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NATURAL VENTILATION TEST OF AN
ABOVEGROUND FALLOUT SHELTER
IN CHICAGO, ILLINOIS

by

R. H. Henninger
C. A. Madson

GARD Report 1268-81

August 1966

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NOV 15 1966

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This interim report describes environmental tests performed in a specific shelter. The discussion of the results is preliminary and should not be used as the basis for general conclusions. A subsequent final report will include a comparative evaluation of data from subsequent tests having a variety of configurations and locations.

FOREWORD

The natural ventilation tests reported herein were conducted by General American Research Division of General American Transportation Corporation, Niles, Illinois, during the period of 12 July to 28 July 1965, under Stanford Research Institute (SRI) Contract No. B-64220(4949A-16)-US. Mr. C. A. Grubb of SRI monitored this Civil Defense project. The major objectives of this shelter ventilation test program are: "(a) to evaluate parameters that determine the resultant shelter environment, (b) to develop a rationale for estimating minimum shelter equipment requirements, and (c) to obtain and correlate experimental data in support of current or modified computational methods or for direct use as empirical information". These tests were confined exclusively to the evaluation of natural ventilation effects.

The authors wish to acknowledge the assistance provided by Mr. Walter Sterling, Housing Administrator and Mr. James Merutka, Superintendent of Fire Prevention and Safety for the University of Illinois, Medical Center Campus and also Mr. Philip Voegtli, Superintendent of Fire Prevention and Safety for the University of Illinois, Chicago Circle Campus. Through their efforts we were able to obtain the test site on the University's Medical Center Campus.

ABSTRACT

A 12-day natural ventilation test was conducted in a 275-occupant above-ground corridor-type shelter using wind forces only to supply ventilation air. This test is one in a series run to develop procedures to predict natural ventilation rates in aboveground shelters. An overall window ventilation efficiency (effectiveness factor) of 0.15 was determined experimentally with windows open on two walls. This effectiveness factor is independent of wind direction.

Based upon the experimentally determined effectiveness factor and a total openable window area of 119 square feet, the shelter will be adequately ventilated by natural ventilation 98.2 per cent of the days during the year. That is, in the Chicago area, the effective temperature of this shelter when occupied by 275 people at 10 square feet per person will not exceed 83°F for more than seven days during an average year.

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SECTION 1

INTRODUCTION

Ventilation tests of an aboveground corridor-type fallout shelter located in Chicago, Illinois, were performed during the month of July 1966 to determine air temperatures, humidities, and ventilation rates obtained using natural ventilation through existing windows and corridors. Shelter occupancy was simulated by the use of electromechanical devices (Simocs) which duplicate the sensible and latent metabolic output of shelter occupants.

Throughout all tests, hourly data were recorded on wind speed and direction, ambient and shelter temperatures and humidities, and psychrometric conditions. The window ventilation efficiency was then determined.

SECTION 2

DESCRIPTION OF TEST SITE

The shelter tested was a portion of the fifth floor of the Student Residence Hall located in Chicago at the corner of Polk and Wolcott Streets on the Medical Center Campus of the University of Illinois (see Fig. 1). The test area consisted of the north and south wings of a T-shaped corridor and included 21 single and double bedrooms with individual closet space (see Figs. 2 and 3). A temporary plastic and plywood partition separated the test area from the rest of the fifth floor.

2.1 Occupancy Level

The total useable floor area of the north and south wings is 5200 square feet; however, only the corridor (800 feet square) and approximately half of each dormitory room (the half away from the windows) provides a protection factor of 40 or more (see Section 2.4) and therefore was considered to be occupied by shelterees during the test. Hence, the maximum occupied floor area was approximately 2750 square feet. At an occupancy loading of 10 square feet per person, the maximum number of occupants is 275.

2.2 Ventilation Openings

The only ventilation openings present in the shelter are 41 identical 50 inch by 39 inch double-hung windows (wooden sash type). Each of the 20 double bedrooms has two windows (see Fig. 4) while the single bedroom has only one window. Twenty-four windows are located in the east wall and 17 in the west wall of the shelter. Throughout the test, the upper sash of each window was closed. The bottom sash has a total openable area of 5.8 square feet.

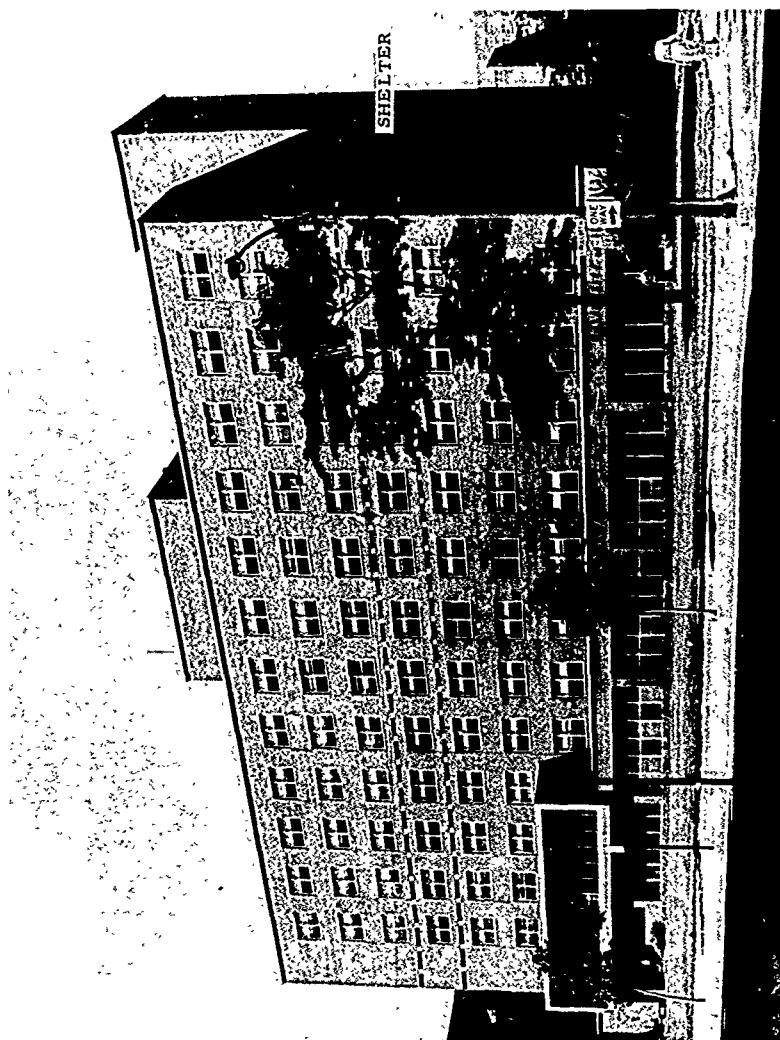


Figure 1 EXTERIOR VIEW OF STUDENT RESIDENCE HALL, CHICAGO, ILLINOIS



Figure 3 TYPICAL DORMITORY ROOM



Figure 4 TYPICAL SHELTER WINDOWS

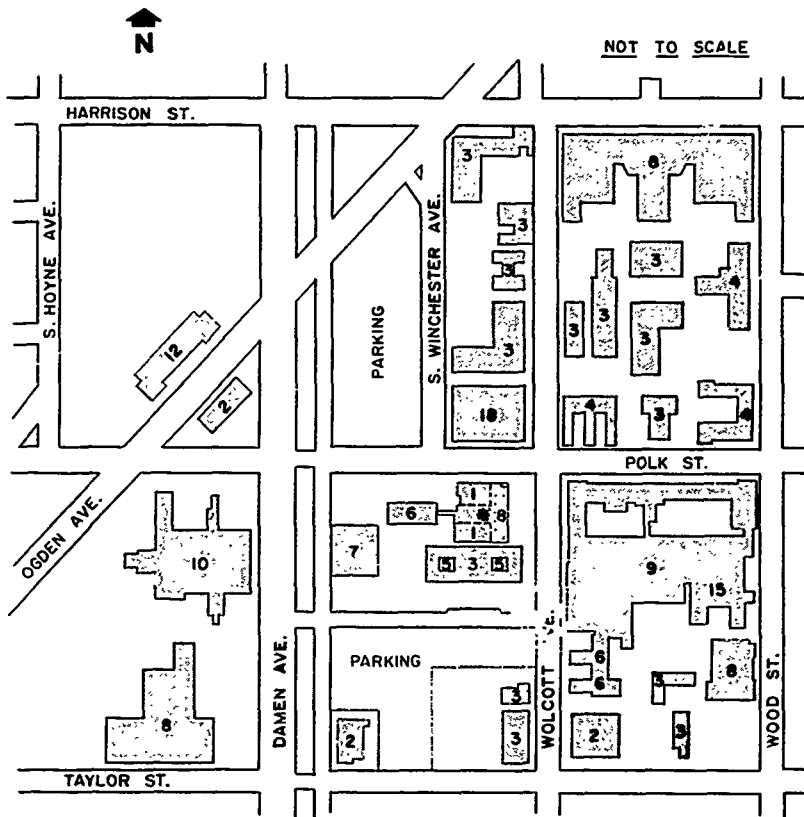
Although stairwells are present at both ends of the corridor, they could not be used as ventilation openings since the other floors in the building were occupied by students during the entire test.

2.3 Shelter Surroundings

Fig. 5 shows the locations and heights of buildings surrounding the shelter. An eighteen-story building (see Fig. 6a) lies directly opposite the shelter and approximately 110 feet away on the north side of Polk Street. Another large building, nine stories high, is located directly east of the shelter 190 feet away (see Fig. 6b). The nearest large buildings or obstructions south of the shelter are at least a block away (see Figs. 6c and 6d). West of the shelter is the east wing of the Student Residence Hall which divides the west wall of the shelter (see Fig. 7) and a six-story dormitory which lies 160 feet from the west wall of the shelter. All other structures within half a block of the shelter are of height and location such that they would have little effect on the wind conditions at the shelter windows.

2.4 Radiation Protection

An analysis of the shelter's radiation protection factor was made by Mr. W. B. Cobb, Registered ASHRAE Shelter Analyst (see Appendix A). Half of each dormitory room (the half away from the window) has a protection factor of 42 and therefore qualifies as shelter space. The corridor, providing better protection, has a protection factor of 110. This made 2750 square feet of floor area available for occupancy.

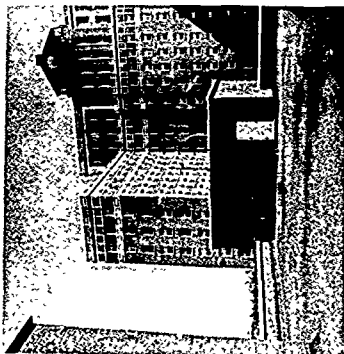


LEGEND

- * WINDSCOPE AND WIND SPEED TRANSMITTER
LOCATION ON ROOF
- SHELTER TEST SITE
- SURROUNDING BUILDINGS - Number Indicates Height in Stories

Figure 5 PLOT OF BUILDINGS SURROUNDING SHELTER

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(a) North View



(b) East View



(c) Southeast View



(d) Southwest View

Figure 6 VIEW FROM ROOF OF STUDENT RESIDENCE HALL

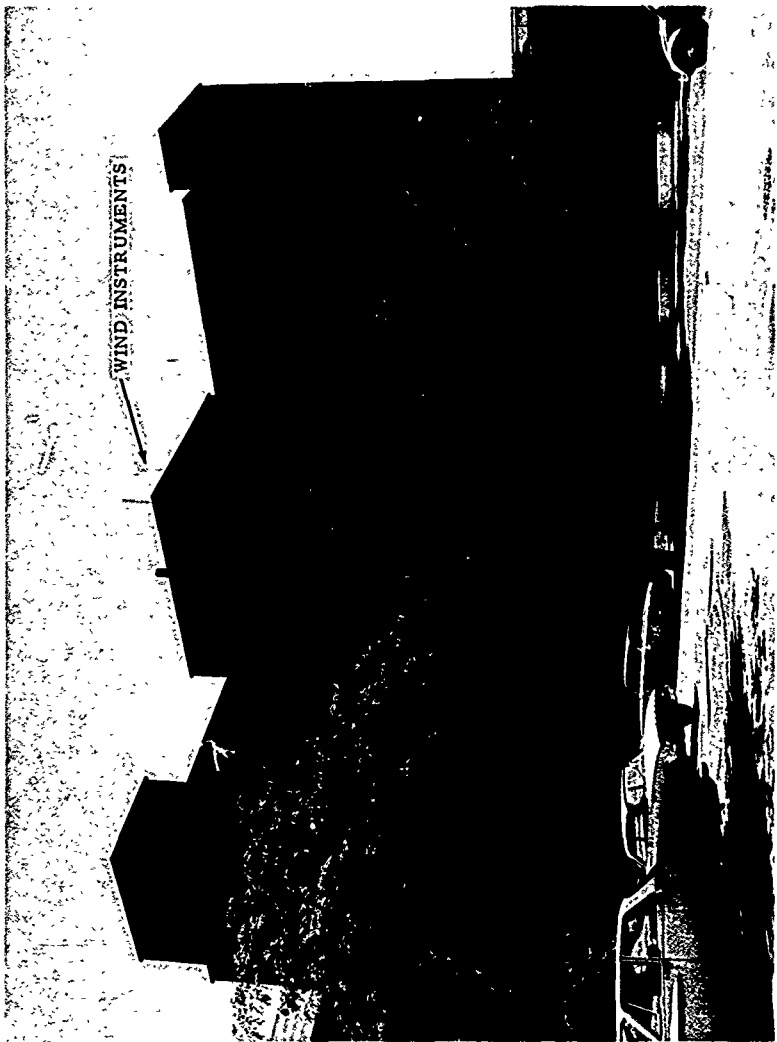


Figure 7 EXTERIOR VIEW OF NORTHWEST CORNER OF STUDENT RESIDENCE HALL

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SECTION 3

INSTRUMENTATION

3.1 Temperature Measurement

Shelter and ambient dry-bulb and wet-bulb temperatures were measured with nine aspirating psychrometers (Sargent Model S-42610), five of which were equipped with resistance type thermometers (Minco #1119) and the remaining four equipped with mercury-bulb glass thermometers. Three of each type were located within the shelter four feet above the floor (see Fig. 8), and the remaining three psychrometers were positioned outside windows of rooms 504 and 510 to measure ambient weather conditions (see Fig. 2). All resistance bulb readings were recorded continuously on a Honeywell strip-chart multi-point recorder.

3.2 Shelter Energy and Moisture Inputs

Aggregate Simocs* (Ref. 1) were used to simulate the sensible and latent metabolic output of shelter occupants. Four Simocs were located along the corridor (Figs. 2 and 9) and adjusted to simulate uniform shelter loading of either 100 occupants or 185⁺ occupants.

The total occupant energy input to the shelter was measured each hour with a kilowatt-hour meter (Sangamo Model #P30DS, Class 200). This power input was adjusted, as required by line voltage variation, to maintain 400 Btu per occupant-hour.

*Simulated Occupants

+Maximum number of occupants that could be simulated due to limited electrical power.



Figure 8 INTERIOR VIEW OF SHELTER CORRIDOR
LOOKING FROM SOUTH TO NORTH

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Looking South From
Center of Corridor



Looking North From
Center of Corridor

Figure 9 OTHER INTERIOR VIEWS OF SHELTER CORRIDOR

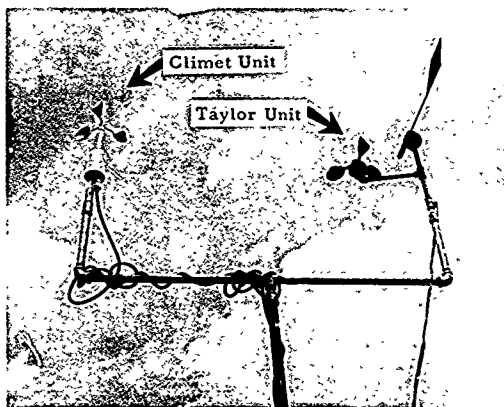


Figure 10 WIND INSTRUMENTS

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During the entire test the shelter lighting and instrumentation loads were constant at 4780 Btu per hour.

The rate at which water (latent energy input) was discharged by the Simocs was measured hourly on a balance-beam platform scale. This rate was compared to the computed rate for 100 or 185 occupants, and the Simocs were adjusted as necessary to maintain the desired rate.

3.3 Wind Speed and Direction

Wind instruments (see Fig. 10) were placed on the penthouse roof which is about 95 feet above ground level. The instrument stand extended another 20 feet into the air which enabled readings of wind speed and direction to be measured at an elevation of 115 feet above ground level.

A Taylor Windscope (Model 3105) and a Climet Wind Speed Transmitter (Model 011-1) were placed atop the instrument stand. The Taylor Windscope gives instantaneous readings of wind speed and direction on a meter. The Climet Wind Speed Transmitter records an integrated time average wind speed on a digital counter.

SECTION 4

PROCEDURES

The eight tests that were conducted evaluated the effects of natural ventilation. These tests are summarized in Table 1.

4.1 Data Recording

The shelter and ambient air dry-bulb and wet-bulb temperatures and water input to the Simocs were logged hourly. The total Simoc power was also recorded each hour from the kilowatt meter. Every hour the average wind speed and direction were recorded during a one minute observation; in addition, an hourly integrated value of the wind speed was recorded with the Climet Wind Speed Transmitter.

From the U.S. Weather Bureau at Midway Airport, 7.6 miles southwest of the shelter, hourly conditions of the wind speed and direction were obtained and compared to the observations at the shelter site.

