VENTILATION AND LANDSCAPING
Design Implications for Hot Humid Climates

Ashish Karamchandani, Nandita Amin
College of Environmental Design
University of California, Berkeley, U.S.A.

ABSTRACT

This paper explains for the architect the physics of airflow patterns, the aerodynamics of buildings and their implications on effective ventilation. Also discussed are ventilation influenced design strategies of sunshading, daylighting and landscaping.

KEYWORDS

Ventilation; landscaping; passive cooling; sunshading; daylighting; Hot-Humid climate design.

INTRODUCTION

Human comfort requirements in hot humid climates can only be achieved through reduction of solar insolation and increased air movement (as explained in Reference 1). The architect can maximize air movement by site manipulation, building orientation, fenestration, roof design and landscaping. However, this form of ventilation oriented design results in large window space and hence requires design for daylight control. Also important is the reduction of solar insolation through techniques of roofing, sunshading and landscaping. The first step in ventilation oriented design is to understand the underlying principles of airflow and their design implications.

PRINCIPLES OF AIRFLOW

The exact analysis of airflow patterns in buildings is extremely complex (Chandra, 1980) and involves the modeling of three dimensional bluff bodies with appertures n turbulent shear flow and constant varying flow characteristics due to variation openings and external landscape. However, a qualitative understanding of airflow acteristics is adequate for building design. These are:

1) Air moves from high pressure regions to low pressure regions;

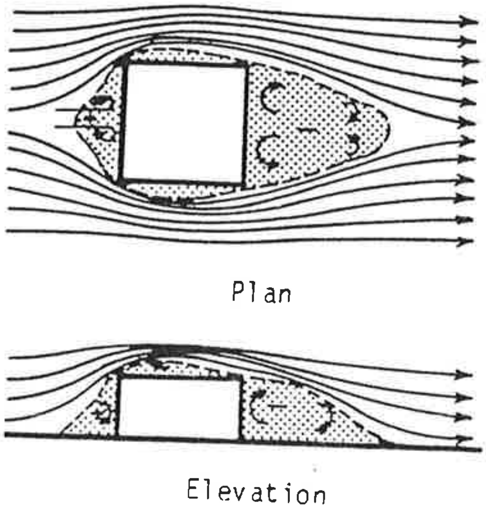


Fig. 1 Airflow for a "Box" building.

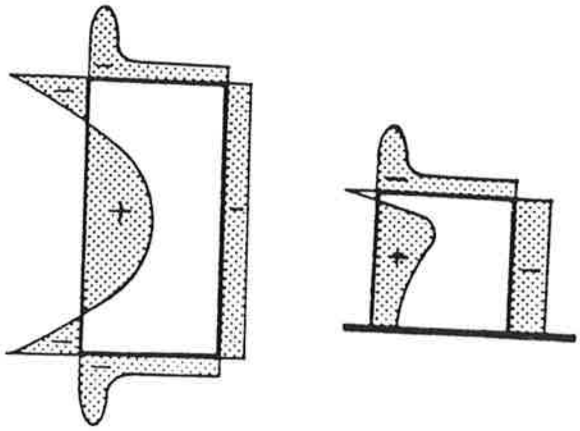


Fig. 2 Pressure distribution for the "Box" building of Fig. 1.

(II) Air has inertia and, hence, changes direction only when obstructed (it does not always travel in straight lines);
(III) Friction is developed when moving air comes in contact with surfaces and this causes the air stream to slow down and form eddies;
(IV) Airflow is laminar, but when it comes into contact with buildings or other obstructions, it turns turbulent.

We now examine the airflow past a rectangular "box" building (Fig. 1). The ele-
vation view shows how a wedge of high pressure is built up on the wall facing the
wind (windward side) and a low pressure region is created at the rear (leeward
side). The plan view shows the extent of these regions and it is noticed that a
large area on the leeward side is protected from the wind. This region of low air
movement is termed "windshadow". Fig. 2 describes the relative pressure distri-
bution on the "box" building of Fig. 1.

BUILDING LOCATION

Locating the building directly on the leeward side of a neighboring structure (i.e., in its windshadow) will result in low airflow around the building and hence poor ventilation. It is very important during design to locate the building away from the wind shadow of neighboring structures. Conventionally the windshadow depth is taken as "six times width". Fig. 3 illustrates how staggering of buildings greatly reduces the wind shadow problem and in fact increases the wind velocities due to a funneling effect, aiding ventilation.

