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DIVISION OF BUILDING RESEARCH

ST. LAWRENCE BURNS

RADIANT TEMPERATURE OF OPENINGS

by

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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 Dr. D. G. Stephenson, research officer with the Building Services Section of this Division, who assisted the Fire Section in this project by arranging for and analysing the readings of radiant temperature of window openings.

Ottawa
December 1959

N. B. Hutcheon
Assistant Director

REPORTS ON THE ST. LAWRENCE BURNS

No.	Sub-Title	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

RADIANT TEMPERATURE OF OPENINGS

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Since a burning building can ignite neighbouring structures if the radiation reaching the exposed surfaces is sufficiently intense, building codes usually specify a minimum separation between buildings. It is possible to calculate the separation which is required to prevent fire spread by radiation if the following data are available:

1. The intensity of the radiation emitted by a burning building;

2. The radiant energy flux which will ignite the exposed wooden parts of an adjacent building.

A quite complete investigation of "The Ignition of Wood by Radiation" was made by Lawson and Simms (1952), but very few measurements of the radiation emitted by a burning building have been reported. When calculating the energy which may be transferred by radiation it is common to assume that the openings in the shell of a burning building radiate as black bodies at 1000°C. The variation in radiation intensity with time is normally not taken into account, i.e., the 1000°C intensity is assumed to exist long enough for the exposed surfaces to come to an equilibrium temperature.

The St. Lawrence burns provided an ususual opportunity to obtain field measurements of the radiation emitted by different types of burning buildings at various stages in the development of a fire. A representative of the Joint Fire Research Organization (Great Britain) measured the total radiation incident on a surface located a known distance from the burning building. To supplement his results it was decided to measure the equivalent black body temperature of a window in the room where the fire started. These radiant temperature measurements are the subject of this report.

Description of Apparatus and Procedure

A thermopile radiometer designed by Linke and Feussner and manufactured by P.J. Kipp and Zonen of Delft was used as the radiation sensing device. The instrument was modified by replacing one of the 1/2-in. diameter glass filters by a double walled screen with a 1/4-in. diameter hole at its centre. With this aperture the instrument could be located up to 20 ft from an opening 2 ft wide and still have the opening completely fill the field of view of the instrument.

The electromotive force generated by the radiometer thermopile was recorded by a self-balancing potentiometer strip-chart recorder. The recorder had a range from -5 to +5 millivolts and a chart speed of 1 in. per minute. A 5-millivolt bias voltage was put in series with the potentiometer input so that the effective range was from 0 to +10 millivolts.

The radiometer was set on a surveyor's tripod about 5 ft above the ground. The tripod was located directly in front of and 20 ft from a window of the room in which the fire was started. To ensure that the instrument was accurately sighted on the centre of the window the following procedure was followed:

1. A 250-watt infra-red lamp was attached at the centre of the window.

2. The radiometer output was connected to a d-c amplifier with an output meter which served as a galvanometer.

3. The radiometer was sighted on the lamp using the peep sight which is attached to the barrel of the instrument.

4. The fine sighting was done by adjusting the azimuth and elevation to give a maximum output from the thermopile. With a 250-watt lamp at 20 ft the radiometer is very sensitive to angle.

The procedure during a burn was as follows:

1. The instrument was set up on the tripod at least an hour before the burn started.

2. The sighting was done as described and the radiometer output was then connected to the recording potentiometer. The polarity of the connection was checked to make sure that increasing radiation caused an on-scale deflection.

3. With the radiometer shutter closed the bias voltage in the input circuit was adjusted to give a recorder reading of zero on the chart.

4. The shutter was replaced by the 1/4-in. diameter aperture.

5. At the official start of the test the recorder chart feed was started and then the recorder was left unattended.

6. The operator went to the radiometer and stayed there during the remainder of the test. He read and recorded the radiometer temperature at 1/2-min intervals and recorded observations of the progress of the fire, e.g., when the glass broke, when the flames started coming out of the window, etc.

7. The radiometer was removed when the operator thought it might be damaged by the collapse of a wall or when the heat was so intense that he could no longer stay by the instrument.

A. Calibration

The radiometer was purchased as a laboratory standard which could be used to calibrate solar radiation recorders. As soon as it was received it was checked against the Silver Disk Pyrheliometer No. 14 which is the standard used by the Meteorological Branch of the Department of Transport. The comparison was made on a clear day using the sun as a source. The average of many comparisons indicated that the factor for this instrument is

$$J \text{ (Langley/min)} = E(\text{mv}) \left\{ \frac{1 + 0.002\ (t-20)}{11.68} \right\}$$

t = instrument temperature °C

This is based on the International scale of 1956, which gives radiation values 2 per cent lower than does the 1913 scale.

This calibration was determined for the standard aperture, not the small one. To obtain the factor for the reduced aperture, the radiometer was set up in front of a gas-fired radiation panel and the thermopile output was recorded as the two apertures were alternated. The ratio of output with small aperture to output with large aperture was 0.260. This is also the ratio of the solid angle of view for the two apertures. The solid angle of view for the standard aperture is given by the instrument manufacturer as $W = \pi/125$. Thus the angle for the reduced aperture is $\frac{0.260 \times \pi}{125} = \pi/480$.

The radiation from a burning building has a peak intensity at wavelengths between 2 and 2.5 microns, whereas solar radiation has its peak intensity at about 0.5 micron. It was decided to check the radiometer calibration for long wavelength radiation since the instrument had only been calibrated with solar radiation. The Division does not have a high temperature furnace which is suitable for calibrating a radiometer in the 2.5-micron range, so that a black body at 100°C (10-micron wavelength) was used. The results are given in Appendix A. This test showed that the calibration constant for the infra-red radiation is slightly higher than that for the solar spectrum. The factor appropriate for solar radiation was used for calculating the radiant temperature of the burning buildings.

B. Calculation of Radiant Temperature from Radiometer Output

The normal radiation intensity from a black body at T° Kelvin is

$$I_n = \frac{\sigma T^4}{\pi} \quad \text{Langley/min Steradian}$$

where $\sigma = 81.3 \times 10^{-12}$

The radiation incident on the thermopile when the radiometer field of view is completely filled by a radiator at T° Kelvin is I_n times the solid angle of the field of view.

