DOCUMENT RESUME

ED 031 889 EF 002 711

By-Wilson, A. Grant

Control of Air Leakage in Buildings.

Pub Date 3 May 67
Note-17p.; Speech presented at the NAPPA Annual Meeting (54th, Universite de Montreal, Quebec, Canada, April 30-May 5, 1967)
EDRS Price MF-$0.25 HC-$0.95
Descriptors-Air Conditioning, *Building Design, *Climate Control, *Climatic Factors, Controlled Environment, Fuel Consumption, Glass Walls, Heating, Temperature, *Thermal Environment, *Ventilation
Identifiers-NAPPA, Natl Assn Physical Plant Administrators of Univ

This discussion of air leakage emphasizes cause and provides suggestions for elimination of undesirable effects. Cause parameters described are--(1) pressure differential, (2) building shape, (3) temperature differential, (4) opening sizes, (5) mechanical system pressures, and (6) climatic factors. Effects discussed are--(1) increased mechanical costs, (2) disruption of proper thermal and humidity levels, (3) condensation problems, and (4) transfer of contaminants and smoke from area fires. Ten tables, charts, and photographs concerning building leakage parameters and effects are included. (MH)

CONTROL OF AIR LEAKAGE IN BUILDINGS

By A. Grant Wilson, National Research Council.

Air leakage is the uncontrolled flow of air into, within, and out of buildings and building components. It occurs across the building envelope through cracks and openings such as those associated with windows and entrances, and within the building through similar cracks and openings in partitions and through vertical shafts used for elevators, stairs and services.

Air Leakage has a number of important implications in relation to the performance of buildings that should be known to those responsible for design and operation. Air infiltration can represent a significant component of the heating and cooling loads. It may also be a source of drafts that cause discomfort to occupants and a source of dust, soot and other contaminants. In buildings without a controlled and conditioned fresh air supply it may provide the principal source of outside air for ventilation and for combustion within heating devices during the winter. In some buildings it will also largely determine wintertime indoor humidities, or the amount of moisture required to maintain a particular value of relative humidity.

One of the most important aspects of air leakage in relation to building performance in northern climates is the extent to which it is responsible for serious condensation problems in heated buildings. Similar problems exist with refrigerated constructions located in warm, humid environments. Unfortunately, this is largely unrecognized in the design and construction of many buildings and even when failures develop the source of moisture is often incorrectly identified.

Air leakage between rooms and floors may lead to undesirable transfer of odours and other contaminants and may adversely affect the control of air conditions, particularly where an intentional difference is being maintained. One special, but important, aspect of this is the transfer of smoke within a building if a fire occurs. To appreciate these and the other implications, the factors influencing air leakage and the patterns of flow must be understood.

Air leakage through various cracks and openings results from air pressure differences across them. These pressure differences are caused by wind forces, buoyancy forces (chimney action of the building and its components) and the operation of mechanical air supply and exhaust systems. Wind around and over a building causes variations in pressure around it; the amount and pattern of the pressure depends on the building shape, topography, juxtaposition of nearby buildings and wind direction. Pressures are positive on windward sides and negative on leeward sides, tending to produce infiltration and exfiltration, respectively. Pressures on remaining sides may be positive or negative, depending upon the angle of the wind. They are generally negative over roofs (except on the windward side of steep ones) and at the very top of walls without overhangs (in the vicinity of parapets).

A typical pressure pattern is illustrated in Figure 1. The pressures are expressed in terms of the stagnation pressure (or velocity head) of the oncoming wind so that the values are independent of actual wind velocity. In the illustration the maximum positive pressure on the windward side is about 0.9 P_v, with a negative pressure of about 0.5 P_v on the leeward side. The negative pressure at the leading edge of the roof is greater than 1.0 P_v.

These are pressures at the outside surface. Air leakage depends upon the pressure differences between the inside and the outside of the building, and these depend on the distribution of cracks in the enclosures. For example, if most of the openings are on the windward side, the pressure inside will be close to that on the windward exterior. Inside pressures must adjust so that total inflow equals total outflow.

In many of the problems associated with air leakage the pressure differences and patterns of flow induced by chimney action have a dominating influence. Buoyancy force, or chimney action, results from the difference in the density of air at different temperatures - the same mechanism that produces draft in a chimney. The mechanics of chimney action and the associated patterns of pressure difference and flow are evident in Figure 2, which illustrates wintertime conditions for a heated building. Figure 3 (a) shows an idealized heated building with no internal separations and hence no internal resistance to flow, with openings in the enclosure at bottom and top. As the air in the building is warmer and therefore lighter than that ouside, it tends to rise and escape through the upper openings while colder outside air comes in through the lower openings to replace it. The total pressure difference available to produce this flow is equal to the weight per unit area of the columns of inside and outside air over the height, H, between openings. If the openings are of equal resistance, this total pressure difference, or theoretical draft, is divided equally among the openings, with a higher pressure outside than inside at the bottom and the reverse at the top. At mid-height there is zero pressure difference across the walls and this level is sometimes called the neutral zone, or neutral pressure plane. The pressure difference increases in proportion to the distance from the neutral zone.

If the openings are of unequal resistance the theoretical draft is distributed across the openings in the proportion required to maintain continuity of flow. For example, if the lower opening has a higher resistance to flow than the upper one it will have the higher pressure difference across it and the neutral zone level will move upward; thus the level of the neutral zone depends upon the vertical distribution of the openings in the enclosure.

