Ventilation measurements in a basement fallout shelter

Tamura, G. T.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20358447
Internal Report (National Research Council of Canada. Division of Building Research), 1962-03

NATIONAL RESEARCH COUNCIL

CANADA

DIVISION OF BUILDING RESEARCH

VENTILATION MEASUREMENTS IN A BASEMENT FALLOUT SHELTER

by

G. T. Tamura

Internal Report No. 246

of the

Division of Building Research

OTTAWA

March 1962

PREFACE

The Government of Canada has published a booklet, Blueprint for Survival No. 1, "Your Basement Fallout Shelter," and has recommended the construction of fallout shelters to the general public. The Division has undertaken to study some of the problems of heating and ventilating of such shelters, as an assistance to the Emergency Measures Organization. A shelter of the type recommended has been constructed in a house made available for the purpose by EMO through Central Mortgage and Housing Corporation and has been under study for the past year. The results of the two winter trials and two summer trials thus far conducted are described in DBR Internal Report No. 243. The ventilation measurements are now described for the benefit of those having special interest in such techniques, the results having been summarized in the general report.

The author, a mechanical engineer and a research officer with the Building Services Section, has been engaged on studies of chimneys and of the indoor climate of dwellings with special reference to ventilation.

Ottawa
March 1962

N. B. Hutcheon,
Assistant Director.

VENTILATION MEASUREMENTS IN A BASEMENT FALLOUT SHELTER

by

G. T. Tamura

A series of tests was carried out to measure the natural ventilation rates of the shelter and the basement, as part of the fallout shelter studies on basement and shelter climate being conducted by the Division of Building Research. The ventilation measurements were obtained during the winter and summer trials as described in the DBR Report No. 243 "Basement Fallout Shelter Climate Studies 1961" (1).

The rate of shelter ventilation is one of the factors that affects the living conditions within a fallout shelter. Because the air drawn into the shelter from the basement is a mixture of the outdoor air and the air exhausted from the shelter, the basement ventilation rate also influences the shelter climate. These ventilation rates affect the temperature, humidity and the odour level of the air inside the shelter. They also affect the oxygen and carbon dioxide content in the shelter air by supplying fresh air and displacing air consumed and expelled by the occupants and by the heaters and lamps used for cooking, heating and lighting.

The shelter and basement ventilation rates were obtained during test No. 1 (unheated trials) and test No. 2 (heated trials) of the winter test series with the door closed to conserve heat inside the shelter. Because the door to the shelter was left open during tests Nos. 3 and 4, permitting unrestricted exchange between shelter and basement air, basement ventilation rates only were recorded during the summer tests. The results of these ventilation tests are now reported.

Method

The ventilation rates of the fallout shelter and the basement were determined by the tracer gas technique using helium as the tracer. The thermal conductivity of the helium gas is six times that of air and the variation of the thermal conductivity of the tracer gas-air mixture is measured to determine the rate of decay of helium concentration with the air change in the enclosure. The change in the thermal conductivity of the tracer gas-air mixture was measured using the katharometer designed by the National Bureau of Standards (2) with certain design modifications.

Assuming a homogeneous mixture of helium and air throughout the enclosure, the relation between the change in helium concentration and the ventilation rate is given by:

$$- V\,dc = Kc\,dt \tag{1}$$

where V = volume of enclosure
K = air infiltration rate
c = volume concentration of helium
t = time.

Integration of this expression gives:

$$\frac{K}{V} = \frac{\ln \frac{c_1}{c_2}}{t_2 - t_1} \tag{2}$$

where $\frac{K}{V}$ = air change rate

At constant ventilation rate the plot of concentration versus time gives a straight line on semi-logarithmic graph paper.

After the helium is released in the shelter, some of it leaves the shelter as a result of ventilation and enters the basement. Part of it returns to the shelter and the remainder flows upstairs and outdoors owing to the ventilation of the basement. Because the volume of the basement is approximately ten times that of the shelter, the resultant helium concentration in the basement as compared with that of the shelter is quite low. Since the basement ventilation rate is small, the rate of decay of helium is lower in the basement. Over the short period when the ventilation rate is determined this basement concentration is assumed to be constant. Therefore the helium concentration in the basement should be subtracted from the helium concentration in the shelter to obtain the correct ventilation rate of the shelter. The equation for the shelter ventilation rate would then become:

$$- V\,dc = K(c - c_o)dt \tag{3}$$

where c = helium concentration in shelter
c_o = helium concentration in basement.

Two katharometers and their ancillary recording equipment were used to measure the helium concentration in the basement as well as in the shelter. The basement has two horizontally pivoted windows with a total lineal crack of 16.2 ft. These windows were fitted with storm windows and were not weatherstripped.

Description of Apparatus (3)

The katharometer used for measuring helium concentration consists of two matched thermistors enclosed in the cavities of a brass block. One thermistor (sensing) is sealed with the exception of four 1/32-in. diameter holes in the brass block. The other thermistor (standard) is sealed in a glass envelope inside the brass block with one end forming a small open tube which is filled with light oil (Fig. 1).

The thermistors form the two legs of a Wheatstone bridge circuit (Fig. 2). The helium-air mixture enters the cavity that contains the sensing thermistor by diffusion through the small holes in the brass block. This results in an increased rate of heat loss from the sensing thermistor by an amount depending on the helium concentration, since the thermal conductivity of helium is greater than that of air. As a result of the lowering of temperature of the thermistor the electrical resistance of the thermistor is altered. This results in an imbalance of the bridge circuit, which is measured on a single point millivolt recorder.

