St. Lawrence Burns: ventilation rate measurements

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ST. LAWRENCE BURNS

VENTILATION RATE MEASUREMENTS

by

J. H. McGuire

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PREFACE

The circumstances that led to the carrying out of fire tests on eight buildings in the project known as the St. Lawrence Burns, and the objectives and the ways in which these were achieved are fully described in a general report. It constitutes the complete record of the planning and execution of the experiments, together with all general information. The details on each kind of measurement made, including the results obtained, are contained in separate companion reports of which this is one. All the results are combined and are discussed and final conclusions drawn in a summary report.

Duplication has been avoided as far as possible, and it will be necessary to refer to the general report in reading any of the other reports including this one for any information which is pertinent to more than one of them. A listing of all reports on the project follows this preface.

The participation of the British Joint Fire Research Organization in the experiment, the interest and support of the Federal Civil Defence authorities, the assistance of the Ontario Fire Marshal and his staff, and finally the complete co-operation and very considerable assistance extended by the Hydro-Electric Power Commission of Ontario are all gratefully acknowledged. It is a pleasure also to be able to record the special contribution made by members of the staff of the Fire Section who worked long hours, often under trying field conditions and at great personal inconvenience, to meet the many deadlines and to complete the project in a most satisfactory manner.

The author of this report is Mr. J. H. McGuire, now research officer with the Fire Section of this Division, who as a member of the staff of the British Joint Fire Research Organization planned and supervised the measurements made with the radiometers, anemometers and resistance thermometers.

Ottawa
December 1959

N. B. Hutcheon
Assistant Director

REPORTS ON THE ST. LAWRENCE BURNS

NO.	SUB-TITLES	AUTHOR
150	General Report	G. W. Shorter
151	Smoke and Sound Measurements	G. Williams-Leir
152	Temperature Measurements	G. Williams-Leir
153	Radiometer Measurements	J. H. McGuire
154	Ventilation Rate Measurements	J. H. McGuire
155	Resistance Thermometer Measurements	J. H. McGuire
156	Radiant Temperature of Openings	D. G. Stephenson
157	Gas Analysis	J. R. Jutras
158	Summary Report	G. W. Shorter and J. H. McGuire

ST. LAWRENCE BURNS

VENTILATION RATE MEASUREMENTS

by

J. H. McGuire

Ventilation is an important factor influencing the rate of burning in building fires. As very little information has been available on this subject, it was decided to take measurements during the course of the St. Lawrence experimental building fires carried out at Aultsville, Ontario, by the Fire Section of the Division of Building Research, National Research Council. Inlet air speed was measured and the scope of this note is confined to a theoretical investigation of the air speeds to be expected, instrumentation, and a statement of results.

THEORETICAL

By adopting certain simplifying assumptions, estimates of the speed of air entering a burning building can be obtained. If frictional resistance is neglected and the ratio of the inlet area to the horizontal cross-sectional area of the building is small, so that the gases within the building can be considered stagnant, the speed of the inlet air can be shown (see Appendix A) to be:

$$v_1 = \sqrt{\frac{2gH\theta'/T'}{1+(A_1/A_2)^2(T_H'/T_o)}} \qquad (1)$$

where T_o = ambient temperature (abs.)

T_H' = absolute temperature of gases within building

θ' = temperature rise, above ambient, of gases within building

H = height between inlet and outlet

A_1 = inlet area

A_2 = outlet area

g = acceleration due to gravity.

The above expression was used to assess the ranges of wind speed for which a suitable instrument should be designed. A value of 1000°C was assumed for θ'. Table I lists various possible conditions. During the early stages of a fire the inlet air speeds would be substantially less than those given by equation (1) and Table I, and it was decided that the minimum air speed which a suitable instrument should be capable of registering was 1.5 mph.

The estimates of maximum air speed given by Table I can be expected to be high, principally because they relate to the conditions obtaining after the roof had collapsed, when in fact lower mean gas temperatures might have been expected. For this reason and because interest was focused primarily on the initial stages of the fires prior to the collapse of the roof, it was not considered essential that the anemometer should respond to air speeds higher than 15 mph.

TABLE I

ESTIMATES OF INLET AIR SPEED

Condition represented	Separation inlet-outlet ft	Inlet Air Speed mph
House, roof intact	10	6.4
House, roof open	16	19
Community Hall, roof intact	24	10
Community Hall, roof open	30	26

INSTRUMENTATION

To measure induced ventilation rates under the conditions which prevailed during the St. Lawrence experiments it was necessary for an anemometer to operate over a wide range of temperatures; at the start of a test the anemometer temperature might have been -20°F, while at a later stage it might have risen several hundred degrees centigrade.

To meet this requirement and to ensure simplicity and portability, a deflection type was chosen, the final design being illustrated in Fig. 9. The calibration of the instrument can be altered by changing the distance between the vane and the pivot. The movement is damped electromagnetically as a result of eddy currents induced in the copper plate when it moves in the field created by the permanent magnets. It was not practical to attempt to read the scale of each instrument directly because of the intense heat and the danger of personal injury from falling debris. Telescopes which allowed readings to be taken at a range of 50 ft were therefore used.

Two identical anemometers were constructed and the calibration of one of them is given in Fig. 10.

SITING AND RECOVERY OF ANEMOMETERS

Anemometers were placed on the sills of the ground floor windows, which were of the sash type and were opened at the bottom to leave about a third of the window area uncovered. The precise locations in the various tests are illustrated in Figs. 1, 6 and 8.

In order to recover the anemometers when it became apparent that they were likely to be damaged by falling debris or by overheating, each was attached to a continuous wire passing through an eye-bolt fixed to the wall above the window. It was thus possible to withdraw an instrument safely from a distance of about 50 ft.

RESULTS

The results are shown in Figs. 11 to 14. During the fire in house No. 1 the outdoor wind speed ranged from zero to 6 mph, and since the air speeds given in Fig. 11 are small compared with this value it cannot be said whether they represent variations in the outdoor wind conditions or induced ventilation air speeds. In the light of this experience no further measurements were attempted during subsequent house burning experiments.

In the case of the community hall, the anemometer on the leeward side always gave negative readings and it appeared that no air entered the building from that side. On the windward side the inlet air speed increased from about 4.5 mph at the start of the test to 6 mph, at which time it was thought prudent to withdraw the anemometer. The outdoor wind speed at the time was 6 to 8 mph.

During the school burn the outdoor wind speed was less than 1 mph, which was much less than that which occurred during any of the previous experiments. At the window in the main body of the building an air speed of 7.4 mph was recorded.

The fact that the inlet air speed at the window in the subsidiary rear hall equalled, if not exceeded, this value at a time when the fire was confined to the main hall was unexpected. The connection between the two compartments was by a single open door about 6 ft 6 in. high by 3 ft wide. A possible explanation can be offered: since the connection between the rear hall and the main building was an open doorway, the position of the rear hall window had no significant effect on the induced air speed. The air could be regarded as entering the main burning compartment. However, the actual inlet area was less, and equation (1) suggests that this would tend to increase the value of 'v'.

Prior to the school burn it had been found necessary to withdraw the anemometers some time before the roofs collapsed and it was assumed that this would be the case during the burning of the school. The range adjustment was therefore set to give the best accuracy at low air speeds. This proved to be a wise policy so far as the anemometer in the main building was concerned but not for the one associated with the annex. From the record of the observations it has been found that the time at which this latter anemometer went off scale corresponds very closely to the time at which large openings began to appear in the roof of main building. As discussed previously the open window area in the annex constituted an inlet area to the main building. In the light of this finding it can be expected that the inlet air speeds would be high after the roof in the main building collapsed. As soon as the annex became fully involved in the fire (after 45 minutes) more windows fractured and the ventilation conditions were no longer so closely associated with the fire in the main building. As shown in Fig. 14 the inlet air speeds than dropped to values to be expected in single-story building fires. At about this point the anemometer had to be withdrawn. Prior to the burn it had been expected that the annex would become involved at a relatively early stage and that the conditions described above would never have existed.

It is of interest to compare the results obtained during the school burn with values estimated from expression (1). At the time when the measurements in the main building had to be discontinued all the upstairs and most of the downstairs windows had fallen out. In equation (1) we should therefore assume $A_1 = A_2$. Using the value $\theta' = 1000°C$ as previously gives an estimate of 7.8 mph which corresponds closely with the maximum value recorded (about 7 mph). For the condition where large openings had appeared in the roof of the main building the predicted maximum air speed was 16 mph. In view of the anomalous conditions causing the inlet air speed at the window in the annex to be controlled temporarily by conditions in the main building, it is not therefore surprising that the anemometer in the annex went off scale.