Figure 3 (b) illustrates the effect on the pressure distribution of resistances to flow imposed by floor separations. The theoretical draft and pattern of air flow remains the same, but some of the pressure difference is required to maintain continuity of flow through the openings in the floor so that the pressure difference across the walls is less than if there were no resistance within the building. Figure 3 (c) illustrates the effect on the pressure distribution of vertical stacks such as stairwells and elevator shafts with openings at each floor level. Air flows into the vertical shaft at lower levels and out at higher levels; part of the theoretical draft is required to overcome the resistances imposed by the shaft openings.

In a real building air flow occurs through both paths illustrated in Figures 3 (b) and 3 (c). As the height and number of floors increase, however, the resistance of the flow path through openings in the floors increases more rapidly than that through the vertical sahfts; thus with high buildings upward air flow occurs mainly through the vertical shafts.

As the resistance to flow and the corresponding pressure losses within the building increase, pressure differences across the openings in the building envelope are reduced. If the internal resistance is very high in relation to that in the envelope, essentially all of the pressure differences due to chimney action occur across the various floors and the pressure differences across the envelope are limited to the chimney action for each floor height.

Until recently there has been little information on over-all air leakage characteristics of buildings. Measurements by DBR/NRC on four multi-storey buildings (9 to 44 storeys) indicate that the resistance to flow within typical buildings is less than that through the envelope. The actual chimney effect developed is generally from 60 to 80 per cent of the theoretical chimney effect. Neutral zone levels, which depend upon the vertical distribution of the resistances in the flow path into, through, and out of the building, are at a level between 35 and 70 per cent of the building height.

With these two figures known, the pressure drop across the envelepe at any level can be readily calculated. For example, with the pressure differences across the envelope equal to 80 per cent of the total theoretical draft and with a neutral zone level of 70 per cent, the pressure drop across the entrance is equal to 56 per cent of the total theoretical draft of the building.

The relative magnitude of pressure differences due to chimney action and wind can be assessed from Table 1. Pressure differences across the envelope resulting from wind will generally be less than 1.0 P_v on the windward side and may be very small at street level in large cities; on leeward walls they will generally be less than 0.5 P_v. Pressure differences due to chimney action are proportional to the distance from the neutral zone; they also act continuously and in a consistent pattern, with inflow at the bottom and outflow at the top. With multi-storey buildings in cold climates, pressure differences resulting from chimney action will often predominate.

Figure 4 illustrates the general pattern of flow resulting from chimney action in a heated building. Note that infiltration occurs below the neutral zone level and exfiltration above. There is a general upward movement of air inside the building, with air flow into vertical shafts from the lower floors and outflow to the upper floors. This has implications with regard to the maintenance of uniform temperatures and humidity in buildings, perticularly around entrances and in lower floors. It is also a factor in the spread of contaminants. In the special case of fire, if it occurs in the lower floors there will be a tendency for smoke to move to upper floors via the vertical shafts and for stairwells and corridors in upper floors to become smoke filled. Some thought is being given to this problem by the Fire Research Section of DBR/NRC One proposal involves the use of a forced fresh air supply to pressurize the stairwells and thus prevent inflow of air from any floor.

Pressures inside buildings can be altered by mechanical ventilation systems through the balance of air supply and exhaust. These systems are sometimes designed and operated to provide an excess of supply air and thus to pressurize the building and reduce infiltration, particularly that resulting from chimney action in lower levels of multi-storey buildings. The amount of pressurization for a given excess of supply air will depend upon the tightness of the enclosure. If it is introduced uniformly at all levels the effect will be not only to reduce the pressure difference at lower levels, but also to increase (correspondingly) the pressure differences at upper lovels and the tendency for exfiltration. Figure 5 illustrates this effect. Note that pressurization does not eliminate the chimney pressures; it does alter the distribution of pressure differences across the enclosure. Although infiltration is reduced, there is a penalty in higher heating costs, because the total outside air supply required is equivalent to about 290 per cent of the air infiltration, with no pressurization for the condition shown. In measurements on a 34 storey-building uniform pressurization of up to 0.5 in. of water was observed under normal operating conditions.

If the objective is to reduce at the entrance the pressure differences that result from chimney action, a possible alternative to pressurizing the building uniformly might be to pressurize only the ground floor. This is illustrated in Figure 6. The total excess supply air required on the entrance floor is about equal to the total original air infiltration without pressurization. Infiltration on other floors is about 37 per cent of the original total, so that the penalty in higher heating costs is considerably less than with uniform pressurization. Again, chimney action is not eliminated; the distribution of pressure differences is altered, with greater pressure losses occuring across the first floor ceiling and floors immediately above.

These greater pressure losses across the building floors are also reflected in larger pressure differences across stairwell and elevator doors, and there is a greater tendency for upward air flow from lower floors. The pressure pattern in Figure 6 is similar to that which would occur without pressurization if entrance doors were wide open so as to sustain no pressure difference. With such a pressure pattern the large pressure differences across stairwells and elevator shafts at the top and bottom of the building might interfere with proper functioning of the doors and might also cause excessive air noise. One solution is to incorporate a vestibule around the elevators and to introduce doors within the stairwell to sustain some of the pressure loss.

In many multi-storey buildings where there is concern for excessive air leakage at entrances, special attention is given to the type and arrangement of doors. With high rates of traffic through the entrances there is a considerable advantage in the use of vestibule entrances and a still further one with revolving doors. This is illustrated in Table II. Note that air leakages and heat requirements with vestibule entrances are about one half of those without them, and that revolving doors have leakages of about one tenth of the latter.

When building complexes are joined through enclosed corridors or tunnels there will be an interaction that will affect their pressure differences and the air flow condition. For example, if a low building is connected to a high one, there will be a tendency for air to flow from the low one to the high one owing to the greater chimney draft of the latter. Similarly, if one is pressurized with respect to the other, there will be a potential for air flow through the interconnection.

