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DESIGN GUIDELINES ON LATERAL AIRFLOW THROUGH AND AROUND BUILDINGS

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ABSTRACT

A mass of sketches are available, in professional literature, on air movement through building interiors and around groups of buildings Much of this information is misleading, as it is frequently based on the limited knowledge and expansive imagination of designers, who have not thoroughly researched this topic. This paper records airflow patterns established in reliable laboratory experiments and field studies and identifies their original sources. It is intended to assist architects, builders and designers of the urban environment.

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KEYWORDS

Airflow, Airmotion, Movement, Openings, Inlet, Outlet, Pressure, Positive, Negative.

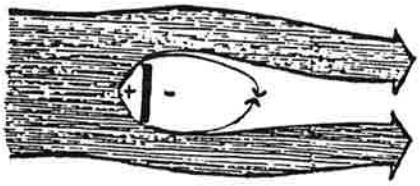
INTRODUCTION

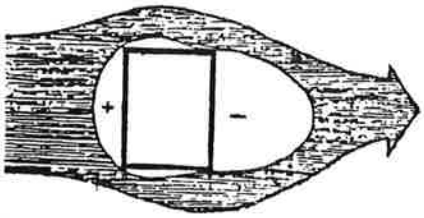
This work is the result of an 18 month literature survey on air flow through and around buildings. The search focussed on the causes and effects of low velocity lateral airflow and excludes the literature relating to high speed winds. One hundred and fifty documents surfaced, of which forty-seven were annotated.** Space does not permit inclusion of the full bibliography or of the annotated references (75 pages). However a "Subject Matrix" of the 47 annotated references is included here, to assist those who wish to further their interests.

The "Vocabulary of airflow patterns" has been collected from photographs and drawings of full-scale and model testing records in the literature. Velocities are not mentioned as they invariably are not mentioned in the recorded reports. Each diagram, totalling 89, has been identified for its source. The obvious omission is the work of B.Givoni, who has recorded his findings in another format.(figs. 9? & 91).

* On sabbatical leave from the University of Miami, Florida, U.S.A.

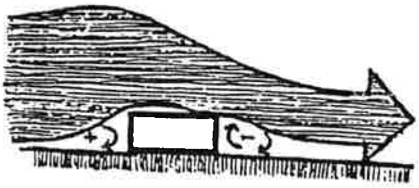
** See report on "World Literature Review and Annotated Bibliography on Air Movement in and Around Buildings" by A.Bowen to Florida Solar Energy Center, Jan. '82.

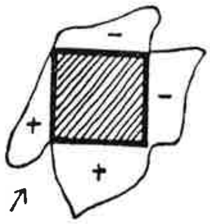




1. When air in motion meets an obstacle, a region of high pressure is created, generally, on the windward surface and the air will flow around the obstacle and reform in a laminated manner beyond a low pressure zone that will result on the leeward side (40).

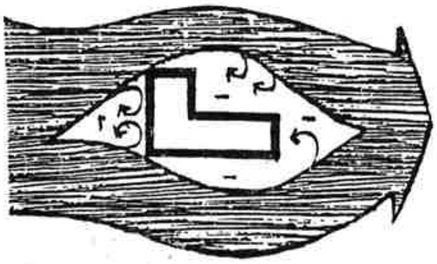
2. Plan showing low pressure zone along the sides parallel to the wind and on the leeward side of the building (3).

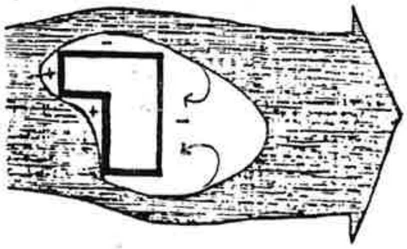




3. Section showing low pressure zone along the sides parallel to the wind and on the leeward side of the building (3).

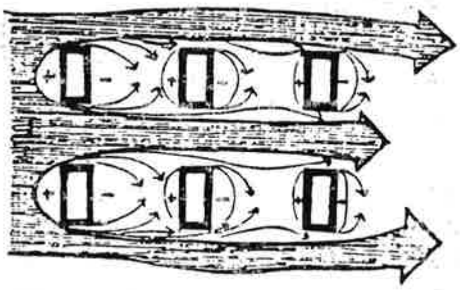
4. When wind blows at an angle to a structure, the airflow divides at the windward leading corner. When wind blows at an asymmetrical angle, conditions for the two windward sides will vary, causing greater pressure on the side presenting the larger face to the wind. There is less upward flow over the roof (3).

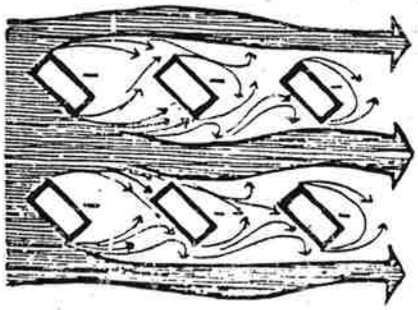




5. An L-shaped structure with a leeward projection, causes a large eddy in its recessed corner, with reversed airflow in its sheltered side (1).

6. When the "L" projects into the wind, the pattern alters with noticeable eddies on the leeward side (30).

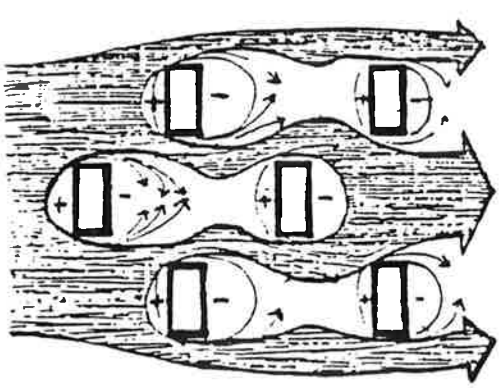


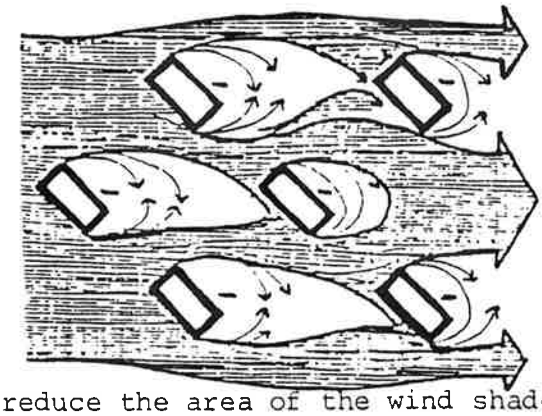


7. Multiple low pressure zones are caused by linear building arrangements (39).

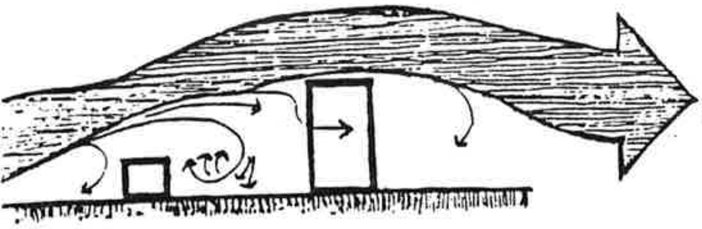
8. An inclined linear arrangement produces turbulence in the wind shadow (39).

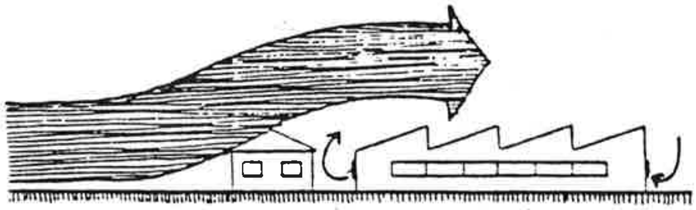
VOCABULARY OF AIRFLOW PATTERNS



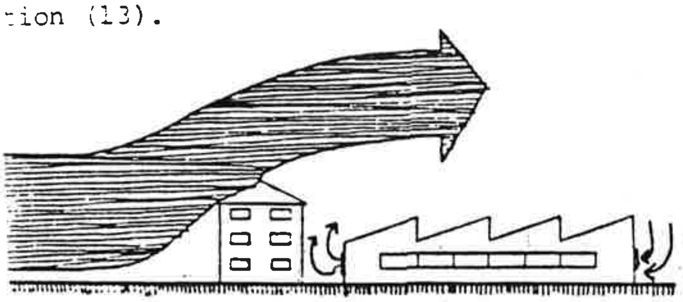


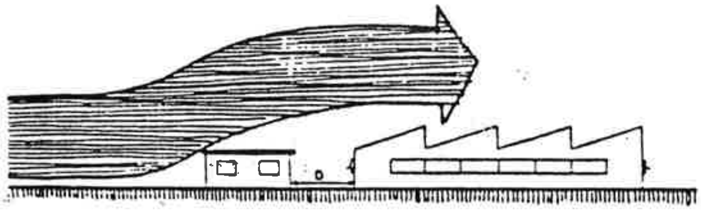
. Staggered building arrangements further reduce the area of the wind shadow and low pressure zones (39).
. Inclined staggered arrangements minimize low pressure zones (39).