Thus

$$\text{incident radiation} = \frac{\pi}{480} \cdot \frac{\sigma T^4}{\pi} \quad \text{Langley/min}$$

and the radiation emitted by the radiometer within this same solid angle is

$$\frac{\pi}{480} \cdot \frac{\sigma T^4_R}{\pi} \quad \text{Langley/min}$$

Then radiometer output emf is

$$E = K \left\{ \frac{\sigma}{480} (T^4 - T^4_R) \right\} \text{ mv}$$

where $K = \frac{11.68}{1 + .002\ (t - 20)}$ mv /Langley/min

Thus

$$\left(\frac{T}{1000}\right)^4 = \left(\frac{T_R}{1000}\right)^4 \div \frac{480}{81.3} \cdot \frac{E}{K}$$

C. Test Results Obtained During St. Lawrence Burns

The buildings involved in the experiments are shown in plan in Figs. 1 to 8. Figures 9, 10 and 11 are photographs of the recorder charts with the radiometer temperature and the calculated radiant temperature of the window noted at 1/2-min intervals. The record for house No. 1 is not included because for this first burn a preamplifier was used to increase the sensitivity of the recorder. The random fluctuations of the radiometer output were about equal to the recorder span (1 mv) so that the results are ambiguous. Since the records from houses No. 4 and No. 7 shown in Fig. 9 are very similar, they may be taken as representative of houses with incombustible linings. Figure 10 shows the records for houses No. 2 and No. 3, both of which had combustible linings. The dense smoke issuing from the test window of house No. 5 reduced the radiant temperature of the window during most of the test.

A comparison of Figs. 9 and 10 shows that radiation reaches a high intensity much sooner for houses with combustible linings, and that the maximum value of radiation intensity is slightly higher for houses with combustible linings. The recorder charts for the school and the community hall show that the peak value of radiation intensity occurs much later for a large building than for a house. At the school, the test finished when it became too hot for the operator to remain with the radiometer, and at the community hall the test was abruptly ended when a chimney collapsed and upset the radiometer. It is doubtful, therefore, whether the maximum radiation intensity occurred while the radiometer was in operation in either of these tests.

CONCLUSIONS

1. The radiation from the openings in burning buildings with combustible linings reaches a peak intensity more quickly than for buildings with incombustible linings.

2. The usual assumption that windows radiate as black bodies at 1000°C seems to be justified for the type of buildings burned during these tests.

Acknowledgment

Mr. Bernard Brulé, Research Technician with Building Services Section was largely responsible for the operation of the instrumentation in the field and provided valued assistance.