Psychrometric air properties were determined from the shelter average dry and wet-bulb temperatures using the ASHRAE Psychrometric Chart No. 1 (Ref. 2). Effective temperatures and humidity ratios were determined from tables developed by GARD (see Appendix B).

4.2 Determination of Ventilation Rate

The natural ventilation rate was calculated by the steady-state tracer gas technique using water vapor as the tracer gas (Ref. 3). The increase in shelter humidity ratio over ambient humidity ratio is related to the average

Table 1

Summary of Shelter Tests

TEST NUMBER	LOGSHEET NUMBER (S) (see Appendix C)	DATE (S)	TEST DURATION (HOURS)	NUMBER OF OCCUPANTS	"OCCUPIED" SHELTER AREA	VENTILATION OPENINGS **
1	1, 2	7/12 to 7/14	48	100	Corridor only	All 41 windows open 3 inches
2	3	7/14 to 7/15	24	100	"	All 41 windows open 6 inches
3	4, 5, 6	7/17 to 7/19	50	100	"	4 windows on NW wall (rms. 531 & 532) open 21, 5 inches 4 windows on SE wall (rms. 519 & 520) open 21, 5 inches
4	6, 7, 8	7/19 to 7/21	50	185	Corridor and approximately half the area of each room	All 41 windows open 3 inches
5	9, 10	7/21 to 7/23	48	185	"	All 41 windows open 6 inches
6	11, 12	7/25 to 7/27	48	185	"	2 windows on NW wall (rms. 531 & 534) open 21, 5 inches, 1 window on SW wall (rm. 516) open 21, 5 inches, and 3 windows on East wall (rms. 521, 524, & 528) open 21, 5 inches
7	13	7/27	12	185	"	3 windows on NW wall (rms. 531, 533, & 535) open 21, 5 inches, 2 windows on SW wall (rms. 515 & 517) open 21, 5 inches, and 5 windows on East wall (rms. 520, 522, 524, 527, & 529) open 21, 5 inches
8	14	7/27 to 7/28	16	185	"	One window in each of twenty-one rooms open 21, 5 inches

** Dimension given is the height to which bottom sash is raised above sill

shelter ventilation rate in accordance with the following equation:

$$Q = \frac{(v_o)(M_w)}{60(W_s - W_o)} \quad (1)$$

where:

Q = ventilation rate, cfm

v_o = specific volume of ambient air, $\text{ft}^3/\text{lb d.a.}$

M_w = mass of water vapor supplied to shelter by Simocs, lb_w/hr

W_s = humidity ratio of shelter air, $\text{lb}_w/\text{lb d.a.}$

W_o = humidity ratio of ambient air, $\text{lb}_w/\text{lb d.a.}$

Equation 1 assumes:

1. construction materials impervious to water vapor,
2. no water vapor diffusion through open windows,
3. no moisture storage or release from the volume of the shelter air, and
4. no condensation of liquid water within the shelter.

The error introduced by the first and second assumptions is small when using the steady-state technique. The third assumption could introduce a considerable error when considered on an hourly basis; however, over a period of several hours or more, this error becomes insignificant. The fourth assumption was valid for the entire testing period.

SECTION 5

TEST RESULTS AND DISCUSSION

Natural ventilation moves air through buildings without the help of mechanical equipment. The forces of wind pressure and density (thermal) differences provide the necessary motive forces to move air through ventilation openings and into and through buildings.

Thermal forces are produced when sensible heat and water vapor are added to a volume of air causing it to become less dense, rise and displace denser air. In tall buildings where stairwells, elevator shafts and other ventilation openings provide paths for vertical movement of air, ventilation rates due to thermal forces can be significant. In this test, however, all stairwells and elevator shafts were closed to prevent any air movement due to thermal forces (see Section 2.2).

Since thermally motivated forces were excluded during the testing period, it was expected that the air forced through the shelter was due to wind effects alone. The quantity of air forced through a window or ventilation opening may be predicted by the equation (Ref. 4):

$$Q_w = EAV \quad (2)$$

where:

Q_w = air flow, cubic feet per minute

A = free area of inlets or outlets (assumed equal), square feet

V = wind velocity, feet per minute

E = effectiveness of openings (suggested values range from 0.25 to 0.60 depending upon the direction of the wind on the shelter)

Corrections are presented in the ASHRAE Guide and Data Book for the effect of unequal inlet and outlet areas. This correction (F), expressed as a multiplier of (EAV) and which is always ≥ 1.0 , represents the increase in air flow above that which results for equal inlet and outlet areas (F = 1.0).

The prime objective of the data analysis is to establish a window effectiveness factor (E) for a corridor-type shelter. At first glance it might appear that E is a function of only the angle at which the air approaches the opening, and for the most part this is true; however, other influences such as the type of ventilation opening, the internal configuration of the shelter, the exterior shelter surroundings and the density of occupancy loading can all have an effect on the value of E. To separate these effects is a complex task.

To empirically determine the opening effectiveness, E in equation 2, the data was grouped according to wind direction. These data groupings were then plotted as ventilation rate per square foot of window area versus wind velocity. With the inclusion of appropriate constants, the slope of the least-squares curve fit to the data then represents the window effectiveness factor E.

5.1 Directionally Dependent E-Factor

Previous investigations (Refs. 5 to 8) have indicated that the window effectiveness factor is a function of the angle at which air approaches a ventilation opening. To further evaluate this effect the data was grouped into 16 wind direction intervals. These intervals included the 45° over-

lapping wind sectors of

NNW-N-NNE
NNE-NE-ENE
ENE-E-ESE
ESE-SE-SSE

SSE-S-SSW
SSW-SW-WSW
WSW-W-WNW
WNW-NW-NNW

and the 90° overlapping wind sectors of

NW-N-NE
N-NE-E
NE-E-SE
E-SE-S

SE-S-SW
S-SW-W
SW-W-NW
W-NW-N

The data points included in each of these sixteen wind direction intervals were then fit with a linear least squares curve (linear because equation 2 indicates that Q should be a linear function of V). Figs. 11 to 18 depict the least squares curve fit for the 90° sectors and present the effectiveness factor which was determined by the slope of the curve.

Table 2 summarizes numerically the results for the sixteen intervals for an assumed equal inlet-outlet window pattern ($F = 1.0$) and for various limits of experimental error as determined in Section 5.4. As the value of $[W_s - W_o]$ is decreased, the maximum possible experimental error increases. Hence, the results listed in Table 2 for $[W_s - W_o] \geq 0.00200$ have the least possible experimental error.

Based upon the data collected during the limited testing period, it appears that the 90° wind sector results give a truer indication of the E -factor than the results for the 45° wind sectors. This conclusion is based upon two observations: first, the range of E for the 90° sectors is in closer agreement with the physical conditions which actually surround the shelter and second, too few data points are available for certain sectors of the 45°

analysis to put much faith in their results. Subsequent analysis is therefore based upon the values of E obtained with the 90° wind sector analysis for $[W_s - W_o] \geq 0.00200$.

Table 3 summarizes the same data groupings as were used in Table 2, using, however, the actual inlet-outlet window pattern which existed during the test as determined by hourly observations. Comparison of the two tables show that the experimental values of E remain almost the same for the results with $[W_s - W_o] \geq 0.00200$. This indicates that the open window area was split evenly between inlets and outlets during most of the testing period.

5.2 Overall E-Factor

During any designated time period (whether it be for a day, week, month or year), the wind direction does not remain constant, therefore, the calculation of average ventilation rates based upon the directional E-factors would have little value. An overall or average E which is independent of wind direction would have more applicability.

An overall E-factor of 0.15 was calculated for this shelter with a least squares analysis similar to that discussed previously. The overall E was determined by a least squares fit of all data points from all wind directions with a value of $[W_s - W_o] \geq 0.00200$ (see Fig. 19).

5.3 Comparison of Local and Weather Bureau Data

Local wind speed and direction data were obtained from the U.S. Weather Bureau located at Midway Airport which is 7.6 miles southwest of the shelter. In addition, observations of wind speed and direction were made at the shelter