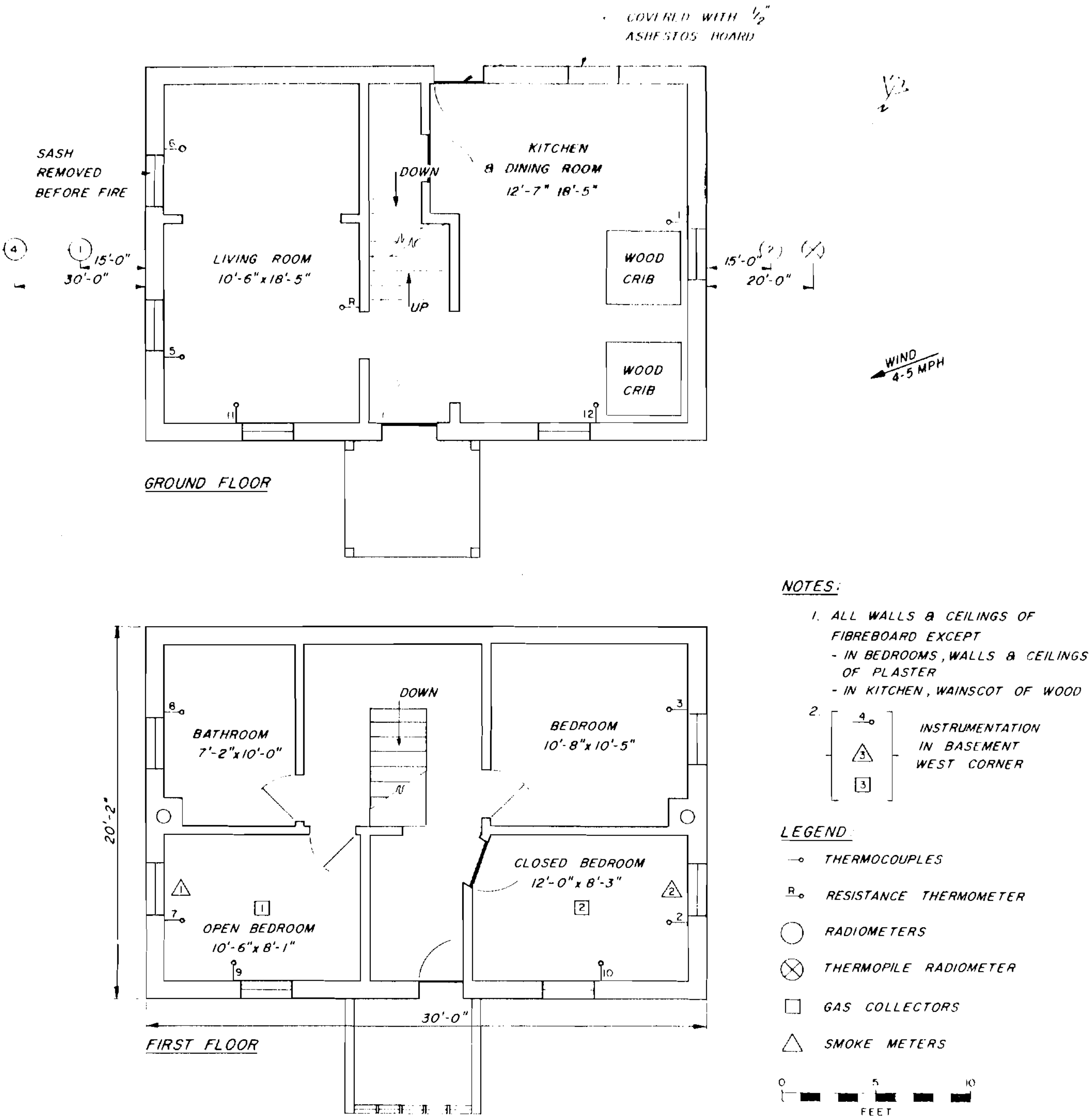


FIGURE 2 - BUILDING No. 2 - TWO-STOREY SOLID BRICK DWELLING

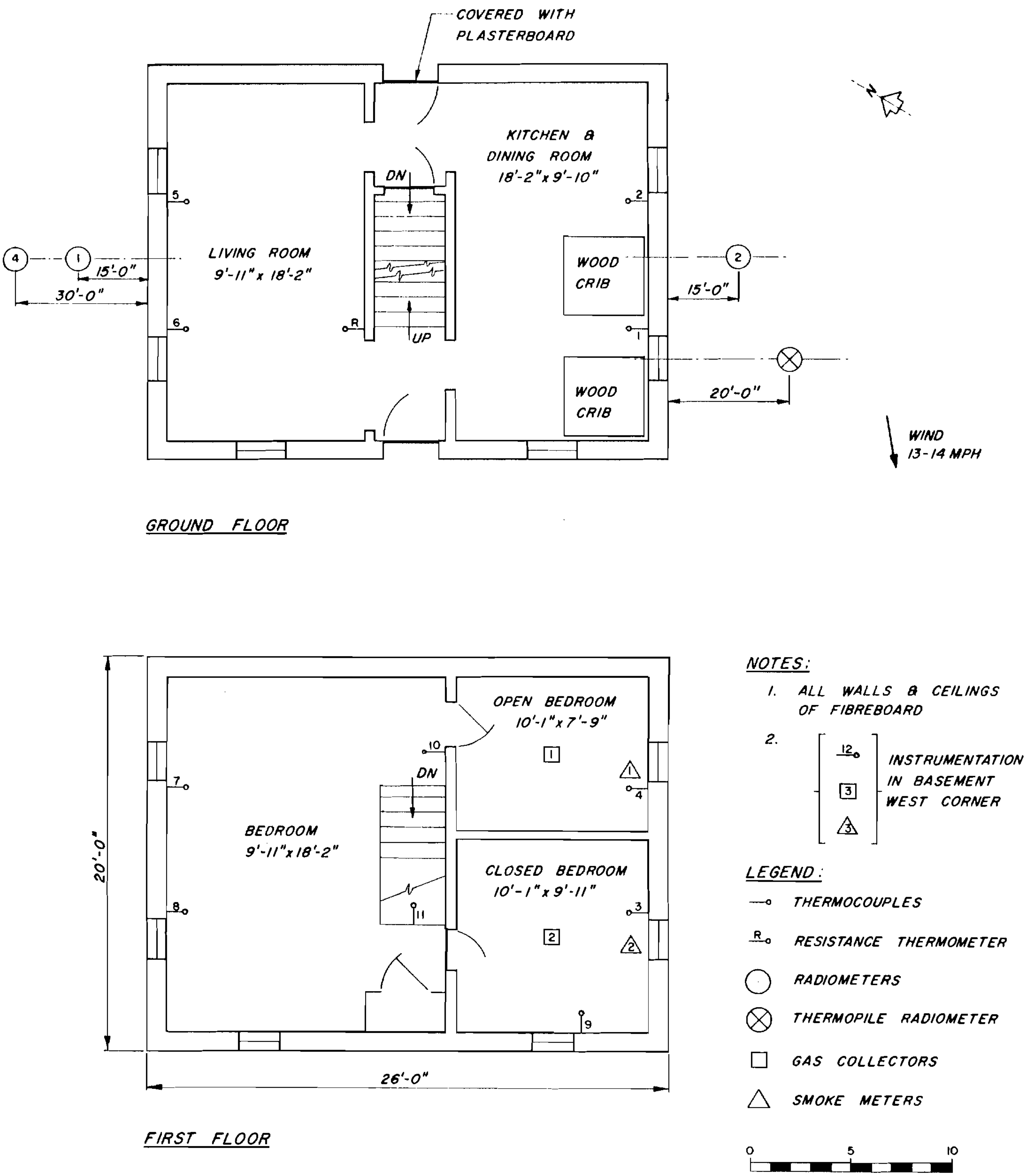


FIGURE 3 - BUILDING No. 3 - TWO-STOREY SOLID BRICK DWELLING

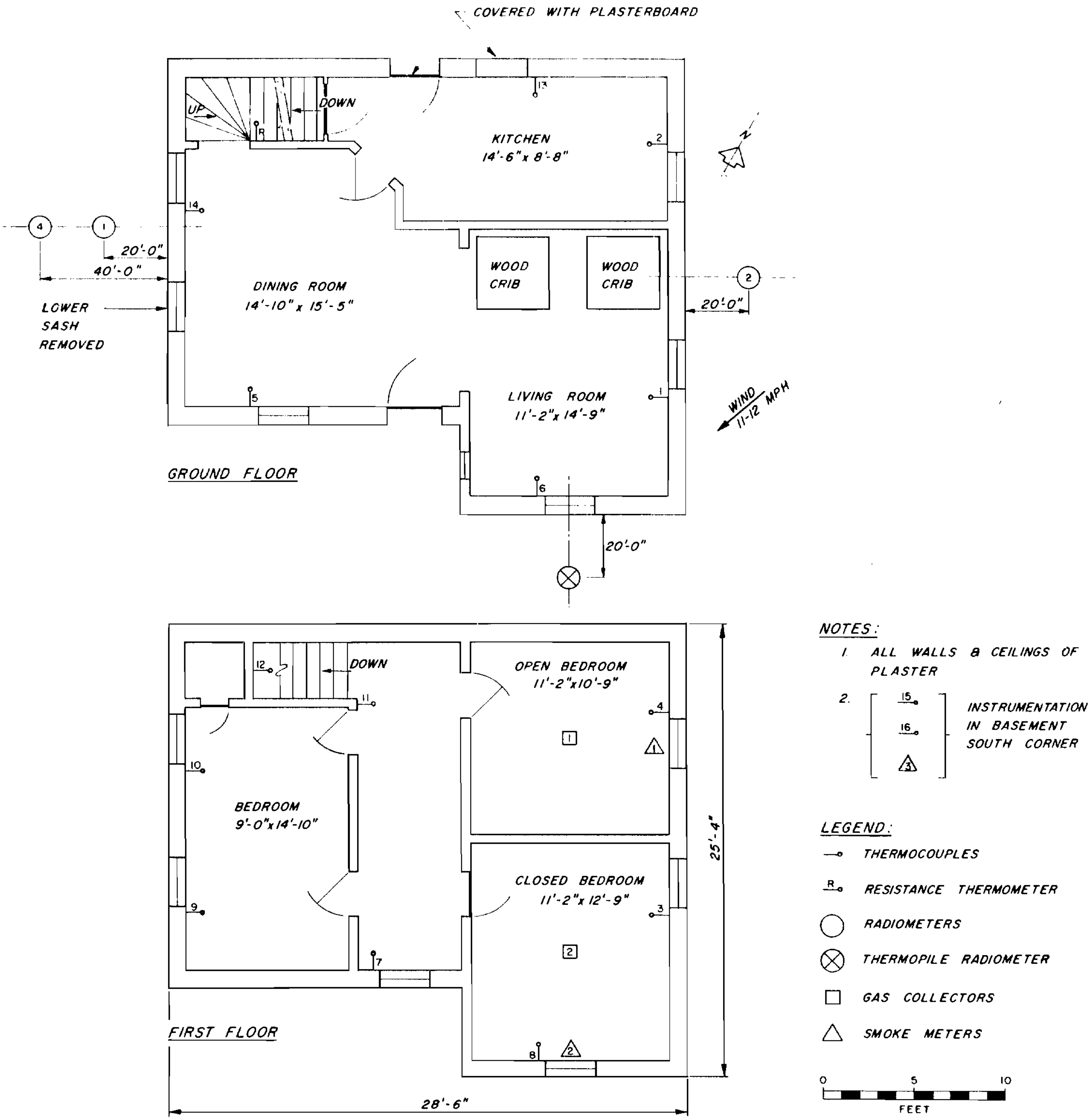


FIGURE 4 - BUILDING No. 4 - TWO - STOREY WOOD FRAME DWELLING WITH CLAPBOARD EXTERIOR AND BRICK INFILLING