BUILDING ORIENTATION:

Conventionally, it is supposed that maximum ventilation is achieved when the building faces the wind direction, but Fig. 4 explains how a 45 degree orientation is superior as it causes a larger "width" of air (b$>$a in Fig. 4) to act on the build-
ing. But in an unsymmetrical building, the long direction should face the wind as
this makes cross ventilation easier.

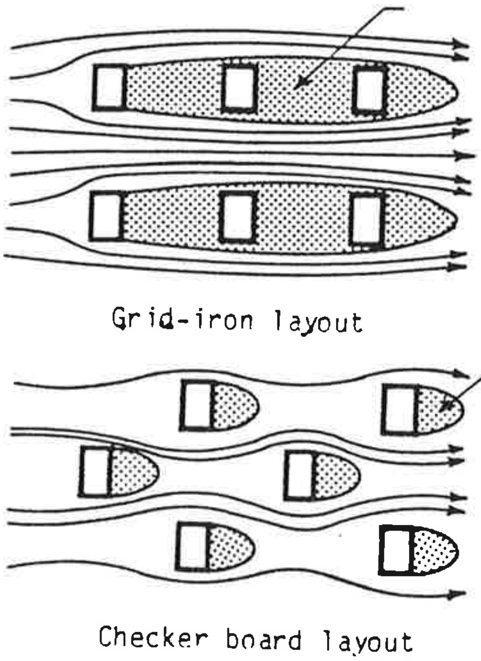


Fig. 3 Building layout influence on windshadow.

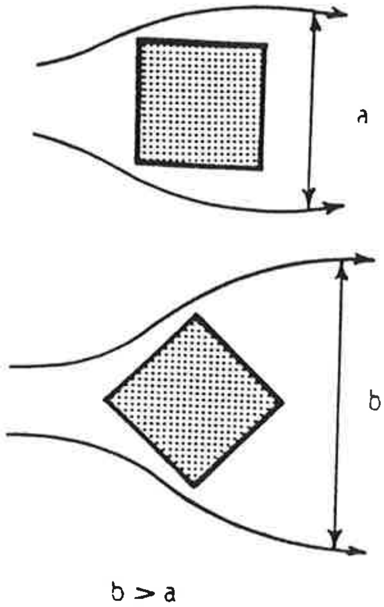


Fig. 4 Building orientation effects.

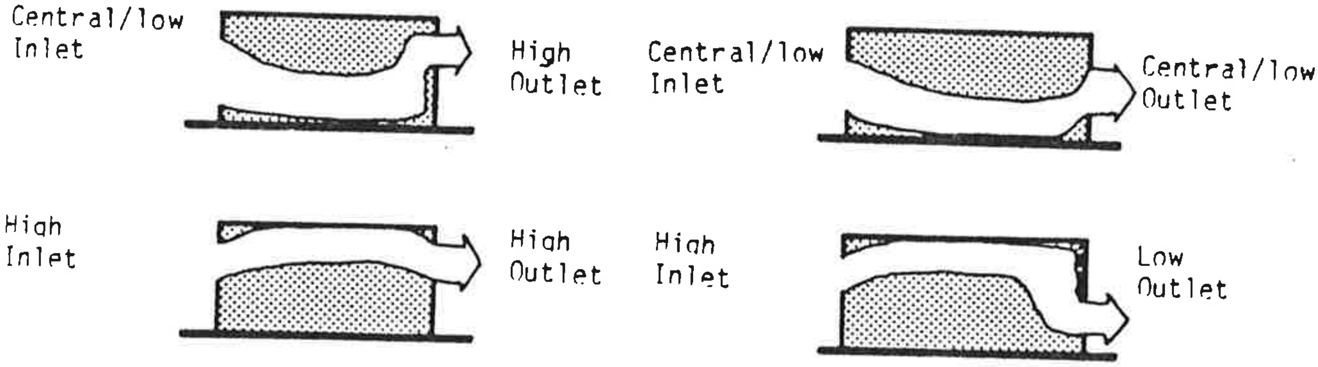
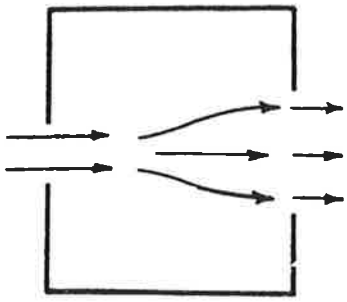