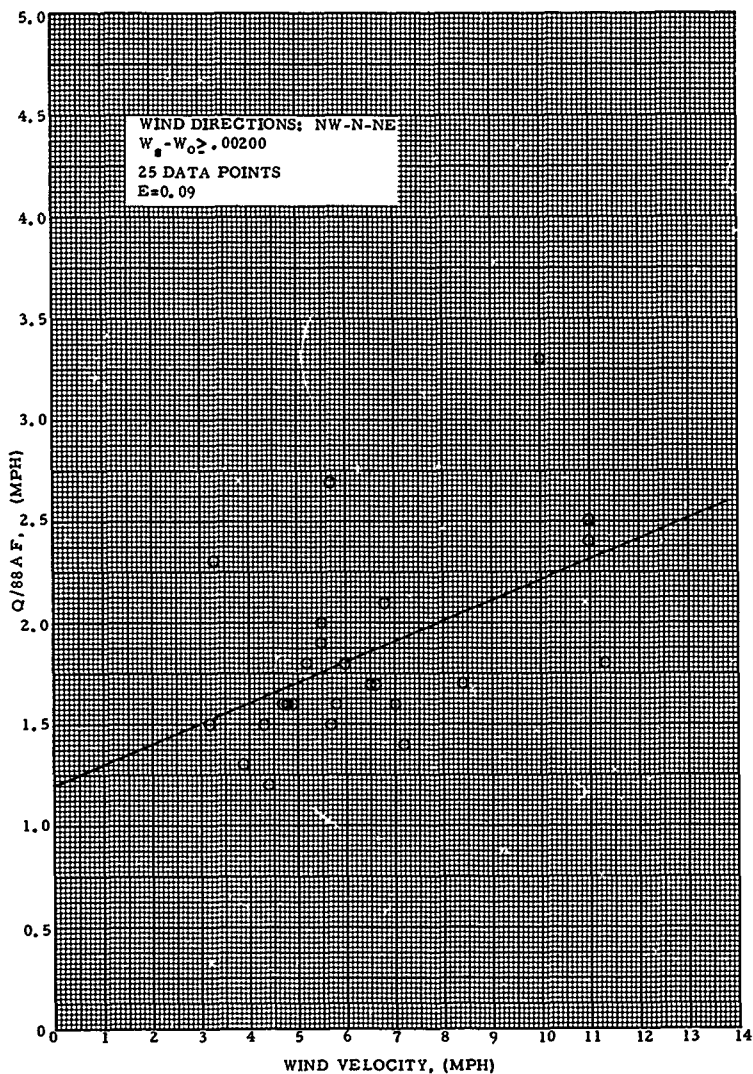


Figure 11 CORRELATION OF DATA FOR NW-N-NE WIND SECTOR

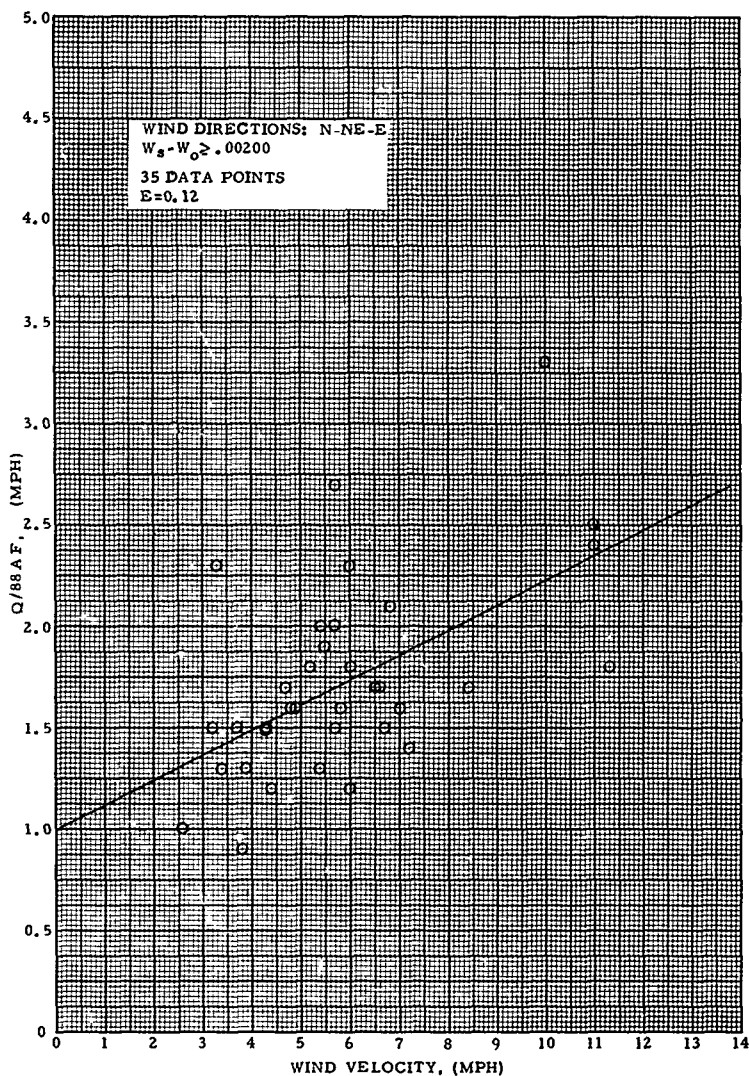


Figure 12 CORRELATION OF DATA FOR N-NE-E WIND SECTOR

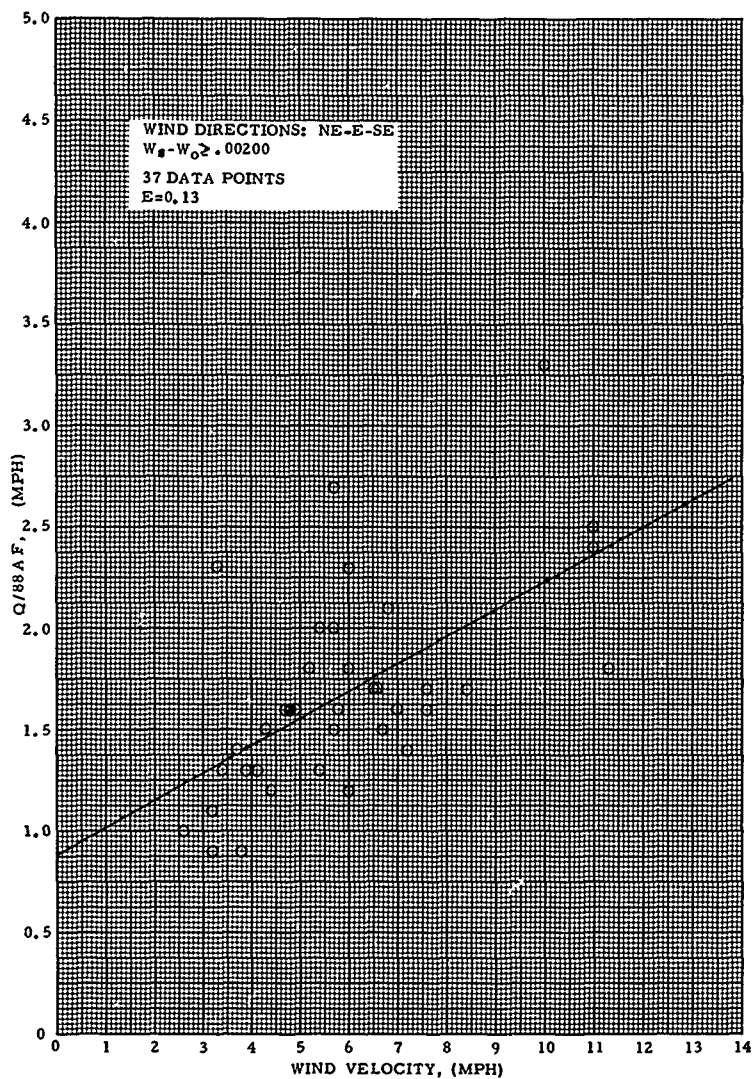


Figure 13 CORRELATION OF DATA FOR NE-E-SE WIND SECTOR

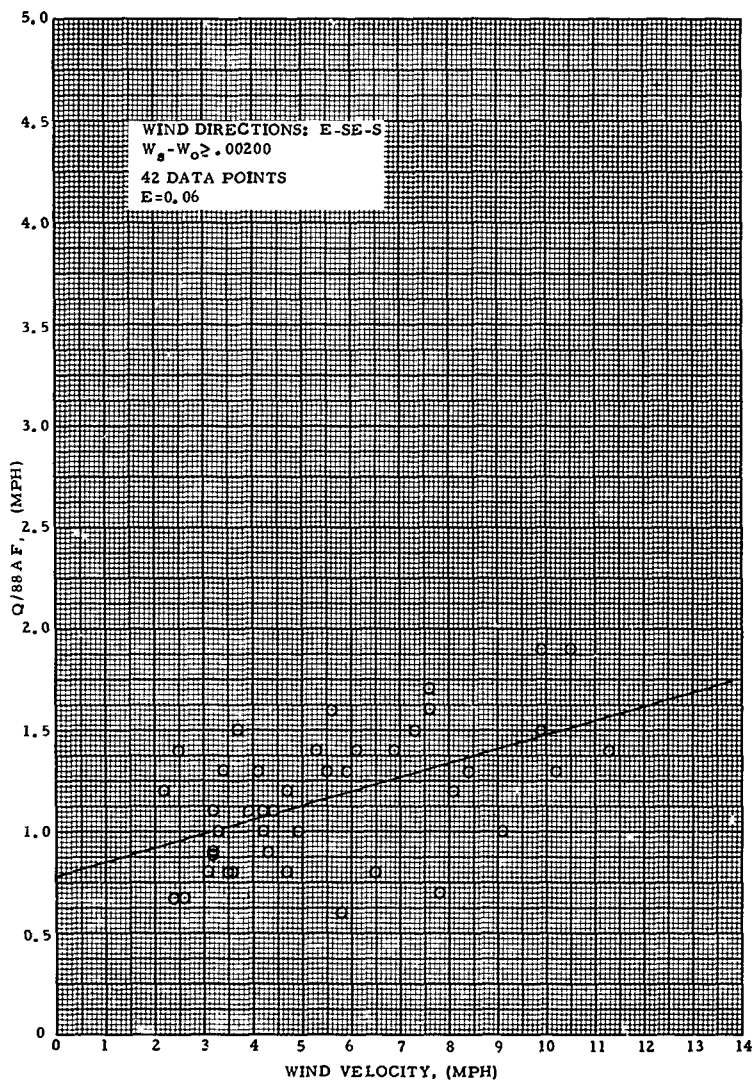


Figure 14 CORRELATION OF DATA FOR E-SE-S WIND SECTOR

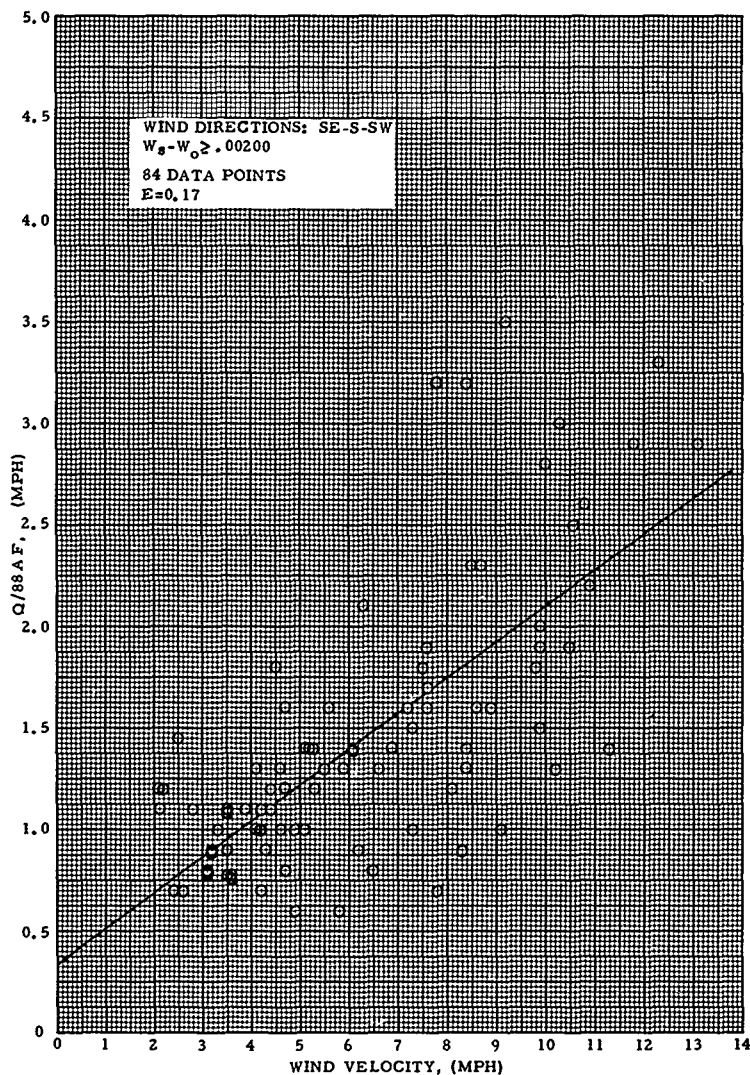


Figure 15 CORRELATION OF DATA FOR SE-E-SW WIND SECTOR

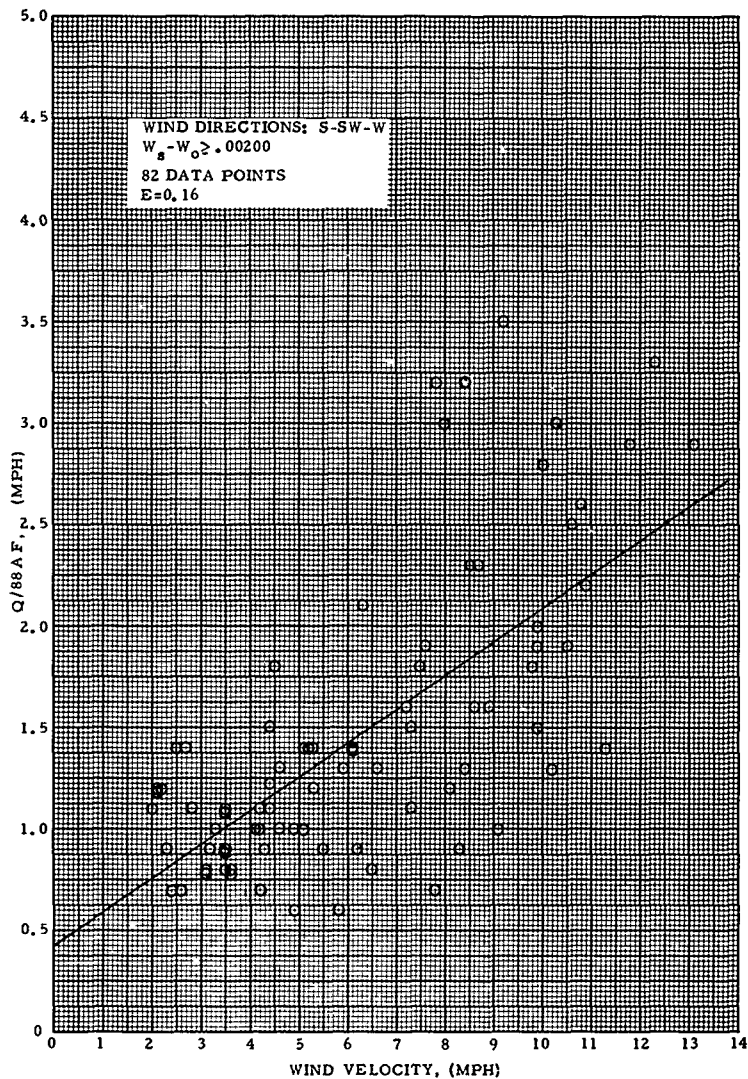


Figure 16 CORRELATION OF DATA FOR S-SW-W WIND SECTOR

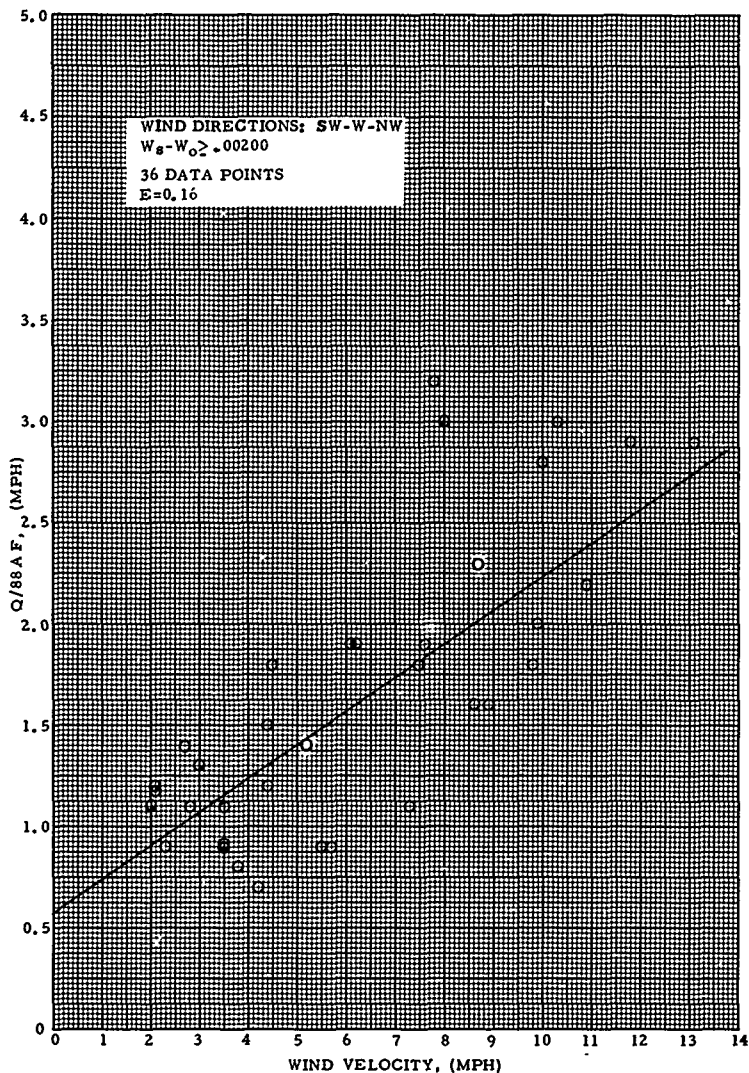


Figure 17 CORRELATION OF DATA FOR SW-W-NW WIND SECTOR

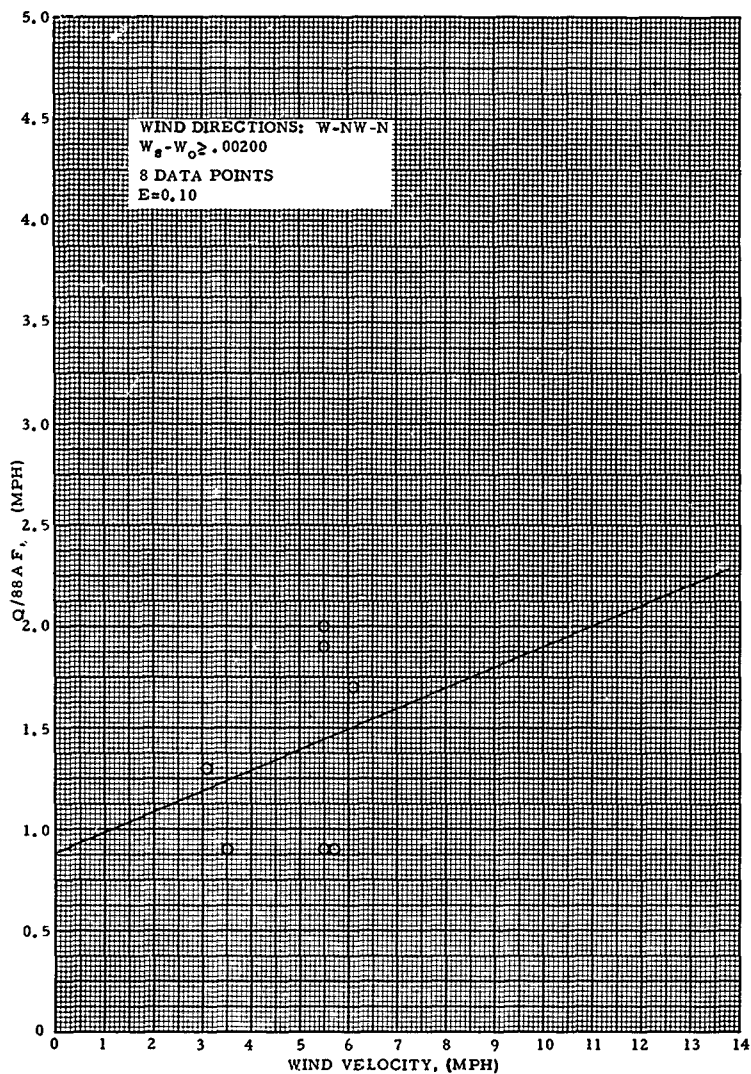


Figure 18 CORRELATION OF DATA FOR W-NW-N WIND SECTOR

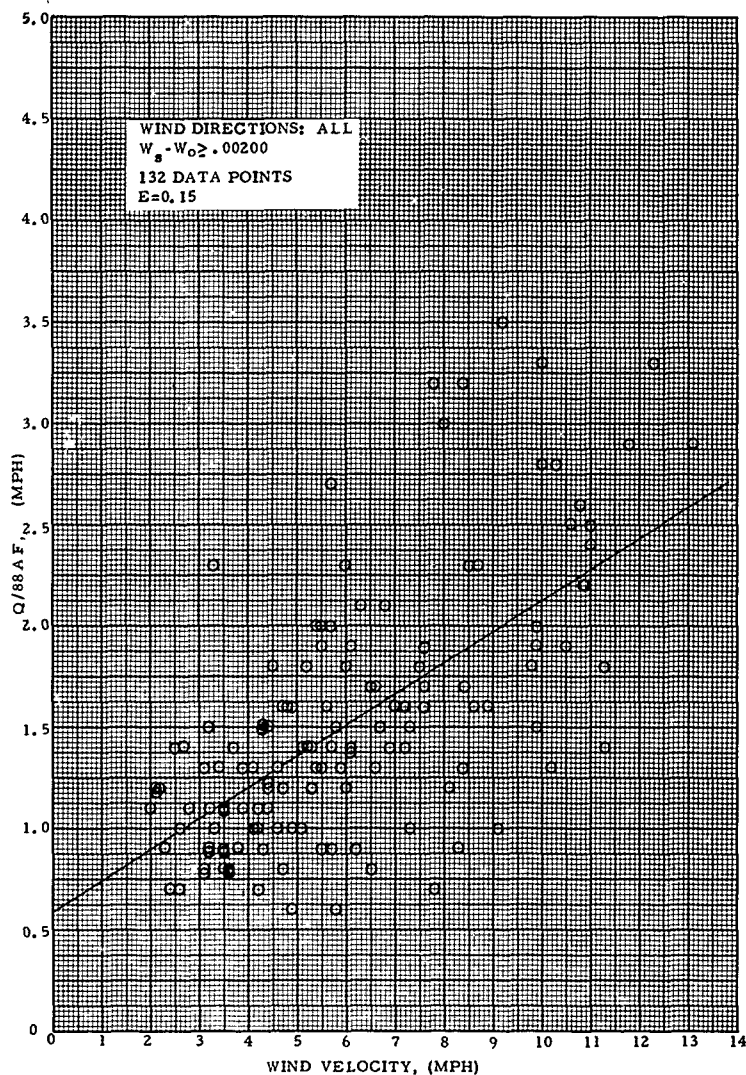


Figure 19 CORRELATION OF DATA FOR ALL WIND SECTORS

Table 2 DIRECTION DEPENDENCE OF E-FACTOR (for F = 1.0)

Wind Directions		Humidity Difference - $\frac{1b_w}{lb_{d.a.}} \left[\frac{W_s - W_o}{100} \right]$		
		$\geq .00200$	$\geq .00150$	$\geq .00100$
ALL		0.15 (132)	0.16 (164)	0.24 (225)
NNW-N-NNE	45° Wind Sectors	0.21 (4)	0.24 (6)	0.33 (17)
NNE-NE-ENE		0.12 (32)	0.17 (49)	0.22 (73)
ENE-E-ESE		0.19 (12)	0.32 (17)	0.49 (23)
ESE-SE-SSE		0.13 (11)	0.15 (12)	0.15 (12)
SSE-S-SSW		0.16 (55)	0.15 (59)	0.16 (66)
SSW-SW-WSW		0.20 (50)	0.21 (55)	0.21 (69)
WSW-W-WNW		0.12 (11)	0.12 (15)	0.15 (24)
WNW-NW-NNW		0.10 (4)	-0.03 (7)	0.13 (15)
NW-N-NE	90° Wind Sectors	0.09 (25)	0.15 (41)	0.21 (73)
N-NE-E		0.12 (35)	0.18 (54)	0.27 (89)
NE-E-SE		0.13 (37)	0.18 (55)	0.25 (79)
E-SE-S		0.06 (42)	0.07 (46)	0.20 (53)
SE-S-SW		0.17 (84)	0.18 (91)	0.18 (105)
S-SW-W		0.16 (82)	0.17 (91)	0.17 (109)
SW-W-NW		0.16 (36)	0.17 (44)	0.16 (63)
W-NW-N		0.10 (8)	0.16 (14)	0.27 (30)

NOTES: Number of hourly data points for each correlation are given in parenthesis.

Results are for all tests, day and night hours, and for all wind velocities.

Table 3 DIRECTION DEPENDENCE OF E-FACTOR (for $F = F_{\text{actual}}$)

Wind Directions		Humidity Difference - $\text{lb}_w/\text{lb}_{\text{d.a.}} (W_s - W_o)$		
		$\geq .00200$	$\geq .00150$	$\geq .00100$
ALL		0.15 (132)	0.21 (164)	0.26 (225)
NNW-N-NNE	45° Wind Sectors	0.18 (4)	0.34 (6)	0.40 (17)
NNE-NE-ENE		0.11 (32)	0.29 (49)	0.26 (73)
ENE-E-ESE		0.23 (12)	0.44 (17)	0.60 (23)
ESE-SE-SSE		0.09 (11)	0.11 (12)	0.11 (12)
SSE-S-SSW		0.18 (55)	0.17 (59)	0.18 (66)
SSW-SW-WSW		0.25 (50)	0.26 (55)	0.25 (69)
WSW-W-WNW		0.12 (11)	0.12 (15)	0.19 (24)
NWN-NW-NNW		-0.07 (4)	-0.13 (7)	0.13 (15)
NW-N-NE	90° Wind Sectors	0.09 (25)	0.25 (41)	0.24 (73)
N-NE-E		0.12 (35)	0.30 (54)	0.33 (89)
NE-E-SE		0.11 (37)	0.29 (55)	0.31 (79)
E-SE-S		-0.01 (42)	0.00 (46)	0.16 (53)
SE-S-SW		0.17 (84)	0.17 (91)	0.18 (105)
S-SW-W		0.16 (82)	0.17 (91)	0.17 (109)
SW-W-NNW		0.15 (36)	0.16 (44)	0.16 (63)
W-NW-N		0.11 (8)	0.16 (14)	0.28 (30)

NOTES: Number of hourly data points for each correlation are given in parenthesis.