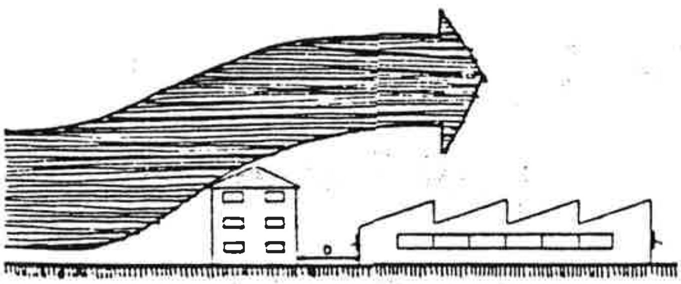


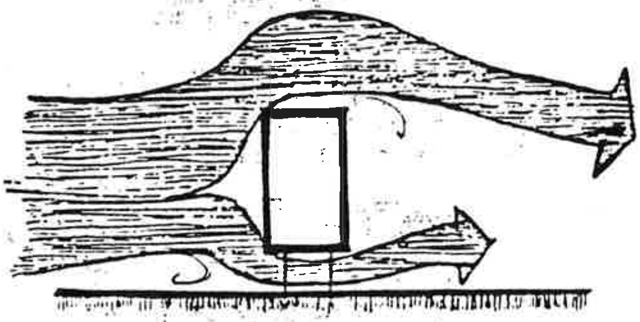
11. A low building placed in the windward path of a tall building produces much turbulence between the two (30).
12. A low obstruction can prevent increased pressure on the windward wall of an obstructed building but may not provide as intense a reduced pressure as a high obstruction (13).





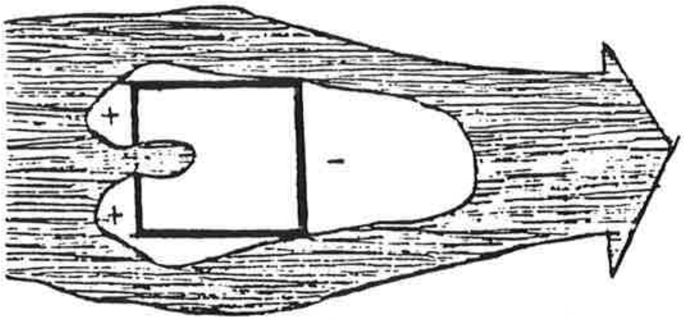
13. When there is little separation between buildings, a high obstruction can induce better air movement in an obstructed building than can a low one, because of the greater intensity of the reduced pressure behind it (13).
14. When an obstruction is low, increasing the distance of separation produces an immediate improvement in air movement in the obstructed building (13).

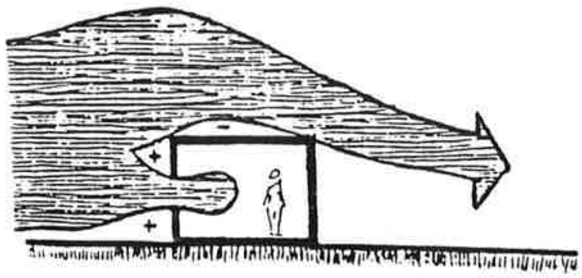




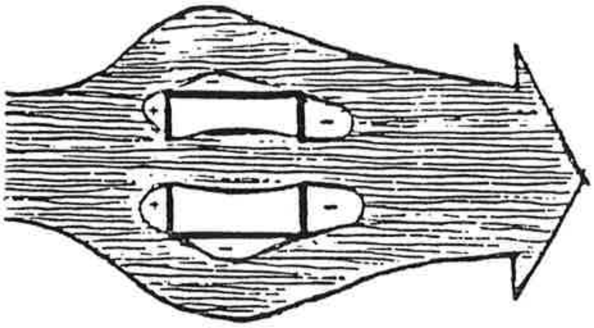
15. When an obstruction is high and the distance of separation small, an increase in distance causes an initial reduction in air movement in the obstructed building (13).
16. Raising a tall building on piloti reduces the high pressure in the windward side by allowing additional airflow under the building (30).

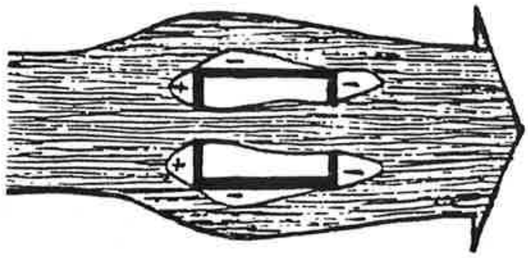
VOCABULARY



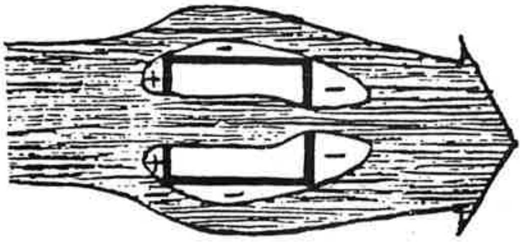


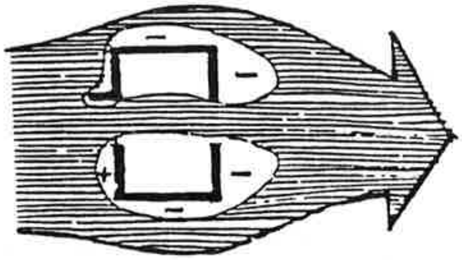
17. One opening in windward side results in poor ventilation, in plan (3).
18. One opening in windward side results in poor ventilation, in section (3).



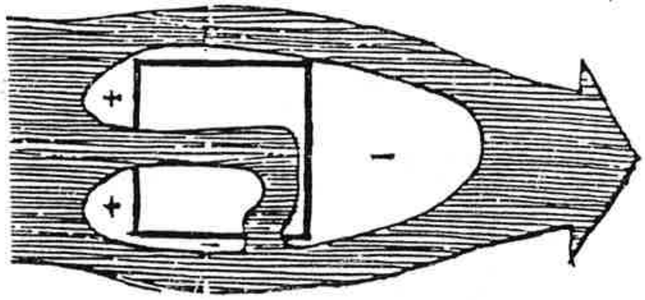


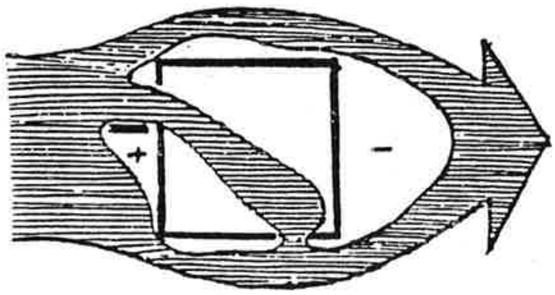
19. Openings on opposite walls relieve high pressure on the windward side, permitting good cross-ventilation of interior space (39).
20. Small inlet and large outlet increases velocity of airflow through interior space (39).



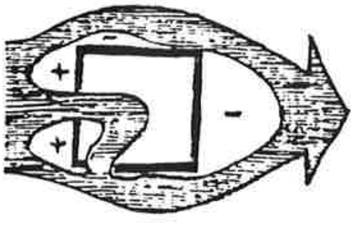


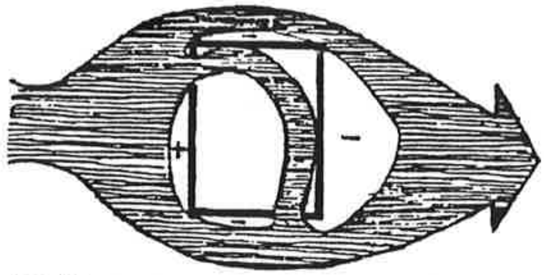
21. Large inlet and small outlet reduces velocity of airflow through interior spaces (39).
22. A baffle wall, placed at right angles to the opening, changes the direction of airflow through interior space, with small reduction in velocity (39).



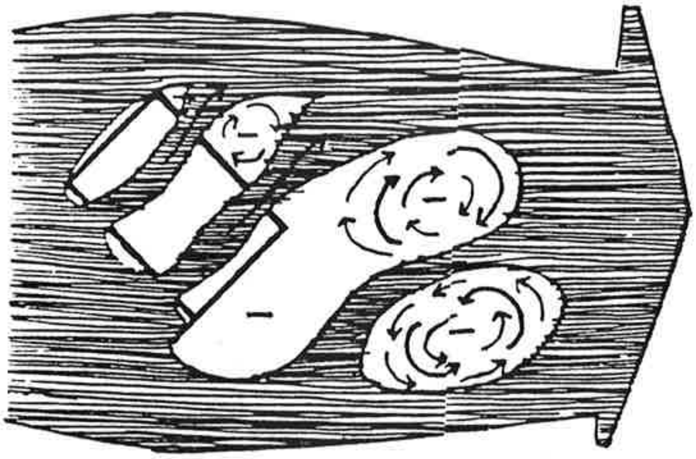


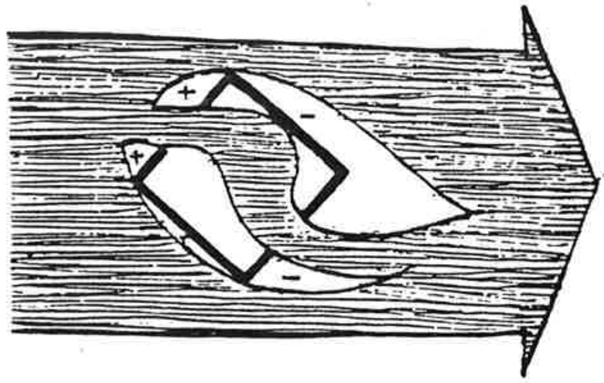
23. An inlet located in the center of a wall, causes air speed to slow due to an abrupt change in direction (3).
24. ~~An~~ inlet, with baffle, in an eccentric location on the windward wall, will promote unequal pressures on both sides of the opening, causing air to enter the opening diagonally, until it finds the outlet in a remote corner of an adjacent wall (3).



