NATIONAL BUREAU OF STANDARDS REPORT

9543

INTERIM REPORT ON FHA WALL SYSTEM PERFORMANCE
COVERING HEAT, AIR AND MOISTURE PENETRATION AND
RESULTING PHYSICAL DEFLECTION CAUSED BY THE ENVIRONMENT

Thomas K. Faison
and
Henry E. Robinson

Report to
Federal Housing Administration
Washington, D. C.

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Environmental Engineering Section
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IMPORTANT NOTICE

NBS

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INTERIM REPORT ON FHA WALL SYSTEM PERFORMANCE
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AND RESULTING PHYSICAL DEFLECTION CAUSED BY THE ENVIRONMENT

1.0 Objectives and Scope

The objectives of this test, applied to prototype exterior walls, are: (A) to measure the rate of air penetration through the wall at specific pressure differentials simulating wind loads, (B) to monitor specific locations in the wall to determine if or when moisture condensation occurs, (C) to measure deflections out-of-plane of the wall system resulting from its exposures on the two sides, and (D) to obtain approximate heat transmission rates and changes in heat transmission rate through the wall by the use of heat flow meters.

2.0 Test Apparatus

There shall be two environmentally-controlled chambers, open on their facing sides, capable of closing with an air-tight seal against an intermediate steel support frame within which the test wall is constructed. An overall view of the testing apparatus is shown in Figure 1.

2.1 Warm-Side Environmental Chamber (No.1)

One chamber shall be capable of controlling temperature and relative humidity between 75 ^{o}F and 40 percent RH and 100 ^{o}F and 70 percent RH, to within ±0.5 deg F and ±1 percent RH. The chamber when sealed shall not leak air if at all practical. If chamber leakage does occur, then appropriate corrections shall be made when determining wall penetration rates.

2.2 Cool-Side Environment Chamber (No.2)

One chamber shall be capable of controlling temperature and relative humidity between 0 °F and 35 percent RH and 80 °F and 50 percent RH, to within ±0.5 deg F and ±1 percent RH at the higher temperature. The chamber when sealed shall not leak air if at all practical. If chamber air leakage does occur, then appropriate corrections shall be made when determining wall penetration rates.

2.3 Support Frame

A steel support frame shall be constructed to house the wall specimen. The working surfaces of the frame shall be made smooth and flat to enable air-tight sealing of the edges of the hot and cold environmental chambers and of the edges of the test specimen. The frame shall be rigid enough to restrain movement in the plane of the specimen. The support frame shall be mobile to enable rotation or turning of the specimen so that the indoor surface of the wall can be exposed to either the warm chamber or the cold chamber.

3.0 Preparation of Test Specimen

The test specimen shall be installed in the support frame in such a manner as to simulate a portion of the exterior wall system in a building. The ceiling and floor joints are to be prepared in the same manner (FHA Minimum Property Standards) as would be used in regular construction. The vertical edges where the test specimen meets the support frame, are to be caulked at both faces to prevent passage of air around these edges. Moisture indicating devices are to be placed in joints and on surfaces where the formation of condensation seems most likely. Temperature measuring devices

and heat flow meters are to be located at positions most likely to indicate changes in conditions within the wall. Judgment must be exercised in selecting positions for instrumentation. A deflection gage shall be used to measure at the midpoint of the specimen on the interior surface any deflection of the specimen out of its original plane. Figure 2 shows the location of the instrumentation as tentatively established.

4.0 Tests Conducted

4.1 Test Specimen: The test wall, type No. 2, was of wood frame construction. The framing was of nominal dimensioned 2 x 4's with studs on 16 inch centers between the wall plate and the top plates. A 1 x 4 corner brace was inset diagonally across the panel . A fiberboard sheathing material as per FHA M.P.S of 4 ft. by 8 ft. sheets was installed directly onto the studs. Wood siding of 3/4" thickness covered the sheathing material to provide the outdoor surface. Gypsum dry wall of 1/2 inch thickness was applied directly to the studs to provide the interior surface. All nailing was as prescribed by FHA M.P.S. The outdoor surface was covered with a coat of exterior wood primer and a coat of exterior wood white finish paint, both being of oil base. The interior finish was of two coats of latex base white paint. Both exterior and interior paints complied with FHA M.P.S. Figure 3 shows the cross section of the wall system giving details of construction, components and typical ceiling and floor joints. Figures 4 and 5, are views of the outdoor and indoor surfaces of the wall, respectively.

4.2 Air Penetration

4.2.1. Apparatus Air Leakage: Wall type No. 2 was installed in the support frame and sealed with tape at the joints of the frame and boxes. The warm and cold chambers were joined by a hose line and thereby equally pressurized with air. The flow of air necessary to maintain the desired pressure differential between the interior of the chambers and the ambient atmospheric pressure was metered by a laboratory wet gas meter. The leakage flow of the apparatus under isothermal (room temperature) conditions was measured *vs* Δp over the range from 0.1 to 0.5 in. H_2O. See Figure 6, Curve 1 for a plot of q *vs* Δp.

4.2.2. Air Penetration Through Wall, Isothermal Conditions: The test wall was subjected to pressure differentials within the range from 0.025 to 0.425 in. H_2O. The outdoor surface of the wall (facing the cold chamber) was exposed to the higher pressure and the pressure differentials were imposed under isothermal (room temperature) conditions. The air flow leaving the warm chamber was metered and is shown in Figure 6 as Curve 2, Q' *vs* ΔP.

4.2.3. Air Penetration Through Wall, Non-Isothermal Conditions: The test wall was subjected to simulated winter conditions (the warm chamber at 75 °F and 40% RH; the cold chamber at 0 °F and DP ≤ 35% RH) for two continuous periods. During the first period the air flow was forced from the cold chamber to the warm chamber by a driving pressure difference of approximately 0.05 in. H_2O. Readings were taken daily of the air flow, Q, dis-

charging from the warm chamber and of the average daily pressure difference, Δp. The first period lasted for 11 days. During the second period, of 21 days duration , the pressure difference was reversed to force the air flow from the warm chamber to the cold chamber. Readings were taken daily of the air flow, Q', introduced into the warm chamber, and of the average daily pressure difference, $\Delta p'$. ($\Delta p' \sim 0.05$ in. H_2O).

At the end of the 21-day period, air flow measurements, Q', were made for various values of Δp ranging from 0.075 to 0.425 in. H_2O, while the winter conditions were maintained. The results of the last measurements are shown in Figure 6, as Curve 3, Q' vs Δp.