Results are for all tests, day and night hours, and for all wind velocities.

and compared to the Weather Bureau observations. The temperature and wind conditions, which existed during the testing period are presented in Figs. 20 to 26.

Good correlation between Weather Bureau and shelter observed wind direction were obtained even when the local wind direction was such that the shelter was shielded by adjacent buildings. Wind speed observations compared favorably except when the wind was out of the north or northeast where the shelter was shielded. For these directions, the Weather Bureau readings were approximately 5 mph greater than those observed at the shelter.

During the twelve day testing period, the average wind speed recorded at the shelter was 7.4 mph; the average wind speed as recorded at the Weather Bureau for the same period was 9.7 mph. The difference in agreement is probably due to the shielding effects which existed during certain wind periods and also due to the manner in which the two readings were recorded. The Weather Bureau's determination is an instantaneous reading taken once every hour on the hour for a one minute interval. The shelter observation is an integrated or average determination which was recorded over the entire hour by the Wind Speed Transmitter. The shelter observation would give a truer indication of the average wind speed. Difference in readings may also be due to the Weather Bureau observations being made at a point 20 feet above-grade while the shelter observations were made 95 feet above-grade.

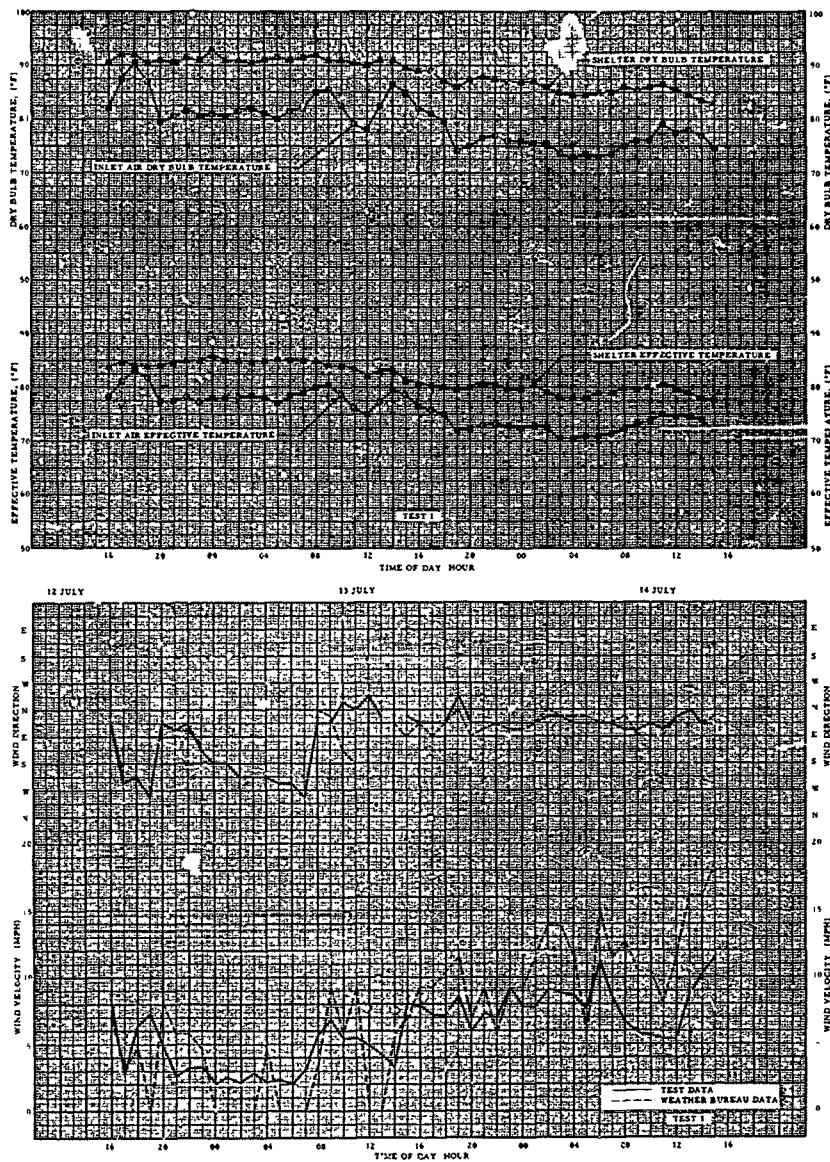


Figure 20 TEST 1 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

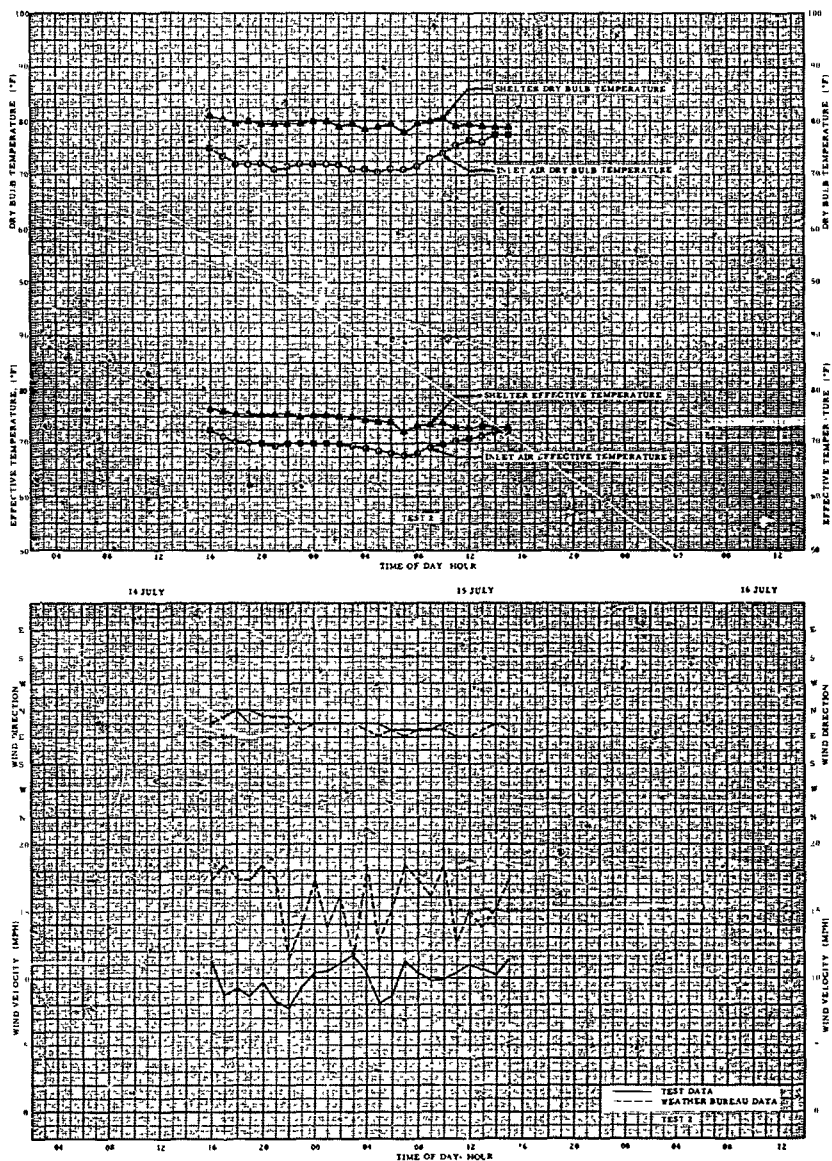


Figure 21 TEST 2 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

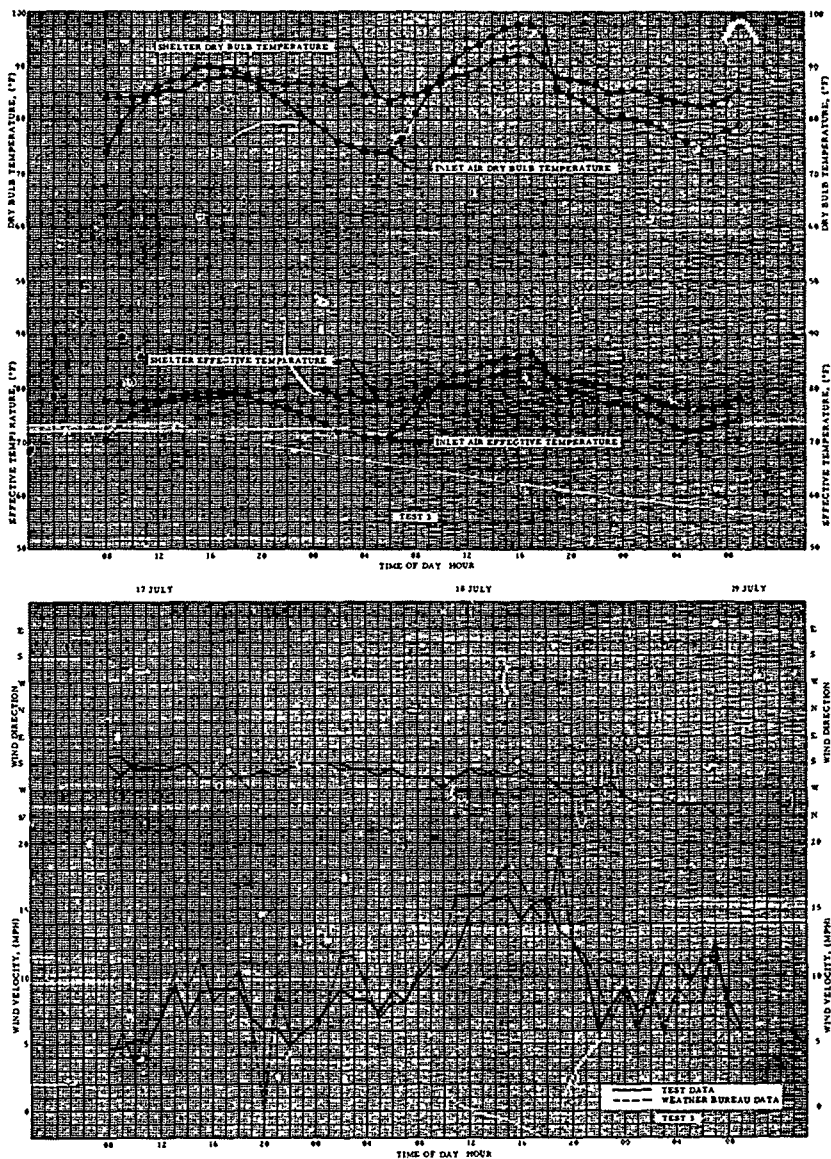


Figure 22 TEST 3 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

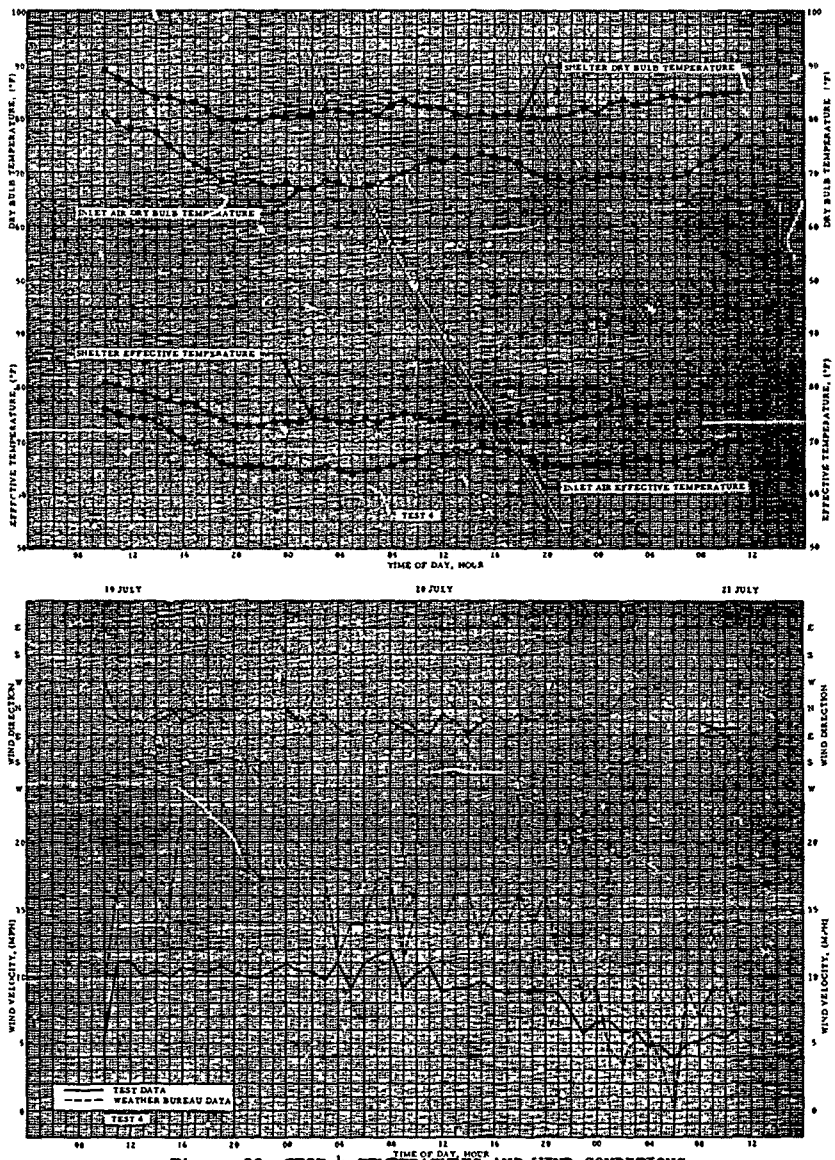


Figure 23 TEST 4 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

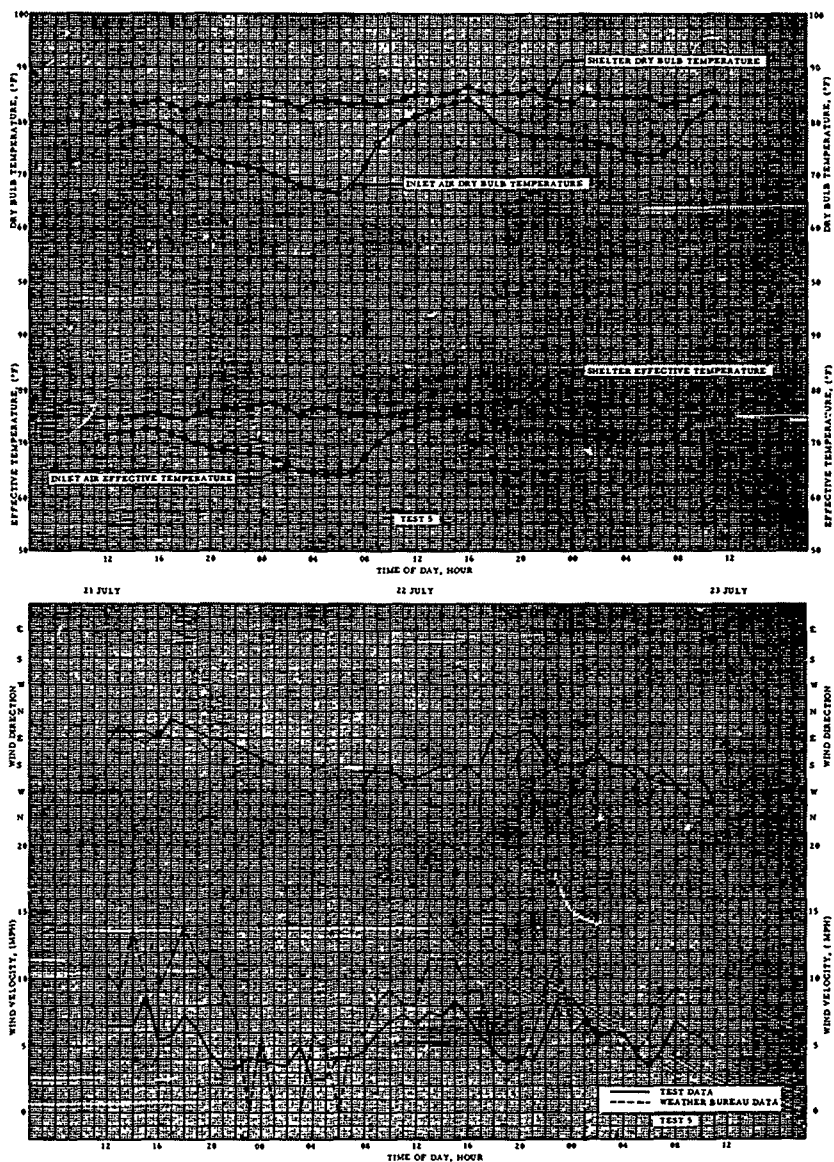


Figure 24 TEST 5 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

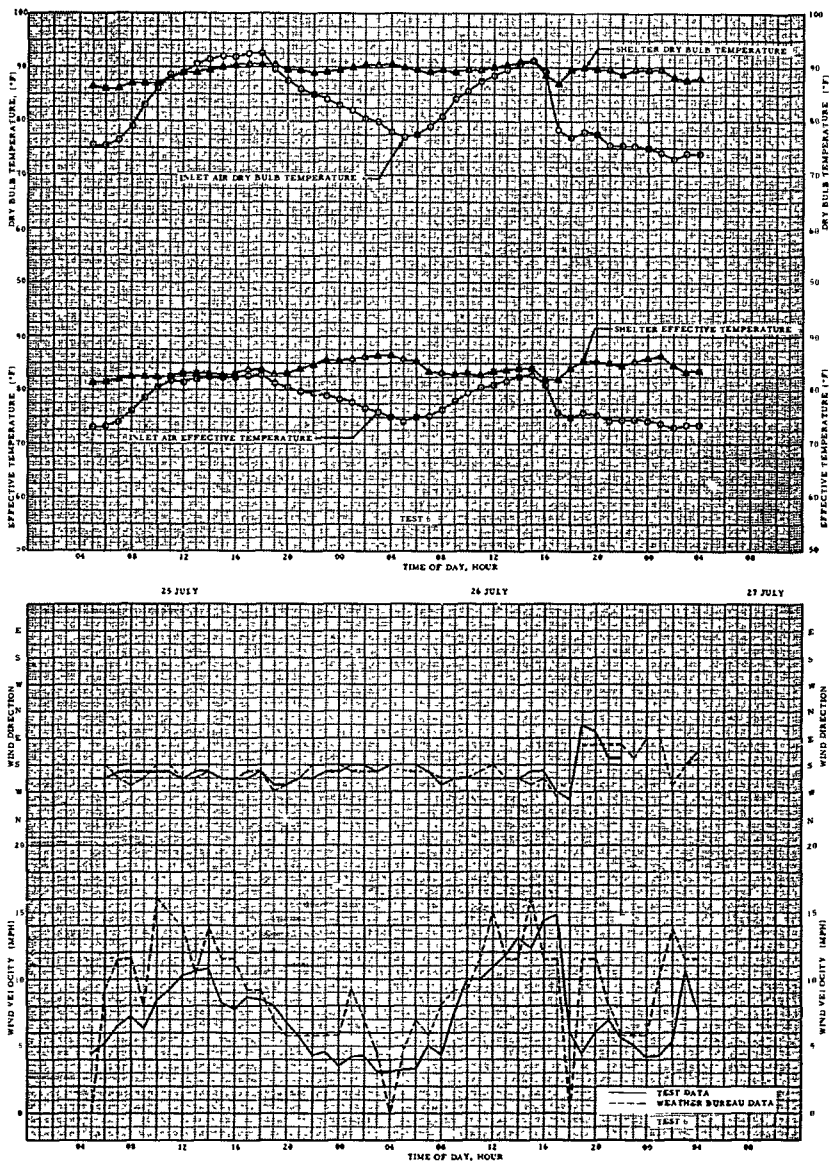


Figure 25 TEST 6 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

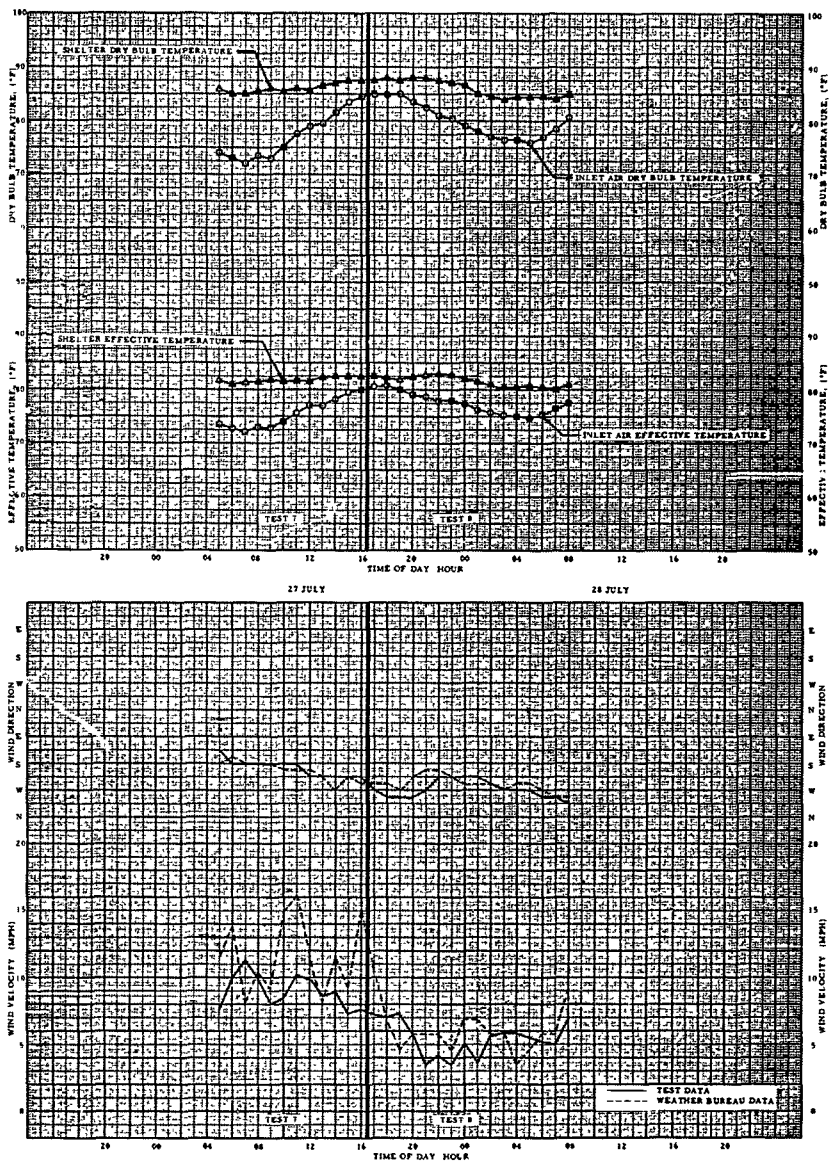


Figure 26 TESTS 7 AND 8 TEMPERATURES AND WIND CONDITIONS

GENERAL AMERICAN RESEARCH DIVISION

5.4 Error Analysis

The following analysis is made in order to evaluate the accuracy of the indicated ventilation rate as measured by equation 1.

Given a function of n number of variables, the relative error in P, $\frac{d(P)}{P}$, is defined as

$$\frac{d(P)}{P} = \frac{1}{P} \left[\left(\frac{\partial P}{\partial X_1} \right) d(X_1) + \left(\frac{\partial P}{\partial X_2} \right) d(X_2) + \dots + \left(\frac{\partial P}{\partial X_n} \right) d(X_n) \right] \quad (3)$$

where:

$d(P)$ = absolute error in the property, P

$d(X_1)$ = absolute error in the variable, X_1 , due to experimental measurement

$\frac{\partial P}{\partial X_1}$ = absolute error contribution to the property, P, due to the variable, X_1 , with all other variables held fixed.

Using this method, an estimation of the relative error in the measured air flow is made in this section.

Applying the above discussion to equation 1, the relative error in the measured ventilation rate is:

$$\frac{d(Q)}{Q} = \left[\frac{d(M_w)}{M_w} \right] + \left[\frac{d(v_o)}{v_o} \right] - \left[\frac{d(W_s - W_o)}{(W_s - W_o)} \right] \quad (4)$$

The water input to the shelter was measured to the nearest half-pound, thus $d(M_w) \leq \pm 0.25$. The specific volume, v_o , can be read from the psychrometric chart within 0.1 cubic feet per pound of dry air, so $d(v_o) \leq \pm 0.05$. Dry-bulb and wet-bulb temperatures were read to the nearest half-degree giving a corresponding inaccuracy to the humidity ratio of $d(W_s - W_o) \leq \pm 0.0005$ (from the psychrometric chart).

Therefore,

$$\frac{d(Q)}{Q} = \left[\frac{\pm 0.25}{M_w} \right] + \left[\frac{\pm 0.05}{v_o} \right] - \left[\frac{\pm 0.0005}{W_s - W_o} \right] \quad (5)$$

Throughout the test these relationships held.

$$M_w \geq 12.0 \text{ lbs/hr}$$

$$v_o \geq 13.0 \text{ ft}^3/\text{lb}$$

Therefore, considering the relative magnitudes of the terms in equation 5, the relative error can be approximated as

$$\frac{d(Q)}{Q} \leq \frac{0.0005}{W_s - W_o}$$

and for periods when

$$[W_s - W_o] \geq 0.0020,$$

we have

$$\frac{d(Q)}{Q} < 0.25$$

or the maximum possible error due to measurement in the measured air flow rate is less than 25 percent. Table 4 summarizes the measurement error for various humidity ratio differences and indicates the corresponding number of hourly data points that are available for analysis.

Table 4
Measurement Error

$[W_s - W_o]$	Max. Possible Error	No. of Data Points
≥ 0.00100	$< 50.0\%$	225
≥ 0.00150	$< 33.3\%$	164
≥ 0.00200	$< 25.0\%$	132

NOTE: As $[W_s - W_o]$ decreases, you are in effect including points which have higher ventilation rates.

5.5 Adequacy of Natural Ventilation

With the aid of results from a companion study (Ref. 9) conducted at GARD it is possible to establish adequacy limits for a shelter located in Chicago and ventilated by natural ventilation only. The results of the study are presented in the form of adequacy curves which were generated based upon ten years of hourly Weather Bureau recordings of wind condition and wet and dry-bulb temperatures. Once the EA value for a particular shelter is known, the adequacy curve can be entered and for a desired maximum shelter effective temperature the adequacy of natural ventilation determined.

For the Chicago shelter, an overall window effectiveness factor of 0.15 was calculated. Assuming that the maximum open window area is obtained when the bottom sash of each window is raised to its extreme, the total area available for inlet air, assuming equal inlets and outlets, is 119 square feet. Using all available floor area that has a radiation protection factor of greater than 40 (see Section 2.4), the maximum occupancy level at 10 square feet per person is 275 occupants. The EA value of the shelter can then be established as:

$$EA = \frac{0.15 \times 119}{275} = 0.065 \text{ square feet per occupant}$$

Entering the abscissa of Fig. 27 at a value of EA = 0.065 square feet per occupant and for a limiting shelter ET of 83°F, the adequacy of natural ventilation for this shelter is 0.982. This means that 98.2% of the time, or for all but seven of the days during the year natural ventilation will adequately ventilate the shelter such that the ET will not rise above 83°F with 275 occupants within the shelter.

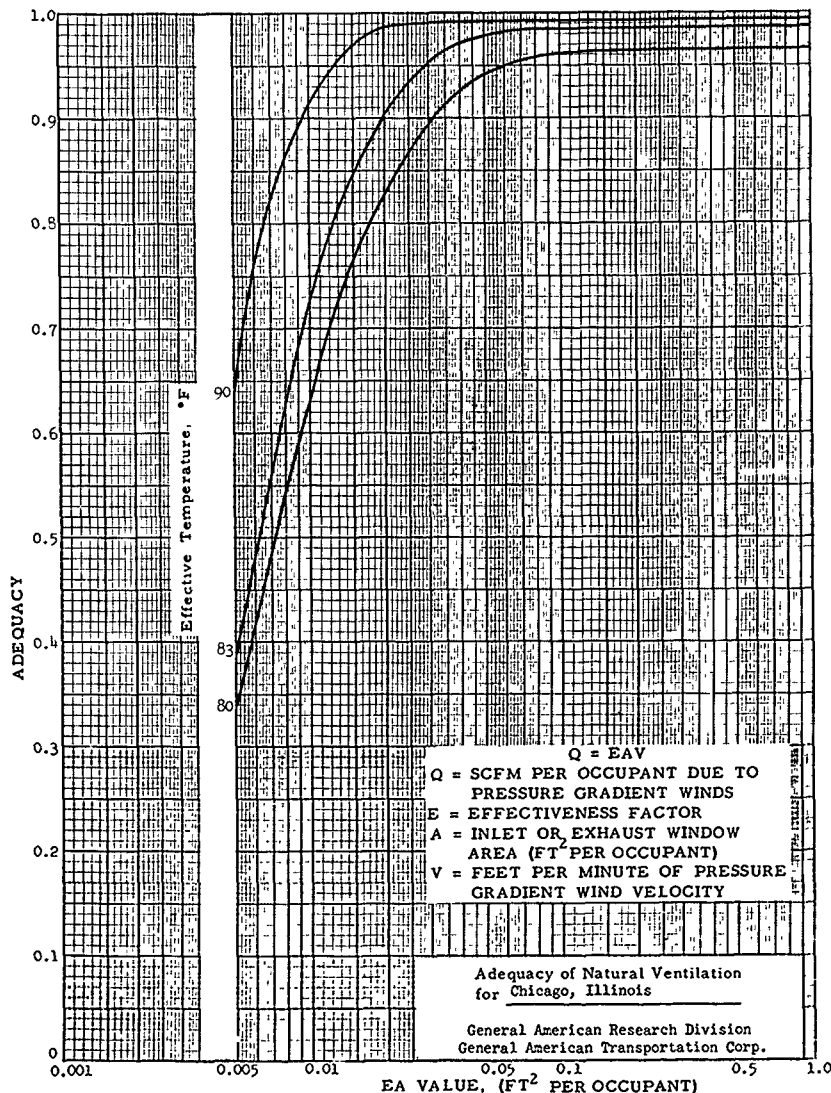


Fig e 27 NATURAL VENTILATION ADEQUACY CURVE FOR CHICAGO, ILLINOIS

If the occupancy density is lowered to 8 square feet per occupant, 344 occupants will be able to be housed within the shelter and the resultant value of EA is 0.052 square feet per occupant. The adequacy for the same limiting shelter ET of 83°F is then reduced to 98.0%. This change is negligible.

If the lowest E recorded in Table 2 for the 90° wind sector analysis was used instead of the overall E, the resulting change in adequacy is less than one percent. The overall E can therefore be used as a design value for a corridor-type shelter located in Chicago.

5.6 Comparison of Ventilation Rates

A simplified equation for estimating natural ventilation due to wind forces for aboveground structures has been proposed by Dr. Richard Condit of Stanford Research Institute (Ref. 10). His work is based upon building codes for various sections of the country, and upon design values of wind speeds which are set forth in the 1963 ASHRAE Guide and Data Book. The following equation resulted:

$$\text{cfm/man} = (\text{floor area in sq. ft./man}) \times (\text{wind speed in mph}) \quad (6)$$

For the wind speed Dr. Condit suggests that the adjusted ASHRAE hot weather design values (Ref. 11) of H (high) = 5.5 mph, M (medium) = 3.5 mph, and L (low) = 2.0 mph be used. For Chicago the design value wind speed is M or 3.5 mph. Using 10 square feet of floor area per man, Dr. Condit's equation predicts 35 cfm/man which gives a ventilation adequacy of 97.7%.

The expected ventilation rate for this shelter can be calculated using the equation $Q = EAV$ and the experimental values for effectiveness factor (0.15) and average wind speed (7.4 mph) obtained from these tests. If we

assume that one-half of the openable window area of the shelter acts as an air inlet, then F, the unequal inlet-outlet area factor, equals 1.0, and A = 119 square feet. It follows that the ventilation rate per shelteree is

$$Q = 88(1.0)(0.15)(119)(7.4)/275 = 42.3 \text{ cfm/man}$$

Therefore, Condit's formula predicts a ventilation rate about 20% less than the rate derived from the average experimental results. With this particular shelter, Condit's method appears to be useful for predicting general expected ventilation rates.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the test data:

1. An overall window effectiveness factor of 0.15 was obtained from the correlation between wind speed and ventilation rate. This window effectiveness factor is independent of wind direction.
2. The shelter will be adequately ventilated 98.2% of the days during the year. This estimate is based upon a compilation of ten years of Weather Bureau data and a calculated EA value of 0.065 sq ft/occ for the shelter.
3. Half the windows functioned as inlets and half as outlets based upon ASHRAE E-factor analysis.
4. In general, the highest winds occurred during the warmest period of the day (1200-1600 hours), and some air movement was observed at all times with the hourly averaged wind velocity never being lower than 2.0 mph.
5. Future natural ventilation work should center around three objectives:
 - a. Run modeling studies using a low speed wind tunnel to test scale models of actual buildings already tested and then formulate a law to predict natural ventilation.
 - b. Determine adequacy curves for natural ventilation of building located in other cities than Chicago using existing weather data.

REFERENCES

1. Behls, H. F., et. al., "Operation and Maintenance Manual For OCD Shelter Test Equipment", Volumes I and II, GATC Report MRD 1191-2, Contract No. OCD-OS-62-99, DDC No. 446238 and 446237, Niles, Illinois, December 1963.
2. ASHRAE Guide and Data Book, 1965 Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, New York.
3. "Measurement of Natural Draft", The College of Engineering, The Pennsylvania State University, Contract No. OCD-OD-62-64, University Park, Pennsylvania, December 1963, p. 35.
4. ASHRAE, op. cit., eqn. 5, p. 465.
5. Madson, C. A., et. al., "Natural Ventilation Test of an Aboveground Fallout Shelter in Bozeman, Montana", GATC Interim Report, MRD 1195-56-2, Contract No. OCD-OS-62-134, DDC No. 453070, Niles, Illinois, November 1964.
6. Madson, C. A., et. al., "Natural Ventilation Test of an Aboveground Fallout Shelter in Baton Rouge, Louisiana", GATC Interim Report, MRD 1268-20, Contract No. B-64220(4949A-16)-US, DDC No. 456893, Niles, Illinois, January 1965.
7. Meier, H. A., et. al., "Natural Ventilation Test of an Aboveground Fallout Shelter in Evanston, Illinois", GATC Interim Report, GARD 1268-51, Contract No. B-64220(4949A-16)-US, Niles, Illinois, January 1966.
8. Henninger, R. H., et. al., "Natural Ventilation Test of a Basement Fallout Shelter in East Chicago, Indiana", GATC Interim Report, GARD 1268-61, Contract No. B-64220(4949A-16)-US, Niles, Illinois, January 1966.
9. Baschiere, R. J., et. al., "Summary Report On The Reliability of Natural Ventilation and Evaporative Cooling In Shelters", GATC Report 1266-1, Contract No. B-60421(4949A-4)-US, Niles, Illinois, November 1966.
10. Personal Communication with Dr. R. I. Condit of Stanford Research Institute, Menlo Park, California.
11. ASHRAE, op. cit., Table I, p. 470.
12. ASHRAE, op. cit., Fig. 7, p. 107.