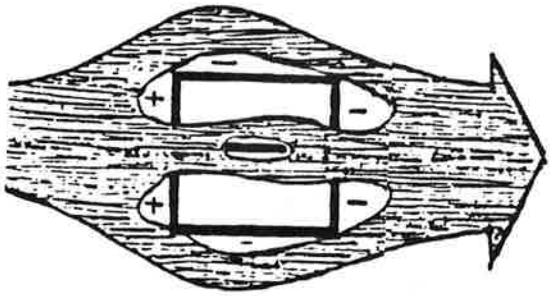


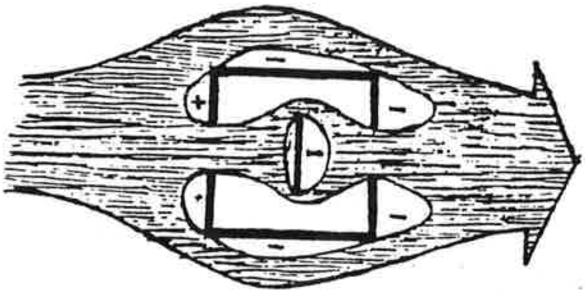
25. Air entering a centrally located opening, tends to keep moving straight into the interior for quite some distance, before being finally overcome by differences in pressure, causing it to turn and seek the outlet at the side (3).
26. Undivided interior spaces vented by eccentrically located openings, results in airflow at an angle responding to unequal external side pressure. Inertia carries the motion in the same direction until it finds the outlet in a smooth curve (10).



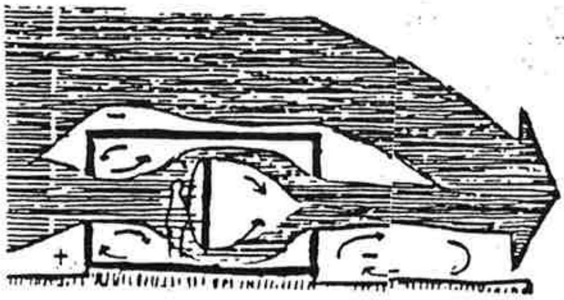


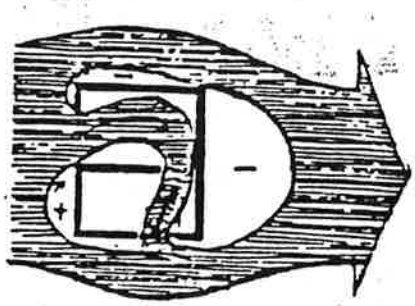
27. When a building is angled into the direction of the airflow much turbulence and eddying is experienced on the leeward side (19).
28. Pressure increases according to the dimensions, inclination and size of openings, of a solid (28).





29. A partition located parallel to the direction of wind flow, only slightly affects the existing wind pattern (27).
30. A barrier placed perpendicular to the airflow within a room, re-directs the airflow pattern resulting in high and low pressure zones immediately in front and behind the partition (27).





31. The same effect is seen in section (27).
32. A partition wall located close to the opening will not interfere with the airflow pattern, as the main airstream far exceeds the velocity of the cartwheeling eddies (39).

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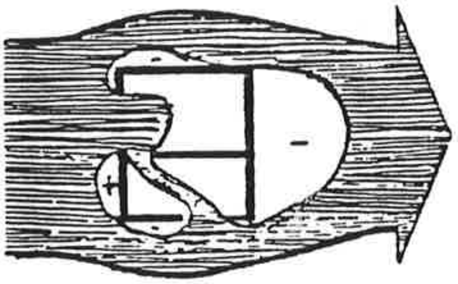
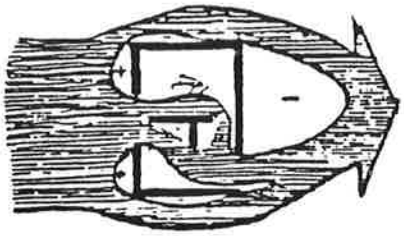
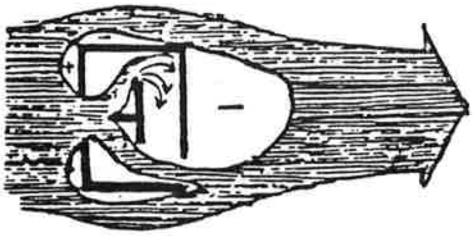
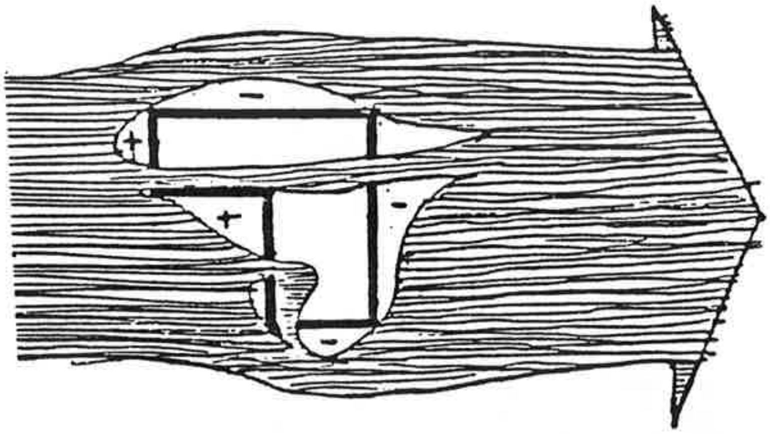


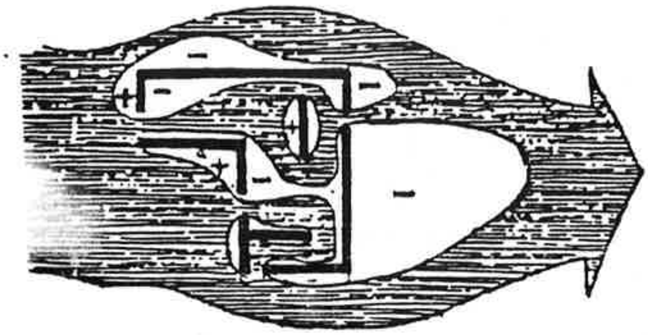


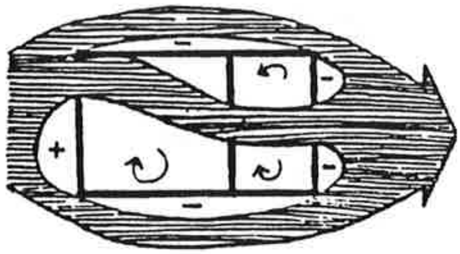
33. However, when the partition is attached to the opposite wall and an opening near the entry window, then the pattern is considerably altered, with the airstream seeking the shortest exit; velocity is decreased with little air entering the anteroom (39).
34. A partition placed parallel in the initial entry path, splits the airstream resulting in an acceptable flow in rooms serviced with an outlet, with a very poor airflow in other areas (39).



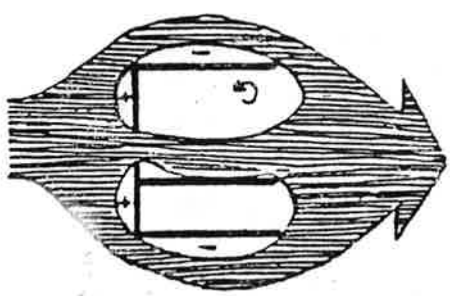


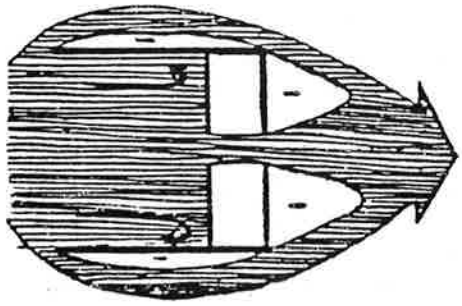
35. Back room, is meagrely supplied with air at cooling speed, when a partition is located perpendicular to the entry flow (39).
36. Air pattern results from the airstream seeking the nearer outlet whether the outlet is located in adjacent or opposite walls (40).





37. The location of internal partitions results in small deviations of airflow that will always seek the nearest outlet (40).
38. The direction of the airstream is altered by unaligned openings (10).





39. The direction will coalesce with parallel walls (10).
40. Airflow discharged through windward openings is increased by close proximity to a similarly aligned downstream opening (10).

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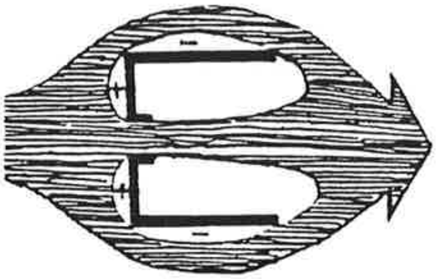
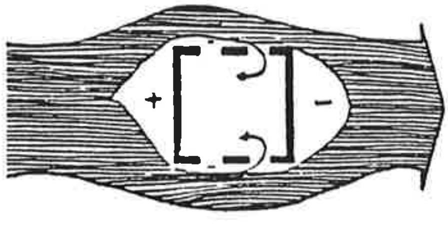
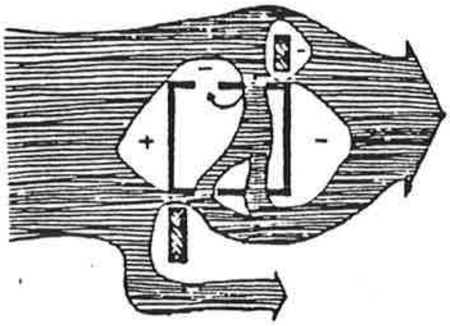
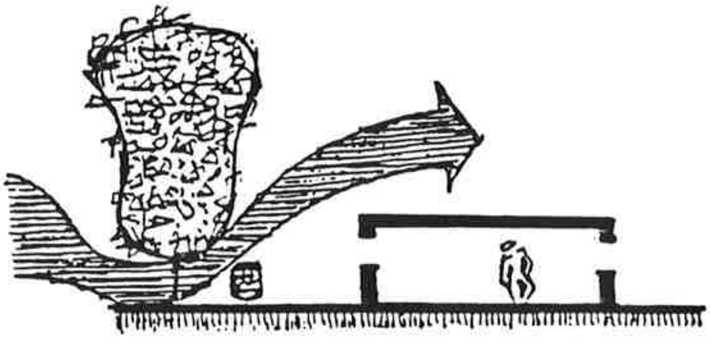