The data obtained daily on air flow rates Q and Q' during the first and second periods are shown in Figure 7, in which the daily values of $Q/\Delta p$ and $Q'/\Delta p'$ are plotted against time.

4.3 Physical Deflection

For the first period of 11 days and the second period of 21 days, both under non-isothermal conditions, measurements were made at the center of the indoor surface of the test wall to determine the deflection caused by a combination of thermal loading, air pressure differences and moisture changes. The deflection of the test wall resulting from exposure to the test conditions for the two periods is shown in Figure 8, deflection vs time.

4.4 Moisture Detection

Humidity sensing elements were used to monitor selected locations within the structure of the wall for accumulation of moisture in the area of sensor location. The sensors were of the lithium chloride type, which respond to

a change in relative humidity by a change of the electrical conductance of the salt solution. The location of humidity sensors and thermocouples is shown in Figure 2. Measurements of the RH and temperature were made twice daily to determine when and where changes were occurring.

4.5 Heat Transmission

Four circular heat flow meters were installed as shown in Figure 2. Two of the meters were on the indoor surface of the gypsum dry wall near the top and bottom quarter-heights of the wall. The other two were placed at the corresponding positions on the stud-side surface of the fiberboard sheathing. Readings were taken twice daily to obtain an indication of momentary transmission rates and to determine if significant changes in transmission rate were occurring.

5.0 Discussion

5.1. Air Leakage and Flow Measurements: The measured air flow rates representing, respectively; the air leakage outward through the two chambers (see 4.2.1.), the air flow from the warm chamber in the isothermal wall penetration test (see 4.2.2.) and the air flow from the warm chamber in the non-isothermal test (see 4.2.3.) are plotted versus Δp on log-log coordinates in Figure 9. The straight lines faired through most of the data points represent the function:

$$\text{flow} = A(\Delta p)^n \text{ , CFH .}$$

For the three sets of data, the coefficients and exponents were:

	A	n
Data of 4.2.1	20	0.869
Data of 4.2.2	270	.849
Data of 4.2.3	120	.885

Since the apparatus leakage was determined only for the two chambers combined, the individual leakage of each chamber has yet to be evaluated, and the necessary corrections made to the gross wall penetration data. Assuming that each chamber has equal leakage, the leakage coefficient for each chamber is 10. Thus, the corrections to be applied to the gross coefficients of the wall penetration tests are small, of the order of 5 to 10 percent. The exponents of Δp in these tests were closely the same for the uncorrected data. Further refinement in evaluating the exponents and leakage coefficients will be possible when corrections for chamber leakages can be applied on the basis of measurements to be made.

5.2 Wall Deflection and Air Penetration

For tentative consideration the process of deflection of the test wall might be explained as a redistribution of moisture in the studs within the wall structure causing expansion near the colder surface. For example, the studs had a certain distributed moisture content at the beginning of the test period and upon subjection of one face to the cold environment, the moisture would have a tendency to migrate to the colder portion of the stud. The greater moisture content of the stud at its colder edges would cause the stud to swell and bow in the direction of the cold surface. If this did in fact occur then it would tend to explain why the

wall deflected toward the cold surface even with the air pressure difference causing a flow of quite dry air in the opposite direction. The data presented in Fig. 8 shows that at the end of the first non-isothermal period the rate of change in deflection was decreasing. It seems possible that if a test of long enough duration had been made under this particular condition, the wall would reach a condition of constant deflection and might even return to its original position.

Upon changing the direction of air flow the relatively moist warm-side air would be forced into the stud space thus causing the expansion process to continue as the moisture was deposited on the colder surfaces of the studs and sheathing material. Data from the second non-isothermal period indicate that the moisture absorbing capacity of the material was not reached since the deflection continued at nearly a constant rate.

The sharp rise in air penetration rate shown in Figure 7 for the first few days of testing might be explained by cracks being opened on the indoor surface by the deflection toward the colder side. Once the cracks were opened, the coefficient of leakage due to these cracks would not change appreciably.

Under the condition of forcing warm moist air through the wall to the cold chamber, the openings on the cold surface would tend to be filled by freezing action. The data showed that even though the wall continued to deflect, the air flow rate decreased with time being relatively low and constant after the first week. At the termination of the second non-isothermal

period the wall was allowed to reach an equilibrium temperature between the cold condition of 0 °F and the warm condition of 75 °F. Approximately 12 hours after the termination of the test, the cold chamber was entered and small amounts of water were found to have dripped from the wall to the floor of the chamber. A total amount of approximately 1/2 cup was mopped from the floor at the base of the wall. A small pool of water is shown at the base of the wall in Figure 10.

5.3 Moisture Indication

Even though there was an indication of moisture accumulation within the wall structure during the non-isothermal test periods by the appearance of pools of water after thawing, there was no indication of a nearly saturated condition at the locations of the humidity sensors. The humidity sensors were 1/4 inch in diameter and approximately 2-1/2 inches in length. These particular sensors were narrow range, indicating relative humidity in the range above 81%. During the testing periods the relative humidity at the sensor locations was not high enough to cause the sensor to register it. A wide range sensing element was located in the center of the stud space to indicate the relative humidity of the air in the space. From the observed temperature and relative humidity at the center of the stud space, the dew-point of the stud space air was about 28 °F during the winter test. The observed temperatures of all interior surfaces of the wall facing the air space were more than 10 deg. F higher than the air space dew-point,

which indicates that moisture condensation in this wall must have occurred at regions to the cold side of the interior face of the sheathing, and not on air space surfaces. Calculation of the temperature at the interface between the sheathing and the siding indicates that moisture would be condensed at this interface. Figure 11 shows a typical set of temperature and humidity conditions existing at observed points throughout the wall system during the winter condition test.

5.4 Heat Transmission

The use of heat flow meters on wall type No. 2 to indicate heat transmission rates was of limited value. There was considerable ambiguity between the heat transmission into and out of the wall structure. One possible reason for the lack of agreement was that the wall was of the cavity type. Because the walls of the stud spaces were at different temperatures, a convective circulation was established within the stud space, leading to non-uniform heat transmission rates over the face areas of the specimen. Improved techniques will be incorporated into the next test in an effort to obtain more reliable heat transmission values.