Because these thermistors are sensitive to ambient air temperature change, the standard thermistor in a glass envelope which forms the second leg of the Wheatstone bridge circuit is chosen so that its resistance characteristic is closely matched to that of the sensing thermistor. In this manner any changes in the brass block temperature will affect the resistances of both thermistors equally. Although care is taken to match the thermistors, deviations in their characteristics do occur and therefore the katharometer is mounted on the side of an insulated copper container filled with water. With this arrangement fairly good temperature control is obtained over a short duration.

It was found that the katharometer is also sensitive to changes in barometric pressure. The oil in the glass tube of the standard thermistor allows for the fluctuation in the barometric pressure so that the thermistors are subjected to pressures of a constant difference. In addition to the change in the barometric pressure, the relative humidity of the air may also change during the course of a test. Therefore the sample helium air mixture is passed through a drying bottle filled with calcium chloride before exposing the gas to the katharometer.

In this way the effect of the changes in the ambient air condition on the katharometer is reduced. To compensate further for this effect and, also, for the variation in the d-c power supply voltage, a third leg was added to the Wheatstone bridge circuit. This leg has a fixed resistor (200 ohms) and the balance between the second and third leg of the circuit is observed with a millivolt ammeter and maintained by adjusting the d-c power supply voltage. In this manner the resistance of the standard thermistor is kept at a constant value.

The katharometer was calibrated in the laboratory by determining the air change rate of a box (4 by 8 by 8 ft) using the tracer gas technique and by measuring the air flow into the box with a variable area flow meter. The result of the calibration showed close agreement up to 4 air changes per hour but above this rate the katharometer gave a lower value of air change rate. This lack of agreement was attributed to the fact that the rate of diffusion of the sample helium air mixture into the katharometer through the four 1/32-in. diameter holes was not rapid enough for the thermistor to sense the real rate of change of helium concentration with the ventilation rate above 4 air changes per hour. Sufficient tests were conducted to obtain a calibration curve up to 10 air changes per hour.

Tests

The layout of the basement (Fig. 3) shows the orientation of the shelter in the basement and the location of the basement windows. Four concrete blocks laid on their sides, 2 in the first course, and 2 in the eighth course of the shelter wall, each block with two 4- by 5-in. cores formed the upper and lower openings for shelter ventilation. Other sources of air exchange between the shelter and the basement air were cracks and interstices around the door and in the ceiling and walls of the shelter.

To evaluate the tightness of the ceiling construction of the shelter, a series of air leakage tests was conducted prior to the ventilation tests. The ceiling consisted of two courses of 4-in. concrete blocks (joints unmortared) on 1-in. boards with flat sides laid on 2- by 8-in. wood joists. With all vent openings covered and the shelter door closed and sealed, two centrifugal fans were used to pressurize the shelter. The air flow delivered to the shelter was measured with pitot and static pressure probes installed in the fan outlet ducts; the pressure developed inside the shelter was measured with a micromanometer (Fig. 4). To compare the roof leakage rate with that of the ventilation opening, one opening (4 in. by 5 in.) was uncovered and the air leakage test was repeated.

Winter Tests

During tests Nos. 1 and 2 of the winter trials, the door to the shelter was kept closed to conserve heat inside the shelter. The two katharometers to measure the ventilation rates of the shelter and the basement were placed on a table located centrally in the basement (Fig. 5). The helium bottle was placed close to the outer wall of the shelter and plastic tubing was run from the valve of the helium bottle into the shelter. With this arrangement helium was released inside the shelter for approximately 10 seconds at 10 psi pressure from outside the shelter by manually controlling the valve. This amounted to 1 to 2 per cent of the volume of the shelter. Because the time taken to complete the test was approximately 3 hr, the control box and the recording instruments were placed in the kitchen, so that the operator would not disturb the condition of the basement and the shelter (Fig. 6). During test No. 1 four measurements of shelter ventilation rate and three of the basement were taken. During test No. 2 four measurements of shelter ventilation rate and two of the basement were recorded. A typical helium concentration decay curve for the shelter and the basement is shown in Fig. 7.

Summer Test

Ten basement ventilation rate measurements were made during tests Nos. 3 and 4. The door to the shelter was left open. The basement windows and door to the upstairs were kept closed. Upstairs doors and windows were allowed to be opened and closed according to the needs of the occupants. Nine ventilation rates were recorded during the day, with one of the nine recorded with the upstairs doors and windows closed and locked, and one ventilation rate was measured at night.

Results and Discussion

The air leakage characteristic of the shelter ceiling construction is shown in Fig. 8. It should be noted that part of this is due to air leakage through the walls and extraneous cracks around the shelter . Comparison of the air leakage rate of the ceiling and of the one 4- by 5-in. ventilation opening at pressure differentials expected under actual conditions shows that the former is about one half of that of the one ventilation opening. This would indicate that the construction of the roof is fairly tight and that the outflow of air through the roof is approximately 10 per cent of the total air outflow with the shelter under winter conditions.

Shelter ventilation rates measured during tests Nos. 1 and 2 are shown in Table I. Shelter ventilation is due to the stack effect caused by the temperature difference between the shelter and the basement air; temperature difference vs ventilation rate is plotted in Fig. 9. During the unheated trials the average temperature difference was 13°F and the corresponding ventilation rate was 4.1 air changes per hour. During the heated trials the average temperature difference was 26°F and the ventilation rate was 7.8 air changes per hour. With the shelter volume of 400 cu ft the airflow rates are 27.4 and 52.0 cfm and the corresponding Reynolds numbers for the ventilation openings are 2100 and 3900 respectively. It would appear that the airflow rate is almost linear with temperature difference in this range of Reynolds number. For purposes of comparison, airflows can be calculated by treating the vent holes as orifices. Since the flow is in the transition region substantial difference in the values of the coefficient of discharge can be expected for the two cases. Actual values of the coefficient of discharge, however, are lacking. If a coefficient of discharge of 0.60 and an exponent of flow of 1/2 are taken for both cases the calculated ventilation rates are 5.8 and 8.1 air changes per hour. This might be regarded as some support for the values of ventilation rates obtained experimentally.