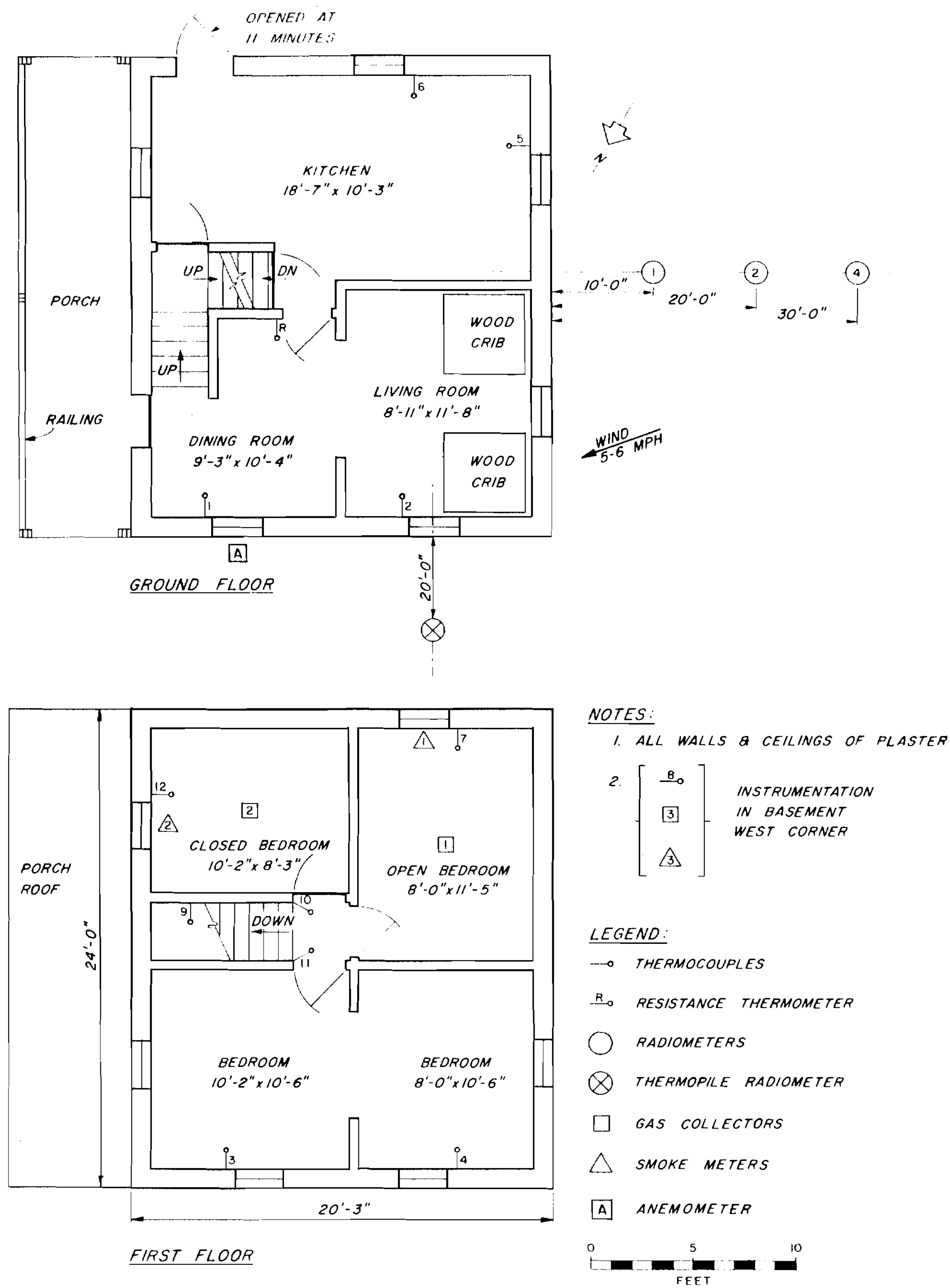


FIGURE 1 - BUILDING No. 1 - TWO-STOREY SOLID BRICK DWELLING

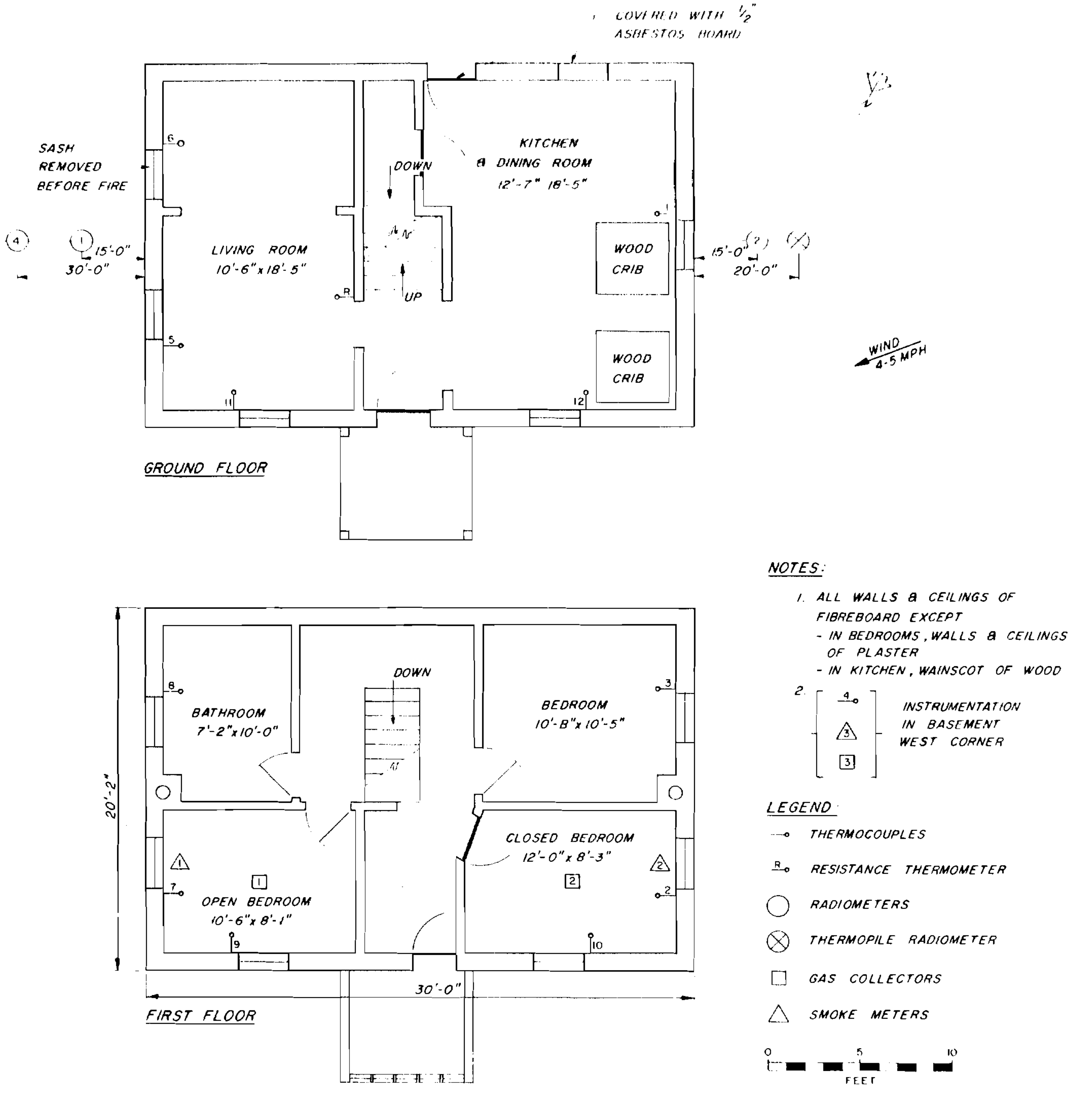


FIGURE 2 - BUILDING No. 2 - TWO - STOREY SOLID BRICK DWELLING