APPENDIX A

PROTECTION FACTOR ANALYSIS
FOR STUDENT RESIDENCE HALL

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CALCULATION SHEET

Page 1 of 6

Shelter Analysis of 818 S. WilcottJob Order No.
1268-80

Contract No.

Wall Mass: 8" Brick = 74 psf
 $\frac{3}{4}$ " Plaster = $\frac{6}{80} = X_e$

Corridor Partition 4" Tile = 18
 $1\frac{1}{2}$ " Pls = $\frac{12}{30}$

Closet Partition: 3" Tile = 13
 $1\frac{1}{2}$ " Pls = $\frac{12}{25}$

Floor Mass:
 4 Concrete = 50 Xf

Roof Mass
 4" Concrete = 50
 5 Ply Roof'g = $\frac{7}{57} X_r$

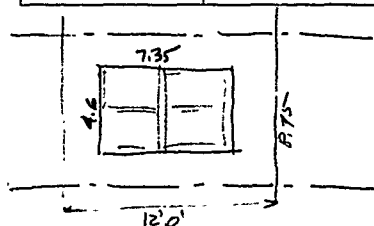
Average of Corridor plus Closet Partitions

Corr. Part'n Area = $8.4 \times 12.0 = 100 \text{ sf}$
 less Door $2.67 \times 6.67 = \frac{17.8}{82.2 \text{ sf} \times 30 \text{ psf} = 2460 \#$

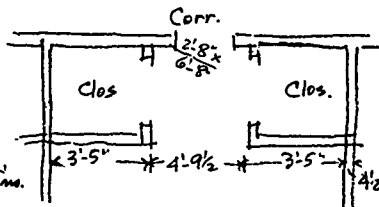
Closet Part'n. $6.83' \times 8.4' \times 25 \text{ psf} = \frac{1440 \#}{3900 \# = 100 \text{ sf}}$
 $= 39 \text{ psf} = X_i$

End Walls: 8" Brick = 74 psf
 3" Tile = 13
 $\frac{3}{4}$ " Plaster = $\frac{6}{93 \text{ psf}}$

Spandrel Beam
 4" Brick = 37
 13" Conc = $\frac{163}{200 \text{ psf}}$



$A_p = \frac{4.6 \times 7.35}{8.75 \times 12.0} = .322 \text{ (Area)}$
 $P_q = \frac{7.35}{12} = .612$

Prepared By W. B. CobbW. B. Cobb
Registered Fallout Shelter AnalystDate July 12, 1966

Checked By

Date



GENERAL AMERICAN RESEARCH DIVISION
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7438 NORTH MATCHES AVENUE NILES ILLINOIS 60440

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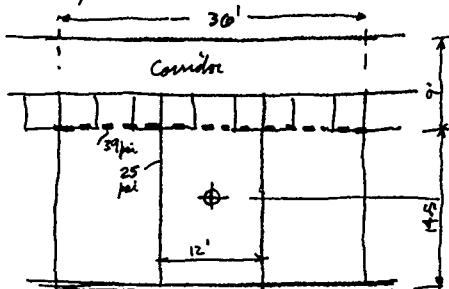
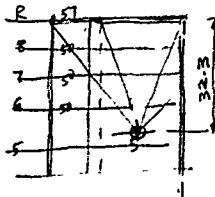
Page 2 of 6

Protection Factor at Center of Dormitory Rm.

Job Order No.
1268-80

Contract No.

Overhead Contribution

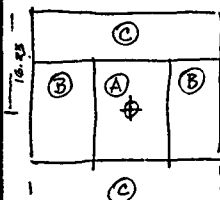


Assumptions:

- 1) Assume no overhead contribution from area beyond adjacent dormitory rooms or from other side of corridor.
- 2) Assume mass of corridor & closet walls ($X_i = 39$ psi) concentrated on m dashed line.

$$X_0 = 207 \quad B'_i(X_i = 39) = .275$$

$$B'_i(X_i = 25) = .425$$



w	W	L	Z	e	n	w	$C_0(X_0 = 207)$
w_A	12	14.5	32.3	.825	1.45	.025	.00015
w_B	14.5	36	32.3	.403	1.8	.07	.00042
w_C	32.5	36	32.3	.403	1.8	.145	.00075

$$\text{Contrib (A)} = C_0(w_A) = .00015$$

$$\text{Contrib (B)} = [C_0(w_B) - C_0(w_A)] B'_i(X_i = 25) = (.00042 - .00015) .425 = .000115$$

$$\text{Contrib (C)} = \frac{1}{2} [C_0(w_C) - C_0(w_B)] B'_i(X_i = 39) = \frac{(.00075 - .00042) .275}{2} = .000045$$

$$\text{Total } C_0 = .00031$$

Prepared By W.B. Cobb

W. B. Cobb,
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Date 7-13-66

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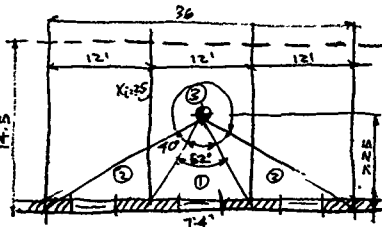
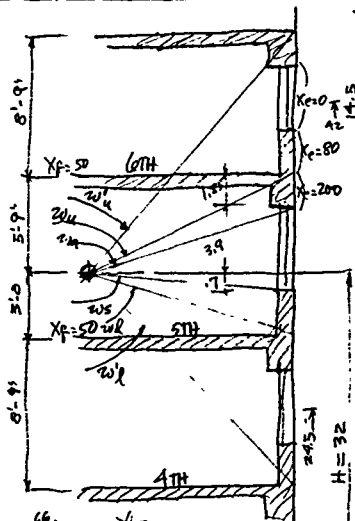
Date

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1268-80

Contract No.



Assumptions

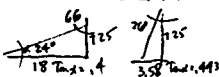
- ① No contribution beyond adjacent room or across corridor
- ② No mutual shielding
- ③ Height to let floor roof which is assumed as infinite contain. plane
- ④ Spandrel beam heavier than wall.

(See p.1)

$$A_{20} = \frac{S_2}{360} = .144 \quad P_a = \frac{7.35}{12} = .612$$

$$A_2 \textcircled{2} = \frac{80}{360} = .222 \quad A_3 = \frac{4.6 \times 7.35}{17} = .222$$

$$A_3 \textcircled{3} = \frac{228}{300} = .634$$



	W	L	Z	e	n	W	G ₁	G ₂	G ₃
W ₄	14.5	36	14.5	.403	.805	.123	—	.094	.45
W ₄	+	+	5.75	+	.319	.54	—	.082	.38
W ₉	+	+	3.9	+	.216	.66	—	.074	.31
W ₅	+	+	.7	+	.039	.934	.06	—	.078
W ₂	+	+	3	+	.167	.73	.375	—	.27
W ₀	+	+	11.75	+	.653	.295	.72	—	.44

$$E(p_{-103}) = 1.3$$

$$S_w(X_p = 80) = .69, (1 - S_w) = .31$$

$$S_w(Y_e=200) = .85 \quad (1 - S_w) = .15$$

$$P_e(X_e=80) = .08$$

$$P_e(x \geq 200) = .0056$$

$$B_i(x_i=25) = .54 \text{ (poin)}$$

$$B_0'(K_0=50) = .066 \text{ (rate)}$$

$$B_L(x_L=50) = .08 \text{ (R. value)}$$

Prepared By W.B. Abbott

W. B. Cobb,
Registered Fallout Shelter Analyst

Date 7-13-'66

Checked By _____

Date _____



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Page 4 of 6

Job Order No.
1268-80

Contract No.

Plot of Q of Down. Rm (Cont'd)

Ground Contribution - Cont'd

① Story of Detector (5th Floor) $Be(floor) = Be(X_e=0, H=32') = .59$

Strip of Wall above Windows: (Fictitious Bldg w/o Part'n)

$$C_g = \left\{ [G_a(w_w) - G_a(w_s)] \left[\frac{1-S_w}{(X_e=200)} \right] + [G_s(w_w) - G_s(w_s)] S_w E \right\} Be \left(\begin{matrix} X_e=200 \\ H=32 \end{matrix} \right) =$$

$$= [(.082 - .074)(.15) + (.38 - .31)(.85)(1.3)] .0056$$

$$= (.0012 + .0772) .0056 = .000438$$

Solid Wall except above windows:

$$C_g = \left\{ [G_d(w_s, H) - P_a G_d(w_s, H) + (1-P_a)(G_a(w_w))] [1-S_w(X_e=80)] + \right.$$

$$\left. [(1-P_a) G_s(w_w) + G_s(w_s) - P_a G_s(w_s)] S_w(X_e=80) E \right\} Be \left(\begin{matrix} X_e=80 \\ H=32 \end{matrix} \right)$$

$$= \left\{ [.375 - (.612 \times .06) + (.388 \times .074)(.31) + [(.388 \times .31) + .27 - (.612 \times .078)] (.69)(1.3) \right\} .08$$

$$[.375 - .0367 + .0287(.31) + (.12 + .27 - .0477)(.91)] .08$$

$$[.367(.31) + (.3423)(.91)] .08 = (.1137 + .3113)(.08) - (.425)(.08) = .034000$$

Glass:

$$C_g = P_a \left\{ [G_d(w_s, H) + G_a(w_s)] \left[\frac{1-S_w(X_e=0)}{H=32} \right] \right\} Be \left(\begin{matrix} X_e=0 \\ H=32 \end{matrix} \right)$$

$$= .612 [.06 + .074](1) .59 = (.612)(.134)(.59) = .0484$$

Total for Floor of Detector (5th) = .0828

For floors above & below, average out weight of wall:

$$\frac{(12 \times 1.85 \times 200) + (12 \times 6.9 \times 80)}{12 \times 8.75} = \frac{11060}{105} = 105 \text{ pf}$$

$$S_w(X_e=105) = .75(1-S_w) = .25 \quad Be(X_e=105, H=42') = .04 \quad Be(X_e=105, H=24.5') = .05$$

(6th Floor) (4th Floor)

Prepared By WBCobb

W. B. Cobb,
Registered Fallout Shelter Analyst

Date 7-13-66

Checked By

Date

Form 127

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GENERAL AMERICAN TRANSPORTATION CORPORATION
7445 NORTH HATCHER AVENUE PALES ILLINOIS 60448

CALCULATION SHEET

Page 5 of 6P_f at & g Down Rm (Cont'd)Job Order No
1268-80

Contract No.

Ground Contam - Cont'd(B) 6th Floor Contribution $Be (Glass) = Be (Xe=0, H=42) = .54$ Solid Wall:

$$C_g = \left\{ [G_a(w_u) - G_a(w_u)] \left[1 - S_w \right] + [G_s(w_u) - G_s(w_u)] S_w E \right\} \left\{ \frac{Be \cdot B_o'}{(Xe=105) (H=42) (X_o=50)} \right\} (1 - A_p)$$

$$= [(0.94 - 0.82)(.25) + (.45 - .38)(.75)(1.3)] [(0.4)(.066)(1 - .322)]$$

$$= [(0.12)(.25) + (.07)(.75)(1.3)] [(0.4)(.066)(.678)]$$

$$= (.003 + .068)(.00179) = (.071)(.00179) = .000127$$

Glass:

$$C_g = \left\{ [G_a(w_u) - G_a(w_u)] \left[1 - S_w \right] \right\} \left\{ \frac{Be \cdot B_o'}{(Xe=0) (H=42)} \right\} A_p$$

$$= [(0.94 - 0.82)(1)] [(0.54)(.066)(.322)] = \frac{.000138}{.000365}$$

Total 6th Fl.

(C) 4th Floor Contribution $Be (Glass) = Be (Xe=0, H=24.5) = .64$ Solid Wall

$$C_g = \left\{ [G_d(w_l) - G_d(w_l)] \left[1 - S_w \right] + [G_s(w_l) - G_s(w_l)] S_w E \right\} \left\{ \frac{Be \cdot B_o'}{(Xe=105) (H=24.5) (X_o=50)} \right\} (1 - A_p)$$

$$= [(0.72 - .375)(.25) + (.44 - .27)(.75)(1.3)] [(0.5)(.08)(1 - .322)]$$

$$= [(0.345)(.25) + (.17)(.75)(1.3)] [(0.5)(.08)(.678)]$$

$$= (.086 + .167)(.00271) = (.253)(.00271) = .000685$$

Glass:

$$C_g = \left\{ [G_d(w_l) - G_d(w_l)] \left[1 - S_w \right] \right\} \left\{ \frac{Be \cdot B_o'}{(Xe=0) (H=24.5) (X_o=50)} \right\} A_p$$

$$= [(0.72 - .375)(1)] [(0.64)(.08)(.322)] = \frac{.005675}{.006360}$$

Total 4th Fl.

Prepared By W.B. CobbW. B. Cobb,
Registered Fallout Shelter AnalystDate 7-13-66

Checked By

Date

Form 127

GENERAL AMERICAN RESEARCH DIVISION

GATX


 GENERAL AMERICAN RESEARCH DIVISION
 GENERAL AMERICAN TRANSPORTATION CORPORATION
 7445 NORTH HATCHEZ AVENUE NILES ILLINOIS 60068

CALCULATION SHEET

Page 6 of 6P_F at Down. Em & (Cont'd)Job Order No.
1268-80

Contract No.

Ground Contribution - Recap.

Detector Floor - 5th = .082800Floor Above 6th = .000365Floor Below 4th = .006360

Total = .089525

Above assumes complete fictitious bldg of uniform perimeter.

Now apply azimuth angle fractions

Az ① Contribution = .0895 x .144 (p3) = .0129

Az ② " = .0895 x .222 x .54 = .0107

Az ③ " (B₁₀₀) = 0

Total Ground Contrib. = .02360

" Roof Contrib = .00031

Total R_F = .02391Protection Factor = $\frac{1}{R_F} = \frac{1}{.02391} = \underline{42}$ at center of Dormitory Room.

In other words, approximately half of the dormitory room (the half away from the windows) qualifies as a fallout shelter.

The corridor is obviously better, approximately, P_F = 110Prepared By WBCobbW. B. Cobb,
Registered Fallout Shelter AnalystDate 7-13-66

Checked By

Date

Form 127

GENERAL AMERICAN RESEARCH DIVISION

APPENDIX B

EQUATIONS FOR THE TABLES OF EFFECTIVE TEMPERATURES
AND HUMIDITY RATIOS AS A FUNCTION OF WET AND
DRY-BULB TEMPERATURES

GENERAL AMERICAN RESEARCH DIVISION

The tables are based on these relationships:

$$ET = \frac{107.5 (DB-WB) + 62.3 WB}{62.3 + DB - WB}$$

where:

ET = Effective temperature, °F

DB = Dry-bulb temperature, °F

WB = Wet-bulb temperature, °F

This relationship is limited to low air velocities and is restricted to the temperature range of

$$45^{\circ}\text{F} \leq DB \leq 110^{\circ}\text{F}$$

$$30^{\circ}\text{F} \leq WB \leq 100^{\circ}\text{F}$$

Effective temperatures from these tables have an error of less than 0.5°F as compared to those determined from the ASHRAE Effective Temperature Nomogram (Ref. 12).

To determine the humidity ratio, Dalton's rule and perfect gas mixture relations are applied:

$$W = 0.622 \left[\frac{P_w}{P - P_w} \right]$$

where:

W = Humidity ratio, lbs water/lb dry air

P_w = Partial pressure of water vapor

P = Barometric pressure (sea level assumed)
(P_w and P in consistent units)

The partial pressure of water vapor is determined from the Carrier equation:

$$P_w = P_s - \left[\frac{(P - P_s)(DB - WB)}{2831 - 1.43 WB} \right]$$

where:

P_s = Saturation pressure of water vapor at wet-bulb temperature WB
(P_w , P_s and P in consistent units)

(The original coefficients were 2800 and 1.30)

Accuracy is 0.5% or better for all but the lowest humidity ratios.