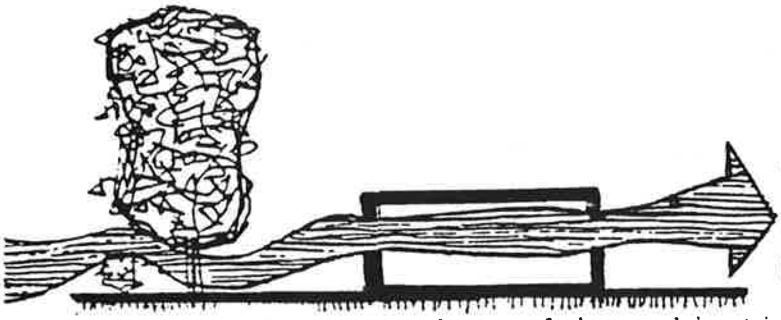


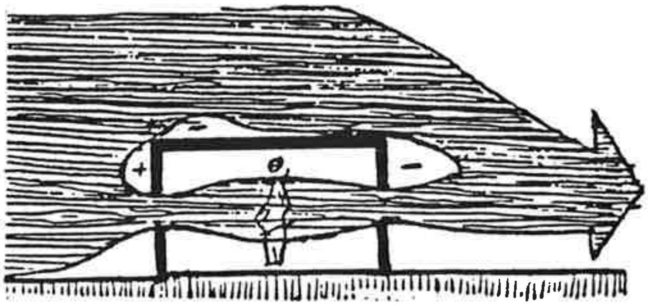
41. Deep reveals restrict air passage, so reducing turbulent losses in airstream(10).
42. A poor cross-ventilation pattern (3).



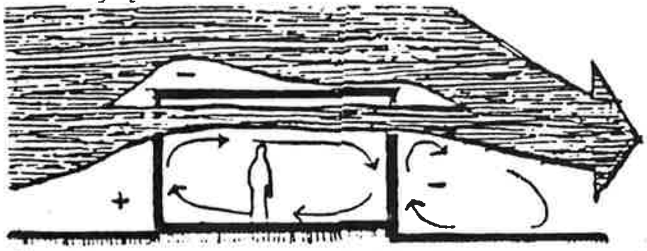


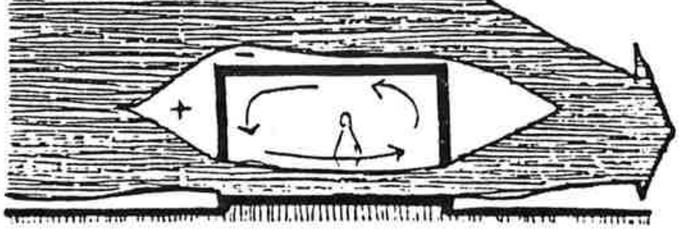
43. A poor cross-ventilation pattern may be improved by the strategic locations of wind barriers (3).
44. Trees and shrubs may be used in combination to divert wind around a building(3).



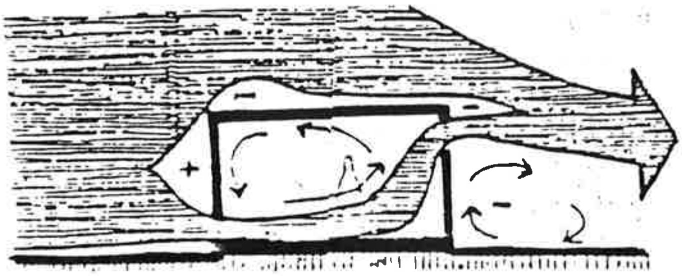


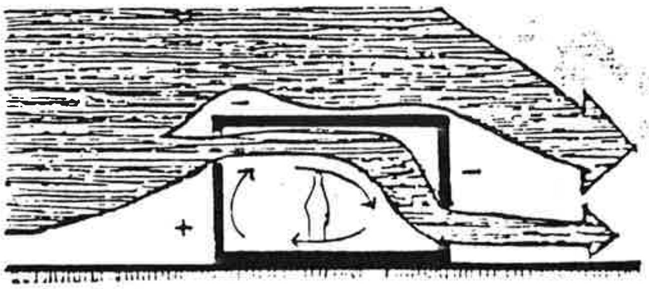
45. Trees and shrubs may be used in combination to divert wind through a building's interior space (3).
46. Identical inlet and outlet, at body height, performs a good cross-ventilation cooling pattern (27).





47. High inlet and outlet do not produce a good pattern at body height (27).
48. Low inlet and outlet produces a beneficial low level airstream (27).





[illegible]. Low inlet and high outlet produces a [illegible] airflow pattern (27).
[illegible]. The bad pattern caused by a high inlet is not corrected by a low outlet [illegible].

[illegible] VOCABULARY

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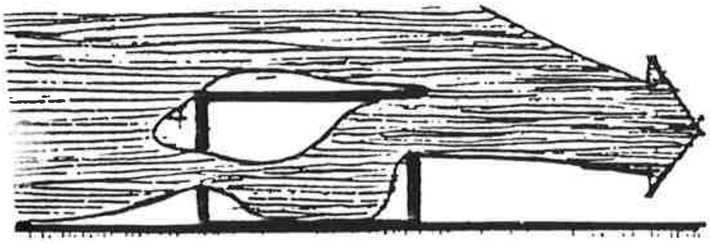
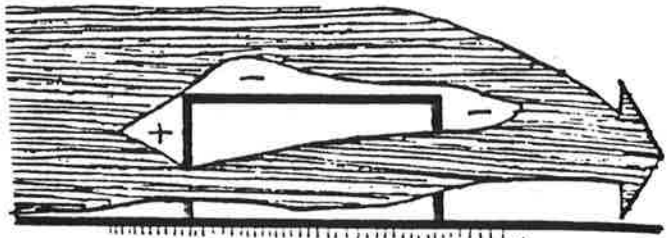
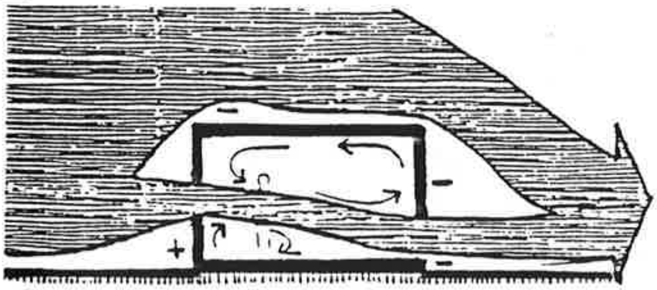
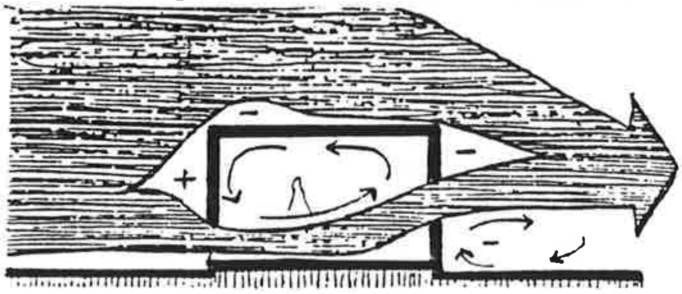


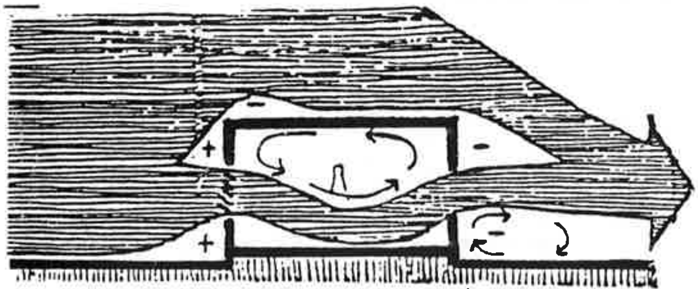


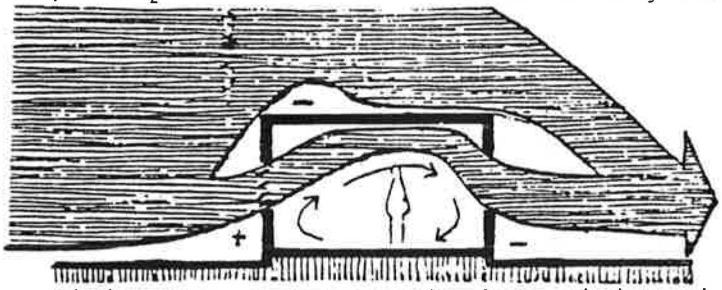
51. Medium height inlet and high outlet provide an acceptable downward flow despite the high outlet (39).
52. Low inlet with medium level outlet provides acceptable cross-ventilation (39).