Although the shelter ventilation rates for the heating trials were well above 4 air changes per hour, as determined from equation (3), it was not necessary to apply corrections for high ventilation rate since the actual rate of decay of helium in the shelter was well below that normally representing 4 air changes due to the return of helium from the basement.

The results of the basement ventilation measurements for both winter and summer tests are given in Table II. The rate of air change in the basement will affect the amount of fresh outdoor air brought into the shelter - basement area. The basement ventilation rate is subject to both wind effect and to the stack effect caused by the differences in temperature between the outdoor and upstairs or basement air, and between upstairs and basement air. Considering the number of variable factors that may influence the ventilation rates, the number of tests was quite limited. The minimum ventilation rate obtained during the winter tests was 0.24 air change per hour. In general the basement ventilation rate was between 1/4 to 1/2 air change rate per hour. With a basement volume of 5800 cu ft, these rates give airflows of 24 to 48 cfm, which are less than the airflow in a heated shelter.

The basement ventilation rates obtained during the summer tests were substantially lower than those obtained during the winter tests. Both the outside-to-basement temperature difference and the prevailing wind velocity were lower during the summer months. The minimum air change rate recorded was 0.11 air change per hour. In Fig. 10 the air temperatures of outdoor, upstairs and basement are plotted against time, together with the ventilation rate reading measured during the day. As can be seen from the graph, outside air temperature is higher during the day than the basement air temperature and, conversely, the outside air temperature is lower than the basement air temperature at night-time. The cross-over takes place at 6.00 to 10.00 a.m. and again at 6.00 to 10.00 p.m. when the temperature difference between the basement and outside air is zero. On a calm day the ventilation rate can be expected to be negligible during these periods. One ventilation rate reading taken at night indicated that the ventilation rate is higher compared to the daytime ventilation rate under similar conditions, probably due to the reversal of air flow through the basement. One ventilation rate recorded with the upstairs doors and windows closed and locked seems to indicate that the ventilation rate is substantially the same whether the doors and windows are left open or closed.

Summary

The ventilation tests gave an indication of the ventilation rate that can be expected in the fallout shelter and the basement of a typical small house. The basement ventilation rate appears to be higher during the winter than in the summer due to the higher prevailing wind and the greater temperature difference between the outdoors and basement air temperatures. The winter tests showed that the air flow into the basement from outdoors may be lower than the air flow into the heated shelter, that is, the amount of fresh air brought into the shelter may be restricted by the basement ventilation rate. The summer tests indicated that, due to the temperature inversion of the basement and outdoor air, there may be periods of negligible amounts of ventilation on a calm day.

Acknowledgments

The author records his thanks to Mr. R. G. Evans for his assistance in setting up instrumentation and in carrying out the tests. The author also acknowledges the guidance given to this project by Mr. A. G. Wilson and Dr. N. B. Hutcheon.

References

(1) Kent, A. D. and N. B. Hutcheon. Basement fallout shelter climate studies. National Research Council, Division of Building Research, Internal Report No. 243, Ottawa, 1962.

(2) Coblenz, C. W. and P.R. Achenbach. Design and performance of a portable infiltration meter. Transactions, Amer. Soc. of Heating and Air-Conditioning Engineers, Vol. 63, 1957, p. 477-482.

(3) Tamura, G. T. Performance of katharometer for infiltration measurements. (To be issued as an Internal Report of the Division of Building Research, NRC.)

TABLE I

SHELTER VENTILATION RATES DURING WINTER TESTS

Date	Shelter Air Temp, °F	Basement Air Temp, °F	Temp Diff, °F	Ventilation Rate, Air change/hr
Test No. 1 (Winter)				
12.1.61	56.5	43.5	13	4.1
15.1.61	53.5	41	12.5	4.4
17.1.61	51	37.5	13.5	3.7
21.1.61	44	31	13	4.1
Test No. 2 (Winter)				
21.2.61	67	43	24	7.3
24.2.61	74	47	27	7.3
27.2.61	75	47	28	8.8
28.2.61	74	48	26	7.8

TABLE II

BASEMENT VENTILATION RATES DURING WINTER AND SUMMER TESTS

Date	Basement Air Temp, °F	Upstairs Air Temp, °F (HTG)	Outside Air Temp, °F	Wind mph	Ventilation Rate, Air change/hr
Test No. 1 (Winter)					
15.1.61	43	37	20	4 E	.26
18.1.61	39	28	5	15 NW	.69
19.1.61	34.5	27	6	5 E	.31
Test No. 2 (Winter)					
23.2.61	49	46	29	13 E	.24
28.2.61	51	49	35	12 W	.37
Test No. 3 (Summer)					
20.7.61	76	86	86	2 SE	.16
21.7.61	75	77	83	3 SW	.11
24.7.61	76	79	84	5 SW	.22
25.7.61	76	77	82	2 SW	.11
25.7.61	76	75	70	1 W	.17
26.7.61	76	80	81	5 NW	.21
Test No. 4 (Summer)					
29.8.61	74	75	75	5 W	.17
30.8.61	76	72	79	1 W	.12
1.9.61	77	83	85	3 S	.16
6.9.61	76	75	72	5 E	.32

