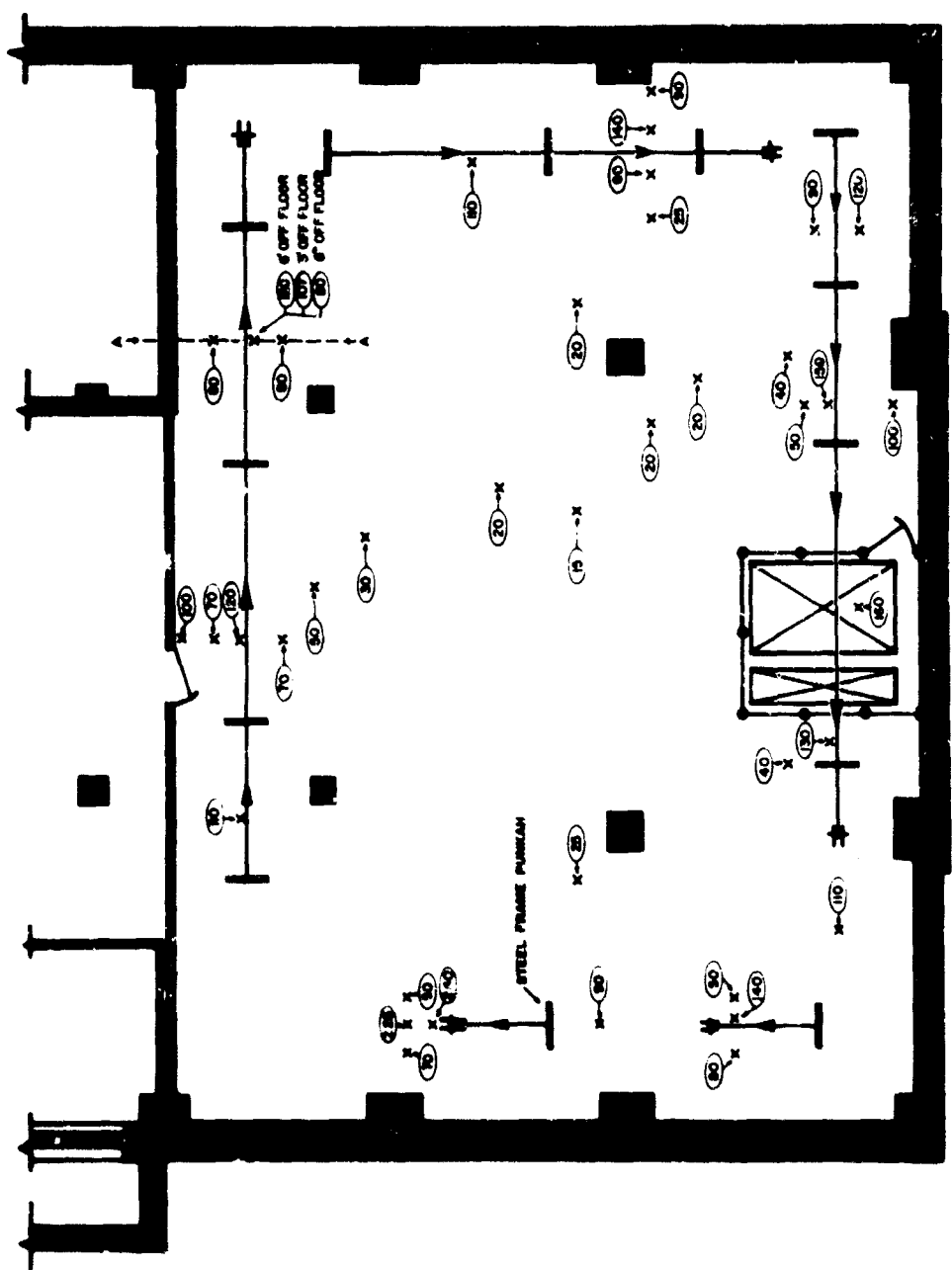
DIRECTIONAL PUNKAH--END OF RETURN STROKE
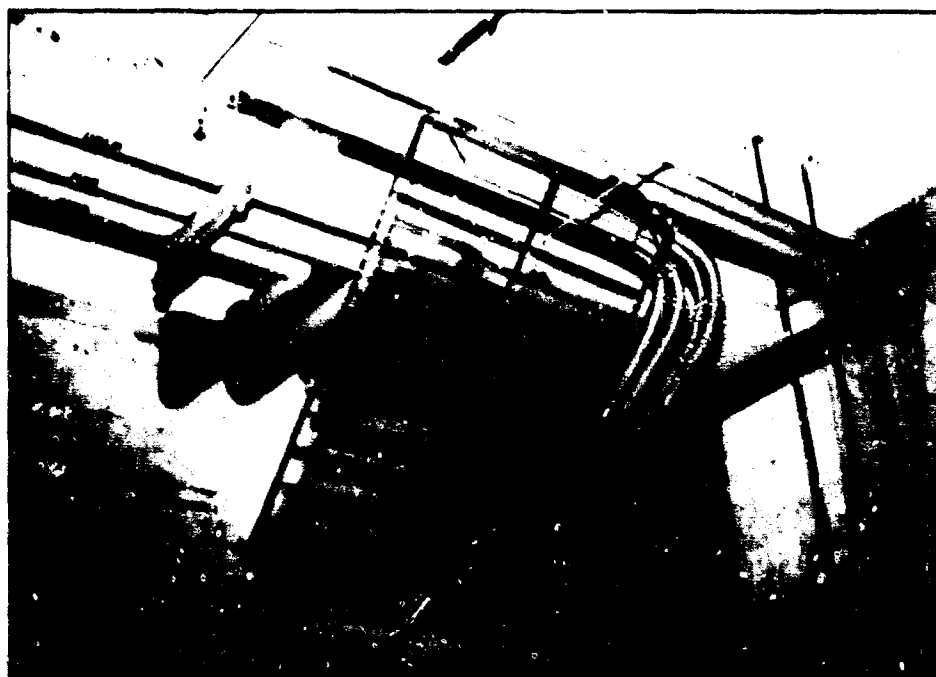
DIRECTIONAL PUNKAH--BEGINNING OF POWER STROKE