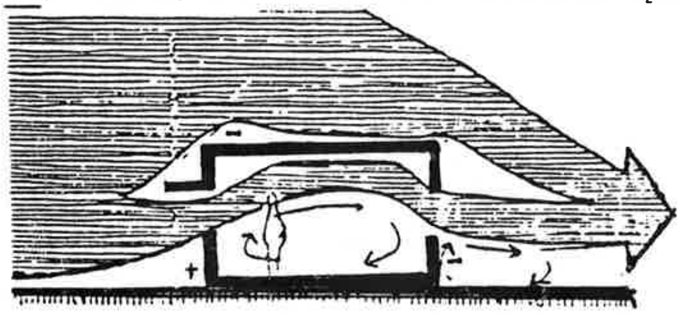


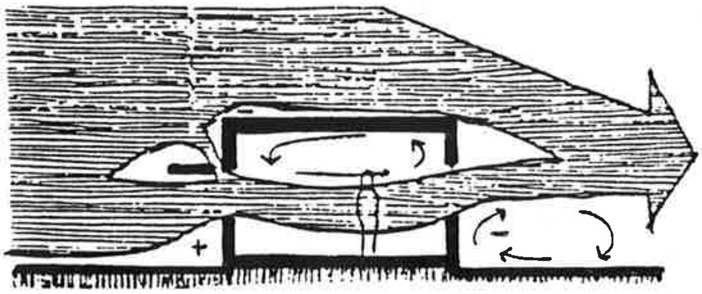
53. Medium height inlet and low outlet also provides agreeable cross ventilation off floor (39).
54. Low level inlet with medium level outlet, sweeps a room floor before exiting (39).



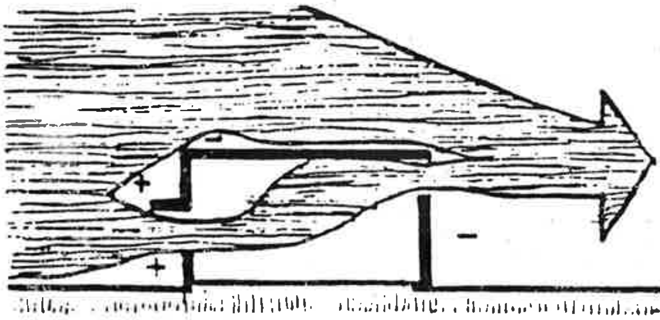


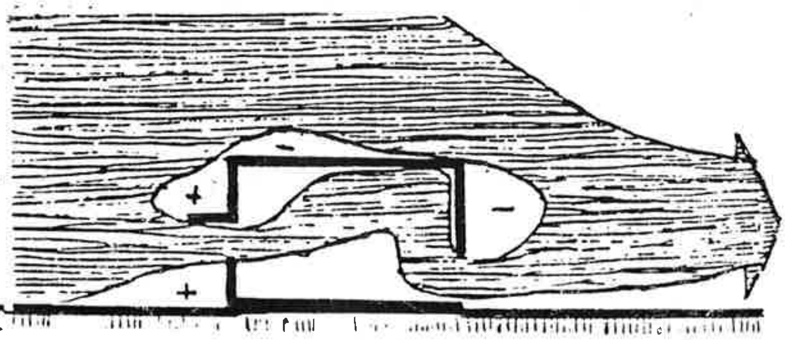
55. The conclusion is that inlets are more critical than outlets, in determining air circulation patterns. Louvers will direct air movement downward as required (2).
56. Louvers will direct air movement upward as required (2).





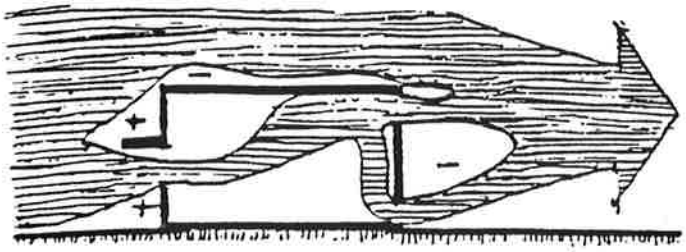
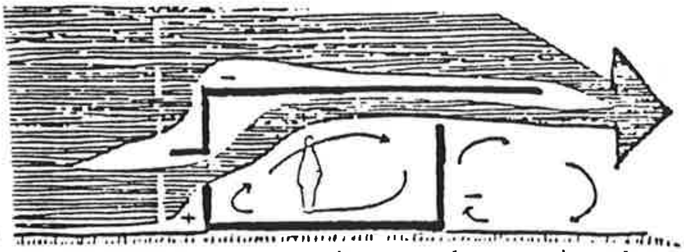
57. A solid overhang over a window results in an upward air circulation pattern (2).
58. An overhang separated from the building equalizes the external pressures to rectify this upward movement (2).



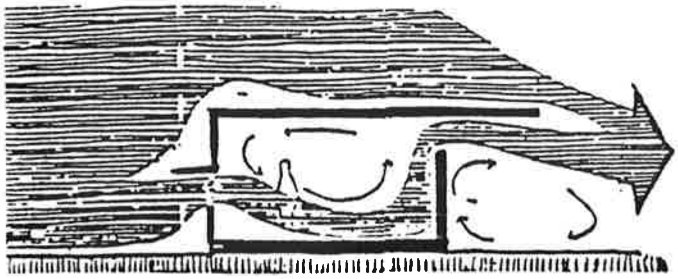
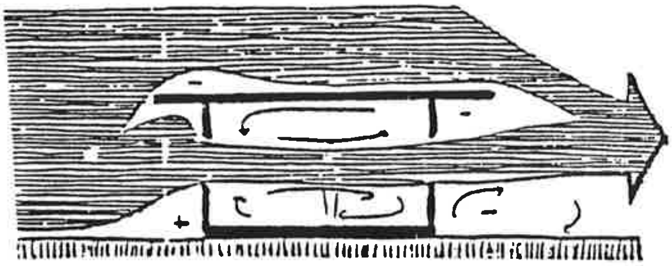


59. Overhang over inlets with high outlets will cause air to flow up to the ceiling on its way to the outlet (46).
60. Low outlets follow the same upward pattern until the rear wall, when there is a downward flow to seek the outlet (46).

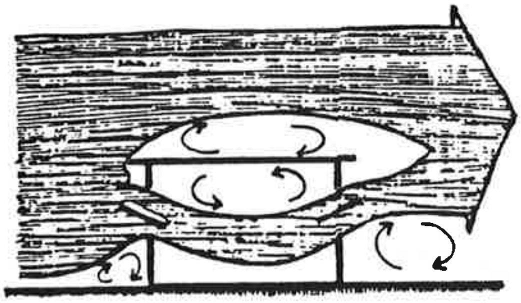
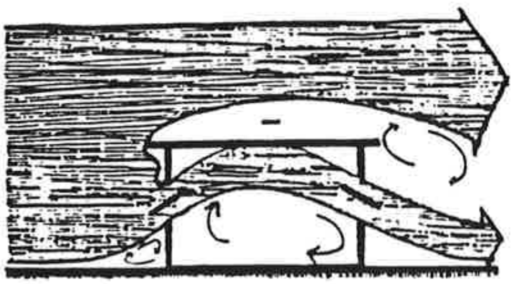
VOCABULARY

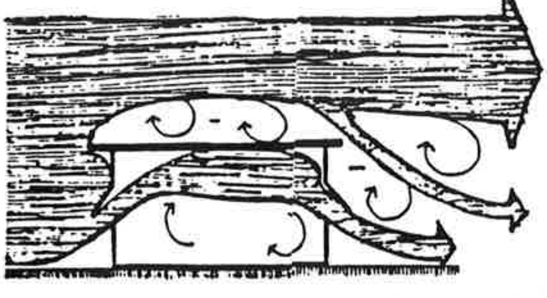
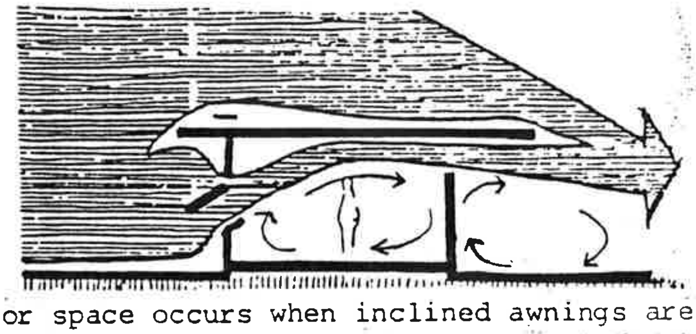
61. When both high and low level outlets are provided, there is no change in the upward flow of air (46).
62. It may be assumed that the location of an outlet is unimportant when there is an overhang over the inlet. An upward airstream will result when canopies exist over a mid-level inlet and a high-level outlet (46).

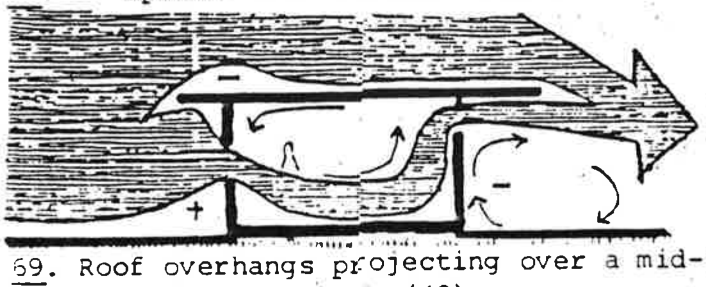
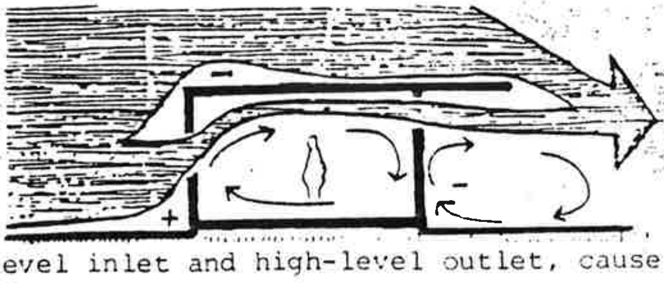
63. This circulation pattern will alter by using directional louvers in the inlet(46).
64. Elevated roof projections over symmetrically located opening,enhance a good cross-ventilation pattern (40).