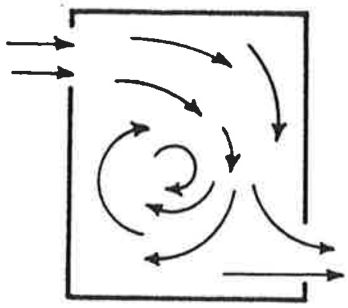
Fig. 5 Window location effect on airflow.

FENESTRATION

The actual entry of air into the building is through its fenestration (windows) and so ventilation is greatly influenced by the size, shape and location of the windows. For air to flow through a building, there should be an opening (inlet) in the high pressure region which causes air to enter the building, a passage through the building, and a corresponding opening (outlet) in the low pressure region to allow the air to exit from the building. As shown in Fig. 2, the center section of the windward side has the highest pressure and so this is the ideal location for an inlet window.

To maximize cooling, the airflow should be at the body surface level and this in turn depends on the activity being performed in the room (like bed level in a bedroom and sitting level in a dining room). The height at which the windows are located affect this airflow height and Fig. 5 shows the effect of window location on airflow patterns.





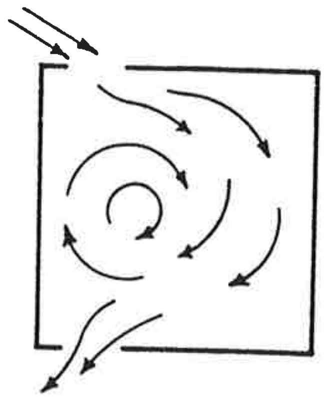


Fig. 6 In-line windows. Fig. 7 Staggered windows. Fig. 8 Inclined winds.

Of the four window location strategies shown in Fig. 5, the central/low inlet combined with high outlet is most effective. The high outlet also helps exhaust hot air as it rises to the top of the room, while the inlet can be positioned to cause maximum airflow at body level.

Air movement in a room is also influenced by the relative location of windows in plan. For windows directly facing each other (Fig. 6), air tends to just pass through the room and causes air movement in only a small portion of the room. But if the windows are staggered as shown in Fig. 7, the air is forced to change direction and this causes air movement in a larger section of the room. Another effective strategy as shown in Fig. 8 is to position the wall containing the inlet at an incline to the wind and cause the air to enter the room obliquely. The above effects of windows can be further enhanced both internally and externally. Internal partitions can be used both to deflect the incoming airstream for greater air movement and to channel the airstream to desired locations. Moveable partitions allow the occupants to channel/ deflect the airstream to suit the activity in the room internally. Wing walls and extended eaves can be used to increase airflow in a room or to modify the direction from which the wind enters a room. As shown in Fig. 9, these external projections can even be used to create an inlet for a wall which is usually in a low pressure region.

Window sizes should be determined by the function of the room, but the inlets should always be smaller than the outlet as this creates desirable higher windspeeds near the inlet and the entering fast airstream can be directed to required spaces using internal partitions.

Another approach (traditionally used in India) is "breathing walls" or hollow brick walls. These are walls built up of bricks in a lattice form with many variations. The resulting geometric pattern is aesthetically pleasing, allows ventilation and protects from glare. Applications include double layered exterior walls with a 4" gap (which satisfies exterior load bearing wall criteria) and interior partitions which separate space but enhance volume by giving the place an airy look.

In hot humid climates during the time it is actually raining, there is usually a strong wind outside but windows have to be kept closed to prevent the wind from driving the rain inside. Louvres can be used to allow air entry without rain. Conventional louvres can be used in conjunction as double layers or special louvres as tested by Koenigsberger, Milar and Costopoulos (Reference 3).