FIG. B1

BASEMENT SHELTER

DIRECTIONAL PUNKAH TEST

LEGEND

—— PUNKAH

→→ PULL WIRE AND PULLEY
(ARROW SHOWS AIR FLOW DIRECTION)

○ AIR VELOCITY IN FPM

NOTE: VELOCITY MEASUREMENTS TAKEN 4 FT
ABOVE FLOOR EXCEPT WHERE NOTED

FIG...B2

APPENDIX C.   PISTON VALVE PUMP

This appendix describes the test made in the corridor
shelter of P.S. 21 of a manual piston pump using the same
one-way valve construction as the directional punkah described
in Appendix B. This pump, illustrated on Figure C1, is
designed to be installed in a shelter doorway; for this test
it was used with a one-inch fiberglass filter.

The pump face measures 29 in. wide by 71 in. high. The
stroke length is 40 in. giving a total displacement of 47.6
cu. ft. per stroke.

For the test, the pump was installed in door D of the
shelter (see Drawing 8 on page 16). Air was then pumped
into the shelter through door D and exhausted at the opposite
end through door C. The pump was operated at the rate of
60 strokes per minute (easily feasible because of the low
resistance in the shelter), and a velocity traverse was
made at nine points in the exhaust door, door C, using a
Hastings Air Meter. Average air velocity through the door
over both the power stroke and the return stroke was
determined to be 140 fpm, pulsating with the pump stroke.
(For example, at one of the traverse points air velocity
varied from 70 fpm to 190 fpm.) Thus through the 7 ft.
by 3 ft. door approximately 2940 cfm were being pumped.
An undetermined quantity of additional air leaked through
other openings in the shelter, so this figure should be
taken as being very conservative for the total ventilation
rate.

Before and after this trial additional measurements were
made of the natural air flow through this door. The velocity
ranged from 0 to 50 fpm, moving in the direction counter
to the pumped air.