5.5 Areas Requiring Additional Attention

Air leakage for the individual chambers will be determined by covering the test specimen with a thin plastic film, sealed around the perimeter to prevent leakage through the specimen. The two chambers will be pressurized to equal pressures to assure that there will be no leakage from one chamber to the other. The leakage from the chambers, each determined individually,

will be measured by metering the air required to maintain a constant pressure difference between the inside of the chambers and the atmospheric pressure. The individual chamber leakage is necessary for correction of the metered air flow in determining the net air penetration rates through the test walls.

Measurement of air penetration through the test wall as contributed by the ceiling and floor joints or joints where prefabricated wall sections are joined will be made later. These measurements will be reported as portions of the total air penetration rate through the test wall.

Figure Captions

1. Overall view of apparatus with the test wall enclosed between the warm and cold chambers.

2. Location of instrumentation within the structure of the wall.

3. Details of construction of the test wall.

4. View of outdoor surface of the test wall.

5. View of indoor surface of the test wall.

6. Air penetration rate through the test wall and apparatus at selected static pressure differences.

7. Relationship between the ratio $Q/_{\Delta P}$ and time of exposure to the environmental conditions.

8. Deflection of the wall at the mid-height during the two periods of exposure.

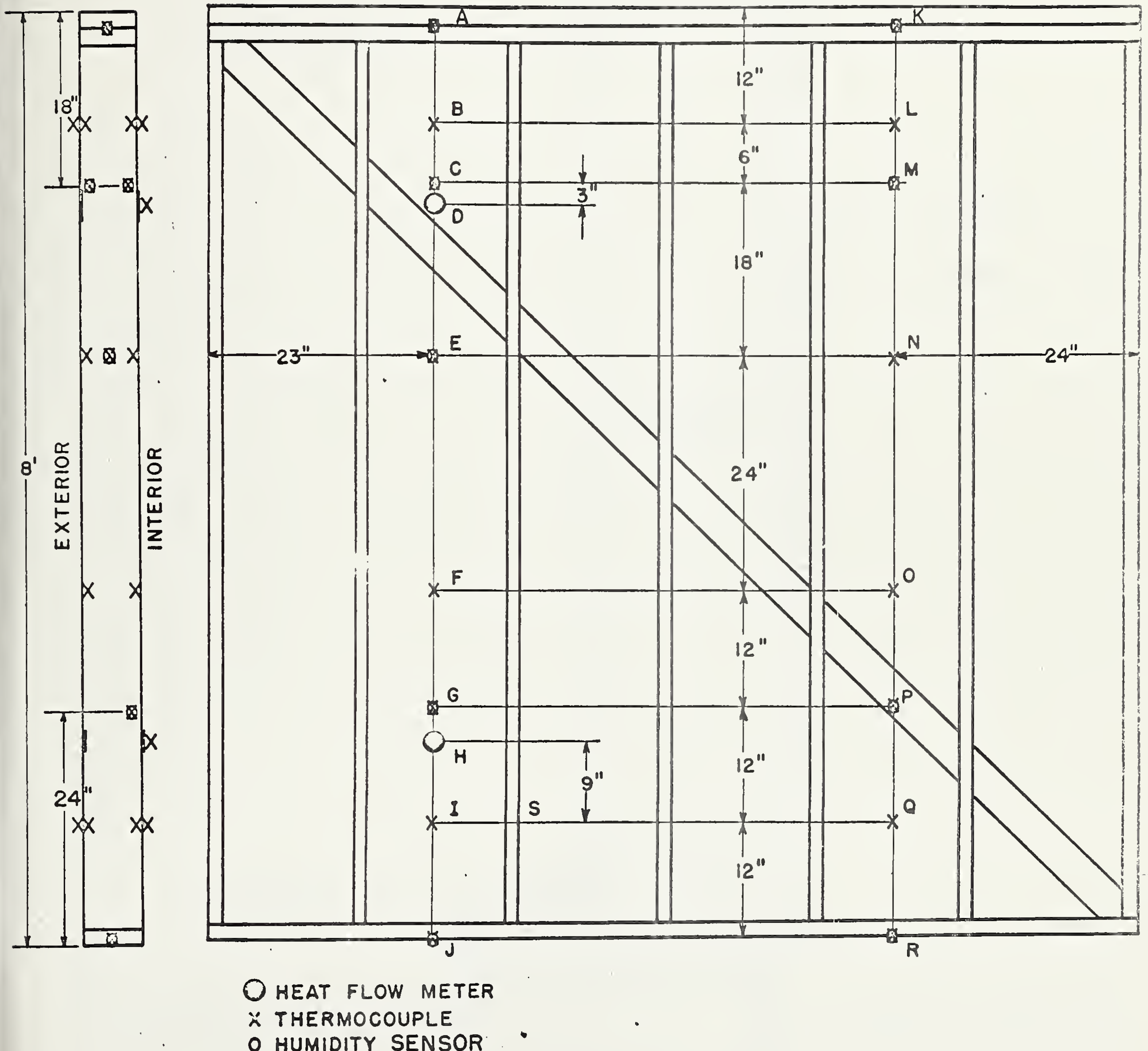
9. Air penetration rate through the test wall and the apparatus as plotted on log-log coordinates.

10. Accumulation of water at the base of the test wall (exterior surface) after termination of the winter tests.

11. A typical set of temperature and humidity conditions within the wall structure during the winter tests.

FIG 1

FIGURE 1



A
K
B
L
C
M
D
E
N
F
O
G
P
H
I
S
Q
J
R
12"
6"
3"
18"
23"
24"
24"
12"
12"
9"
12"
18"
8'
EXTERIOR
INTERIOR
24"
HEAT FLOW METER
THERMOCOUPLE
HUMIDITY SENSOR