Service tunnels are being used increasingly to carry foot traffic in university and similar building complexes. The tunnels themselves may incorporate a mechanical ventilation system providing a net air supply of exhaust, and this will produce a potential for air flow to or from connected buildings. Even if doors are provided at tunnel entrances there is a strong possibility that these will be left open during periods of heavy traffic unless special precautions are taken. Of major concern is the effect of the air flow pattern on smoke contamination in the event of fire.

In the design of these interconnecting systems the possible effects on air leakage and air flow patterns should be recognized. If they are not, problems of excessive air pressure differences and air leakage, including those associated with fire safety, can result.

The implications of air leakage and condensation are so important in northern climates, particularly in humidified buildings, as to warrant some further discussion. In winter, as air exfiltrates through the cracks and joints common to all present methods of construction, the water vapour it contains is cooled below its dew-point temperature at some point and condensation occurs. The extent of condensation depends on the quantity of air flow, its initial moisture content, and the reduction in temperature it undergoes in passing through the building envelope. In general, moisture problems due to exfiltration will increase with increasing building height, decreasing average winter temperature and increasing building humidity. The mechanism is perhaps best illustrated by condensation between panes of double windows. This is graphically illustrated in Figure 7, where the upper windows of a 2-storey school are frost covered between panes while the lower windows are clear.

Condensation problems in vented roofs, whether pitched or flat, are a result of air leakage through ceiling construction. An exaggerated case is illustrated in Figure 8. This was typical of conditions observed in some 2-storey houses in the far North. Similar problems, though usually not so severe, are not uncommon in more southerly areas of Canada.

Condensation in walls is not so readily observed, but can lead to even more serious consequences. The disruption of masonry at the top of a masonry-clad humidified building is not uncommon. It is not unusual in these circumstances for air to leak outward through unplastered portions of the masonry walls (for example, above suspended ceilings, and through cracks between the structural elements and masonry). Many serious moisture problems have been traced to air leakage through cracks and joints or porous construction in the building envelope.

In conclusion it should be re-stated that the many implications of air leakage should be recognized in both the design and operation of buildings. Without proper design for the control of air leakage, the functional adequacy of buildings may be seriously impaired. If the implications of air leakage are not recognized in the operation of buildings, they may fail to provide the condition desired and accelerated failures may occur. Further studies are necessary to define more adequately the air tightness of modern buildings and to ascertain how buildings and their mechanical air handling systems can be designed to control air leakage and its effects.

MR. CLARKE: Thank you, Mr. Wilson. We are very grateful indeed that you took time out to come here and educate us on this very enlightening subject. It was a very interesting presentation.

TABLE	TITLE	PHOTOGRAPH NO
1	Pressure Differences Due to Wind Velocity and Chimney Affect	640
2	Air Leakage Through Building Entrances	2508

FIGURES		
1	Pressure Pattern on a Building as a Result of Wind Action	402
2	Measured Pressure Differences in a 9-Storey Building	713
3	Pressure Differences due to Chimney Action	1634
4	Air Flow Pattern Due to Chimney Action	2509
5	The Effect of Building Pressure Differentials	2484
6	Pressure Differences Resulting With Ground Floor Pressurization	2485
7	Window Condensation Resulting from Air Leakage	1162
8	Roof Condensation Resulting from Air Leakage	624

WIND PRESSURES STAGNATION VALUES		
VELOCITY M.P.H.	PRESSURES IN H_2O	P.S.F.
5	0.012	0.062
10	0.048	0.250
15	0.104	0.541
20	0.193	1.00
25	0.301	1.56

CHIMNEY PRESSURES EFFECTIVE HEIGHT 100 FT.		
TEMPERATURE DIFFERENCE, °F	PRESSURES IN H_2O	P.S.F.
20	0.055	0.296
40	0.115	0.598
60	0.179	0.931
80	0.250	1.30
100	0.326	1.70

TABLE I

AIR LEAKAGE THROUGH BUILDING ENTRANCES

BUILDING HEIGHT = 200 FT TEMP. DIFF. = 90°F		NUMBER OF PEOPLE PER HR	CFM, TOTAL	MILLION BTU PER HR
SWINGING DOORS 4 DOORS, EACH 3 x 7 FT	SINGLE BANK	1000	18,000	2.0
		2000	30,000	3.2
	VESTIBULE TYPE	1000	9,000	1.0
		2000	18,000	1.9
REVOLVING DOORS 2 DOORS, EACH 6 x7 FT	MANUALLY OPERATED	1000	1,550	0.17
		2000	2,000	0.22
	MOTOR OPERATED	5 RPM	2,150	0.23
		10 RPM	2,590	0.28