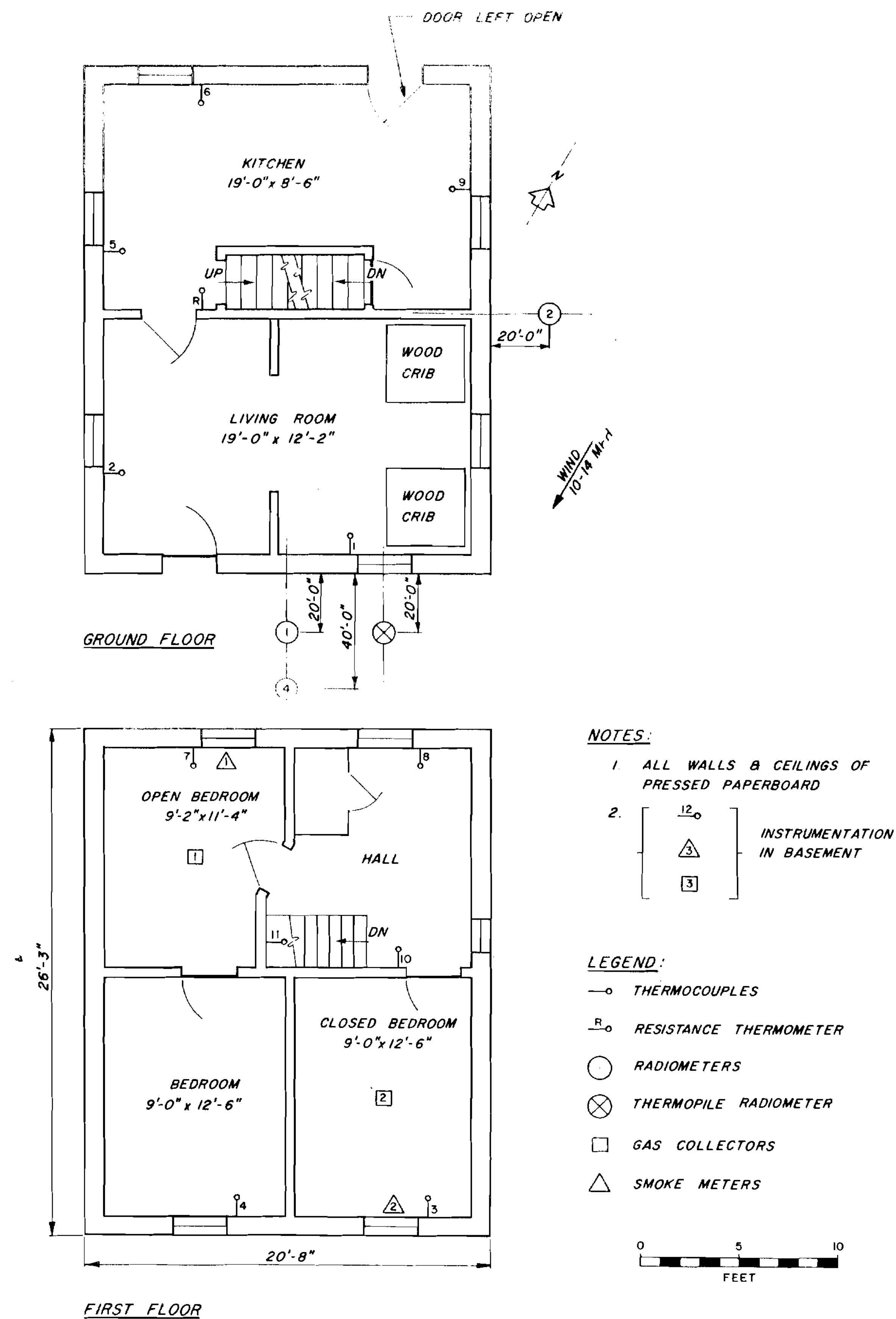


FIGURE 5 - BUILDING No. 5 - TWO - STOREY WOOD FRAME DWELLING WITH CLAPBOARD EXTERIOR

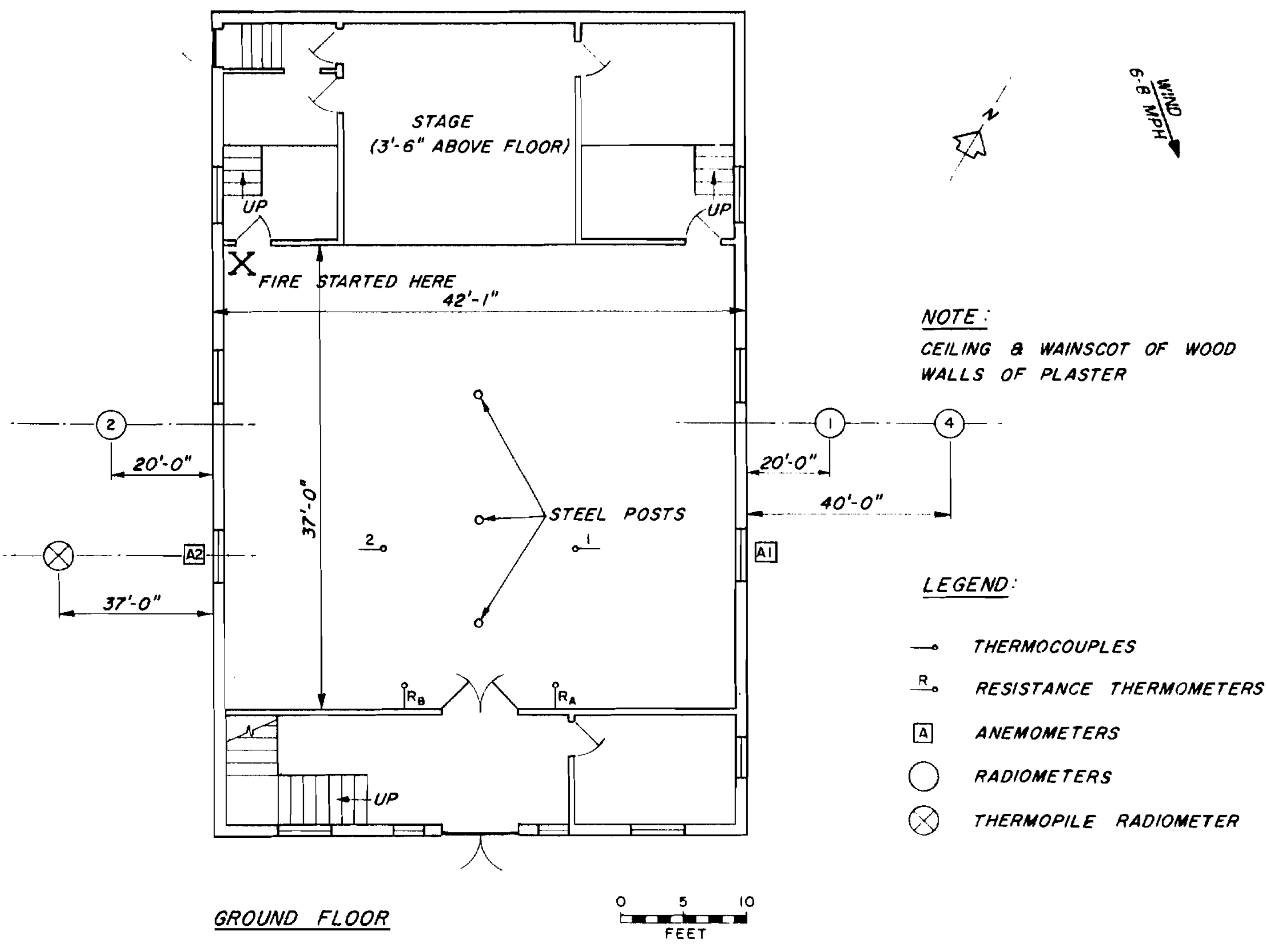
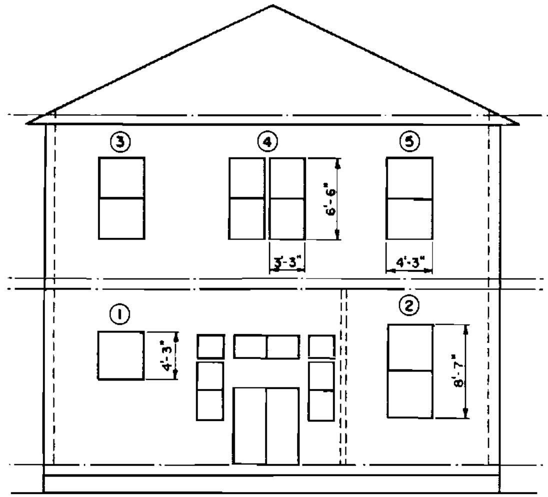
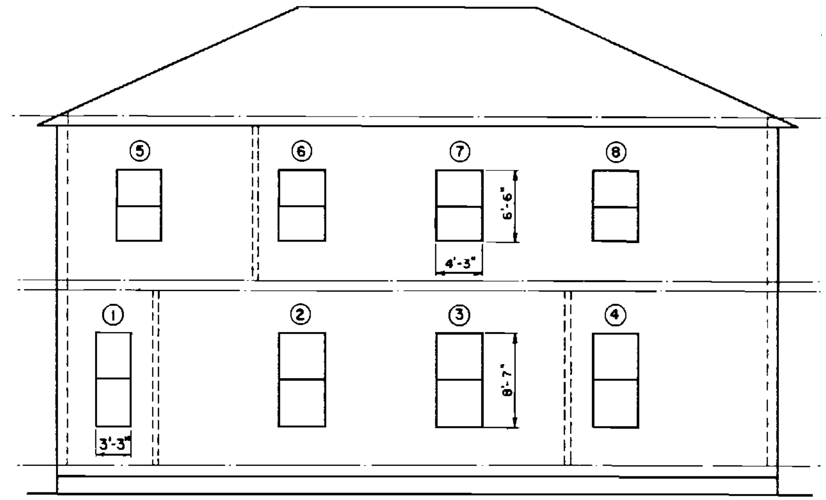