FIGURE 2

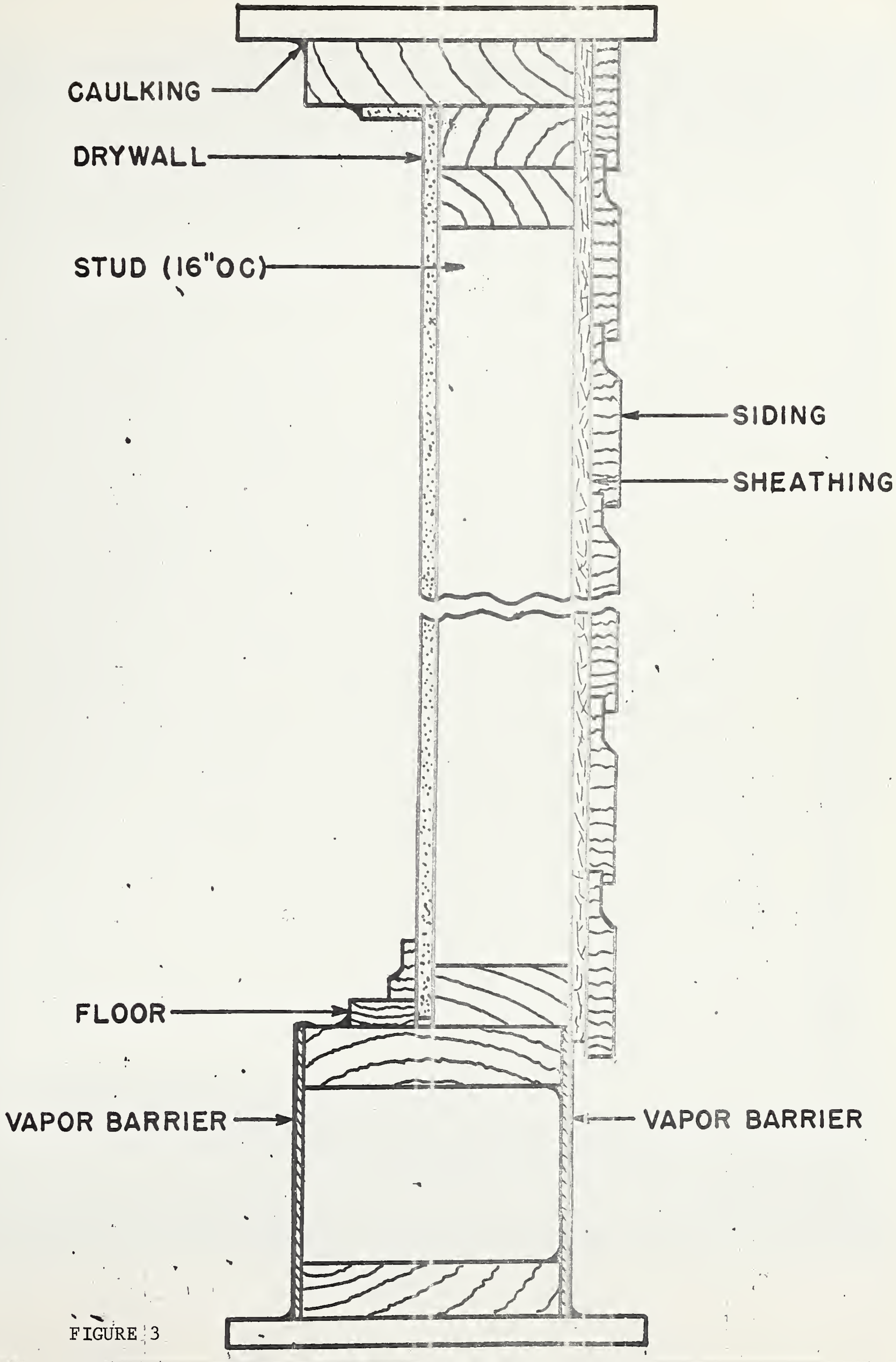

CAULKING
DRYWALL
STUD (16"OC)
SIDING
SHEATHING
FLOOR
VAPOR BARRIER
VAPOR BARRIER

FIGURE 3

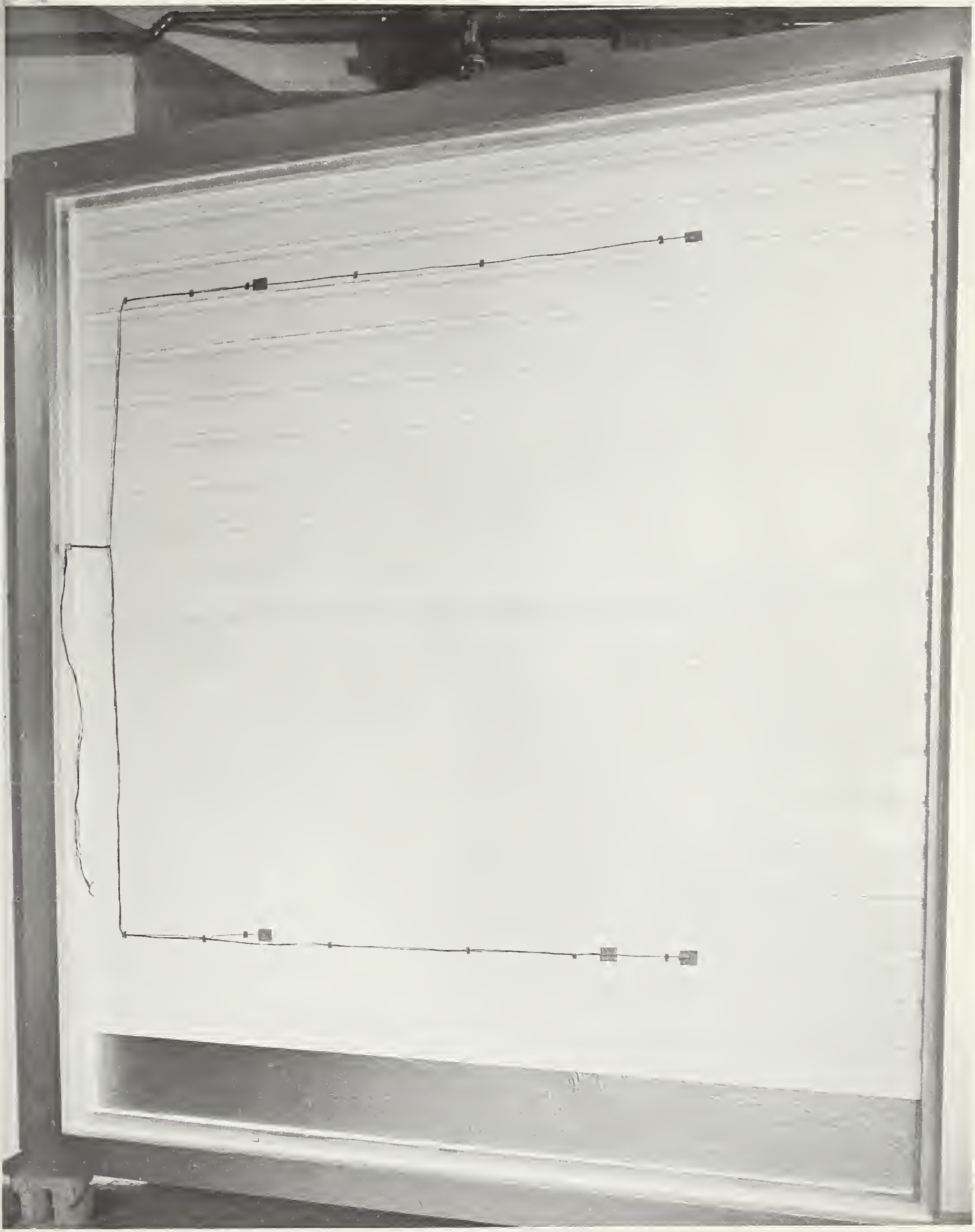


FIGURE 4

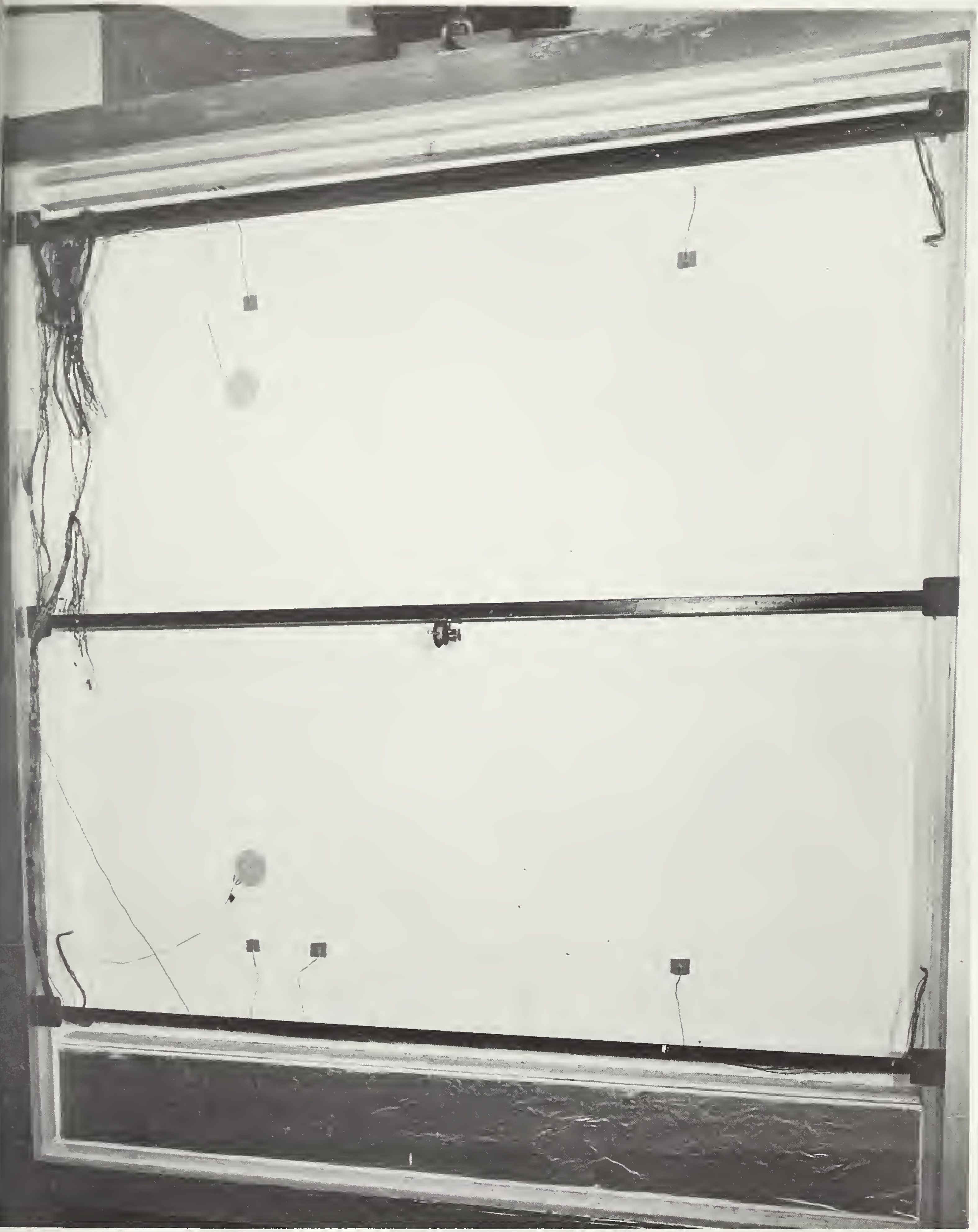


FIGURE 5

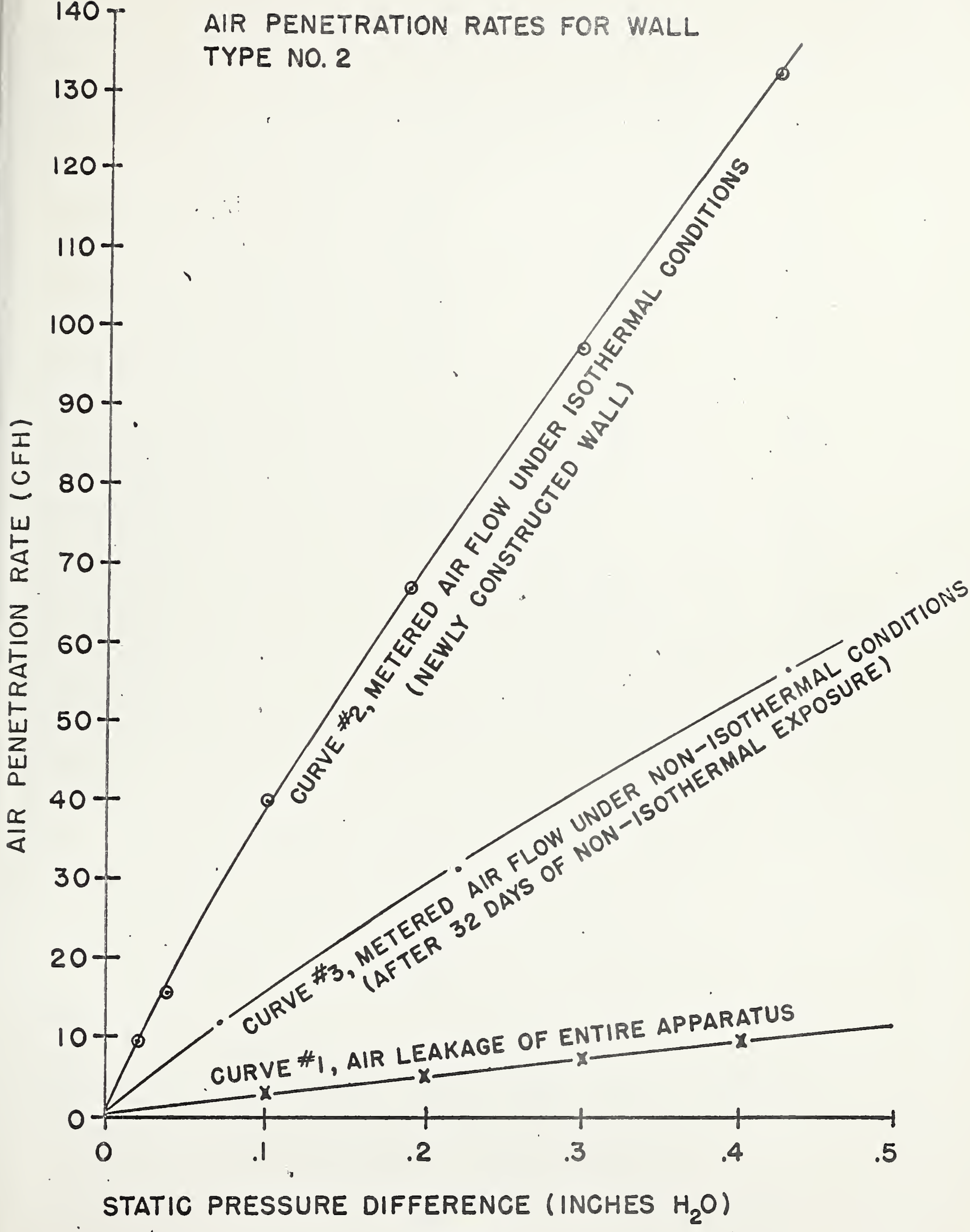