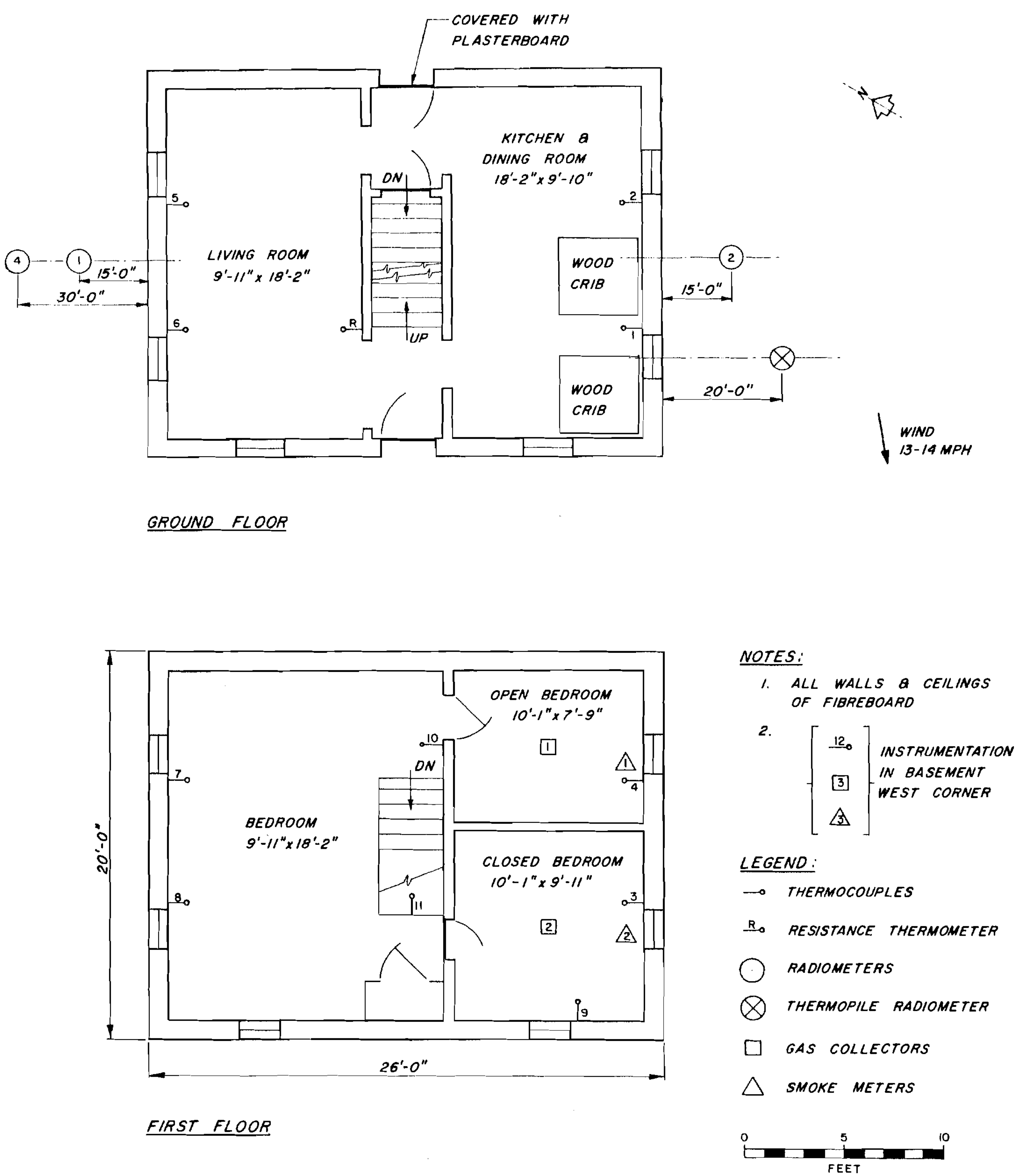


FIGURE 3 - BUILDING No. 3 - TWO - STOREY SOLID BRICK DWELLING

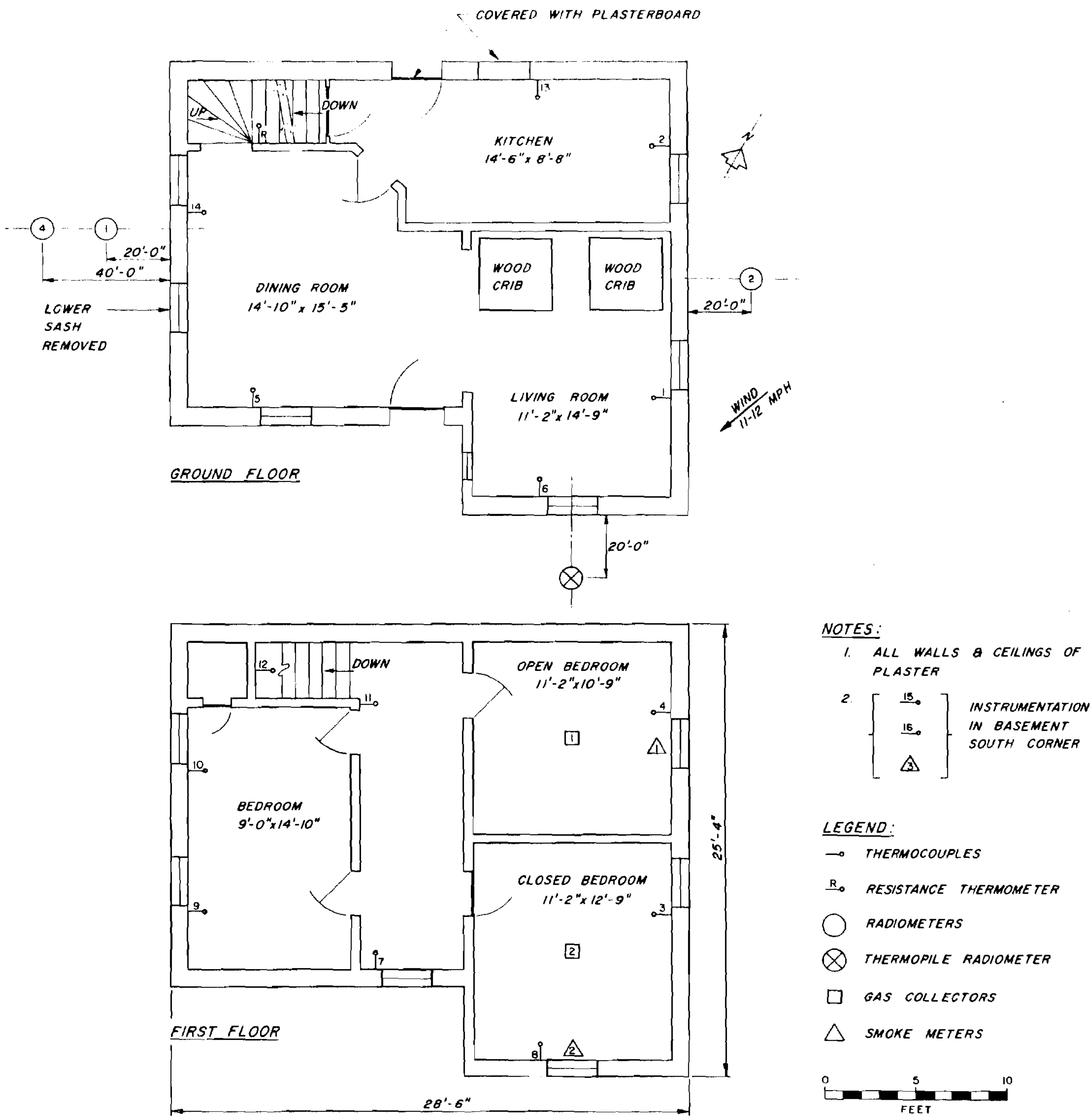


FIGURE 4 - BUILDING No. 4 - TWO - STOREY