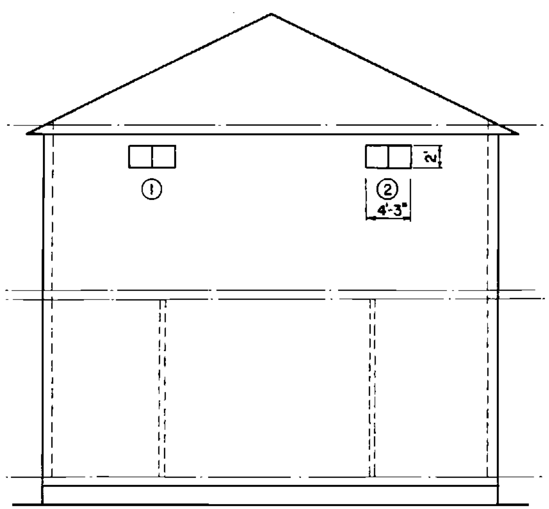
FIGURE 6 - BUILDING No. 6 - TWO - STOREY SOLID BRICK FRATERNITY HALL



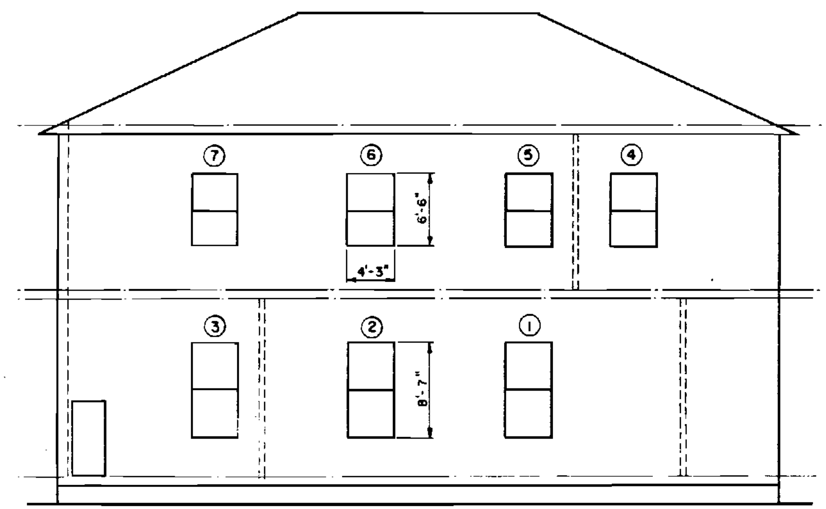
FRONT ELEVATION



EAST ELEVATION



REAR ELEVATION



WEST ELEVATION

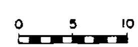


FIGURE 6a - ELEVATIONS OF BUILDING No. 6 (FRATERNITY HALL)