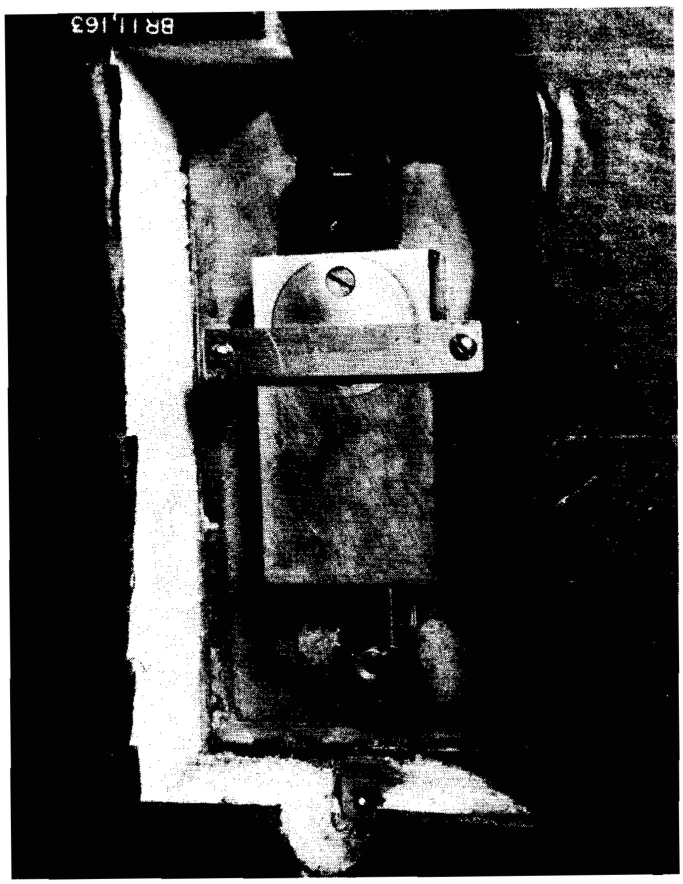
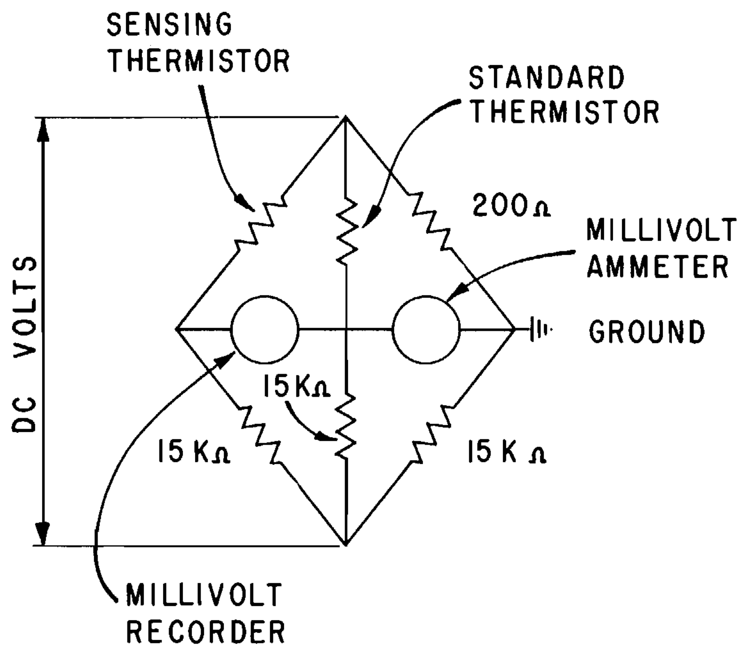


Figure 1 Katharometer cell.