WOOD FRAME DWELLING WITH CLAPBOARD EXTERIOR AND BRICK INFILLING

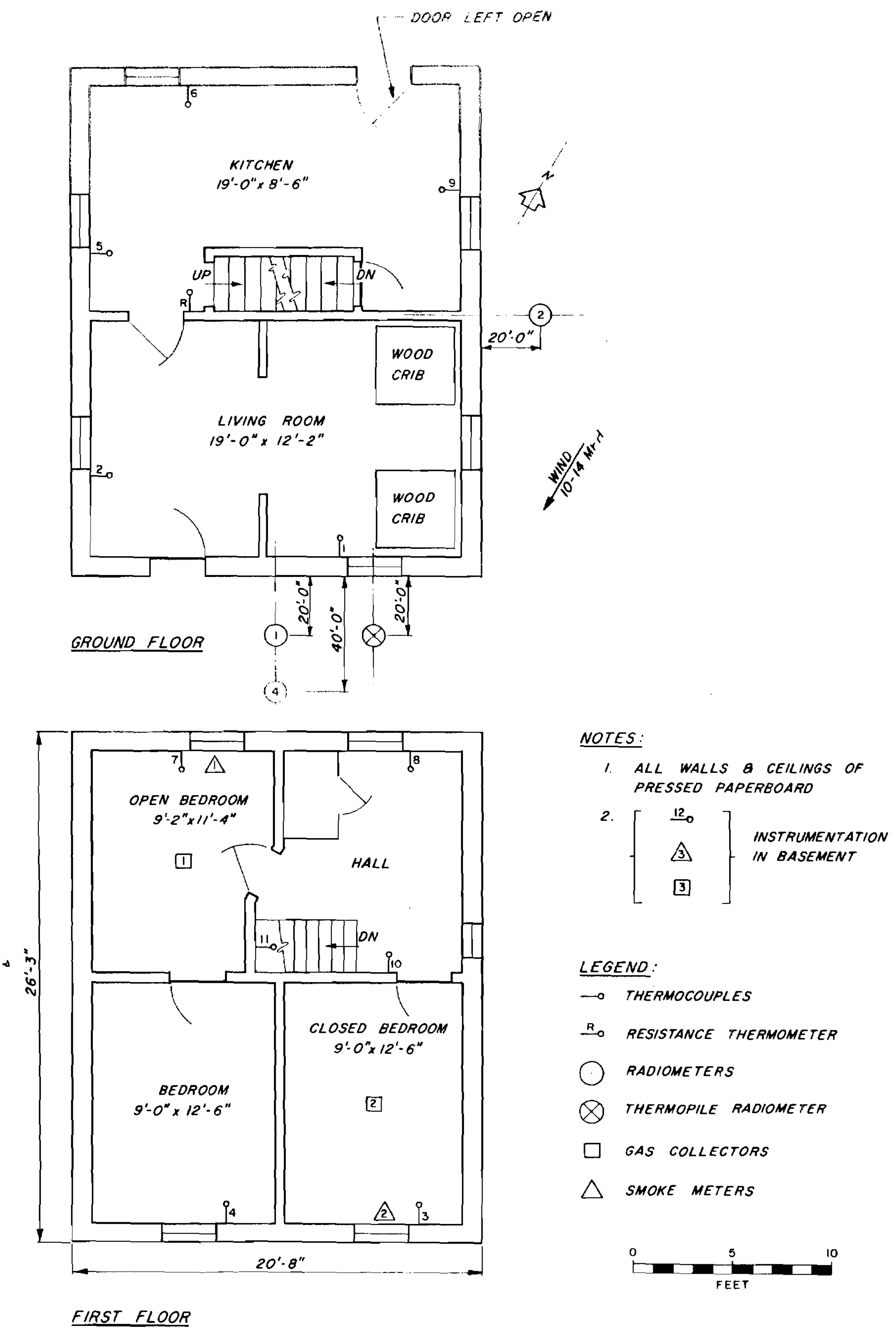


FIGURE 5 - BUILDING No. 5 - TWO - STOREY WOOD FRAME DWELLING WITH CLAPBOARD EXTERIOR