The theoretical volumetric pumping rate, based on the
volume actually displaced by the pump stroke, is 60 times
47.6 sq. ft., or 2860 cfm. This is somewhat below the
measured flow, and probably considerably below the actual
output of the pump. The discrepancy is explained by the fact
that this pump, in displacing air, creates a partial vacuum.
Air behind the pump face is imparted momentum in filling the
vacuum, and during the return stroke the open plastic valves
of the piston offer so little resistance that this air
continues to flow through the pump in the desired direction.
The same effect is observed in the directional punkah and
other similar devices. Had the pump been used without a
filter the flow would probably have been even greater. Indeed,
flow rates exceeding twice the theoretical displacement rate
have been observed when pumping air through low resistance.
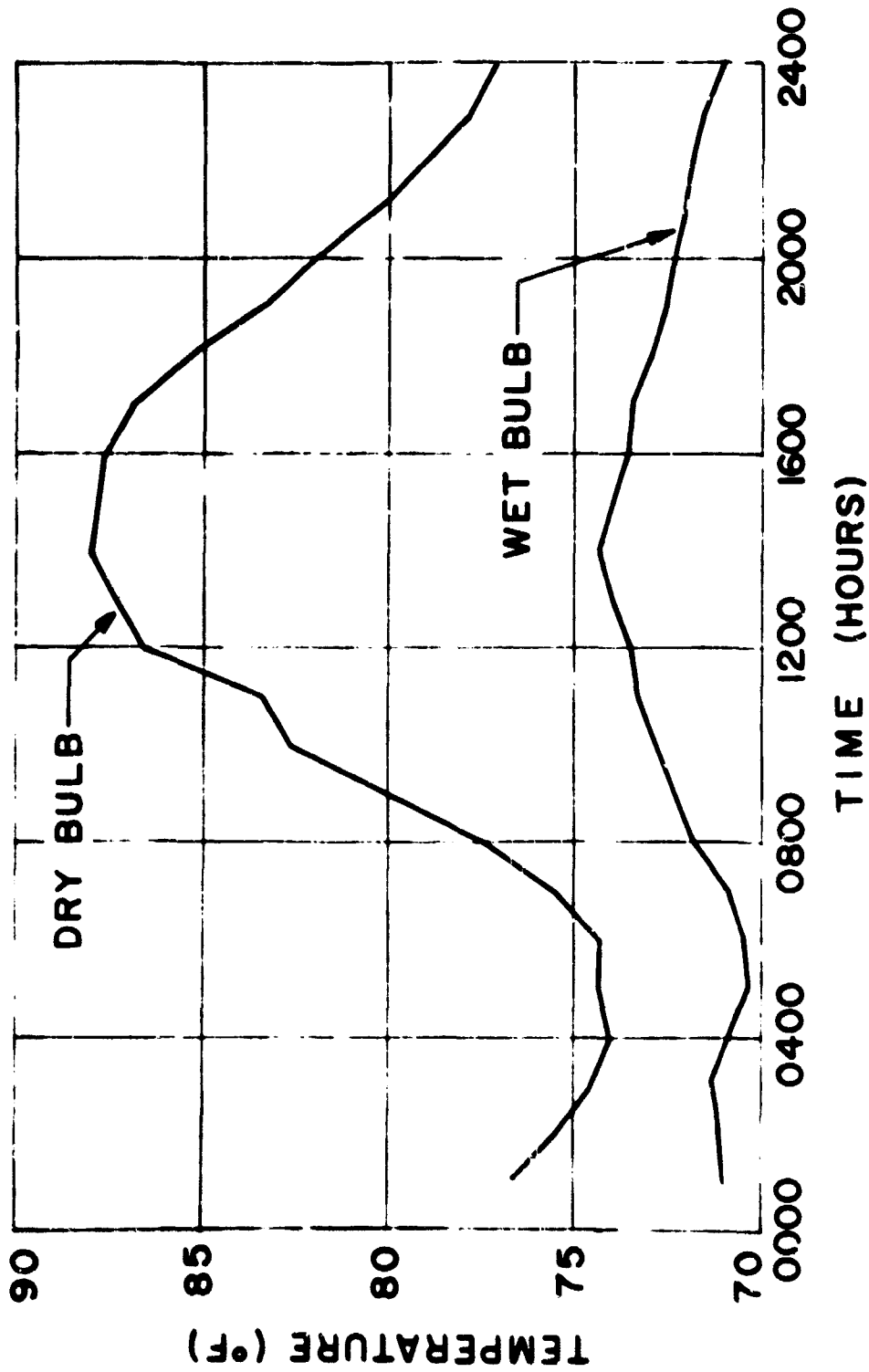
PISTON VALVE PUMP—
POWER STROKE (PULLING)