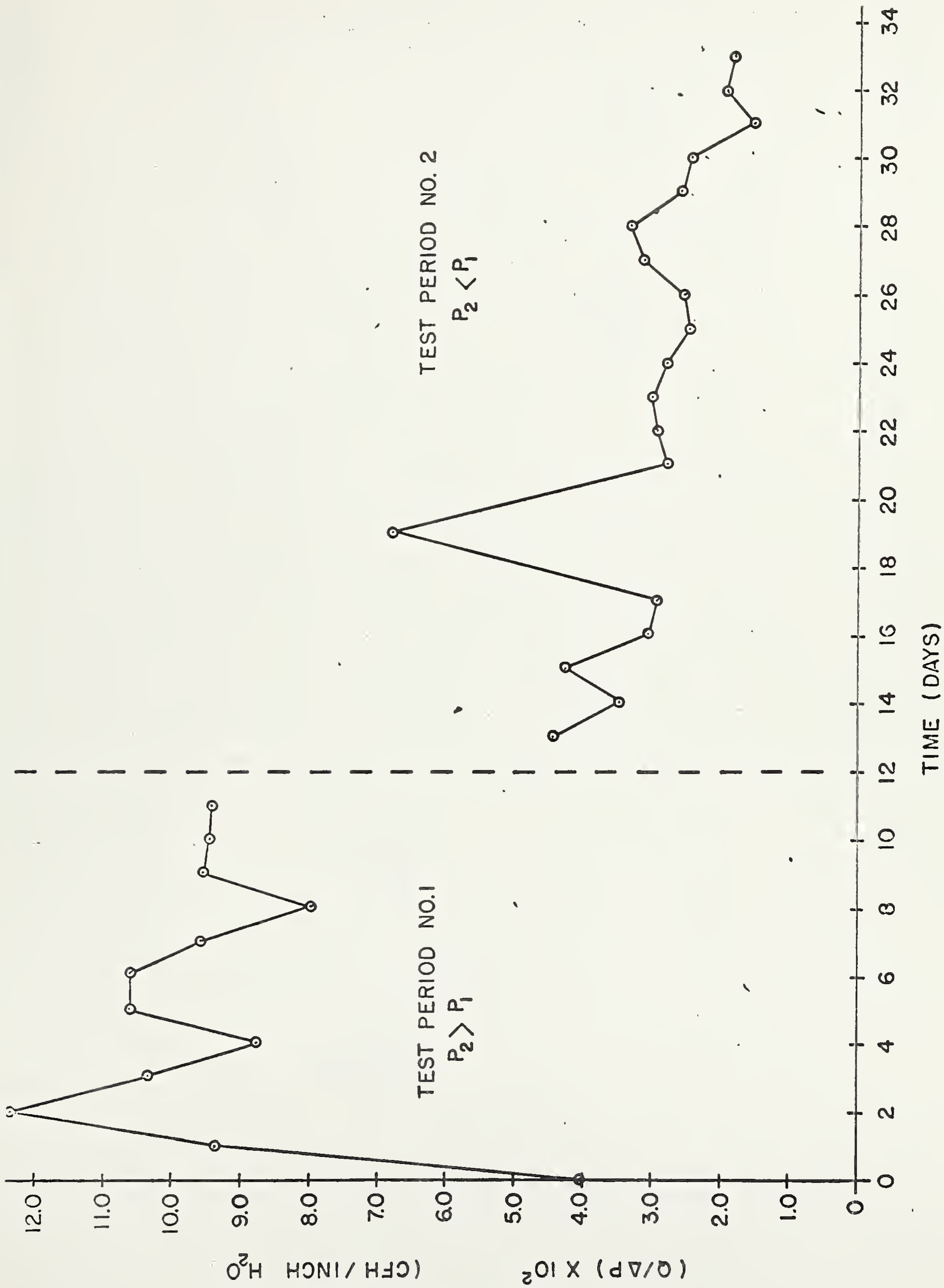

AIR PENETRATION RATES FOR WALL TYPE NO. 2
AIR PENETRATION RATE (CFH)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
CURVE #2, METERED AIR FLOW UNDER ISOTHERMAL CONDITIONS (NEWLY CONSTRUCTED WALL)
CURVE #3, METERED AIR FLOW UNDER NON-ISOTHERMAL CONDITIONS (AFTER 32 DAYS OF NON-ISOTHERMAL EXPOSURE)
CURVE #1, AIR LEAKAGE OF ENTIRE APPARATUS
0
.1
.2
.3
.4
.5
STATIC PRESSURE DIFFERENCE (INCHES H2O)

FIGURE 6



TEST PERIOD NO.1
P2 > P1
TEST PERIOD NO. 2
P2 < P1
TIME (DAYS)
(Q/ΔP) X 10²
(CFH / INCH H2O)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0