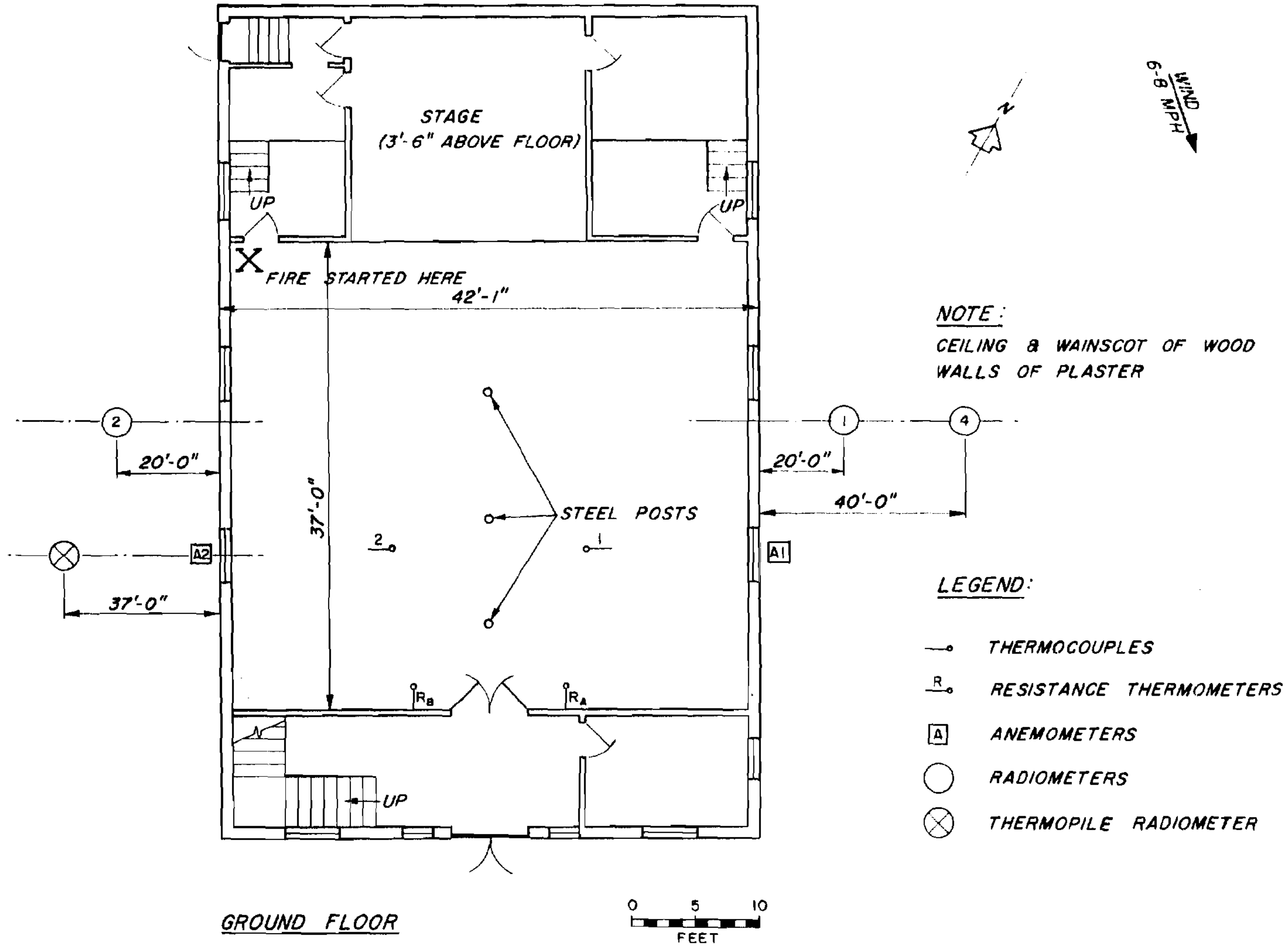


FIGURE 6 - BUILDING No. 6 - TWO - STOREY SOLID BRICK FRATERNITY HALL

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

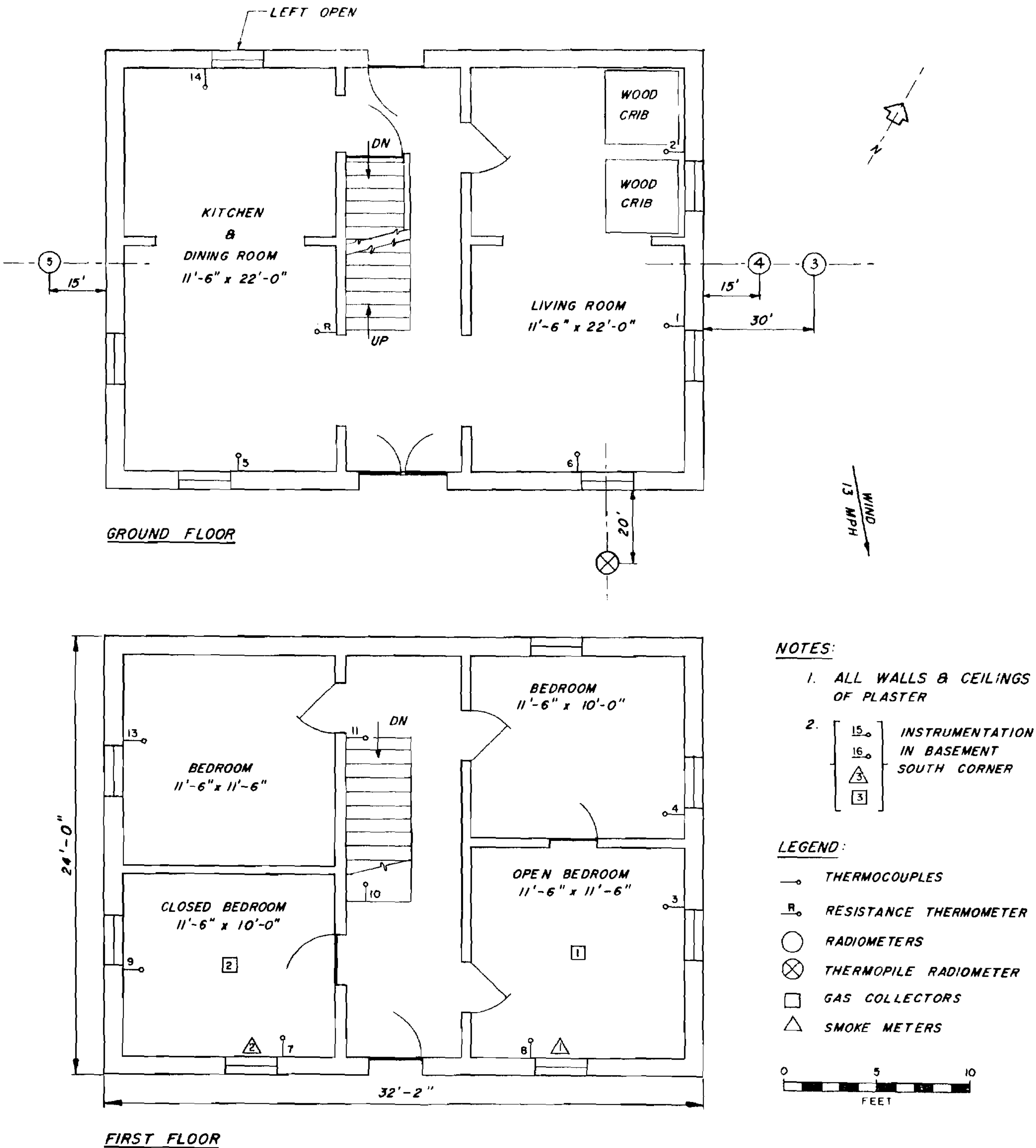