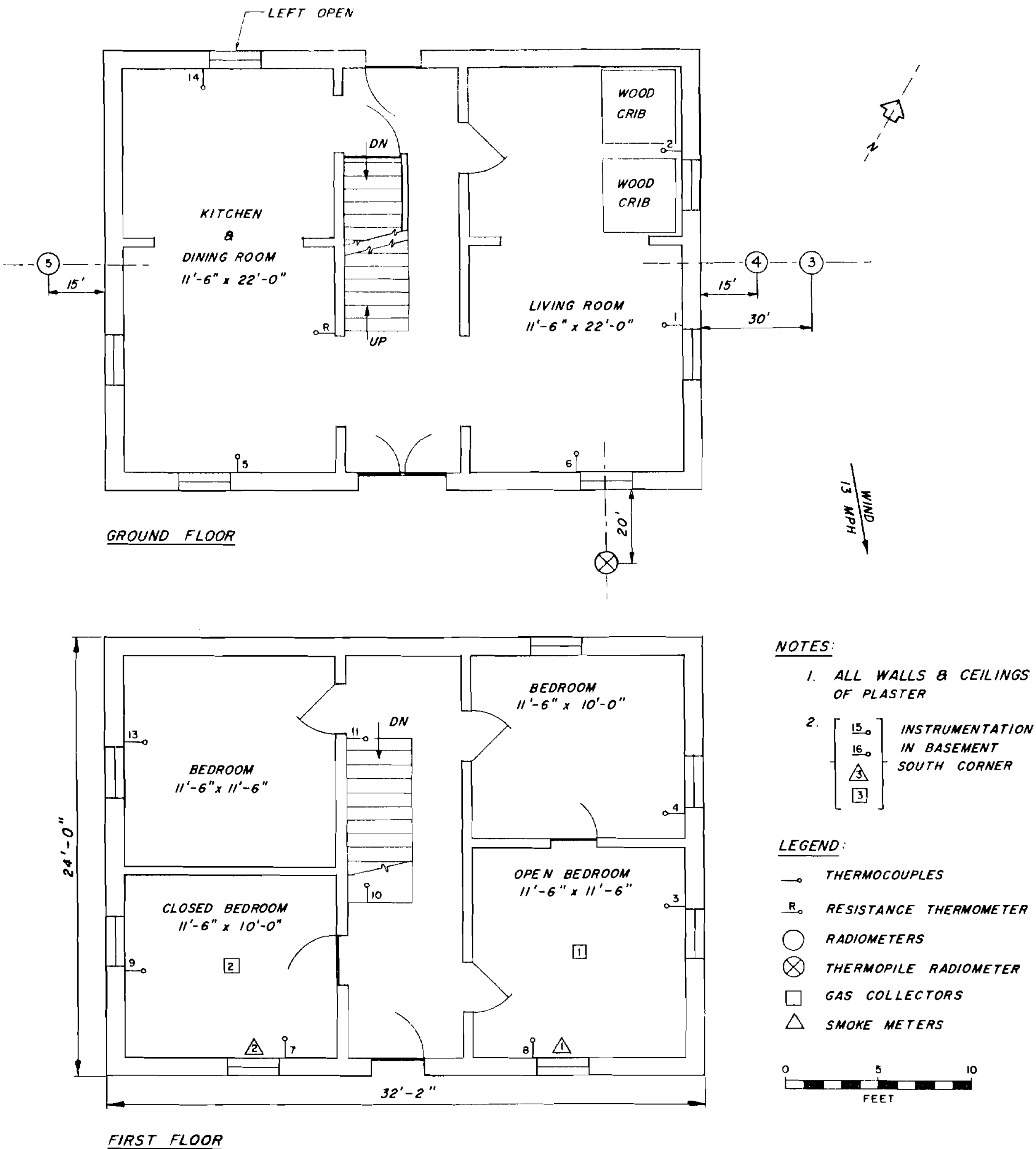


FIGURE 7 - BUILDING No. 7 - TWO - STOREY SOLID BRICK DWELLING

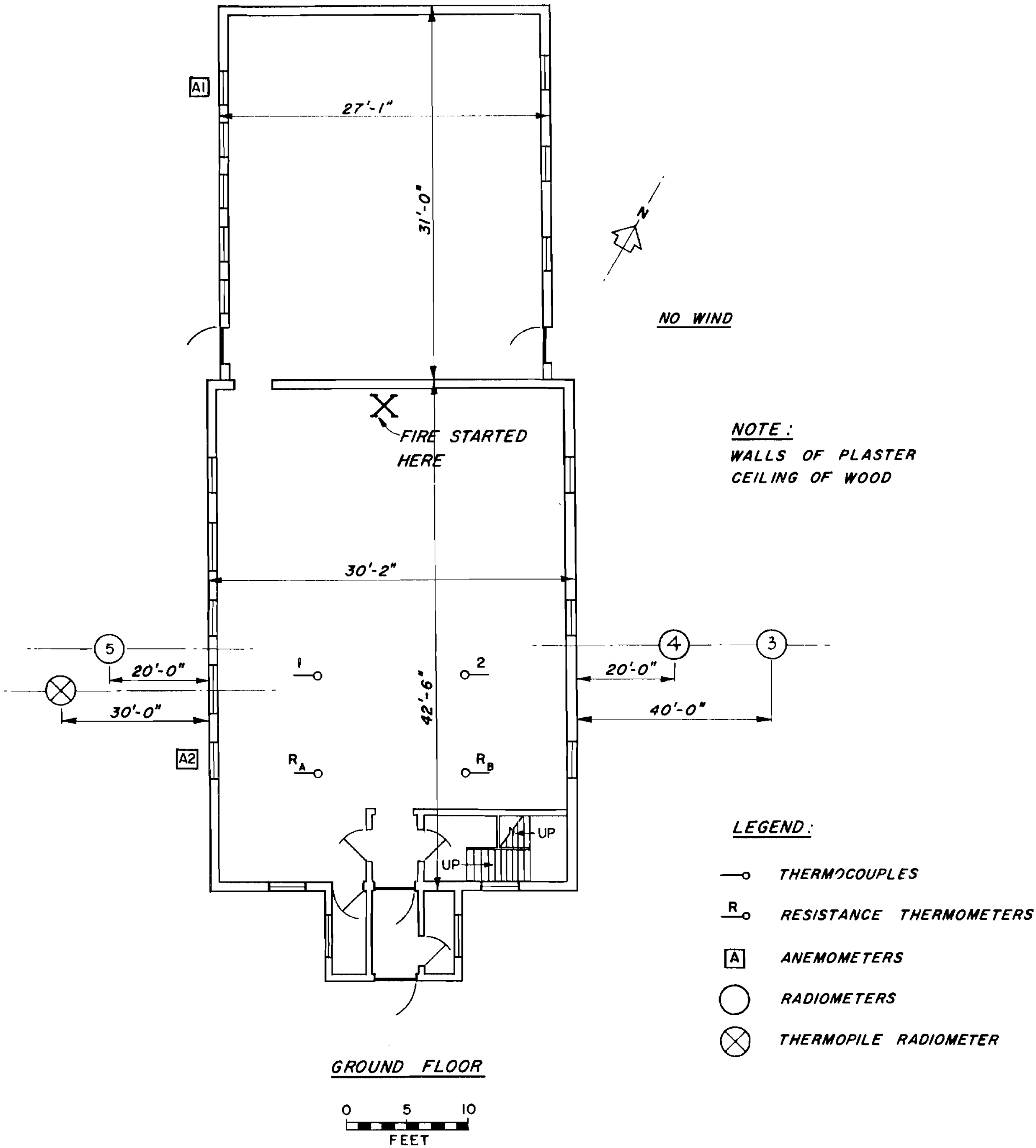


FIGURE 8 - BUILDING No. 8 - TWO - STOREY SOLID BRICK SCHOOL WITH ONE - STOREY EXTENSION AT REAR

FIGURE 8a - ELEVATIONS OF BUILDING No. 8 (SCHOOL)