KATHAROMETER LEADS SHIELDED

FIGURE 2
KATHAROMETER CIRCUIT DIAGRAM

BR 2626 -1

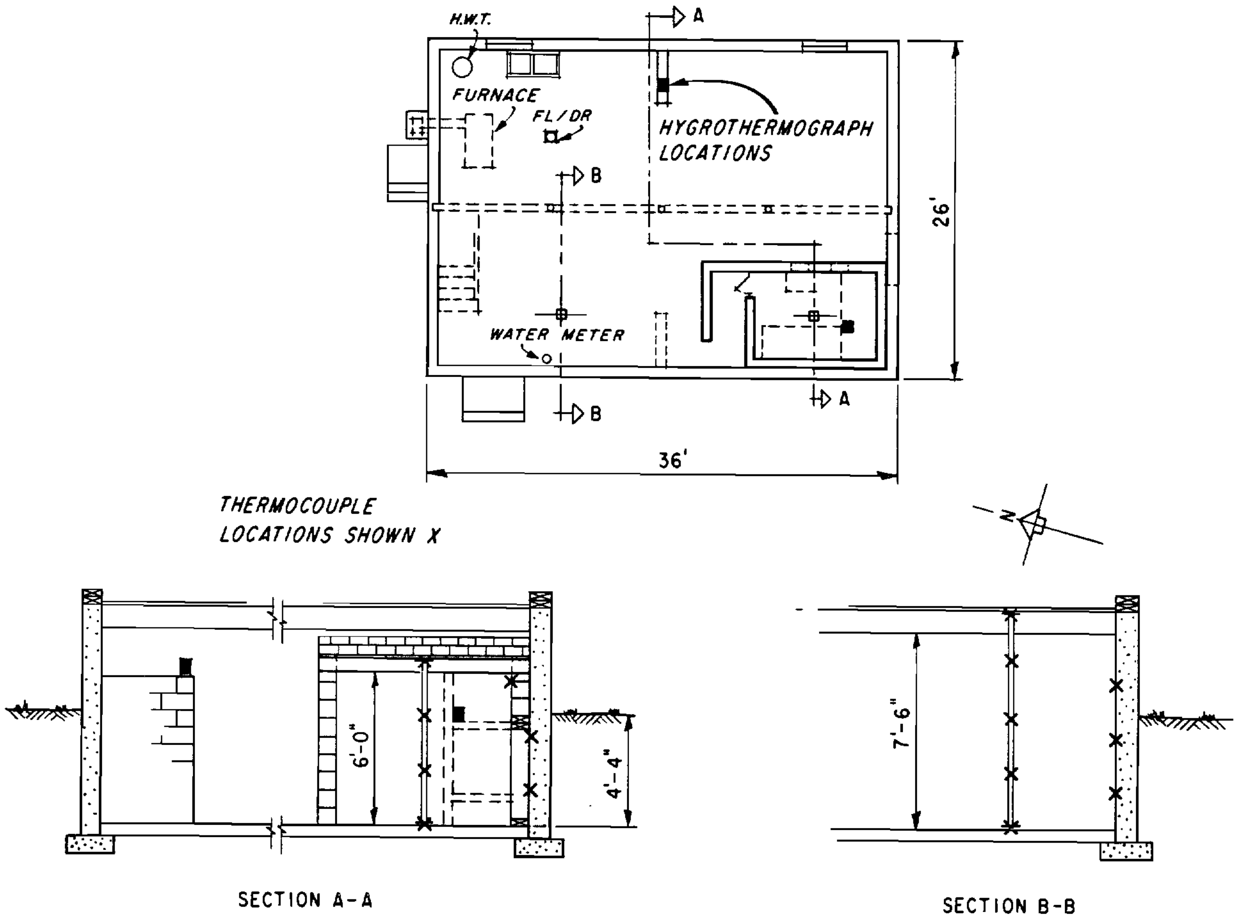


FIGURE 3 LAYOUT OF BASEMENT

BR 2937-1

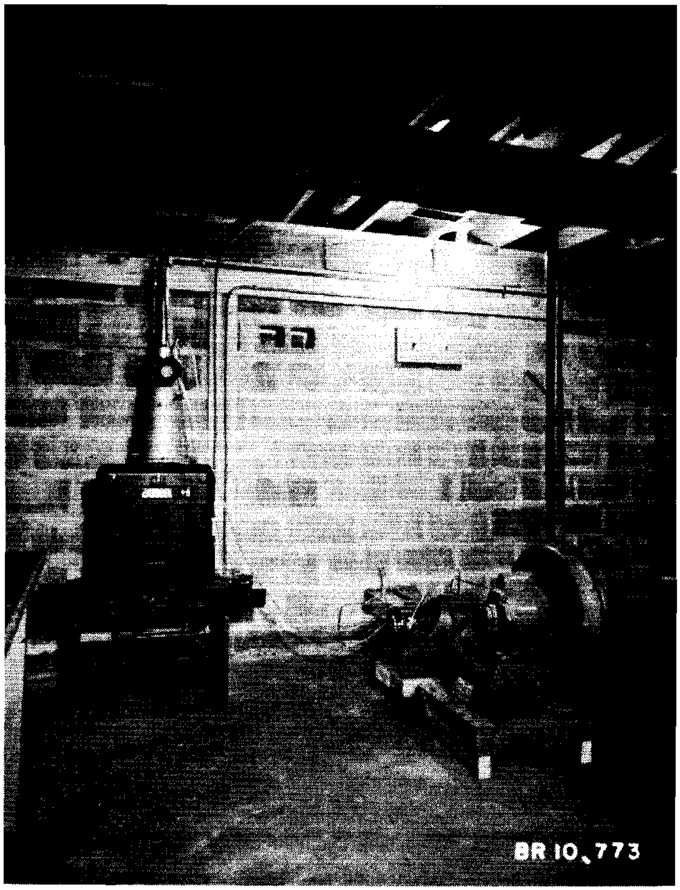


Figure 4 Roof air leakage apparatus.