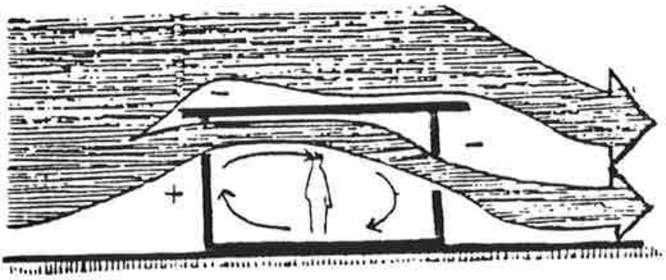
65. Window system for summer ventilation (24).
66. Window system for winter ventilation. Window systems may be used to direct air movement downwards (fig. 65) or upward (fig. 66) (24).

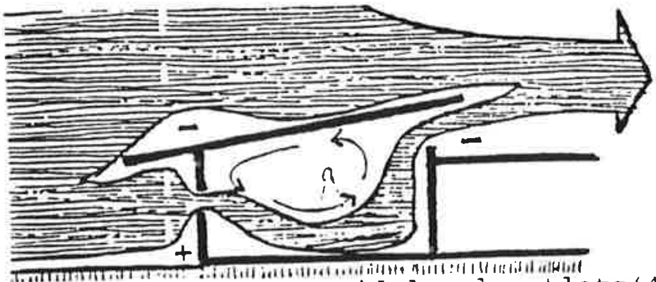



67. An upward movement within the interior space occurs when inclined awnings are placed over windows in opposite walls (24).
68. An upward flow results when a perforated baffle is introduced (24).

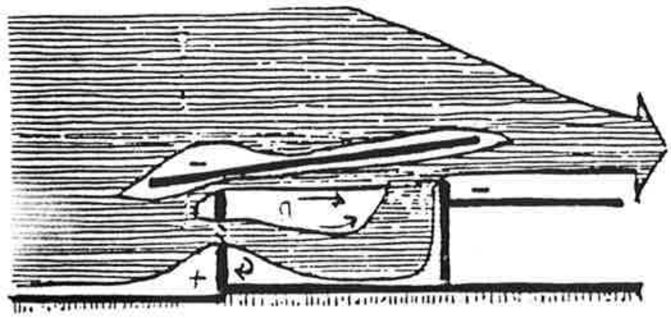



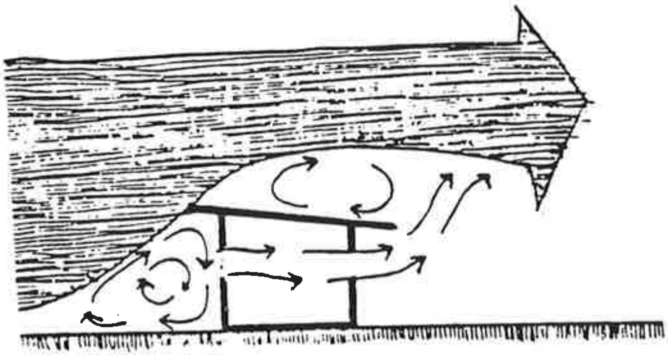
69. Roof overhangs projecting over a mid-level inlet and high-level outlet, cause a downward air pattern (40).
70. Removal of the inlet overhang alters the airflow into an upward stream (40).



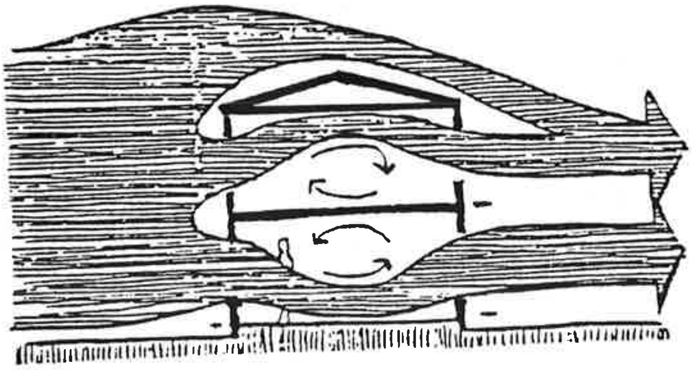


71. Roof overhangs do not alter the pattern of high inlets and mid-level outlets(40).
72. A projecting mono-pitch roof with a high outlet and mid-level inlet produces a downward airstream (3).

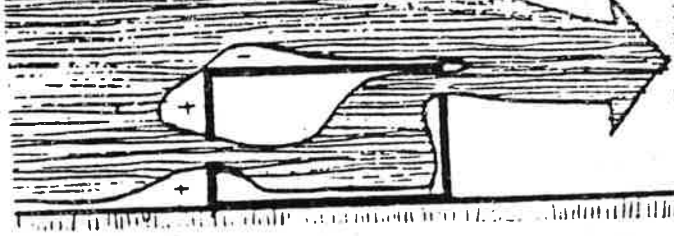


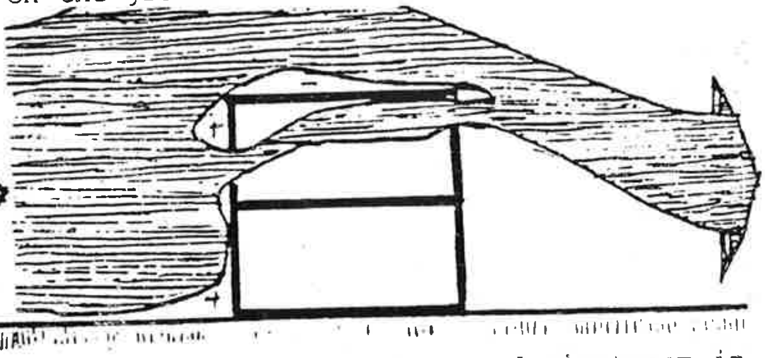


73. When a second high level inlet is added, the pattern takes an upward direction which may be modified by introducing louvers in the lower inlet (3).
74. Airflow is lifted over a mono-pitched roof, resulting in eddies on the windward wall and the above roof (19).



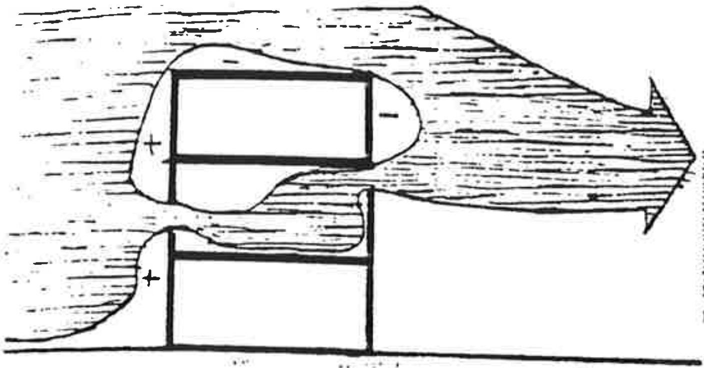
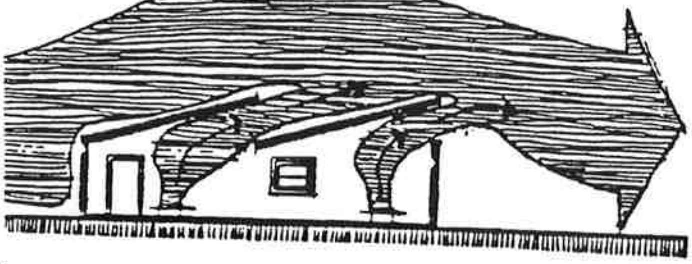
75. Airflow over a dual-pitch high roof, results in a flow pattern that is directed over and hugs the windward slope, while producing negative pressure zones and eddies on the leeward slope. Turbulence is also experienced on the windward wall (19).
76. Symmetrical inlets and outlets in a two-story building, result in an upward flow in the second floor and a downward flow on the ground floor (3).



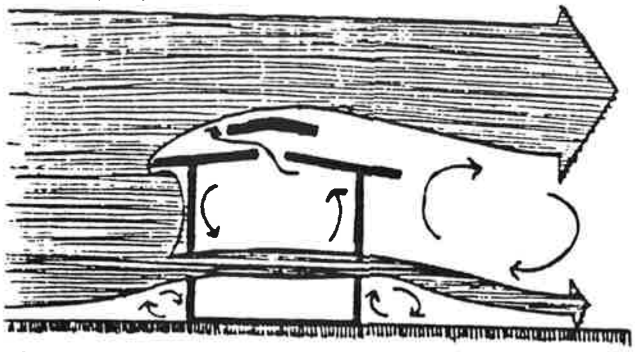
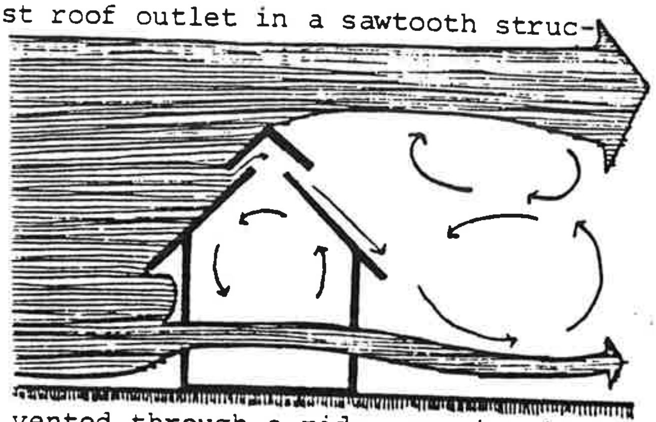


77. A medium-level inlet and a high-level outlet results in a downward airstream in a single-story structure (3).
78. When a similar configuration is located in a second floor structure, with no openings at ground level, an upward airstream is achieved (3).