TABLE II

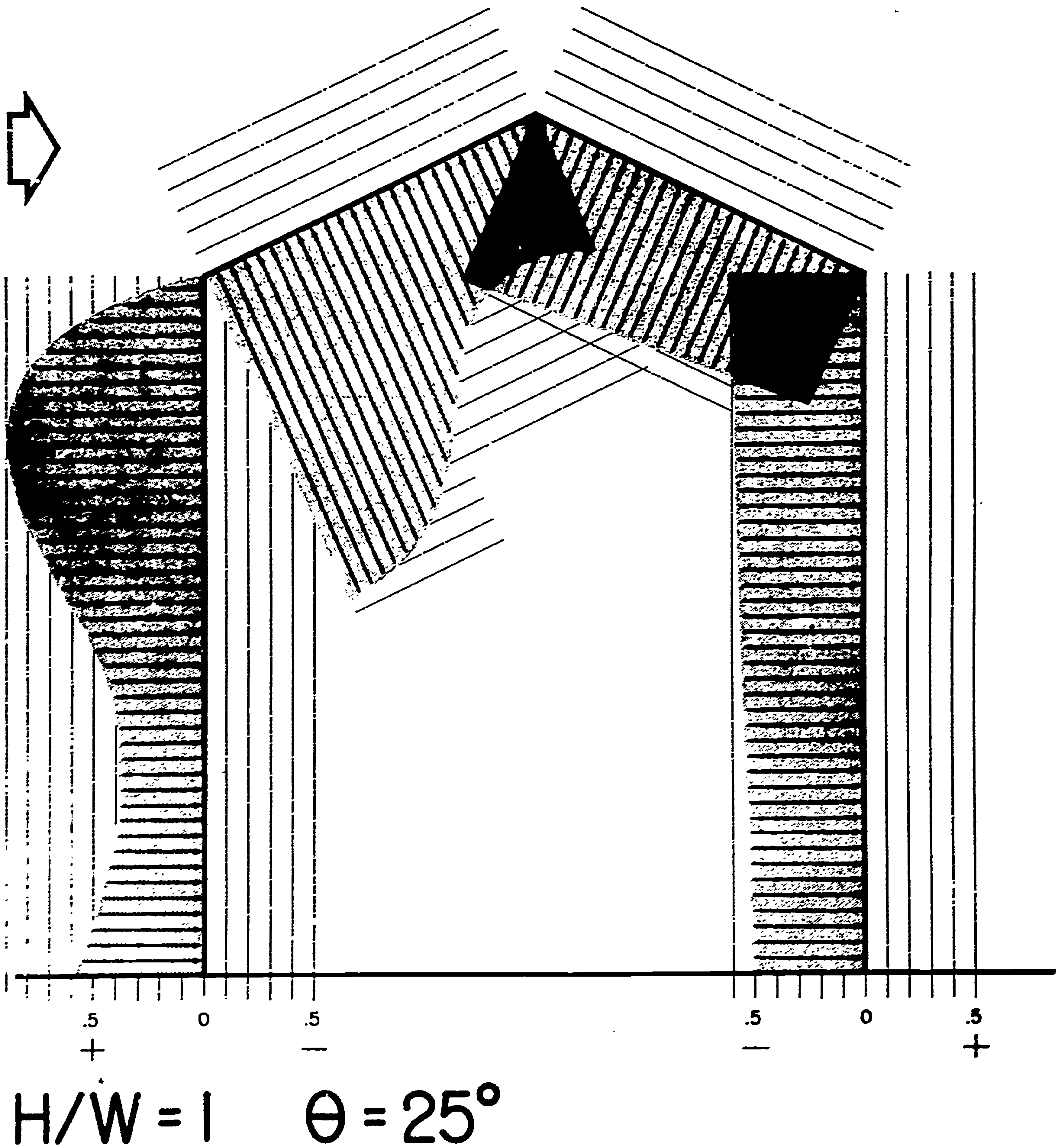