PISTON VALVE PUMP—
RETURN STROKE (PUSHING)
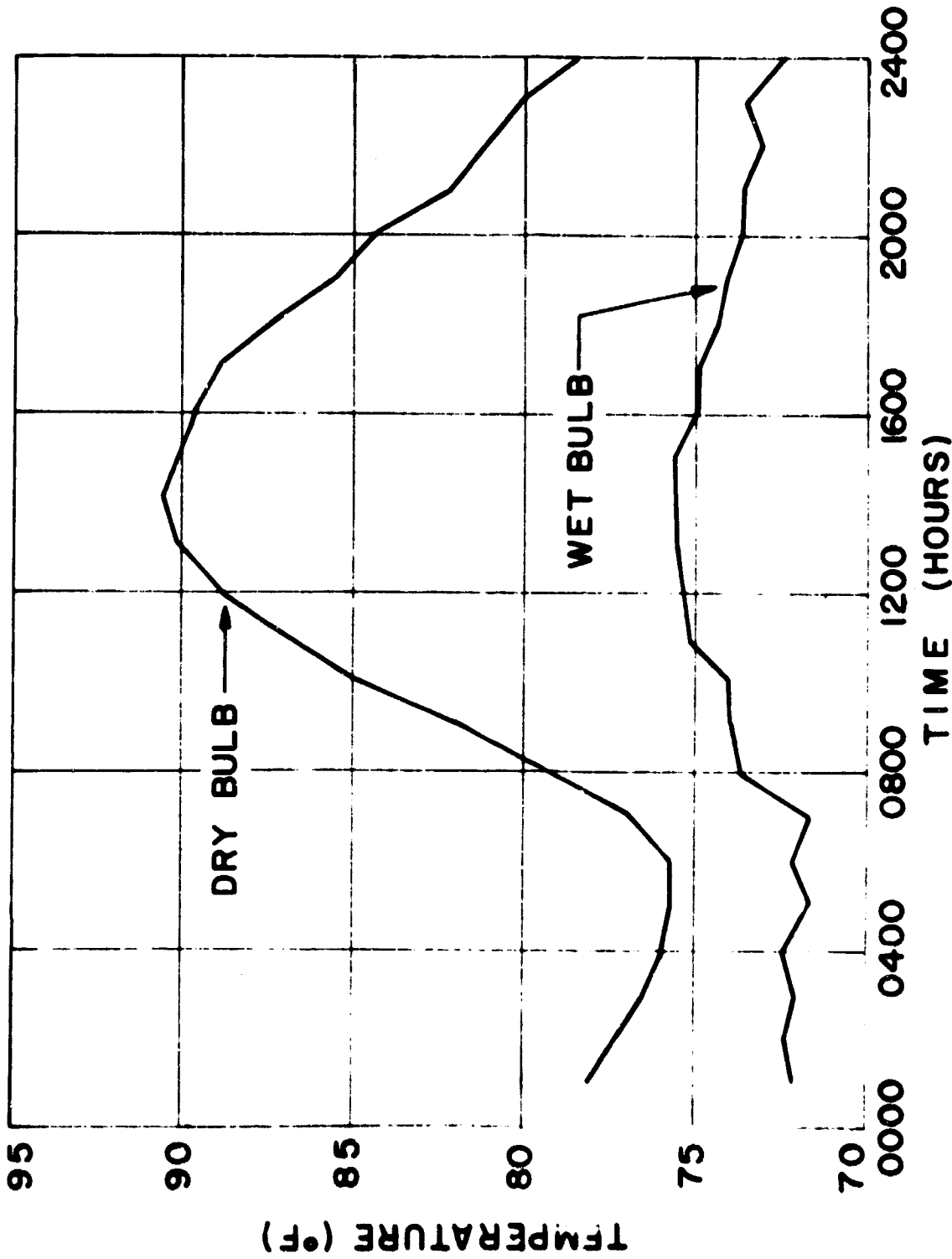
Figure C1