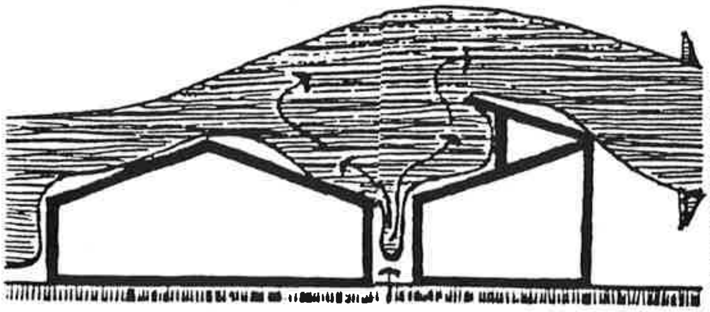
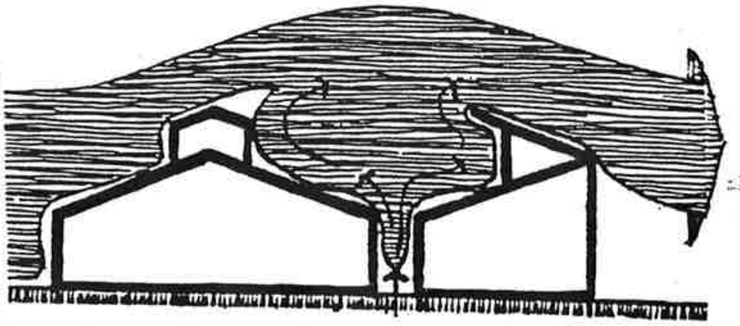
VOCABULARY

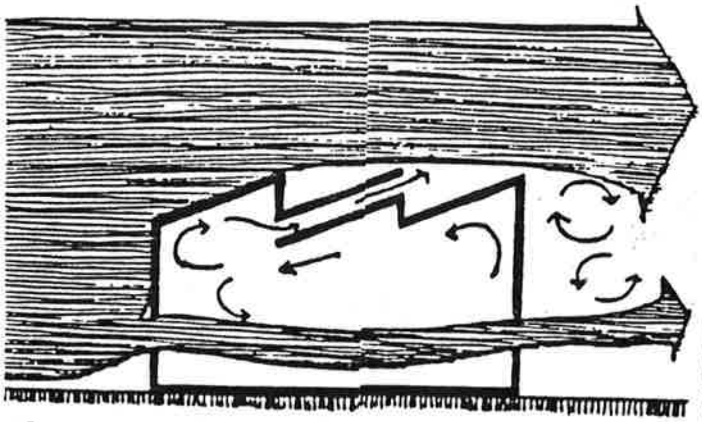
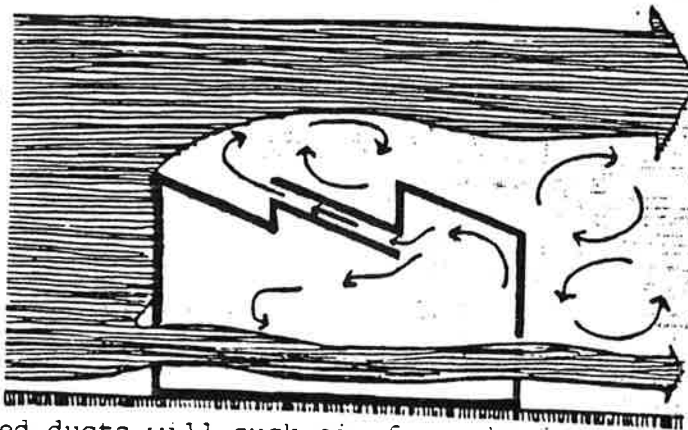
[illegible]. However, if similar openings are located in a multi-story structure, devoid of [illegible]her openings, the airstream resumes a downward trend as though the openings were [illegible] a single-story structure, as in Fig. 77 (3).
[illegible]. Anabatic interior airflow seeks the nearest roof outlet in a sawtooth struc-[illegible]re (14).

81. A roof with a shallow slope is adequately vented through a ridge opening in an anabatic action (24).
82. When the pitch of the roof is increased to a steep angle the anabatic action decreases (24).

83. The airstream migrates towards the ridge of an obstructing building and an adjoining roof monitor (13).
84. This motion continues when a ridge vent is added to the obstructing building(13).

85 & 86. In a sawtooth roof, well defined ducts will suck air from the interior to the exterior, whether the exhaust is facing leeward (fig. 85) or windward (fig. 86) (24).

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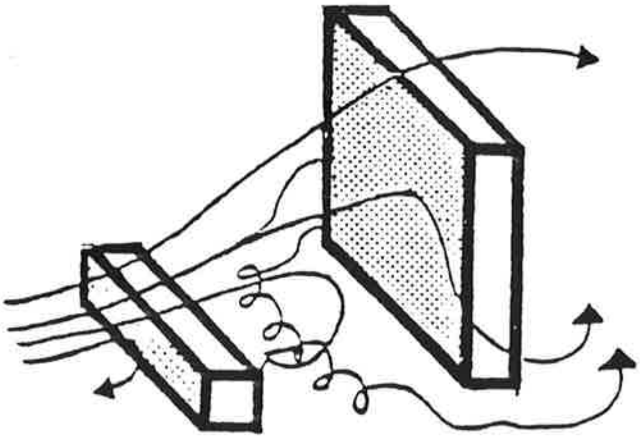
87, 88 & 89. Typical flow around a tall building with a low building to windward is illustrated in fig. 87 (32). Variations in wind speed or model scale have little effect upon such flow patterns. As it approaches the tall building, the wind gradually diverges until, at the windward wall, upward and downward flows occur. Some of the air deflected down forms a vortex, which then stretches out sideways and wraps around the building in a characteristic horseshoe shape. The resulting flow at ground level is typified by fig. 88 (32), where the horseshoe vortex is clearly shown. The effect of increasing the space to windward of the building is to elongate the vortex, as shown in fig. 89 (32), but at large spacings the stabilizing influence of the low building is lost, and the vortex becomes weak and variable in position. Wind speed at ground level in the vortex region are generally greater than on an open site away from a tall building with maxima in the positions shown in figs. 88 & 89 thus:

Fig. 87



approximate position of maximum speed in vortex flow.

approximate position of maximum speed in corner streams.