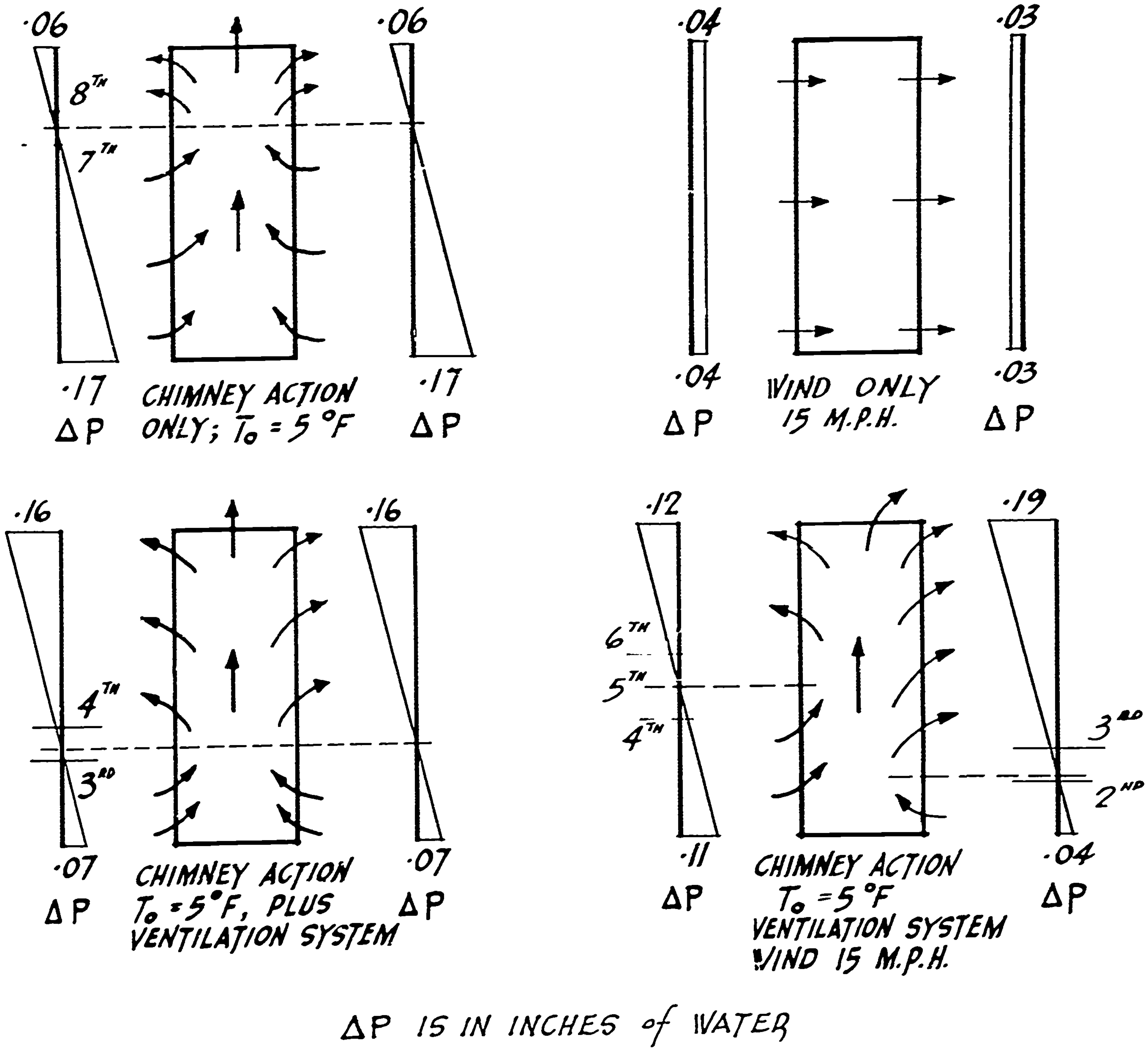
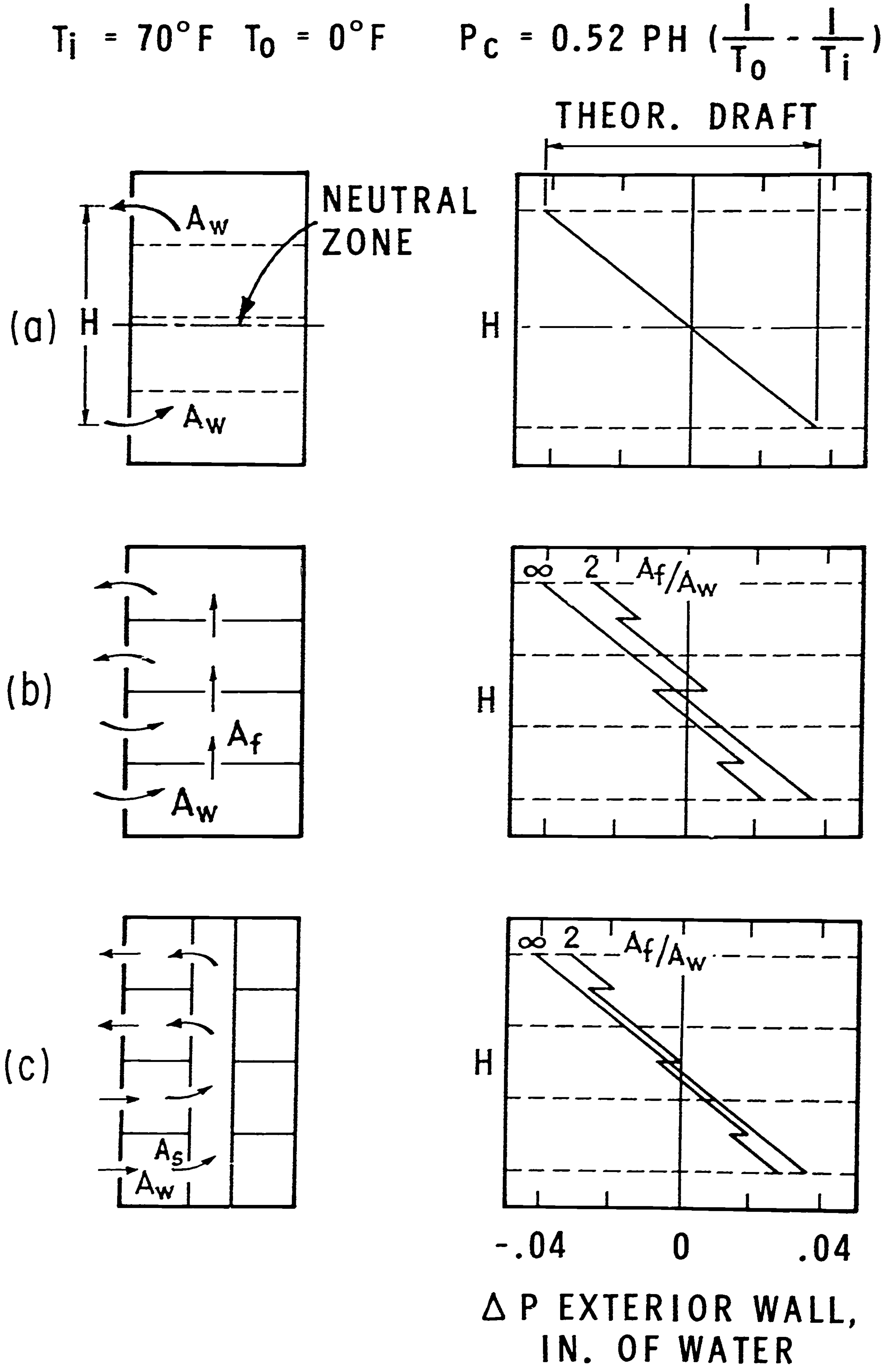