APPENDIX C

TEST DATA LOGSHEETS

1. TITLE OF TECHNIQUE		MOY	
MELTER ENERGY INPUT		1-22-64	
DESIGN METABOLIC EQUIPMENT AND LIGHTING LOADS	MEASURE	1-22-64	1-22-64
ACTUAL POWER MEASUREMENTS	MEASURE	1-22-64	1-22-64
INPUT (FROM POWER METER)	MEASURE	1-22-64	1-22-64
WATER		1-22-64	
DESIGN INPUT	MEASURE	1-22-64	1-22-64
ACTUAL INPUT	MEASURE	1-22-64	1-22-64
ENTHALPY INPUT	MEASURE	1-22-64	1-22-64
TOTAL HEATED ENERGY INPUT		1-22-64	
TEMPERATURES		1-22-64	
PSYCHROMETERS (RESISTANCE WETBULB)	MEASURE	1-22-64	1-22-64
C1 CORRIDOR NORTH DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR NORTH WBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR SOUTH DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR SOUTH WBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR CENTER DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR CENTER WBT	MEASURE	1-22-64	1-22-64
C1 AMBIENT DBT NORTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
C1 AMBIENT WBT NORTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
C1 AMBIENT DBT SOUTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
C1 AMBIENT WBT SOUTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
PSYCHROMETERS (MERCUY WETBULB THERMISTERS)		1-22-64	
C1 CORRIDOR NORTH DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR NORTH WBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR CENTER DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR CENTER WBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR SOUTH DBT	MEASURE	1-22-64	1-22-64
C1 CORRIDOR SOUTH WBT	MEASURE	1-22-64	1-22-64
C1 AMBIENT DBT NORTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
C1 AMBIENT WBT NORTH WALL OF WEST WING	MEASURE	1-22-64	1-22-64
AVERAGES		1-22-64	
AMBIENT DBT BOLD TEMPERATURE	MEASURE	1-22-64	1-22-64
WET BULB TEMPERATURE	MEASURE	1-22-64	1-22-64
EFFECTIVE TEMPERATURE	MEASURE	1-22-64	1-22-64
SPECIFIC VOLUME	MEASURE	1-22-64	1-22-64
WINDSPEED RATIO	MEASURE	1-22-64	1-22-64
MELTER DBT BOLD TEMPERATURE	MEASURE	1-22-64	1-22-64
WET BULB TEMPERATURE	MEASURE	1-22-64	1-22-64
EFFECTIVE TEMPERATURE	MEASURE	1-22-64	1-22-64
SPECIFIC VOLUME	MEASURE	1-22-64	1-22-64
WINDSPEED RATIO	MEASURE	1-22-64	1-22-64
WIND		1-22-64	
WEATHER BUREAU WIND VELOCITY	MEASURE	1-22-64	1-22-64
WIND DIRECTION	MEASURE	1-22-64	1-22-64
ROOF		1-22-64	
COUNTDOWN READING, N	MEASURE	1-22-64	1-22-64
WIND VELOCITY (N = 0.5 WIND)	MEASURE	1-22-64	1-22-64
WIND DIRECTION	MEASURE	1-22-64	1-22-64
WIND VELOCITY (TAYLOR WINDSCOPE)	MEASURE	1-22-64	1-22-64
AIR FLOW RATE		1-22-64	
NUMBER OF WINDOWS ACTIVE AS INLETS	MEASURE	1-22-64	1-22-64
EAST WINDOWS	MEASURE	1-22-64	1-22-64
WEST WINDOWS	MEASURE	1-22-64	1-22-64
WIND DIRECTION	MEASURE	1-22-64	1-22-64
EFFECTIVENESS FACTOR		1-22-64	
COMMENTS	LOG BOOK REFERENCE SUBJECT	PAGE	

TITLE IS OF TECHNIQUE		HOUR		DATE		TIME		WIND		TEMP		PRESS		HUMID		SOLAR		AVG																							
DESIGNED METABOLIC EQUIPMENT AND LIGHTING LOADS		ACTUAL POWER METER READING (JAMPT FROM POWER METER)		WATER DESIGER INPUT ACTUAL INPUT EXTRA INPUT		TOTAL DESIGER ENERGY INPUT		TEMPERATURES		PSYCHROMETER RESISTANCE BULBS		PSYCHROMETER DISCREP BULB THERMOMETER		AVERAGES		WIND WEATHER BREAK		WIND VELOCITY		WIND DIRECTION		ROOF COVER BEARING R WIND VELOCITY (M S - 1) WIND DIRECTION WIND VELOCITY (TAYLOR WINDSCOPE)		AIR FLOW RATE		NUMBER OF WINDOWS ACTING AS INLETS		EAST WINDOWS SW WINDOWS		WIND WINDOWS		WIND WINDOWS		EFFECTIVE AREA (M ²)		COMMENTS		LOG BOOK REFERENCE		PAGE	
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TEST 2 - 45 - 2.
DAYS 7-10-66
7-18-66

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UNIVERSITY OF MINNESOTA
STUDENT RESIDENCE HALL
UNIVERSITY OF MINNESOTA

NATURAL Ventilation Test
100 Occupants

Test 3 45 5
Date 7/11/61

TITLE OF TEST/EXPERIMENT									
METER ENERGY INPUTS									
DESIGN METABOLIC EQUIPMENT AND LIGHTING LOADS									
ACTUAL POWER METER READINGS									
INPUT FROM POWER METER									
WATER									
DESIGNED INPUT									
ACTUAL INPUT									
ENTHALPY									
INPUT									
TOTAL METER ENERGY INPUT									
TEMPERATURES									
PSYCHROMETER RESISTANCE BRIDGES									
C1 CORRIDOR NORTH DAT									
C2 CORRIDOR NORTH WST									
C3 CORRIDOR SOUTH DAT									
C4 CORRIDOR SOUTH WST									
C5 CORRIDOR CENTER DAT									
C6 CORRIDOR CENTER WST									
C7 AMBIENT DAT NORTH WALL OF WEST WING									
C8 AMBIENT DAT SOUTH WALL OF WEST WING									
C9 AMBIENT WST NORTH WALL OF WEST WING									
C10 AMBIENT WST SOUTH WALL OF WEST WING									
C11 AMBIENT WST NORTH WALL OF WEST WING									
C12 AMBIENT WST SOUTH WALL OF WEST WING									
PSYCHROMETER MERCURY BULB THERMOMETERS									
C1 CORRIDOR NORTH DAT									
C2 CORRIDOR NORTH WST									
C3 CORRIDOR CENTER DAT									
C4 CORRIDOR CENTER WST									
C5 CORRIDOR SOUTH DAT									
C6 CORRIDOR SOUTH WST									
C7 AMBIENT DAT NORTH WALL OF WEST WING									
C8 AMBIENT DAT SOUTH WALL OF WEST WING									
C9 AMBIENT WST NORTH WALL OF WEST WING									
C10 AMBIENT WST SOUTH WALL OF WEST WING									
AVERAGES									
AMBIENT DAT DRY BULB TEMPERATURE									
WET BULB TEMPERATURE									
EFFECTIVE TEMPERATURE									
SPECIFIC VOLUME									
HUMIDITY RATIO									
WELTER DAT DRY BULB TEMPERATURE									
WET BULB TEMPERATURE									
EFFECTIVE TEMPERATURE									
SPECIFIC VOLUME									
HUMIDITY RATIO									
WIND									
WEATHER BUREAU WIND VELOCITY									
WIND DIRECTION									
ROOF									
COUNTER READING B									
WIND VELOCITY IN S - S (F14)									
WIND DIRECTION									
WIND VELOCITY (STATION WINDCOVE)									
AIR FLOW RATE									
SAMPLES OF WINDOWS ACTING AS BELTS									
EAST WINDOWS									
S.W. WINDOWS									
S.W. WINDOWS									
EFFECTIVENESS FACTOR									
CONVERTS									
LOG BOOK REFERENCE									
PAGE									

UNIVERSITY OF ILLINOIS
STUDENT RESEARCH HALL
CHAMPAIGN, ILLINOIS

NATURAL VENTILATION TEST
100 W. OLNEY

TEST 3-4 4.5.6
DATE 7-11-61

INSTRUMENTATION		MOL. 2		MOL. 3		MOL. 4		MOL. 5		MOL. 6		MOL. 7		MOL. 8		MOL. 9		MOL. 10		MOL. 11		MOL. 12		MOL. 13		MOL. 14		MOL. 15		MOL. 16		MOL. 17		MOL. 18		MOL. 19		MOL. 20		MOL. 21		MOL. 22		MOL. 23		MOL. 24		MOL. 25		MOL. 26		MOL. 27		MOL. 28		MOL. 29		MOL. 30		MOL. 31		MOL. 32		MOL. 33		MOL. 34		MOL. 35		MOL. 36		MOL. 37		MOL. 38		MOL. 39		MOL. 40		MOL. 41		MOL. 42		MOL. 43		MOL. 44		MOL. 45		MOL. 46		MOL. 47		MOL. 48		MOL. 49		MOL. 50		MOL. 51		MOL. 52		MOL. 53		MOL. 54		MOL. 55		MOL. 56		MOL. 57		MOL. 58		MOL. 59		MOL. 60		MOL. 61		MOL. 62		MOL. 63		MOL. 64		MOL. 65		MOL. 66		MOL. 67		MOL. 68		MOL. 69		MOL. 70		MOL. 71		MOL. 72		MOL. 73		MOL. 74		MOL. 75		MOL. 76		MOL. 77		MOL. 78		MOL. 79		MOL. 80		MOL. 81		MOL. 82		MOL. 83		MOL. 84		MOL. 85		MOL. 86		MOL. 87		MOL. 88		MOL. 89		MOL. 90		MOL. 91		MOL. 92		MOL. 93		MOL. 94		MOL. 95		MOL. 96		MOL. 97		MOL. 98		MOL. 99		MOL. 100		MOL. 101		MOL. 102		MOL. 103		MOL. 104		MOL. 105		MOL. 106		MOL. 107		MOL. 108		MOL. 109		MOL. 110		MOL. 111		MOL. 112		MOL. 113		MOL. 114		MOL. 115		MOL. 116		MOL. 117		MOL. 118		MOL. 119		MOL. 120		MOL. 121		MOL. 122		MOL. 123		MOL. 124		MOL. 125		MOL. 126		MOL. 127		MOL. 128		MOL. 129		MOL. 130		MOL. 131		MOL. 132		MOL. 133		MOL. 134		MOL. 135		MOL. 136		MOL. 137		MOL. 138		MOL. 139		MOL. 140		MOL. 141		MOL. 142		MOL. 143		MOL. 144		MOL. 145		MOL. 146		MOL. 147		MOL. 148		MOL. 149		MOL. 150		MOL. 151		MOL. 152		MOL. 153		MOL. 154		MOL. 155		MOL. 156		MOL. 157		MOL. 158		MOL. 159		MOL. 160		MOL. 161		MOL. 162		MOL. 163		MOL. 164		MOL. 165		MOL. 166		MOL. 167		MOL. 168		MOL. 169		MOL. 170		MOL. 171		MOL. 172		MOL. 173		MOL. 174		MOL. 175		MOL. 176		MOL. 177		MOL. 178		MOL. 179		MOL. 180		MOL. 181		MOL. 182		MOL. 183		MOL. 184		MOL. 185		MOL. 186		MOL. 187		MOL. 188		MOL. 189		MOL. 190		MOL. 191		MOL. 192		MOL. 193		MOL. 194		MOL. 195		MOL. 196		MOL. 197		MOL. 198		MOL. 199		MOL. 200		MOL. 201		MOL. 202		MOL. 203		MOL. 204		MOL. 205		MOL. 206		MOL. 207		MOL. 208		MOL. 209		MOL. 210		MOL. 211		MOL. 212		MOL. 213		MOL. 214		MOL. 215		MOL. 216		MOL. 217		MOL. 218		MOL. 219		MOL. 220		MOL. 221		MOL. 222		MOL. 223		MOL. 224		MOL. 225		MOL. 226		MOL. 227		MOL. 228		MOL. 229		MOL. 230		MOL. 231		MOL. 232		MOL. 233		MOL. 234		MOL. 235		MOL. 236		MOL. 237		MOL. 238		MOL. 239		MOL. 240		MOL. 241		MOL. 242		MOL. 243		MOL. 244		MOL. 245		MOL. 246		MOL. 247		MOL. 248		MOL. 249		MOL. 250		MOL. 251		MOL. 252		MOL. 253		MOL. 254		MOL. 255		MOL. 256		MOL. 257		MOL. 258		MOL. 259		MOL. 260		MOL. 261		MOL. 262		MOL. 263		MOL. 264		MOL. 265		MOL. 266		MOL. 267		MOL. 268		MOL. 269		MOL. 270		MOL. 271		MOL. 272		MOL. 273		MOL. 274		MOL. 275		MOL. 276		MOL. 277		MOL. 278		MOL. 279		MOL. 280		MOL. 281		MOL. 282		MOL. 283		MOL. 284		MOL. 285		MOL. 286		MOL. 287		MOL. 288		MOL. 289		MOL. 290		MOL. 291		MOL. 292		MOL. 293		MOL. 294		MOL. 295		MOL. 296		MOL. 297		MOL. 298		MOL. 299		MOL. 300		MOL. 301		MOL. 302		MOL. 303		MOL. 304		MOL. 305		MOL. 306		MOL. 307		MOL. 308		MOL. 309		MOL. 310		MOL. 311		MOL. 312		MOL. 313		MOL. 314		MOL. 315		MOL. 316		MOL. 317		MOL. 318		MOL. 319		MOL. 320		MOL. 321		MOL. 322		MOL. 323		MOL. 324		MOL. 325		MOL. 326		MOL. 327		MOL. 328		MOL. 329		MOL. 330		MOL. 331		MOL. 332		MOL. 333		MOL. 334		MOL. 335		MOL. 336		MOL. 337		MOL. 338		MOL. 339		MOL. 340		MOL. 341		MOL. 342		MOL. 343		MOL. 344		MOL. 345		MOL. 346		MOL. 347		MOL. 348		MOL. 349		MOL. 350		MOL. 351		MOL. 352		MOL. 353		MOL. 354		MOL. 355		MOL. 356		MOL. 357		MOL. 358		MOL. 359		MOL. 360		MOL. 361		MOL. 362		MOL. 363		MOL. 364		MOL. 365		MOL. 366		MOL. 367		MOL. 368		MOL. 369		MOL. 370		MOL. 371		MOL. 372		MOL. 373		MOL. 374		MOL. 375		MOL. 376		MOL. 377		MOL. 378		MOL. 379		MOL. 380		MOL. 381		MOL. 382		MOL. 383		MOL. 384		MOL. 385		MOL. 386		MOL. 387		MOL. 388		MOL. 389		MOL. 390		MOL. 391		MOL. 392		MOL. 393		MOL. 394		MOL. 395		MOL. 396		MOL. 397		MOL. 398		MOL. 399		MOL. 400		MOL. 401		MOL. 402		MOL. 403		MOL. 404		MOL. 405		MOL. 406		MOL. 407		MOL. 408		MOL. 409		MOL. 410		MOL. 411		MOL. 412		MOL. 413		MOL. 414		MOL. 415		MOL. 416		MOL. 417		MOL. 418		MOL. 419		MOL. 420		MOL. 421		MOL. 422		MOL. 423		MOL. 424		MOL. 425		MOL. 426		MOL. 427		MOL. 428		MOL. 429		MOL. 430		MOL. 431		MOL. 432		MOL. 433		MOL. 434		MOL. 435		MOL. 436		MOL. 437		MOL. 438		MOL. 439		MOL. 440		MOL. 441		MOL. 442		MOL. 443		MOL. 444		MOL. 445		MOL. 446		MOL. 447		MOL. 448		MOL. 449		MOL. 450		MOL. 451		MOL. 452		MOL. 453		MOL. 454		MOL. 455		MOL. 456		MOL. 457		MOL. 458		MOL. 459		MOL. 460		MOL. 461		MOL. 462		MOL. 463		MOL. 464		MOL. 465		MOL. 466		MOL. 467		MOL. 468		MOL. 469		MOL. 470		MOL. 471		MOL. 472		MOL. 473		MOL. 474		MOL. 475		MOL. 476		MOL. 477		MOL. 478		MOL. 479		MOL. 480		MOL. 481		MOL. 482		MOL. 483		MOL. 484		MOL. 485		MOL. 486		MOL. 487		MOL. 488		MOL. 489		MOL. 490		MOL. 491		MOL. 492		MOL. 493		MOL. 494		MOL. 495		MOL. 496		MOL. 497		MOL. 498		MOL. 499		MOL. 500		MOL. 501		MOL. 502		MOL. 503		MOL. 504		MOL. 505		MOL. 506		MOL. 507		MOL. 508		MOL. 509		MOL. 510		MOL. 511		MOL. 512		MOL. 513		MOL. 514		MOL. 515		MOL. 516		MOL. 517		MOL. 518		MOL. 519		MOL. 520		MOL. 521		MOL. 522		MOL. 523		MOL. 524		MOL. 525		MOL. 526		MOL. 527		MOL. 528		MOL. 529		MOL. 530		MOL. 531		MOL. 532		MOL. 533		MOL. 534		MOL. 535		MOL. 536		MOL. 537		MOL. 538		MOL. 539		MOL. 540		MOL. 541		MOL. 542		MOL. 543		MOL. 544		MOL. 545		MOL. 546		MOL. 547		MOL. 548		MOL. 549		MOL. 550		MOL. 551		MOL. 552		MOL. 553		MOL. 554		MOL. 555		MOL. 556		MOL. 557		MOL. 558		MOL. 559		MOL. 560		MOL. 561		MOL. 562		MOL. 563		MOL. 564		MOL. 565		MOL. 566		MOL. 567		MOL. 568		MOL. 569		MOL. 570		MOL. 571		MOL. 572		MOL. 573		MOL. 574		MOL. 575		MOL. 576		MOL. 577		MOL. 578		MOL. 579		MOL. 580		MOL. 581		MOL. 582		MOL. 583		MOL. 584		MOL. 585		MOL. 586		MOL. 587		MOL. 588		MOL. 589		MOL. 590		MOL. 591		MOL. 592		MOL. 593		MOL. 594		MOL. 595		MOL. 596		MOL. 597		MOL. 598		MOL. 599		MOL. 600		MOL. 601		MOL. 602		MOL. 603		MOL. 604		MOL. 605		MOL. 606		MOL. 607		MOL. 608		MOL. 609		MOL. 610		MOL. 611		MOL. 612		MOL. 613		MOL. 614		MOL. 615		MOL. 616		MOL. 617		MOL. 618		MOL. 619		MOL. 620		MOL. 621		MOL. 622		MOL. 623		MOL. 624		MOL. 625		MOL. 626		MOL. 627		MOL. 628		MOL. 629		MOL. 630		MOL. 631		MOL. 632		MOL. 633		MOL. 634		MOL. 635		MOL. 636		MOL. 637		MOL. 638		MOL. 639		MOL. 640		MOL. 641		MOL. 642		MOL. 643		MOL. 644		MOL. 645		MOL. 646		MOL. 647		MOL. 648		MOL. 649		MOL. 650		MOL. 651		MOL. 652		MOL. 653		MOL. 654		MOL. 655		MOL. 656		MOL. 657		MOL. 658		MOL. 659		MOL. 660		MOL. 661		MOL. 662		MOL. 663		MOL. 664		MOL. 665		MOL. 666		MOL. 667		MOL. 668		MOL. 669		MOL. 670		MOL. 671		MOL. 672		MOL. 673		MOL. 674		MOL. 675		MOL. 676		MOL. 677		MOL. 678		MOL. 679		MOL. 680		MOL. 681		MOL. 682		MOL. 683		MOL. 684		MOL. 685		MOL. 686		MOL. 687		MOL. 688		MOL. 689		MOL. 690		MOL. 691		MOL. 692		MOL. 693		MOL. 694		MOL. 695		MOL. 696		MOL. 697		MOL. 698		MOL. 699		MOL. 700		MOL. 701		MOL. 702		MOL. 703		MOL. 704		MOL. 705		MOL. 706		MOL. 707		MOL. 708		MOL. 709		MOL. 710		MOL. 711		MOL. 712		MOL. 713		MOL. 714		MOL. 715		MOL. 716		MOL. 717		MOL. 718		MOL. 719		MOL. 720		MOL. 721		MOL. 722		MOL. 723		MOL. 724		MOL. 725		MOL. 726		MOL. 727		MOL. 728		MOL. 729		MOL. 730		MOL. 731		MOL. 732		MOL. 733		MOL. 734		MOL. 735		MOL. 736		MOL. 737		MOL. 738		MOL. 739		MOL. 740		MOL. 741		MOL. 742		MOL. 743		MOL. 744		MOL. 745		MOL. 746		MOL. 747		MOL. 748		MOL. 749		MOL. 750		MOL. 751		MOL. 752		MOL. 753		MOL. 754		MOL. 755		MOL. 756		MOL. 757		MOL. 758		MOL. 759		MOL. 760		MOL. 761		MOL. 762		MOL. 763		MOL. 764		MOL. 765		MOL. 766		MOL. 767		MOL. 768		MOL. 769		MOL. 770		MOL. 771		MOL. 772		MOL. 773		MOL. 774		MOL. 775		MOL. 776		MOL. 777		MOL. 778		MOL. 779		MOL. 780		MOL. 781		MOL. 782		MOL. 783		MOL. 784		MOL. 785		MOL. 786		MOL. 787		MOL. 788		MOL. 789		MOL. 790		MOL. 791		MOL. 792		MOL. 793		MOL. 794		MOL. 795		MOL. 796		MOL. 797		MOL. 798		MOL. 799		MOL. 800		MOL. 801		MOL. 802		MOL. 803		MOL. 804		MOL. 805		MOL. 806		MOL. 807		MOL. 808		MOL. 809		MOL. 810		MOL. 811		MOL. 812		MOL. 813		MOL. 814		MOL. 815		MOL. 816		MOL. 817		MOL. 818		MOL. 819		MOL. 820		MOL. 821		MOL. 822		MOL. 823		MOL. 824		MOL. 825		MOL. 826		MOL. 827		MOL. 828		MOL. 829		MOL. 830		MOL. 831		MOL. 832		MOL.	
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UNIVERSITY OF MICHIGAN
STUDENT RESIDENCE HALL
JANUARY 1963