FIGURE 7

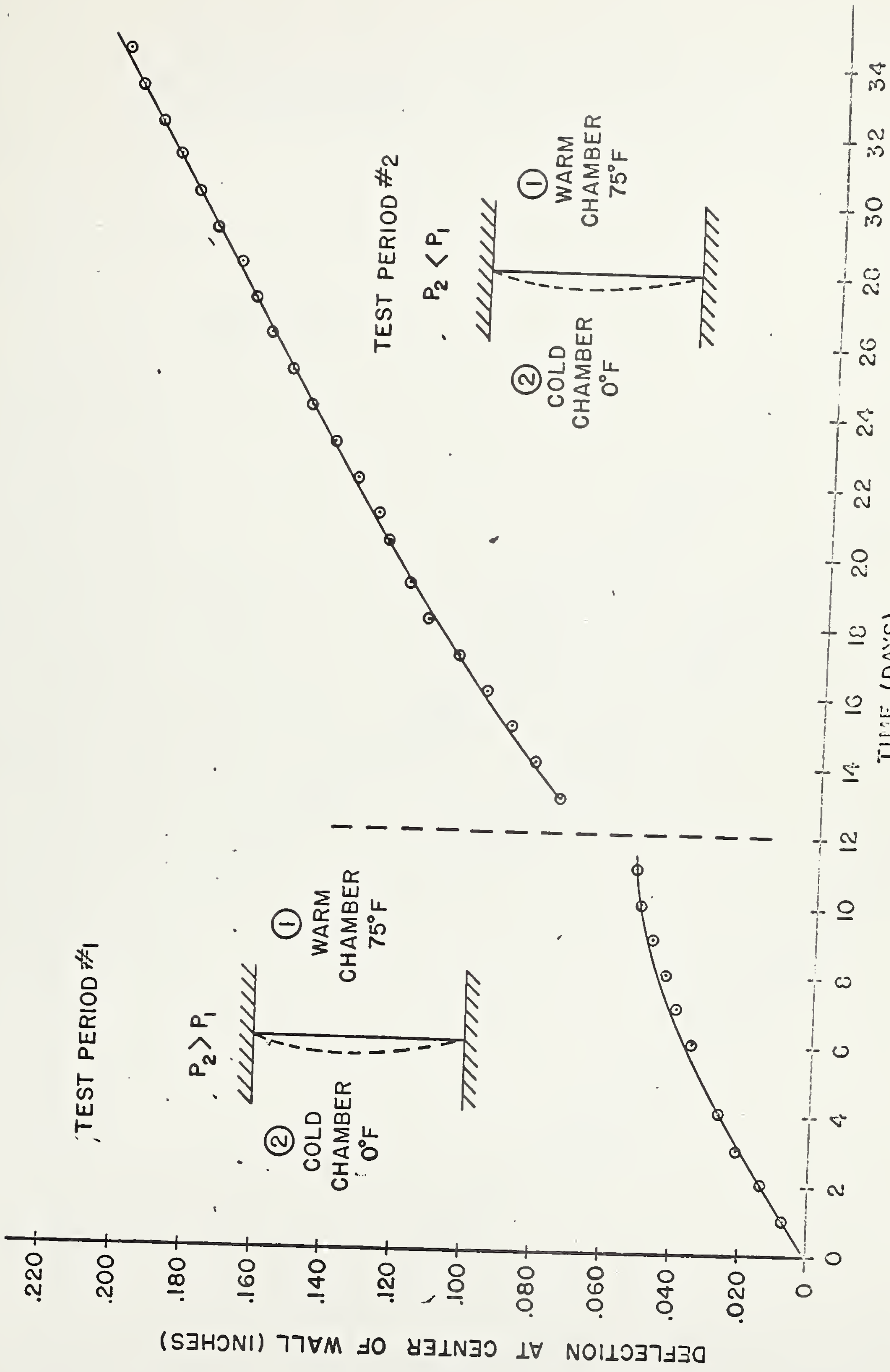

DEFLECTION AT CENTER OF WALL (INCHES)
TIME (DAYS)
TEST PERIOD #1
$P_2 > P_1$
② COLD CHAMBER 0°F
① WARM CHAMBER 75°F
TEST PERIOD #2
$P_2 < P_1$
② COLD CHAMBER 0°F
① WARM CHAMBER 75°F
0
.020
.040
.060
.080
.100
.120
.140
.160
.180
.200
.220
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34