FIGURE 7 - BUILDING No. 7 - TWO - STOREY SOLID BRICK DWELLING

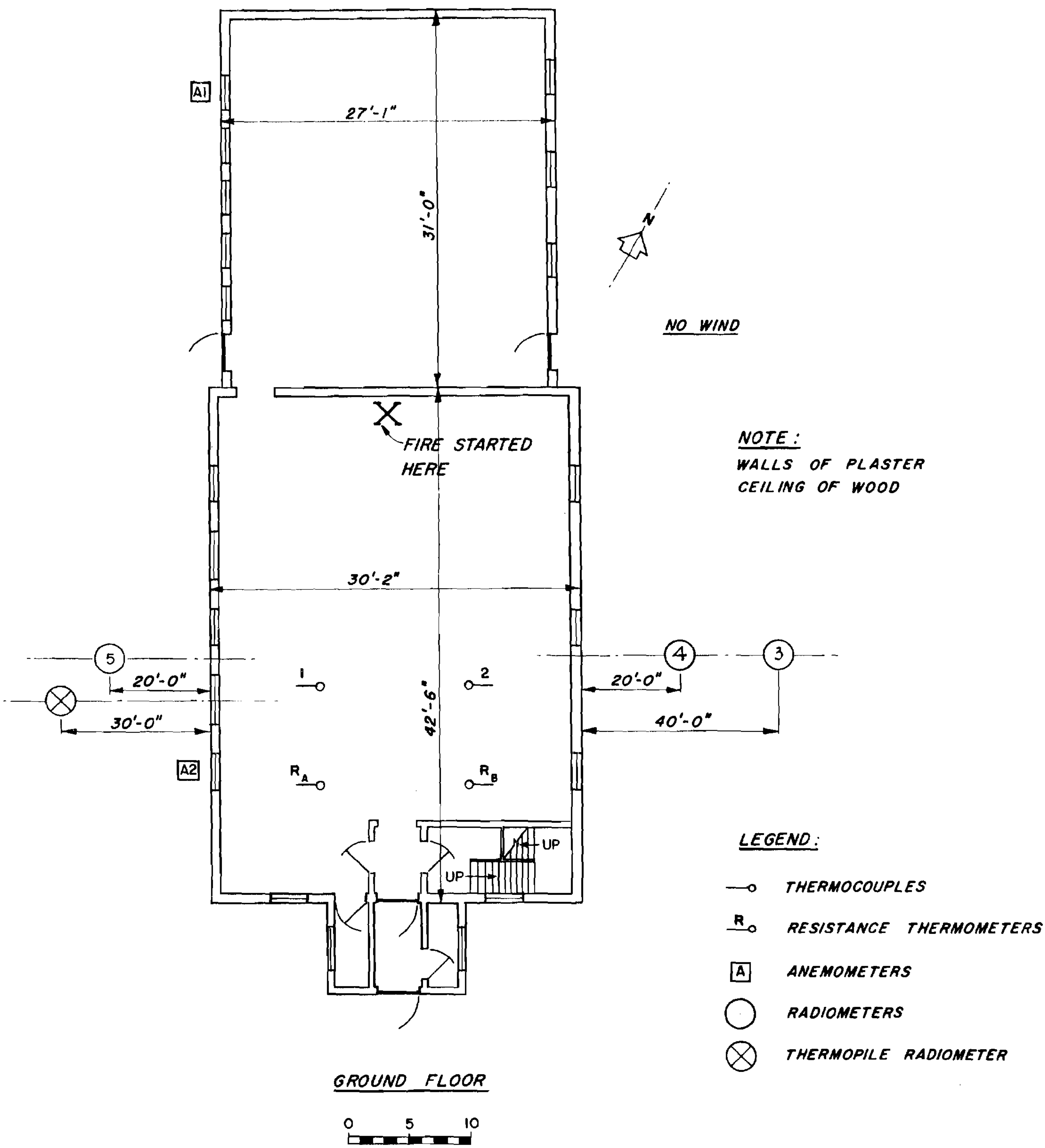
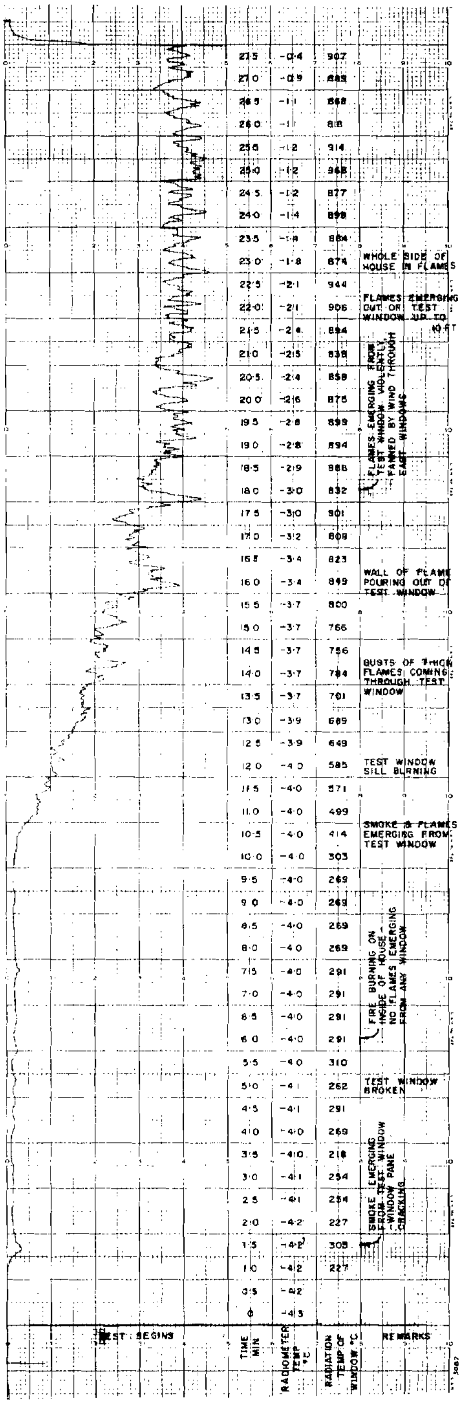
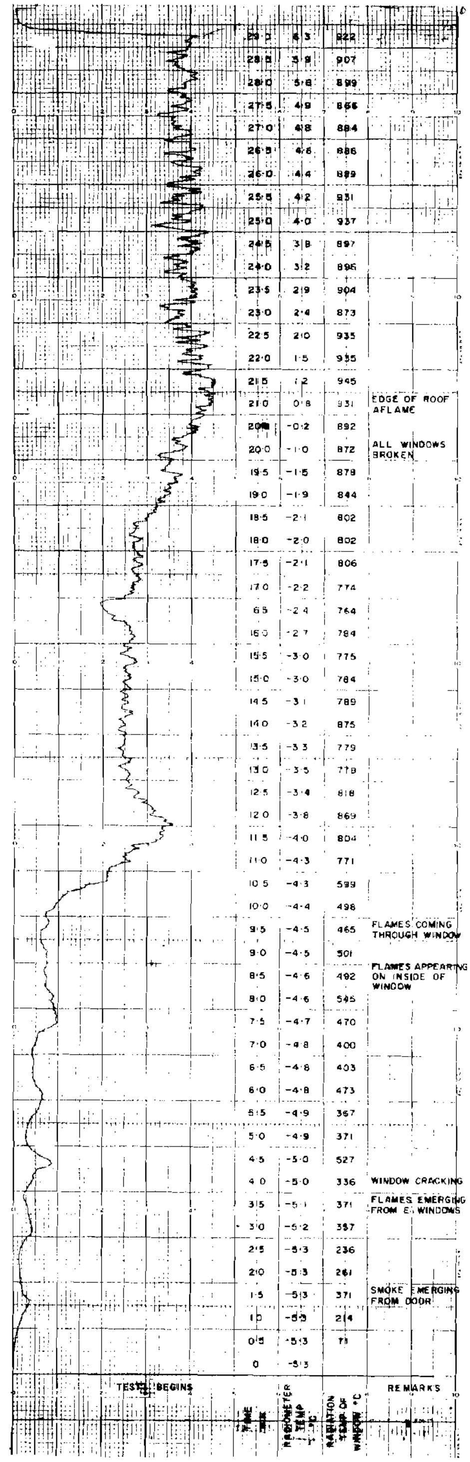