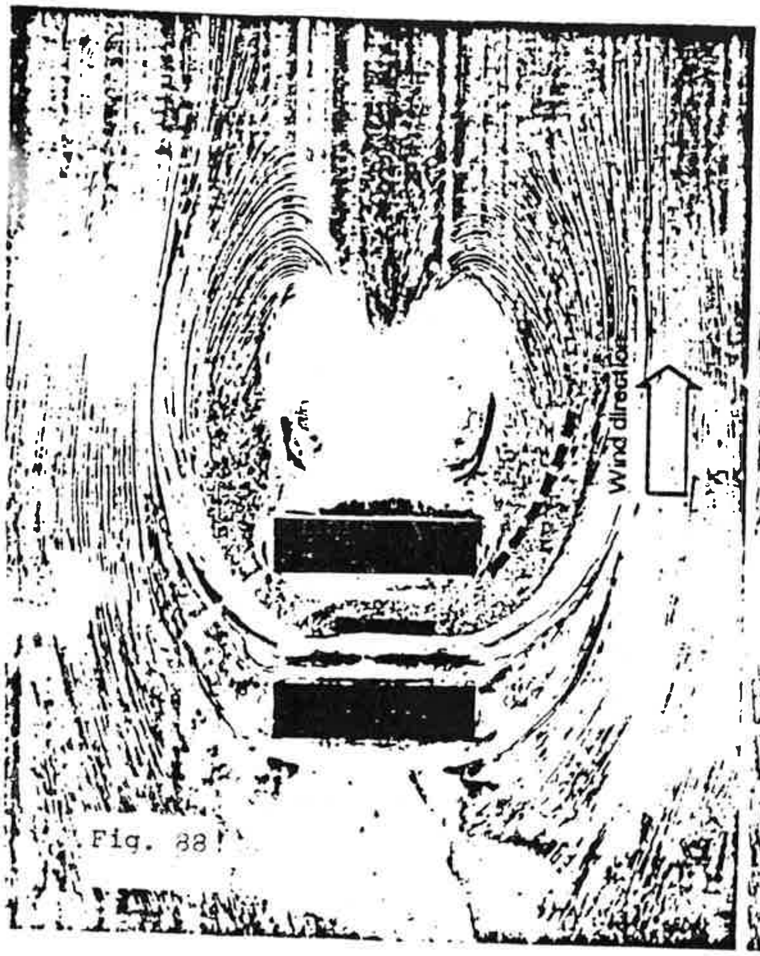


Fig. 88

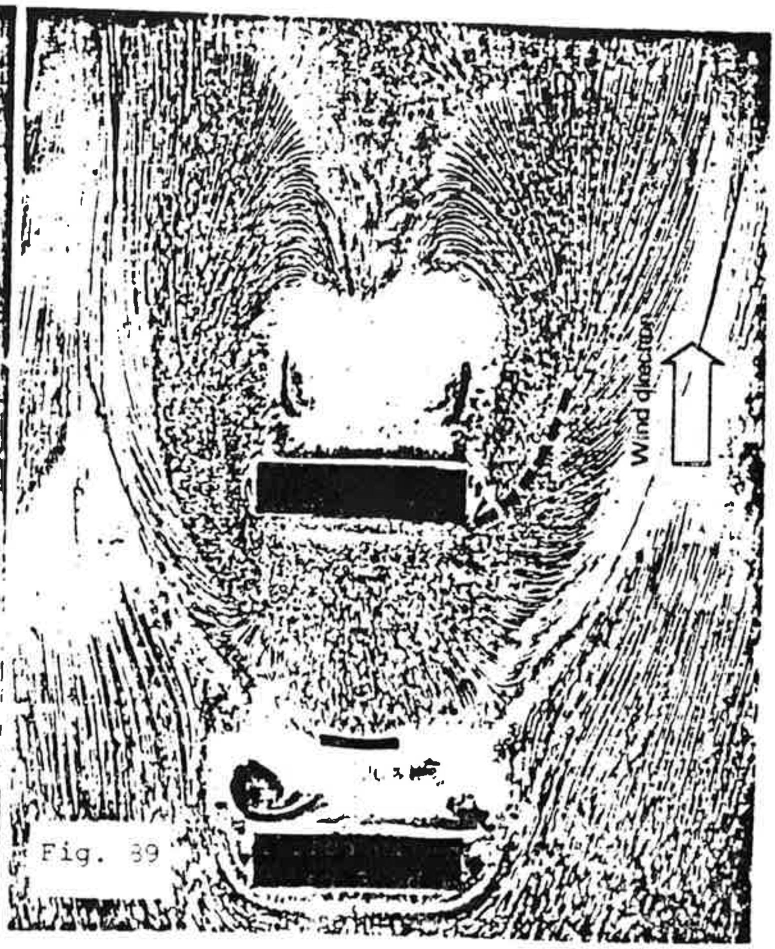
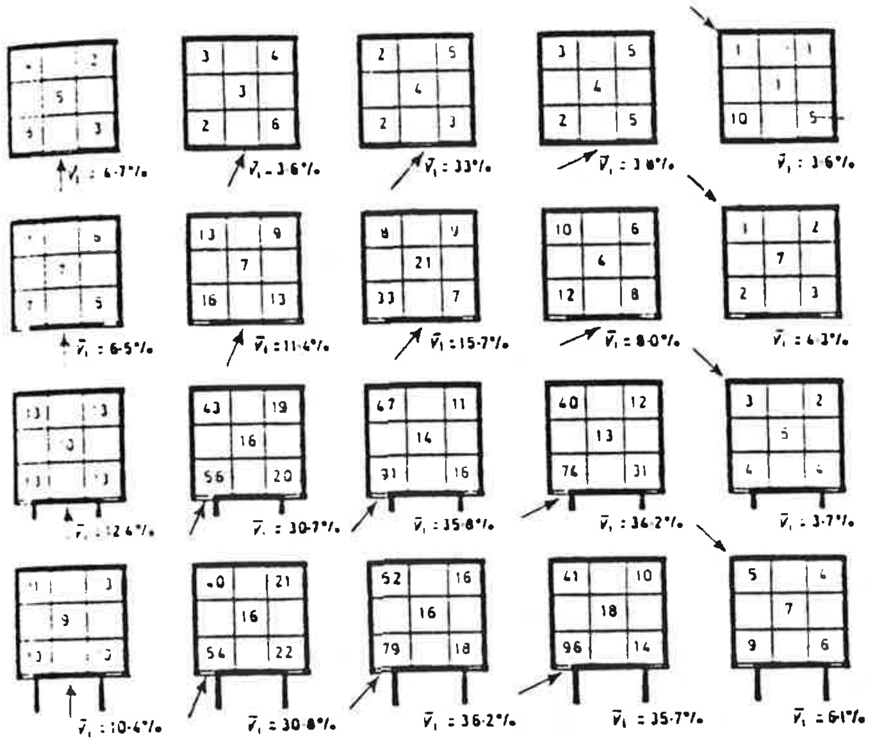


Fig. 89



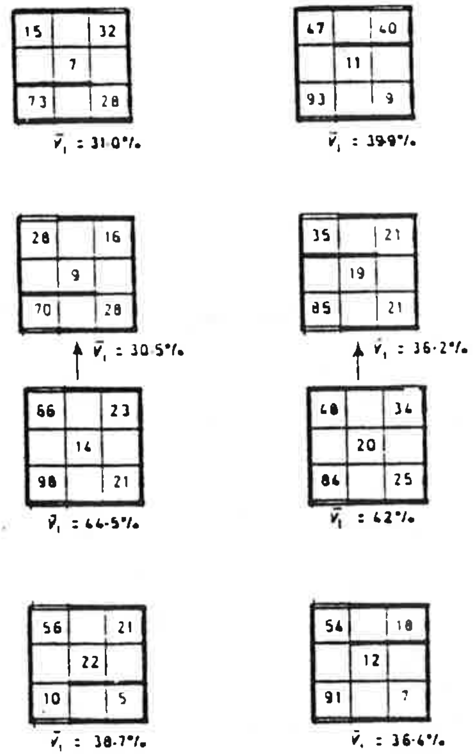


Fig. 91

Fig. 90
Internal air speeds in models with vertical projections of different depths, compared with values in models without projections. Window width 1/3 of wall width (8,9). Givoni, B.

Fig. 91
Effect of sub-division of the interior on the distribution of internal air speeds (8,9). Givoni, B.

CONCLUSION

This literature survey has revealed a small number of authentic sources. It would seem that all other writings on this subject matter have based their discussions on these original sources. The subject index identifies original research. Particular mention is made of work at the following:

1) Texas Engineering Station, Texas A&M College System, College, Texas, USA.
   -Evans, Holleman, Reed, Caudill, Crites & Smith

2) The Building Research Station, Haifa, Israel
   -Givoni, Paciuk and others

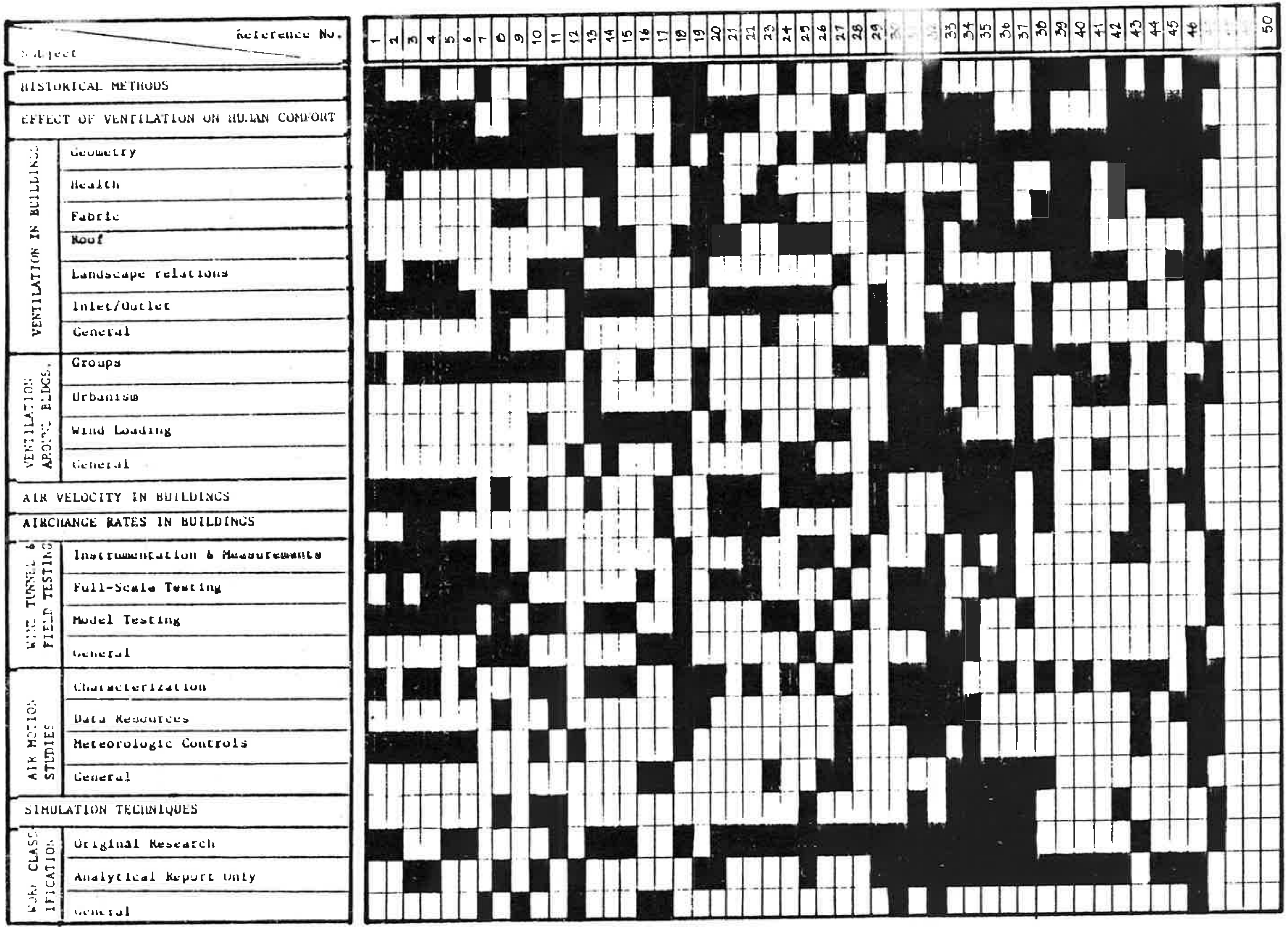
3) Building Research Establishment, Garston, England
   -Dick, Sexton, Wise, Penwarden, Newberry and Eaton

4) The Commonwealth Experimental Building Stations, CSIR, Sydney, Australia
   -Weston and Crane

5) The National Building Research Institute, CSIR, Pretoria, South Africa
   -Van Straaten, Richards, Roux, Olivier and Wannenburg

6) Swedish Council for Building Research, Stockholm, Sweden
   -Handa, Nylund, Bjerregaard and Nielsen

It will be gathered from the foregoing that while much is known on lateral motion, there is little accomplished in the way of a thorough documentation on vertical motion and movement in building envelopes. Work in these two areas are presently being investigated by Eureka Laboratories in California and the Florida Solar Energy Center, respectively.



SUBJECT MATRIX BY REFERENCED AUTHOR

SUBJECT MATRIX BY AUTHOR

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