WIND-ROCK MEASUREMENTS
1/17/63

DATE 1/17/63

INSTRUMENTATION		TIME																Avg
INSTRUMENTATION		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SHELTER ENERGY FLUX	DESIRE: METABOLIT - EQUIPMENT AND LIGHTING LOADS																	185
	ACTUAL: POWER ME. & READING																	21.9
WATER	DESIRE: RAIN																	28.5
	ACTUAL: RAIN																	2.6
TOTAL SHELTER ENERGY FLUX																		72.1
TEMPERATURES																		
PSYCHROMETERS (REAR) - 7C READING																		
C1 CORRIDOR NORTH INT																		
C1 CORRIDOR NORTH INT																		
C1 CORRIDOR SOUTH INT																		
C1 CORRIDOR SOUTH INT																		
C1 CORRIDOR CENTER INT																		
C1 CORRIDOR CENTER INT																		
C1 AMBULANT INT - NORTH HALL OF WEST WING																		
C1 AMBULANT INT - NORTH HALL OF WEST WING																		
C1 AMBULANT INT - SOUTH HALL OF WEST WING																		
C1 AMBULANT INT - SOUTH HALL OF WEST WING																		
PSYCHROMETERS (OVERCUT) 7B READING																		
C1 CORRIDOR NORTH INT																		
C1 CORRIDOR NORTH INT																		
C1 CORRIDOR CENTER INT																		
C1 CORRIDOR CENTER INT																		
C1 CORRIDOR SOUTH INT																		
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C1 AMBULANT INT - NORTH HALL OF WEST WING																		
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C1 AMBULANT INT - SOUTH HALL OF WEST WING																		
C1 AMBULANT INT - SOUTH HALL OF WEST WING																		
WIND-ROCK																		
AMBIENT DRY-BULB TEMPERATURE																		
WET-BULB TEMPERATURE																		
EFFECTIVE TEMPERATURE																		
SPECIFIC HUMIDITY																		
WIND-ROCK																		
SHELTER DRY-BULB TEMPERATURE																		
WET-BULB TEMPERATURE																		
EFFECTIVE TEMPERATURE																		
SPECIFIC HUMIDITY																		
WIND-ROCK																		
WEATHER BUREAU																		
WIND VELOCITY																		
WIND DIRECTION																		
DOOF																		
COMPUTER READING - R																		
WIND VELOCITY (1000 ft/s)																		
WIND DIRECTION																		
WIND VELOCITY (1000 ft/s)																		
AIR FLOW RATE																		
NUMBER OF WINDOWS ACTING AS INLETS																		
EAST WINDOWS																		
SOUTH WINDOWS																		
EFFECTIVE AREA (sq ft)																		
EFFECTIVE AREA (sq ft)																		
COMMENTS																		
LOG ROOM REFERENCE																		
PAGE																		

UNIVERSITY OF ILLINOIS
STUDENT RESOURCE HALL
CHICAGO, ILL. 60637

Natural Ventilation Test
1972 Occupants

Test 4 L5 8
Date 7/2/76

1. LIST OF SYMBOLS		HOUR																Ave
WHEATER ENERGY INPUTS		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	76
DESIRE	METABOLIC EQUIPMENT AND LIGHTING LOAD	MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
ACTUAL	POWER WHEEL RECORDING (INPUT FROM POWER METER)	MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
WATER (HEATED INPUT)		MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
ACTUAL INPUT		MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
ENTH 1 PSI		MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
INPUT		MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
TOTAL WHEATER ENERGY INPUTS		MBTONE	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775	775
TEMPERATURES																		
PSYCHROMETERS (RECORDANCE BULBS)																		
G. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. CORRIDOR CENTER DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. CORRIDOR CENTER DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. AMBIENT DBT NORTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. AMBIENT DBT NORTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. AMBIENT DBT SOUTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
C. AMBIENT DBT SOUTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
PSYCHROMETERS MERCURY BULB THERMOMETERS																		
G. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. CORRIDOR NORTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. CORRIDOR CENTER DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. CORRIDOR CENTER DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. CORRIDOR SOUTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. CORRIDOR SOUTH DBT		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. AMBIENT DBT NORTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
G. AMBIENT DBT NORTH WALL OF WEST WING		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
AVERAGES																		
AMBIENT																		
DBT AIR TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WET BULB TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
EFFECTIVE TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
SPECIFIC HUMIDITY		10 ⁻² LB/LB	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WHEATER																		
WET BULB TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WET BULB TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
EFFECTIVE TEMPERATURE		F	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
SPECIFIC HUMIDITY		10 ⁻² LB/LB	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WHEATER RATIO		10 ⁻² LB/LB	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND																		
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
BOB																		
COUNTY REF. WIND		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
AIR FLOW IN FT																		
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
FACILITIES																		
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
WIND DIRECTION		MPH	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
COMMENTS																		
NO BOOK REFERENCE																		
DATE																		

UNIVERSITY OF ILLINOIS
SUBURB REFERENCE HALL
CHICAGO 100-203

NATURAL VENTILATION TEST
1957 OCCUPANTS

TEST 5-45-1
DATE 7-1-57

INITIALS OF TECHNICIAN		MOI		DATE	
SHELTER ENERGY INPUT		MOI		DATE	
DESIRED METABOLIC EQUIPMENT AND LIGHTING LOADS		MOI		DATE	
ACTUAL POWER METERS (WATTS)		MOI		DATE	
WATER DESIRED IMPLY		MOI		DATE	
ACTUAL IMPLY		MOI		DATE	
ENTRALLY		MOI		DATE	
IMPLY		MOI		DATE	
TOTAL SHELTER ENERGY INPUT		MOI		DATE	
TEMPERATURES		MOI		DATE	
PSYCHROMETERS (RESISTANCE BULBS)		MOI		DATE	
C1 CORRIDOR NORTH DBT		MOI		DATE	
C2 CORRIDOR NORTH WBT		MOI		DATE	
C3 CORRIDOR SOUTH DBT		MOI		DATE	
C4 CORRIDOR SOUTH WBT		MOI		DATE	
C5 CORRIDOR CENTER DBT		MOI		DATE	
C6 CORRIDOR CENTER WBT		MOI		DATE	
C7 AMBIENT DBT NORTH WALL OF WEST WING		MOI		DATE	
C8 AMBIENT WBT NORTH WALL OF WEST WING		MOI		DATE	
C9 AMBIENT DBT SOUTH WALL OF WEST WING		MOI		DATE	
C10 AMBIENT WBT SOUTH WALL OF WEST WING		MOI		DATE	
PSYCHROMETERS (MERCUY BULB THERMISTERS)		MOI		DATE	
C1 CORRIDOR NORTH DBT		MOI		DATE	
C2 CORRIDOR NORTH WBT		MOI		DATE	
C3 CORRIDOR CENTER DBT		MOI		DATE	
C4 CORRIDOR CENTER WBT		MOI		DATE	
C5 CORRIDOR SOUTH DBT		MOI		DATE	
C6 CORRIDOR SOUTH WBT		MOI		DATE	
C7 AMBIENT DBT NORTH WALL OF WEST WING		MOI		DATE	
C8 AMBIENT WBT NORTH WALL OF WEST WING		MOI		DATE	
AVERAGES		MOI		DATE	
AMBIENT DBT BULB TEMPER.		MOI		DATE	
WET BULB TEMPERATURE		MOI		DATE	
EFFECTIVE TEMPERATURE		MOI		DATE	
SPECIFIC VOLUME		MOI		DATE	
HUMIDITY RATIO		MOI		DATE	
SHELTER DBT BULB TEMPERATURE		MOI		DATE	
WET BULB TEMPERATURE		MOI		DATE	
EFFECTIVE TEMPERATURE		MOI		DATE	
SPECIFIC VOLUME		MOI		DATE	
HUMIDITY RATIO		MOI		DATE	
WIND		MOI		DATE	
WEATHER BUREAU		MOI		DATE	
WIND VELOCITY		MOI		DATE	
WIND DIRECTION		MOI		DATE	
ROOF		MOI		DATE	
COUNTER READING		MOI		DATE	
WIND VELOCITY (H.A. 1/4 H.A.)		MOI		DATE	
WIND DIRECTION		MOI		DATE	
WIND VELOCITY (TAYLOR WINDMILL)		MOI		DATE	
AIR FLOW RATE		MOI		DATE	
NUMBER OF WINDOWS ACTING AS INLETS		MOI		DATE	
EAST WINDOWS		MOI		DATE	
N.W. WINDOWS		MOI		DATE	
S.W. WINDOWS		MOI		DATE	
COMMENTS		MOI		DATE	
100 BOMB REFERENCE		MOI		DATE	
SOURCE		MOI		DATE	
PAGE		MOI		DATE	

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NATURAL VENTILATION TEST
1975 Occupancy

EXP. 5-25-76
DATE 7/24/76

3.00 (10/10/76)		H.O.	
EXP. 5-25-76		7/24/76	
DEVICES: METEORIC EQUIPMENT AND LIGHTING LOADS		7/24/76	
ACTUAL: POWER METER READINGS		7/24/76	
(SHEET FROM POWER METER)		7/24/76	
WATER: MEASURED INLET		7/24/76	
ACTUAL INLET		7/24/76	
ENTRIFY		7/24/76	
INPUT		7/24/76	
TOTAL INLET ENERGY INPUT		7/24/76	
TEMPERATURES		7/24/76	
PSYCHROMETERS (RESISTANCE BURST)		7/24/76	
C1 CORRIDOR NORTH INT		7/24/76	
C2 CORRIDOR NORTH INT		7/24/76	
C3 CORRIDOR SOUTH INT		7/24/76	
C4 CORRIDOR SOUTH INT		7/24/76	
C5 CORRIDOR CENTER INT		7/24/76	
C6 CORRIDOR CENTER INT		7/24/76	
C7 AMBIENT INT NORTH WALL OF WEST WING		7/24/76	
C8 AMBIENT INT NORTH WALL OF WEST WING		7/24/76	
C9 AMBIENT INT SOUTH WALL OF WEST WING		7/24/76	
C10 AMBIENT INT SOUTH WALL OF WEST WING		7/24/76	
PSYCHROMETERS (MERCURY BULB THERMOMETERS)		7/24/76	
C1 CORRIDOR NORTH INT		7/24/76	
C2 CORRIDOR NORTH INT		7/24/76	
C3 CORRIDOR CENTER INT		7/24/76	
C4 CORRIDOR CENTER INT		7/24/76	
C5 CORRIDOR SOUTH INT		7/24/76	
C6 CORRIDOR SOUTH INT		7/24/76	
C7 AMBIENT INT NORTH WALL OF WEST WING		7/24/76	
C8 AMBIENT INT NORTH WALL OF WEST WING		7/24/76	
AVERAGES		7/24/76	
TEMP. INT		7/24/76	
TEMP. EXTER		7/24/76	
HUMID. INT		7/24/76	
HUMID. EXTER		7/24/76	
SHELTER		7/24/76	
TEMP. INT		7/24/76	
TEMP. EXTER		7/24/76	
HUMID. INT		7/24/76	
HUMID. EXTER		7/24/76	
WIND		7/24/76	
WEATHER BUREAU		7/24/76	
WIND VELOCITY		7/24/76	
WIND DIRECTION		7/24/76	
ROOF		7/24/76	
COVERED READING		7/24/76	
WIND VELOCITY (10 ft. x 10 ft.)		7/24/76	
WIND DIRECTION		7/24/76	
WIND VELOCITY (10 ft. x 10 ft.)		7/24/76	
A. R. FLOW RATE		7/24/76	
NUMBER OF WINDOWS ACTING AS INLETS		7/24/76	
EAST WINDOWS		7/24/76	
NW WINDOWS		7/24/76	
SW WINDOWS		7/24/76	
EFFECTIVENESS F. C.M.		7/24/76	
COMMENTS		7/24/76	
UNL. BACK REFERENCE		7/24/76	
SUBJECT		7/24/76	

TEST 6 LS 11
DATE 7-18-66

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5 AUTHOR(S) (Last name, first name, initial) Henninger, Robert H. Madson, Charles A.		
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13 ABSTRACT The results are reported on a natural ventilation test of a corridor-type shelter located in Chicago. The effective temperature of this shelter when occupied at a density of 10 square feet per person will not exceed 33°F for more than seven days during an average year. This interim report describes environmental tests performed in a specific shelter. The discussion of the results is preliminary and should not be used as the basis for general conclusions. A subsequent final report will include a comparative evaluation of data from subsequent tests having a variety of configurations and locations.		

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14 KEY WORDS	LINK A		LINK B		LINK C	
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 Natural Ventilation Test of an Aboveground Fallout Shelter in
 Chicago, Illinois
 OGD Work Unit 1214A
 Interim Report 1268-81
 By R. H. Henninger and C. A. Madson
 August 1966 (UNCLASSIFIED), pp. 81

The results are reported on a natural ventilation test of a corridor-type shelter located in Chicago. The effective temperature of this shelter when occupied at a density of 10 square feet per person will not exceed 83°F for more than seven days during an average year. This interim report describes environmental tests performed in a specific shelter. The discussion of the results is preliminary and should not be used as the basis for general conclusions. A subsequent final report will include a comparative evaluation of data from subsequent tests having a variety of configurations and locations.

CIVIL DEFENSE SYSTEMS, FALLOUT SHELTERS, TESTS, WIND, TEMPERATURE, HUMIDITY, VENTILATION

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