FIGURE 1



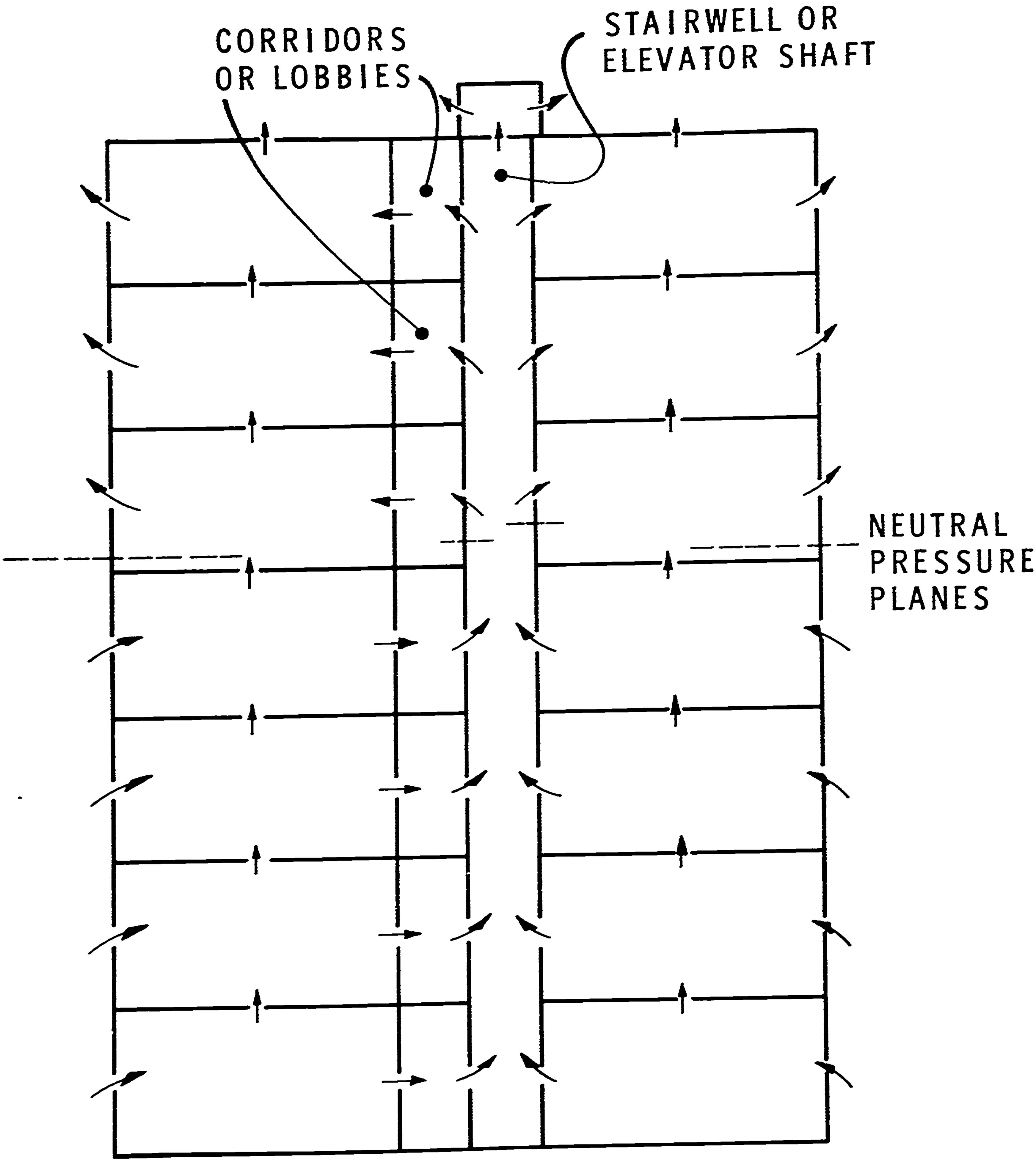
MEASURED PRESSURE DIFFERENCE, 9 STOREY BLDG.

FIGURE 2



Ti = 70°F To = 0°F Pc = 0.52 PH (1/To - 1/Ti)
THEOR. DRAFT
NEUTRAL ZONE
Aw
(a) H
H
Aw
(b)
Af
Aw
∞ 2 Af/Aw
H
(c)
As
Aw
∞ 2 Af/Aw
H
-.04 0 .04
Δ P EXTERIOR WALL, IN. OF WATER