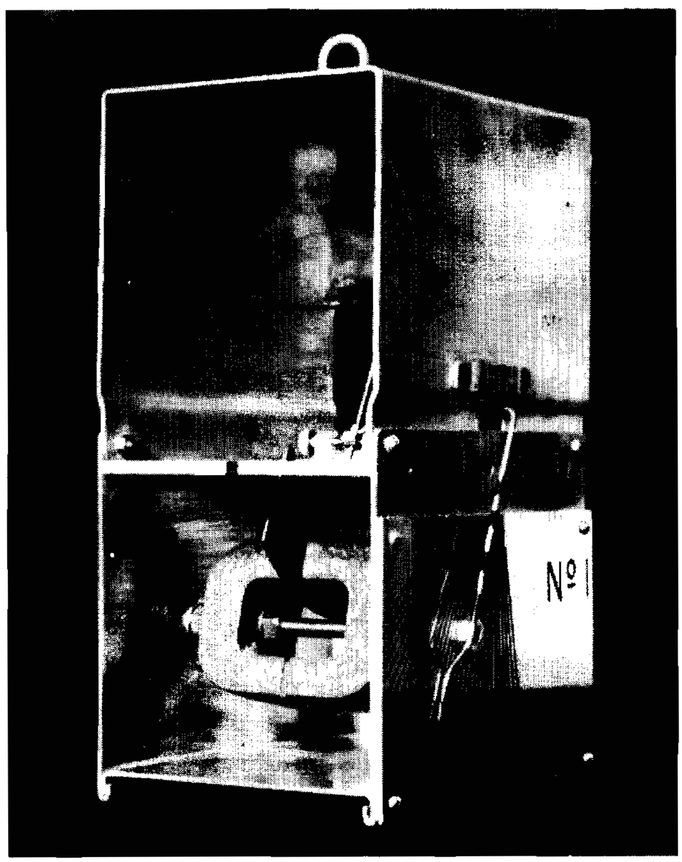


FIGURE 9   ANEMOMETER

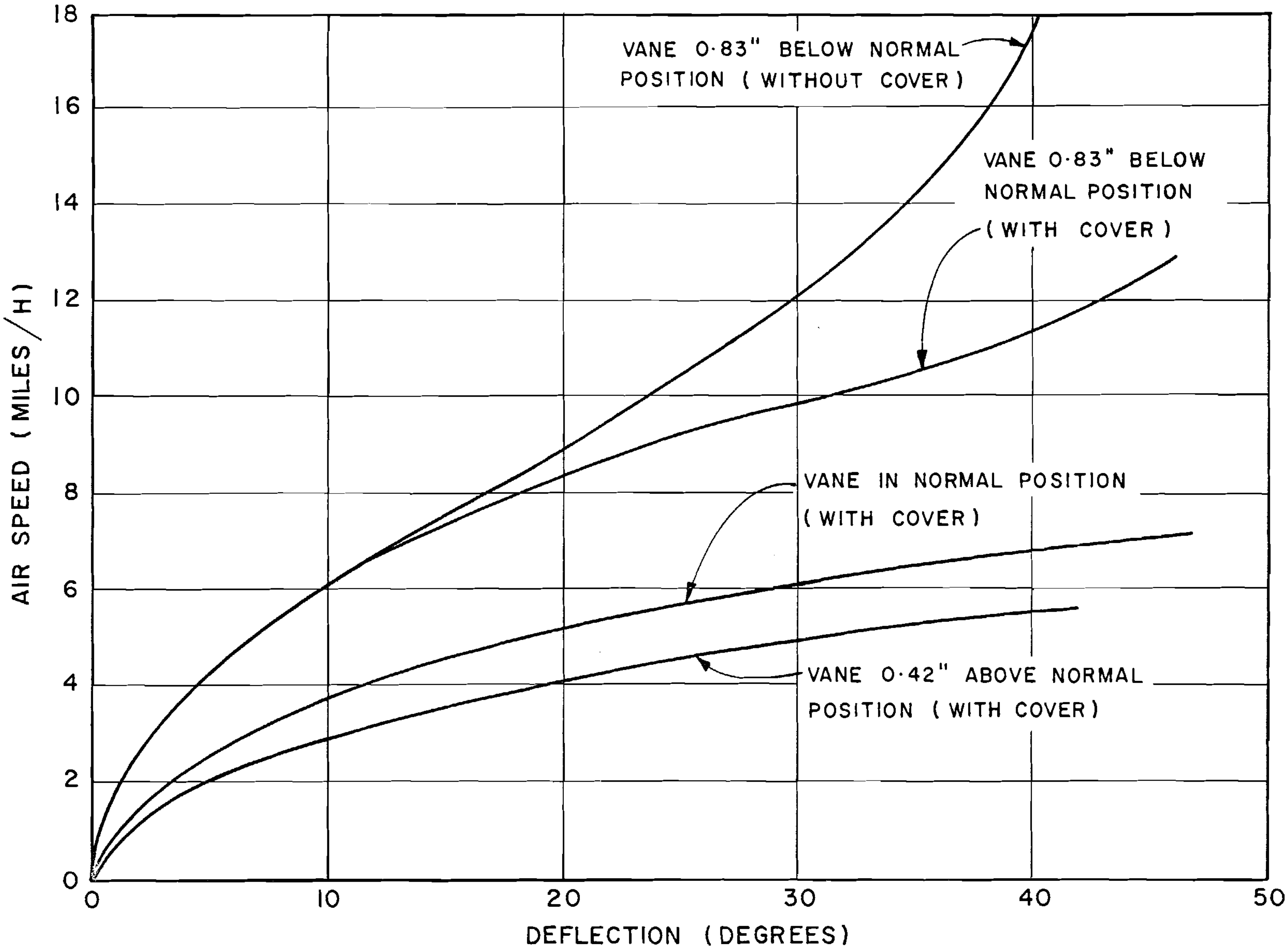


FIGURE 10 CALIBRATION OF ANEMOMETER

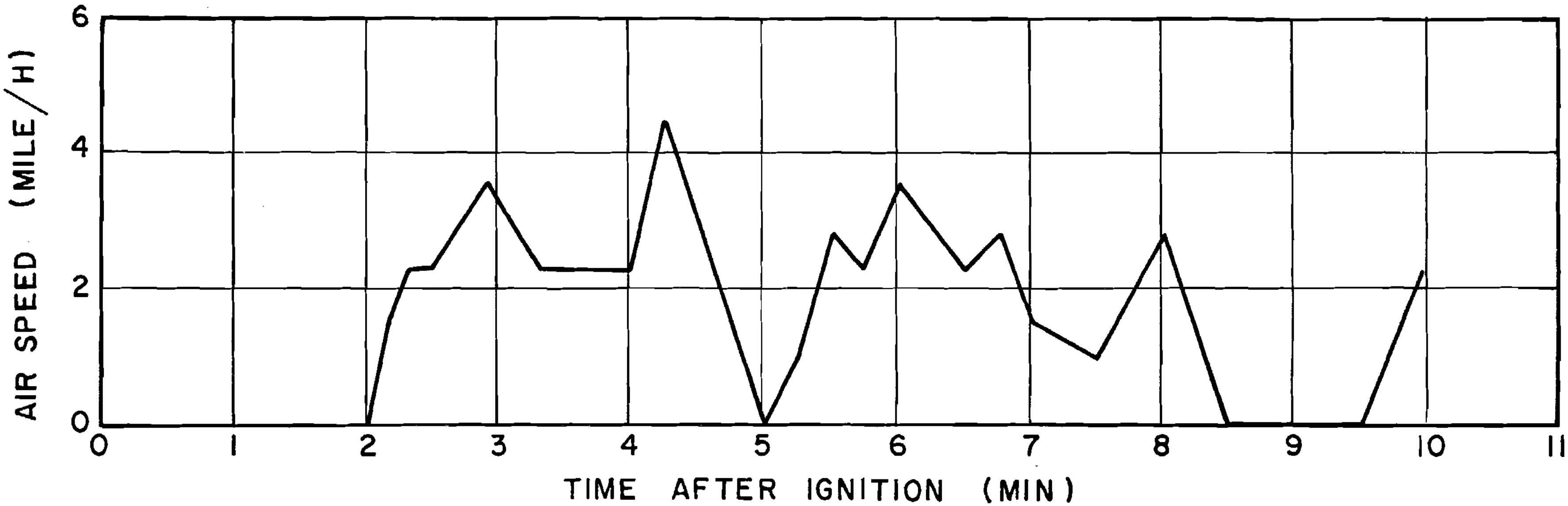


FIGURE 11 INLET AIR SPEEDS - HOUSE No 1