APPENDIX D
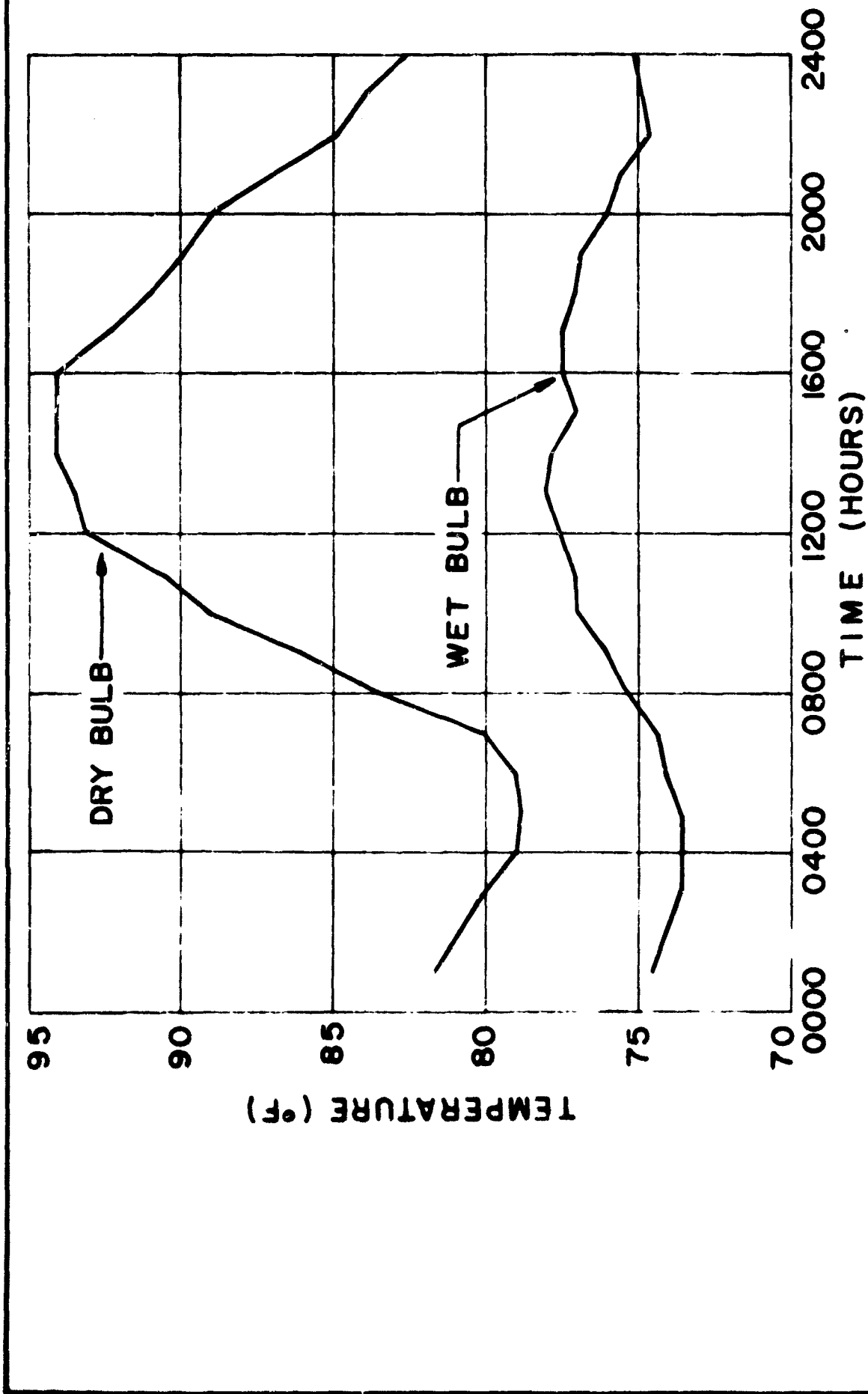
TYPICAL DAILY CYCLE
FOR 10% OF SUMMER DAYS
NEW YORK CITY

FIGURE D1

TYPICAL DAILY CYCLE

FOR 5% OF SUMMER DAYS

NEW YORK CITY

TYPICAL DAILY CYCLE
FOR 1% OF SUMMER DAYS
NEW YORK CITY

FIGURE D3

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13. ABSTRACT

Natural and forced ventilation tests were conducted during 1964 at eight shelter sites. Included were: three (summer) tests in high-rise building core areas; two (summer) tests in public school corridors and basements; one (summer) test in a home basement; one (summer) test in a buried community shelter; one (winter) test in a buried private shelter. Using electro-mechanical "Simocs" to simulate shelter occupancy, the resulting physical environment was measured and analyzed. (U)

Manual ventilation devices and water-cooled heat exchangers were developed and tested to determine their ability to provide a more tolerable shelter environment. (U)

Formulas for predicting shelter ventilation and temperatures are discussed. Methods for improving ventilation rate are suggested. (U)

The report concludes that effective temperature (ET) in naturally ventilated above-ground shelters (loading: one person/10 sq.ft.) will not exceed $85^{\circ}F$ with outside air at N.Y.C. 15% summer design level. In naturally ventilated buried or semi-buried shelters (one person/10 sq.ft.), ET may exceed $85^{\circ}F$ at same design level. During normal winter weather (Conn.), naturally ventilated underground shelters with efficient heat sinks will have uncomfortably low ET ($40^{\circ}F$-$50^{\circ}F$), if loaded with fewer than one person/10 sq.ft. Radiant reflective insulating paper is found to increase ET by 10°-$15^{\circ}F$ while preserving the heat sink. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Fallout shelter.						
2. Ventilation.						
3. High-Rise Buildings.						
4. Public Schools.						
5. Underground shelters.						
6. Ventilating Devices, Manual.						
7. Winter Ventilation.						

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