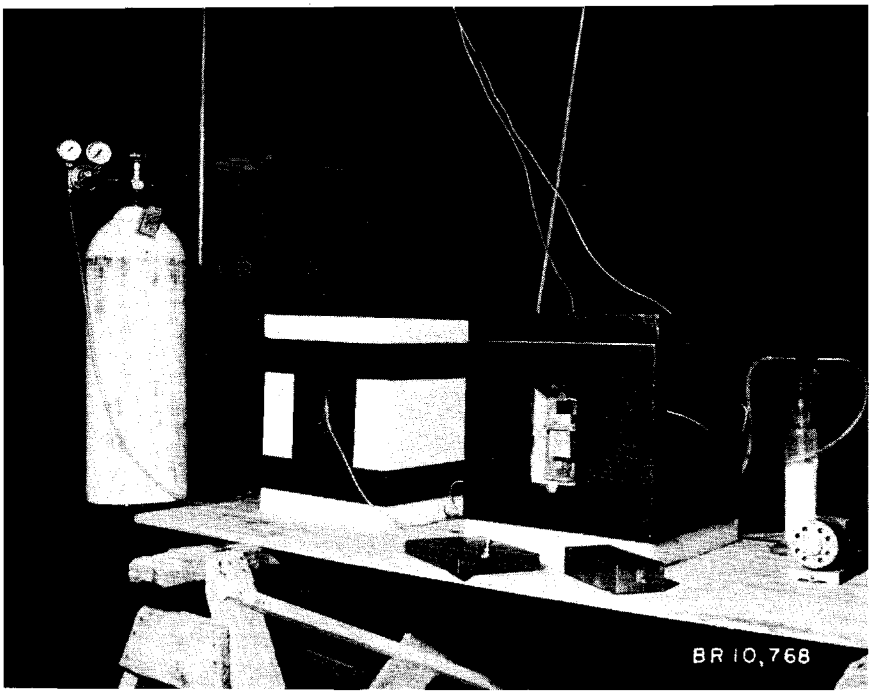


Figure 5 Ventilation equipment in basement

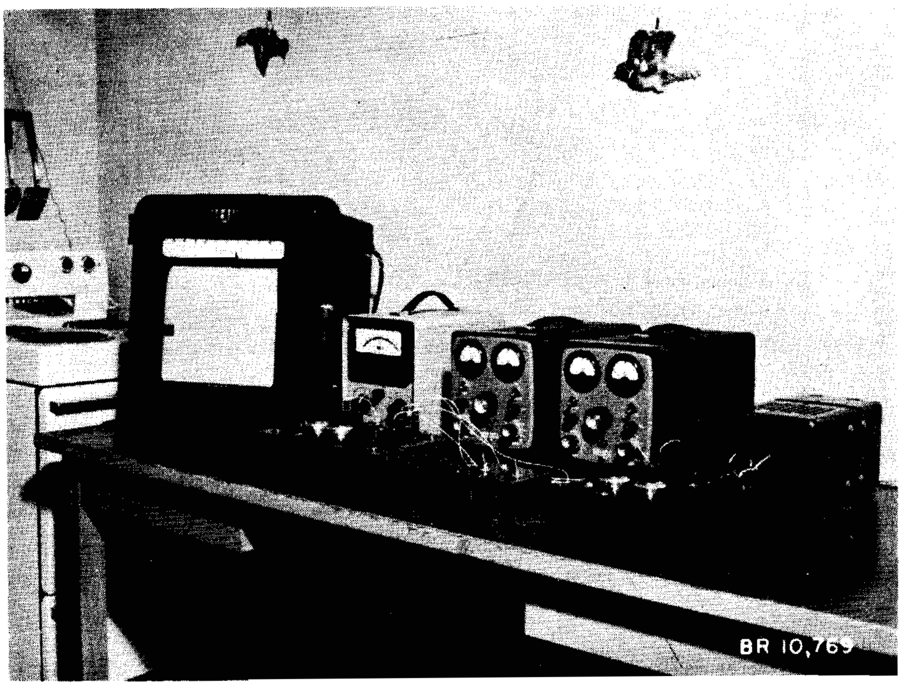


Figure 6 Ventilation equipment in kitchen.