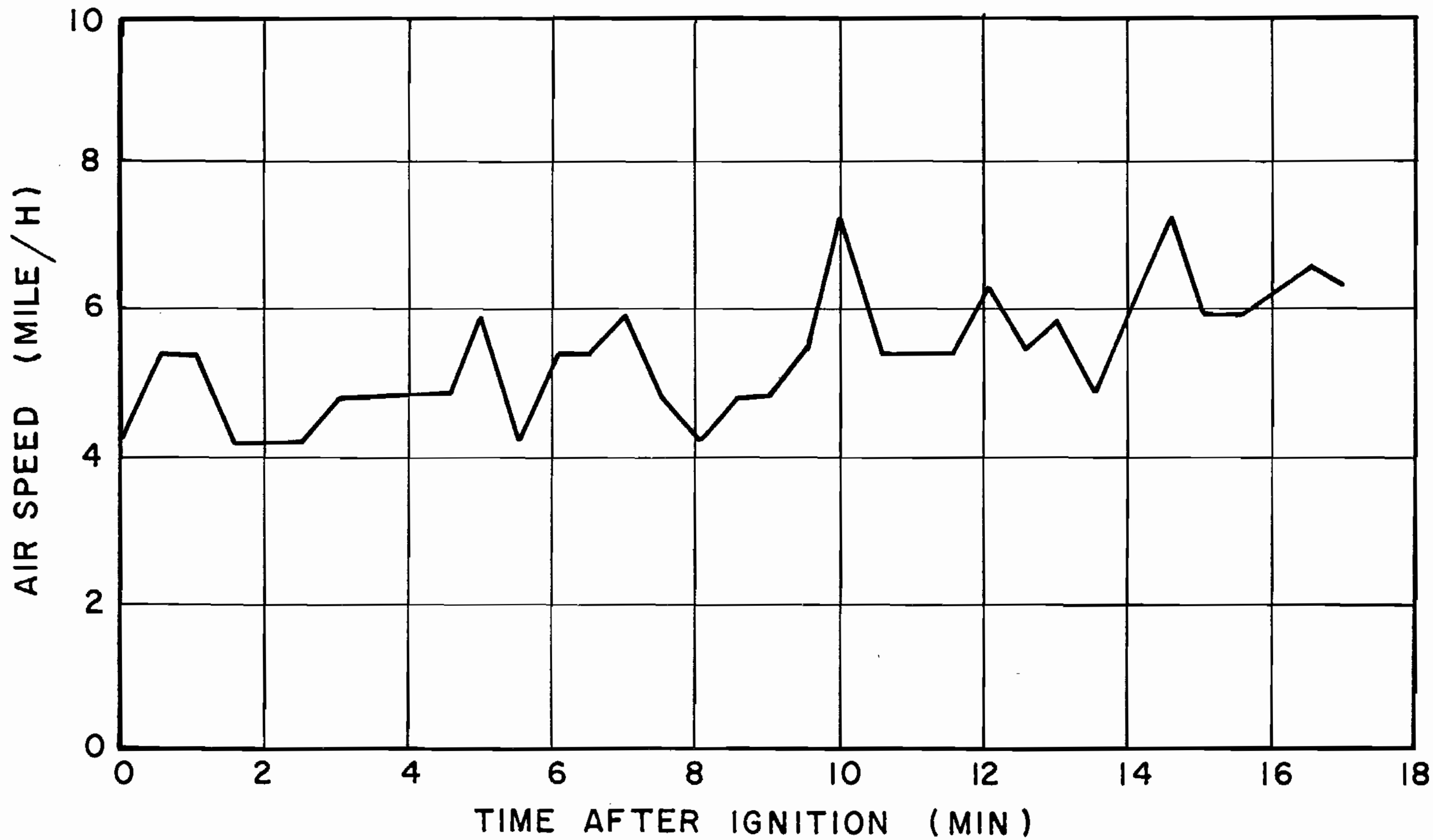


FIGURE 12 INLET AIR SPEEDS - COMMUNITY HALL
(BLDG. No. 6)

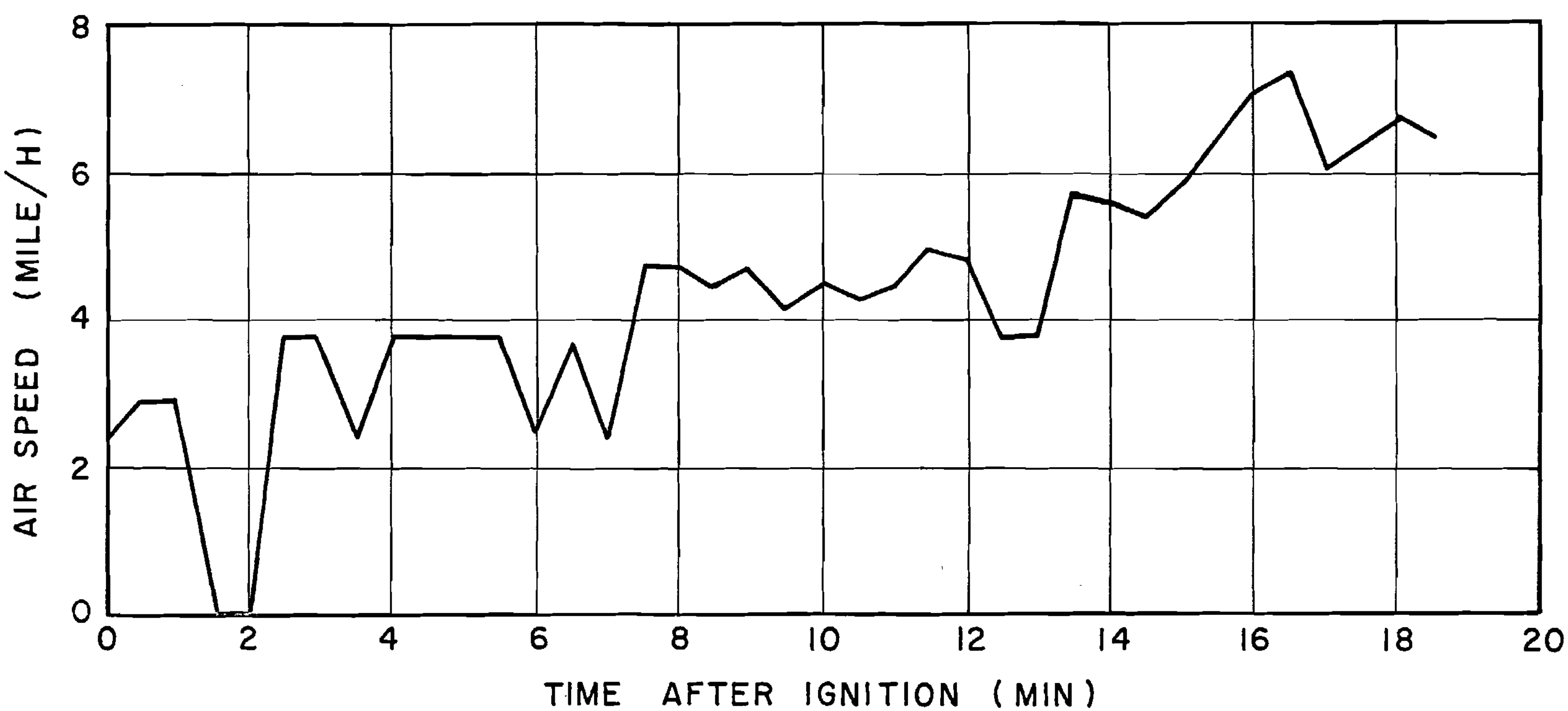


FIGURE 13 INLET AIR SPEEDS- SCHOOL, MAIN BUILDING
(BLDG. No. 8)