FIGURE 8 - BUILDING No. 8 - TWO - STOREY SOLID BRICK SCHOOL WITH ONE - STOREY EXTENSION AT REAR

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

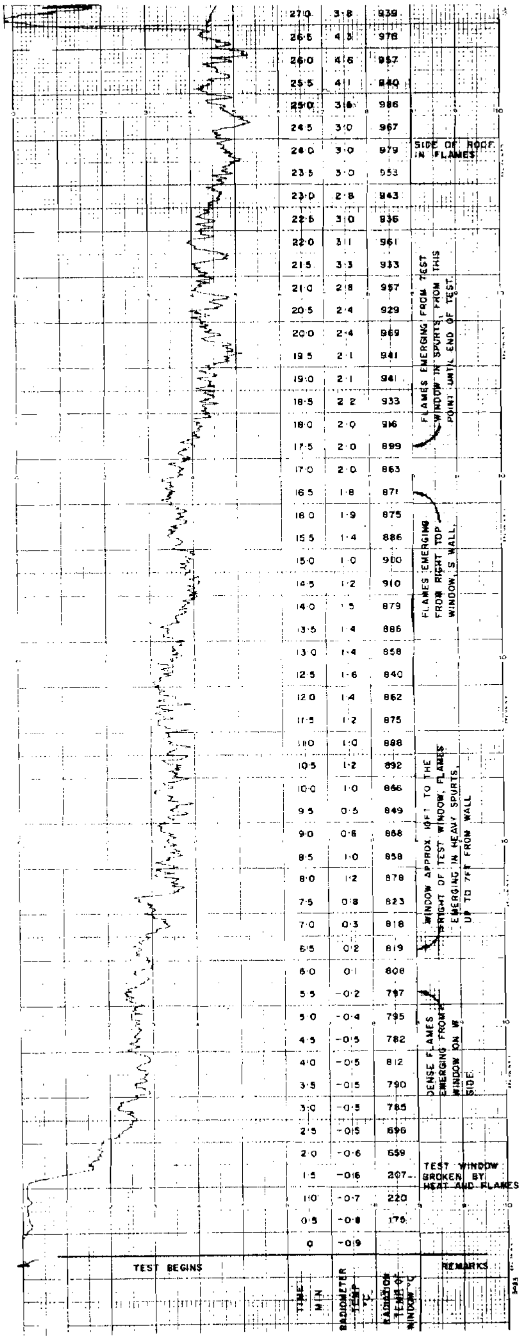


BLDG. No. 4

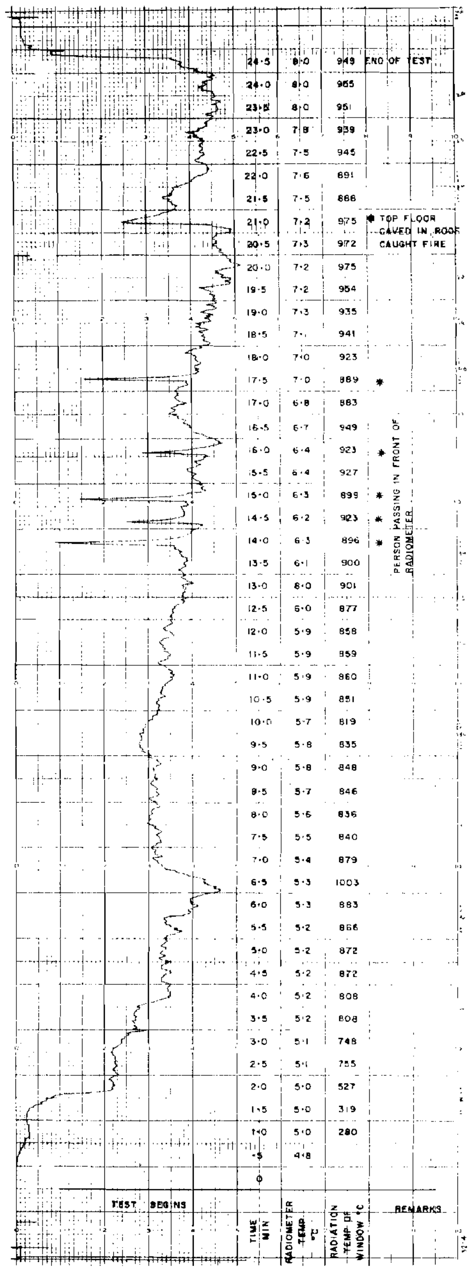


BLDG. No. 7

FIGURE 9 RECORDER CHARTS FOR BURNS OF HOUSES WITH INCOMBUSTIBLE LININGS

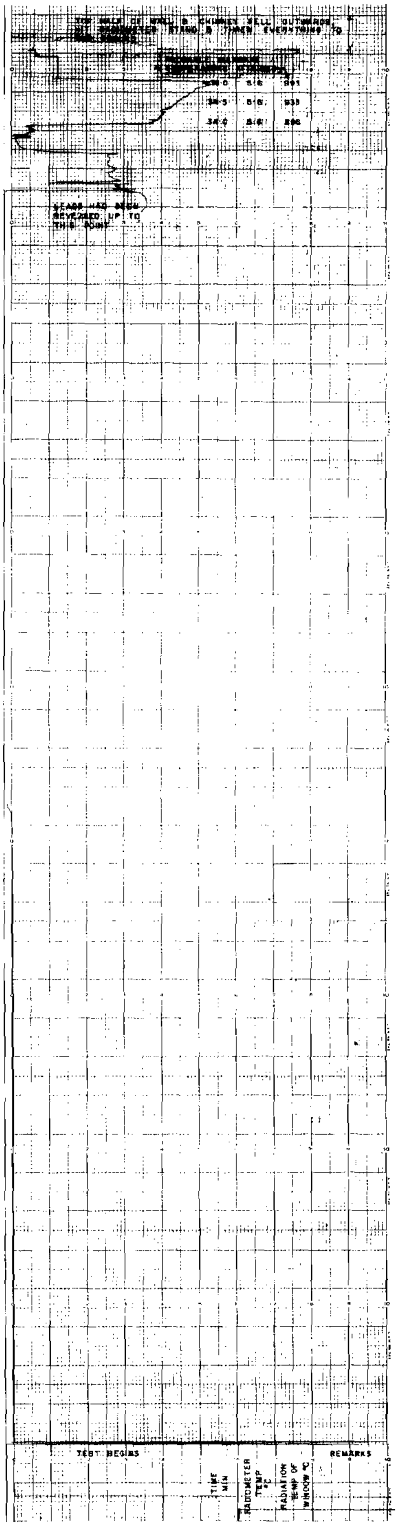


BLDG. No. 3

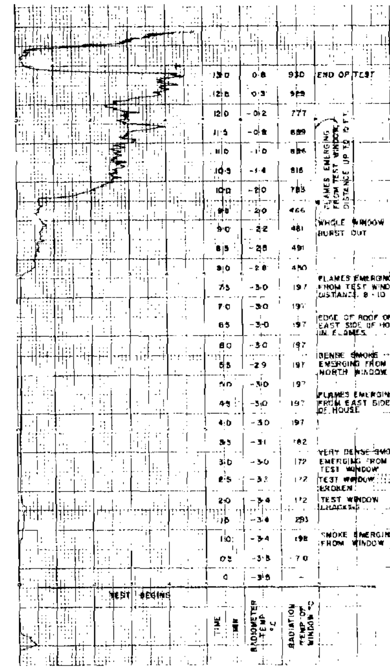


BLDG. No. 2

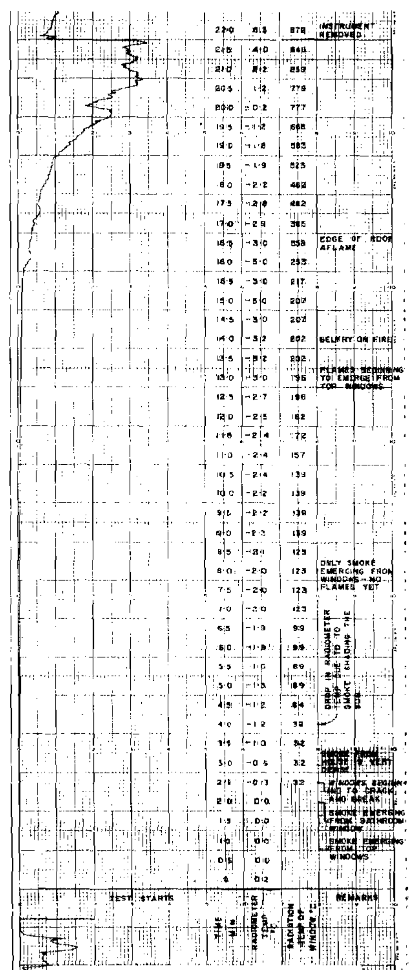
FIGURE 10 RECORDER CHARTS FOR BURNS OF HOUSES WITH COMBUSTIBLE LININGS



COMMUNITY HALL AULTSVILLE



BLDG. No. 5



SCHOOLHOUSE AULTSVILLE

FIGURE 11

RECORDER CHARTS FOR BURNS No. 5, 6, 8

APPENDIX A

CHECK ON RADIOMETER CALIBRATION AT LONG WAVELENGTHS

The radiometer was sighted into a conical black body which was maintained at 100°C by condensing steam at atmospheric pressure.

A. Data for small aperture:

$T = 373°$ Kelvin

$T_R = 298°$ "

$E = 0.0238$ millivolts

Calculation:

$$(0.373)^4 - (0.298)^4 = \frac{480 \times 0.0238}{81.3 \times K}$$

$$\therefore \quad K = \frac{480 \times 0.0238}{81.3 \times 0.01147} = 12.25 \ \frac{mv}{Langley/min}$$

B. Data for standard aperture:

$T = 373°$ K

$T_R = 297°$ K

$E = 0.092$ mv

Calculation:

$$(0.373)^4 - (0.297)^4 = \frac{0.25 \times 0.092}{81.3 \times K}$$

$$\therefore \quad K = \frac{125 \times 0.092}{81.3 \times 0.01158} = 12.22 \ \frac{mv}{Langley/min}$$

The good agreement between the values of K found for the small and the standard apertures is confirmation of the accuracy of the solid angle ratio.