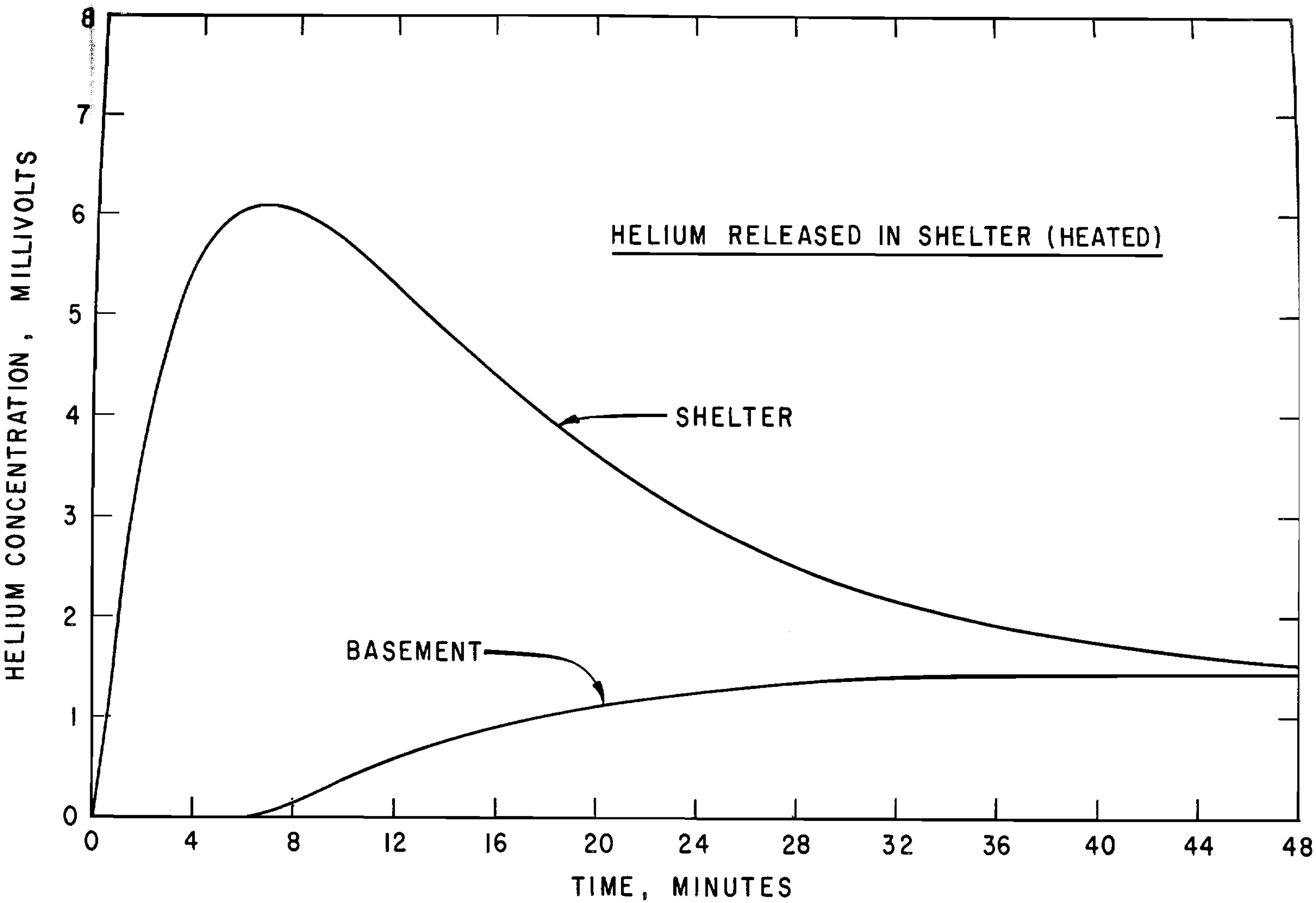


FIGURE 7 SHELTER AND BASEMENT HELIUM DECAY CURVES

BR 2626-2

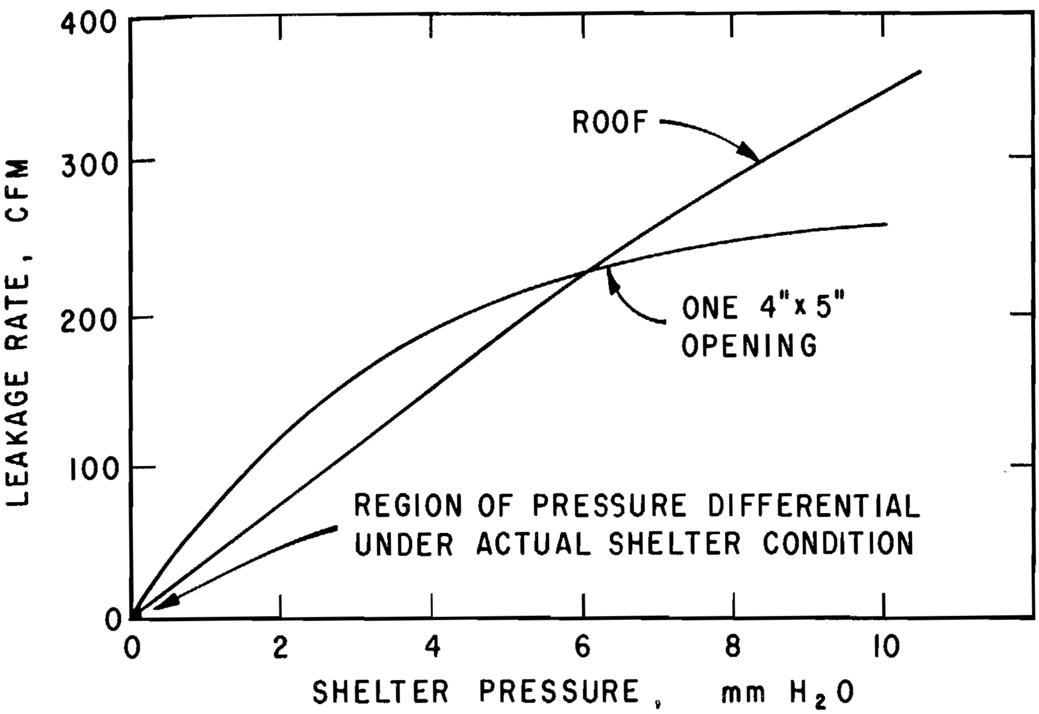


FIGURE 8
SHELTER ROOF LEAKAGE CHARACTERISTICS

BR 2626-3