FIGURE 3



CORRIDORS
OR LOBBIES
STAIRWELL OR
ELEVATOR SHAFT
NEUTRAL
PRESSURE
PLANES

FIGURE 4

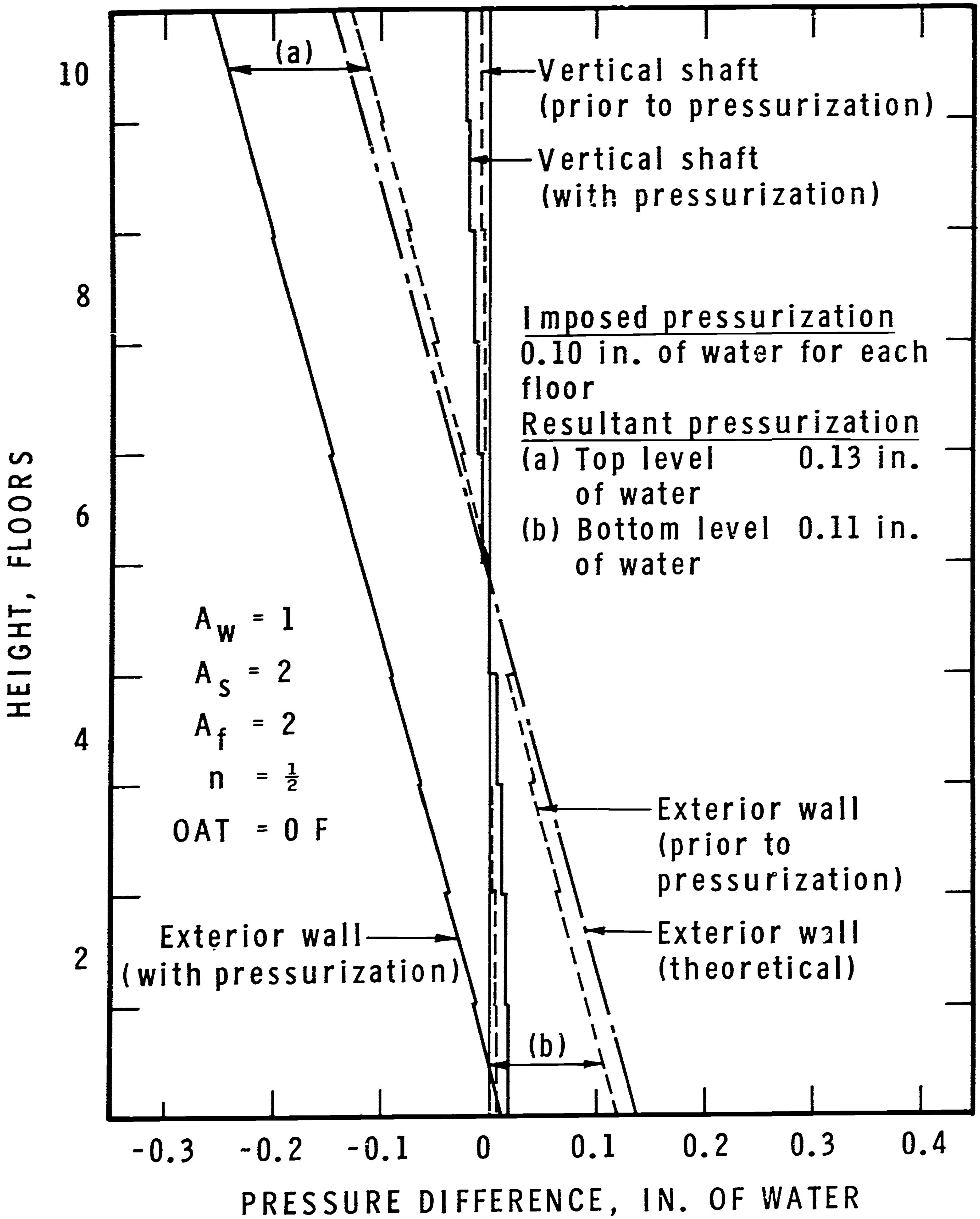
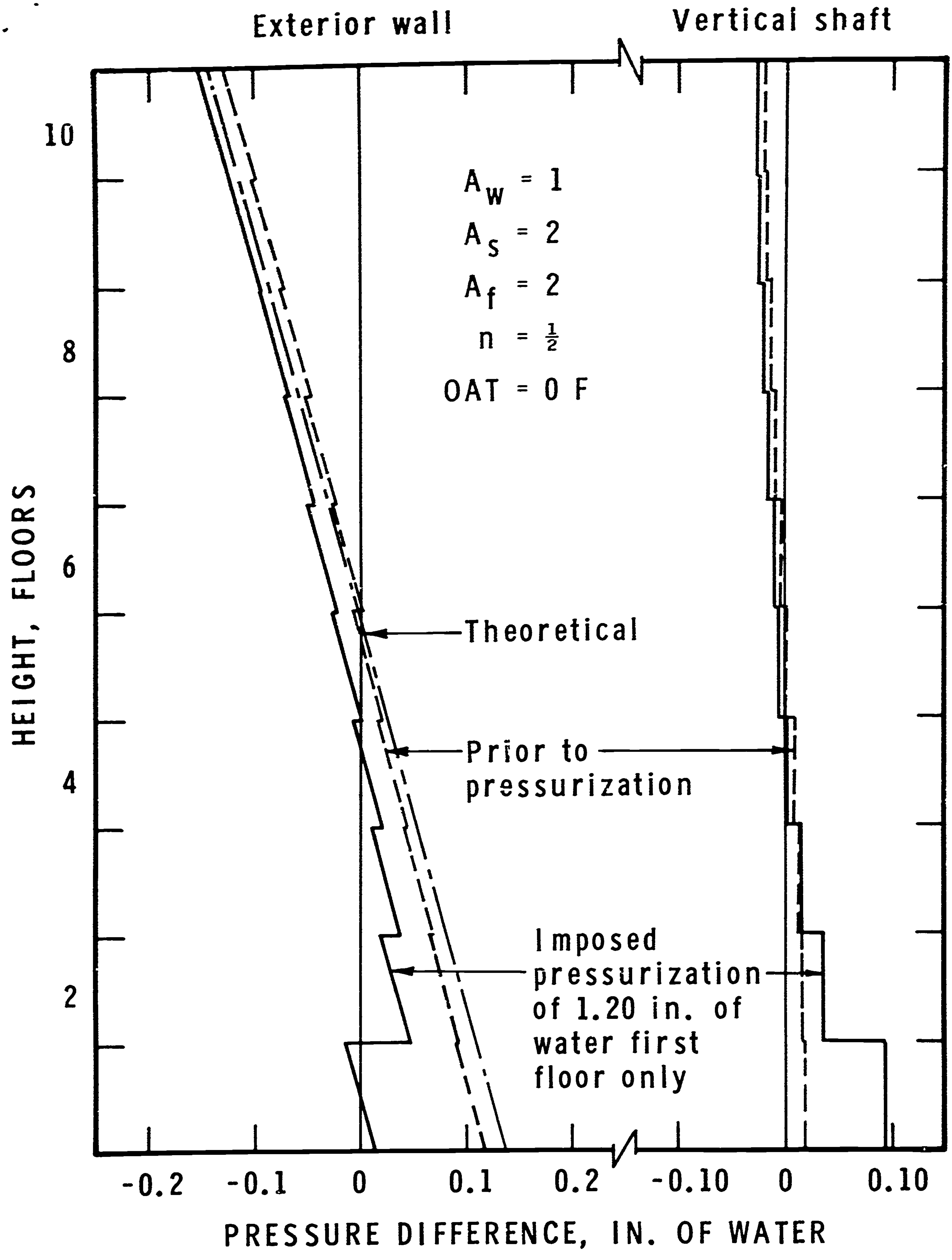