FIGURE 8

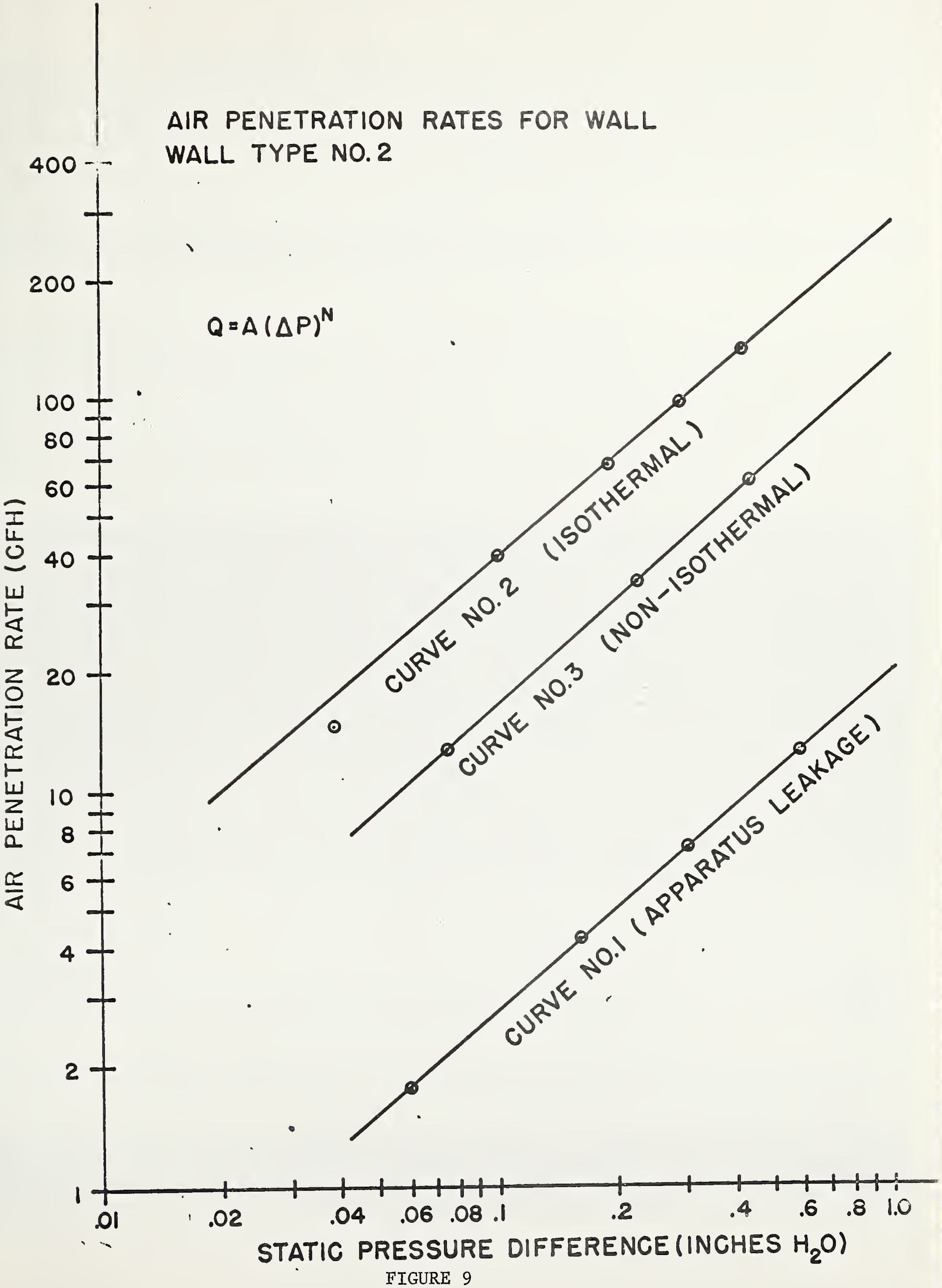
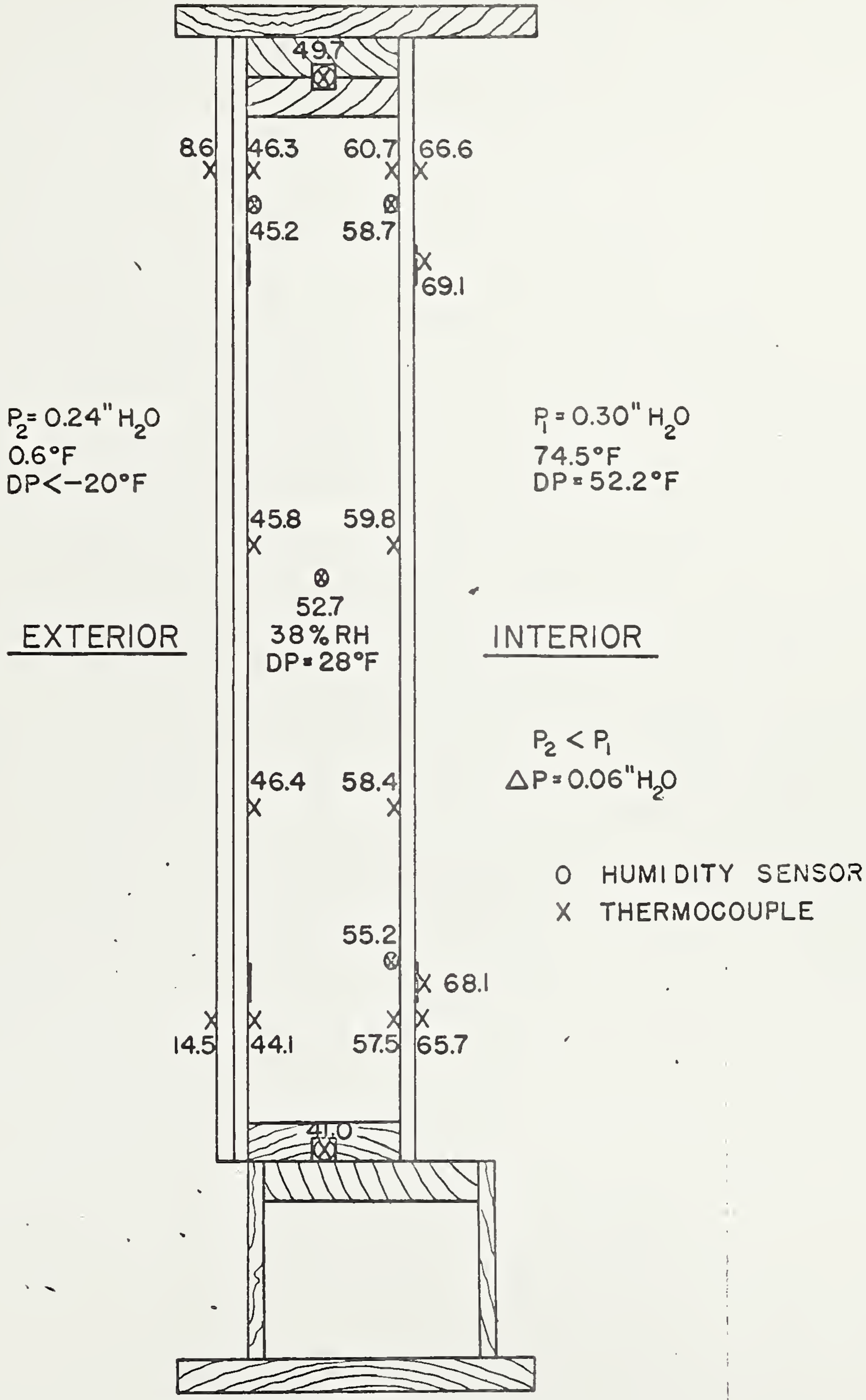

AIR PENETRATION RATES FOR WALL
WALL TYPE NO. 2
Q = A (ΔP)^N
CURVE NO. 2 (ISOTHERMAL)
CURVE NO. 3 (NON-ISOTHERMAL)
CURVE NO. 1 (APPARATUS LEAKAGE)
AIR PENETRATION RATE (CFH)
400
200
100
80
60
40
20
10
8
6
4
2
1
.01
.02
.04
.06
.08
.1
.2
.4
.6
.8
1.0
STATIC PRESSURE DIFFERENCE (INCHES H2O)

FIGURE 9

FIG 10

FIGURE 10



TYPICAL TEMPERATURE PATTERN WITHIN WALL NO. 2 DURING WINTER TESTING

FIGURE 11

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