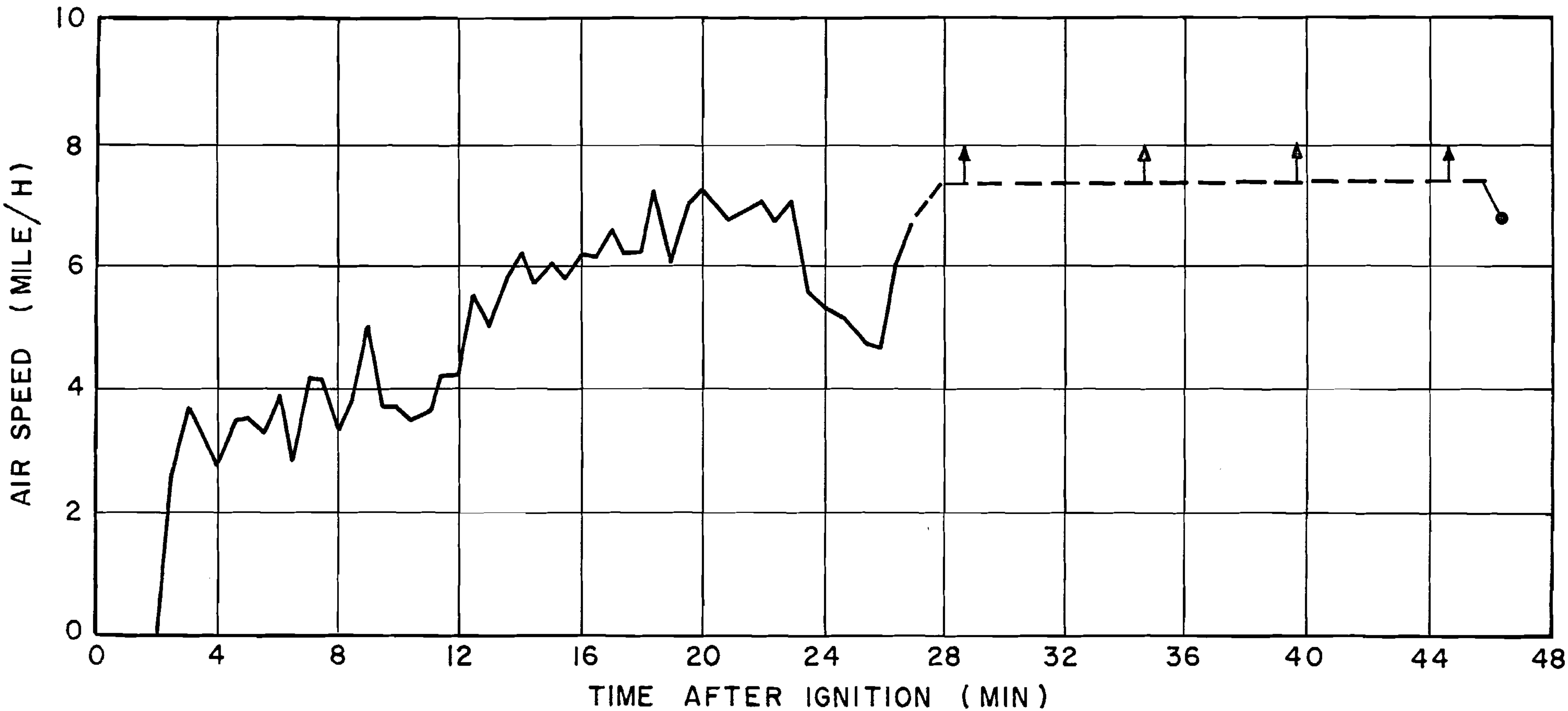


FIGURE 14 INLET AIR SPEEDS - SCHOOL ANNEX

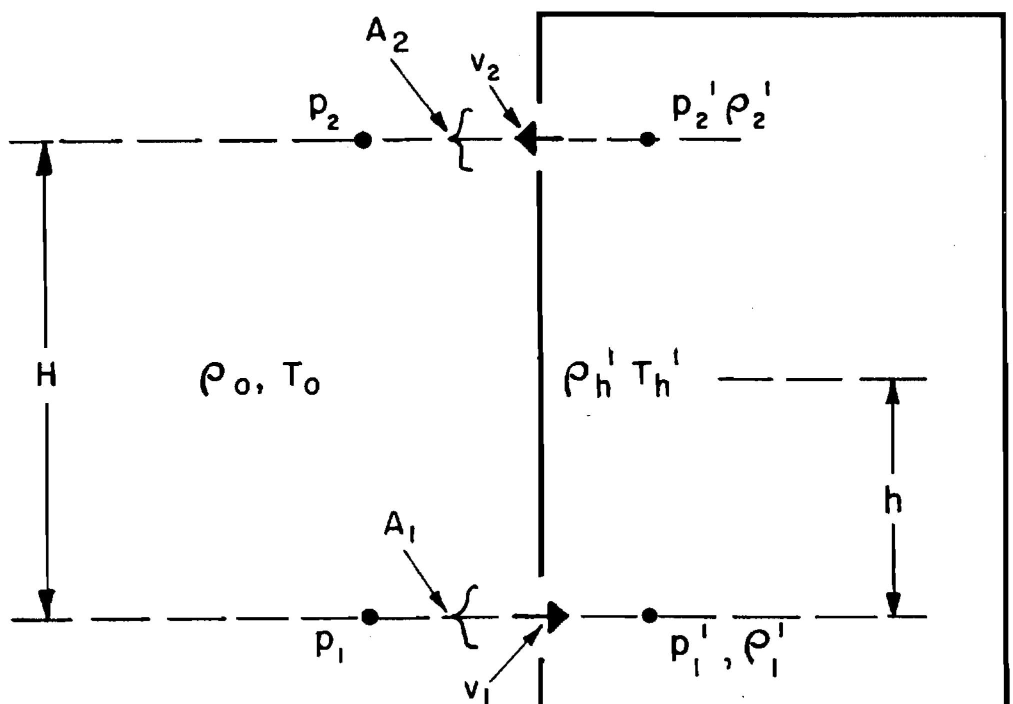


FIGURE 15 APPLICATION OF BERNOULLI'S EQUATION

APPENDIX A

THE SPEED OF AIR ENTERING A BURNING BUILDING

From a consideration of conservation of mass flow at the inlet and outlet,

$$(1 + z)\, A_1\rho_o v_1 \;=\; A_2\rho_2' \, v_2 \qquad (1)$$

where z, A, ρ and v are over-all fuel/air ratio, area, density, and air speed respectively.

The significance of the sub- and super-scripts is indicated in Fig. 15.

Neglecting frictional resistance and assuming that the gas speed within the building is low (i.e. that the inlet and outlet areas are small compared with the horizontal cross-sectional area of the building), energy considerations at the inlet, following Bernoulli, give

$$p_1 - p_1' \;=\; \rho_o {v_1}^2/2 \qquad (2)$$

where p represents pressure.

Similar considerations, at the outlet, assuming that combustion is completed within the enclosure, give

$$p_2' - p_2 = \rho_2' {v_2}^2/2 \qquad (3)$$

Adding equations (2) and (3)

$$(p_1 - p_2) - (p_1' - p_2') = \rho_o {v_1}^2/2 + \rho_2' {v_2}^2/2 \qquad (4)$$

Since the gases within and outside the building may be considered stagnant, the left side of equation (4) is given by the difference in weights of the inside and outside gases. Therefore

$$H\rho_o g - g\int_0^H \rho_h' \,dh \;=\; \rho_o {v_1}^2/2 + \rho_2' {v_2}^2/2 \qquad (5)$$

i.e.

$$g\int_0^H (\rho_o - \rho_h')\,dh \;=\; \rho_o {v_1}^2/2 + \rho_2' {v_2}^2/2 \qquad (6)$$

The effect of pressure changes on density is in this case negligible, so that

$$\frac{\rho_h'}{\rho_o} = \frac{T_o}{T_h'}$$

$$\therefore \int_0^H (\rho_o - \rho_h')\,dh = \rho_o \int_0^H (1 - T_o/T_h')\,dh$$

$$= \rho_o \int_0^H \theta / T_h' \, dh \qquad (7)$$

where θ_h' is the temperature rise, above ambient, of the gases within the building at a height h.

From equations (1), (6) and (7)

$$v_1 = \sqrt{\frac{2g \int_0^H \theta_h' / T_h' \, dh}{1 + (1+z)^2 (A_1/A_2)^2 (T_H'/T_o)}} \qquad (8)$$

If θ_h' is constant then

$$v_1 = \sqrt{\frac{2gH\theta'/T'}{1 + (1+z)^2 (A_1/A_2)^2 (T_H'/T_o)}} \qquad (9)$$

A maximum estimate of the inlet air speed may be obtained by neglecting the contribution of the fuel to the mass flow. For a fuel/air ratio of stoichiometric proportions the error in neglecting z is less than 20 per cent. In the early stages of the fire the fuel/air ratio is much less and the error is correspondingly less.