(a)
Vertical shaft
(prior to pressurization)
Vertical shaft
(with pressurization)
Imposed pressurization
0.10 in. of water for each floor
Resultant pressurization
(a) Top level 0.13 in. of water
(b) Bottom level 0.11 in. of water
A_w = 1
A_s = 2
A_f = 2
n = ½
OAT = 0 F
Exterior wall
(prior to pressurization)
Exterior wall
(with pressurization)
Exterior wall
(theoretical)
(b)
HEIGHT, FLOORS
10
8
6
4
2
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
PRESSURE DIFFERENCE, IN. OF WATER

FIGURE 5



Exterior wall
Vertical shaft
$A_w = 1$
$A_s = 2$
$A_f = 2$
$n = \frac{1}{2}$
OAT = 0 F
Theoretical
Prior to pressurization
Imposed pressurization of 1.20 in. of water first floor only
HEIGHT, FLOORS
10
8
6
4
2
-0.2
-0.1
0
0.1
0.2
-0.10
0
0.10
PRESSURE DIFFERENCE, IN. OF WATER

FIGURE 6

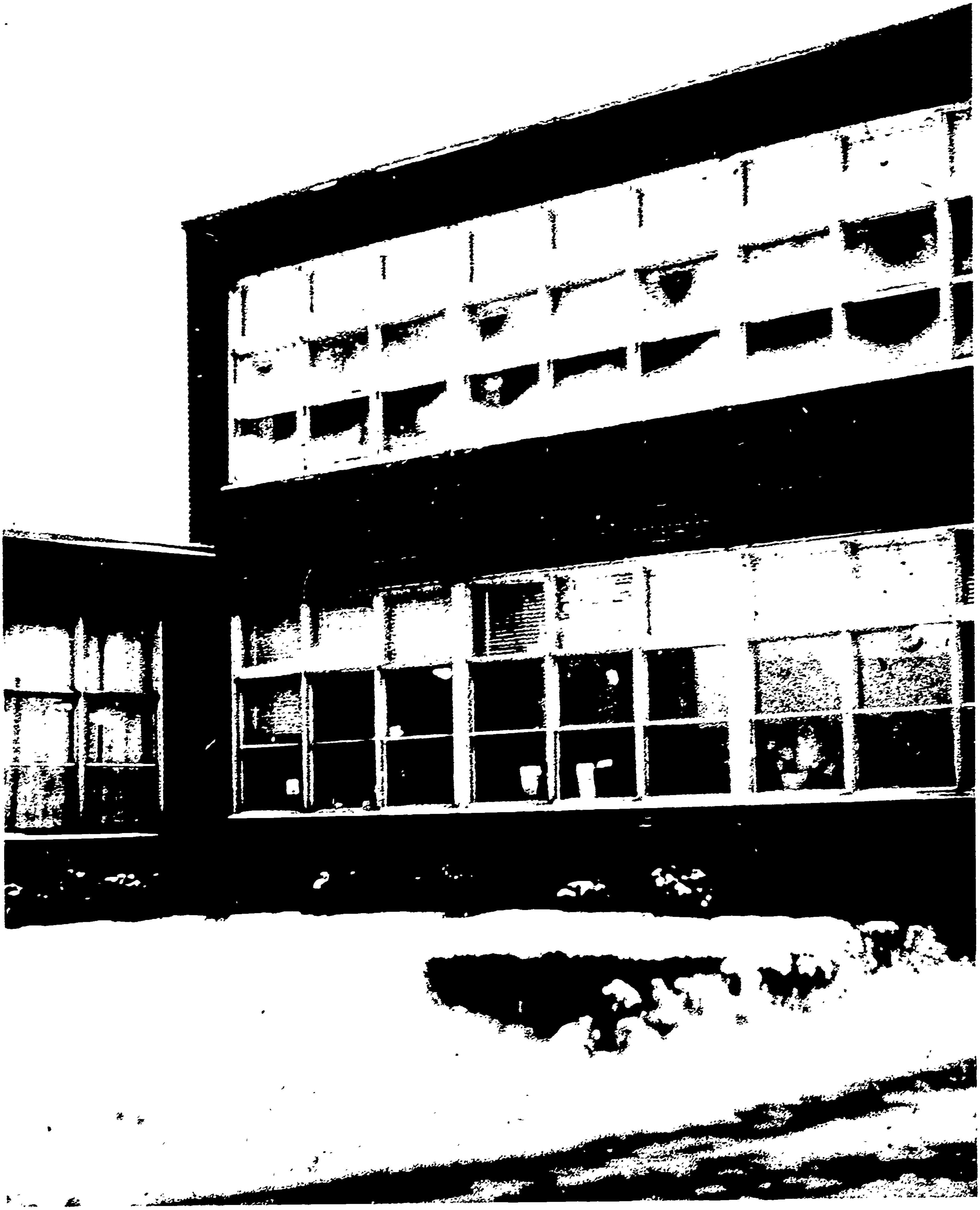


FIGURE 7

FIGURE 8