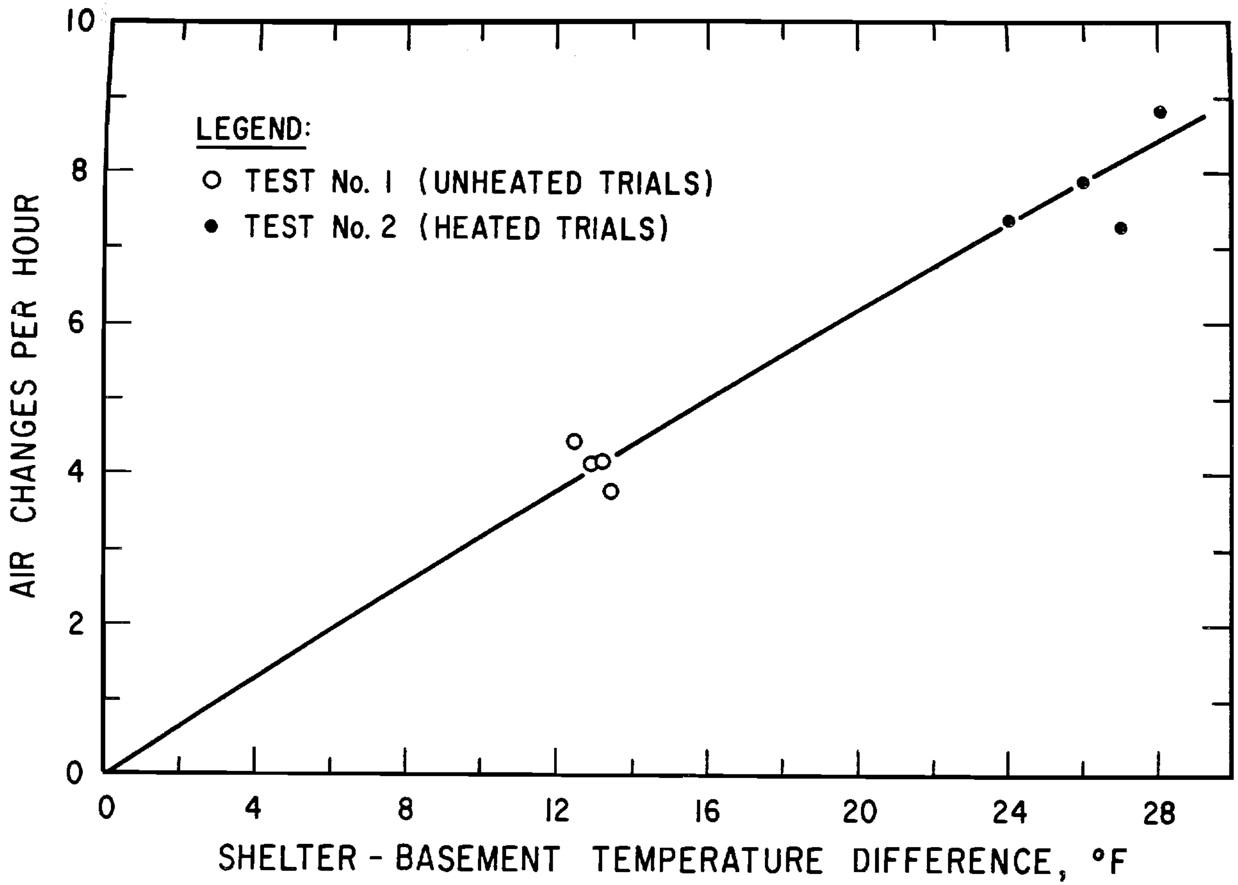


FIGURE 9 SHELTER VENTILATION RATE

BB 2537-17

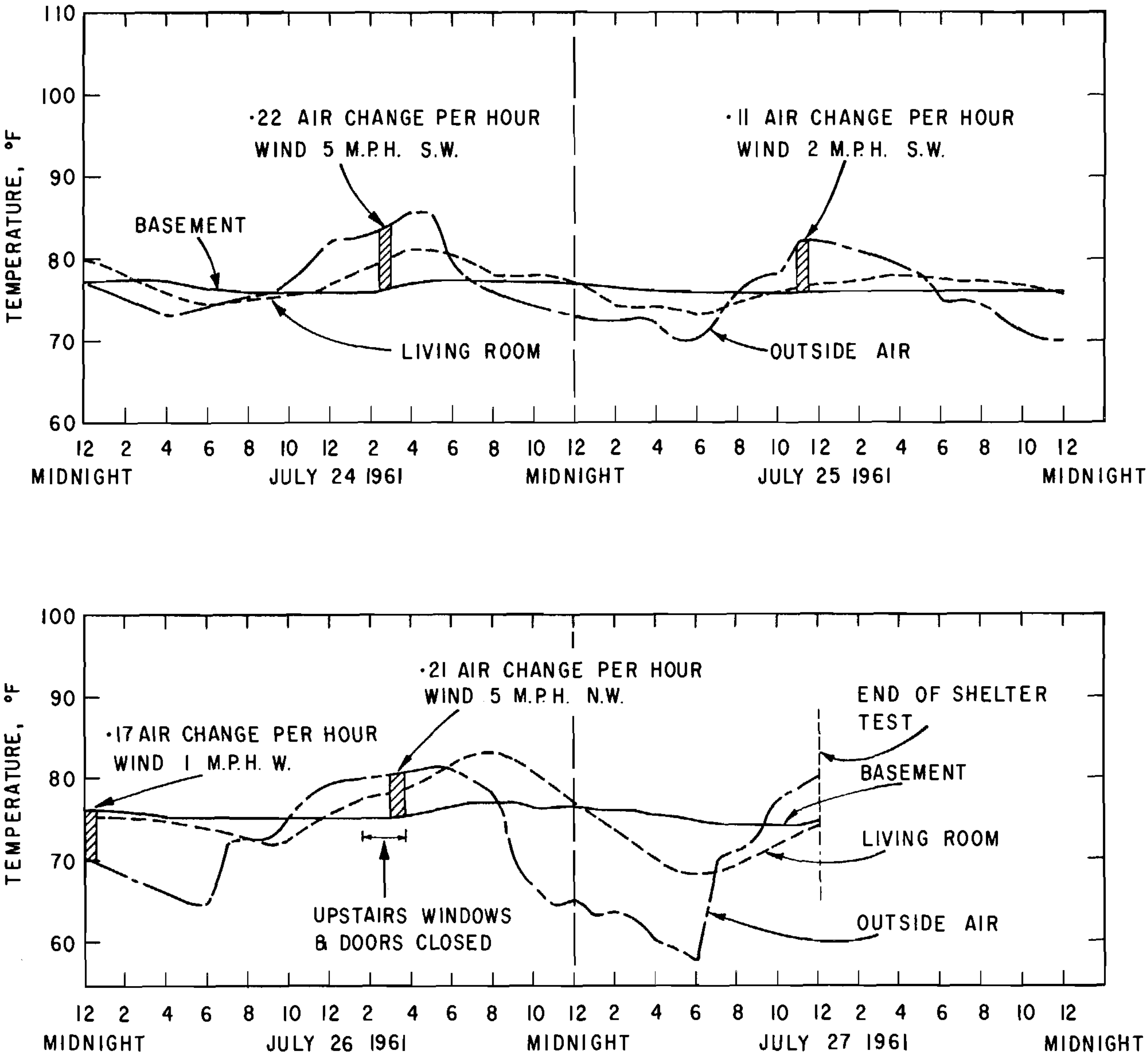


FIGURE 10 BASEMENT VENTILATION CONDITIONS
TEST NO. 3 (SUMMER)

BR 2626 - 4