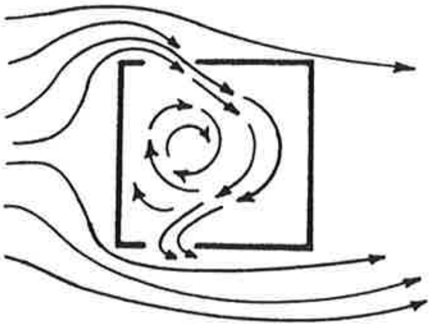


Fig. 9 Wing walls.

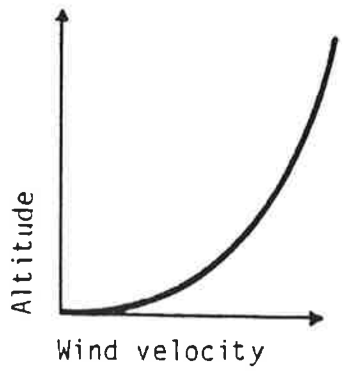


Fig. 10 Wind velocity gradient.

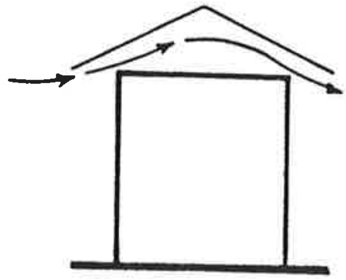


Fig. 11 Double roof.

ROOFS AND STILTS

These two techniques are included here as they are both based on airflow and airflow gradients. Air velocity is low, close to the ground and increases with altitude as shown in Fig. 10. For stilts to be usable, there should be a strong, cold airstream near the ground as in seaside areas. If this is not there, stilts are ineffectual and in fact, contact with the ground can help cool the building as the ground can be regarded as a "reservoir of coolness". Often roofs in urban areas are waterproofed flat concrete slabs which are terrible from the solar input viewpoint. In summer the sun heats up the roof and hence the air below it. This hot air should be vented by upward cross drafts with outlets at the highest point in the room (as hot air accumulates there). Alternatively, pitched roofs with appropriate openings can be used. But in some parts of the world (as in India), people use the roof to sleep on at night in summer and so pitched roofs are not applicable. Another approach is to use a double roof, the exterior pitched roof is constructed at a height of about 6 feet above the flat roof and wind is allowed to circulate in this area (by supporting the exterior roof on a porous structure like pillars or hollow brick wall). Shown in Fig. 11, this acts as an insulation from solar heat during the day and also provides a cool, ventilated area in the evening and night. An effective technique used by the British colonials in the tropics is to have houses with very high roofs. During the day the hot air rises to the top, this is vented out at night, replaced by cool night air and this cool night air is used to provide coolness the next day.

Correct selection of colour and material of the roof can increase reflection and hence decrease heat buildup inside. Insulation adds to this effect, and a layer of aluminum foil on the roof increases reflection.

SUNSHADING

Sunshading is required to minimize heat buildup from solar insolation (both direct sun as well as reflected heat from neighbouring structures). This can be through sunshading devices on the house or extraneously through landscaping and neighbouring structures. An important criteria for the design of sunshading is that it should

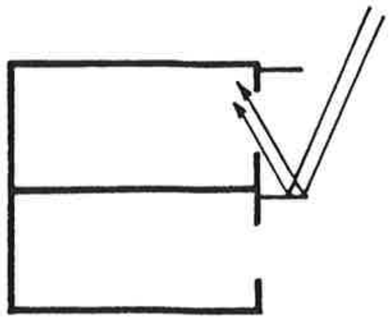


Fig. 12 Horizontal Sunshades.

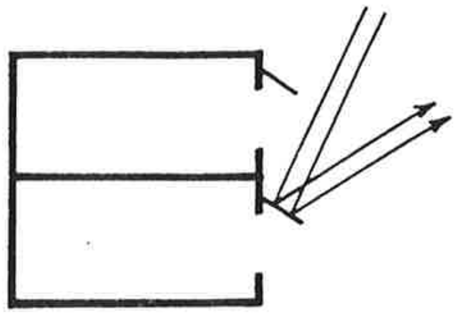


Fig. 13 Inclined Sunshades.

not decrease ventilation. Hence, the shade from a neighbouring structure can be used only if it doesn't coincide with its windshadow. Landscaping is very effective for sunshading, and this topic is discussed under "Landscaping". Sunshading on the house itself can be by shades that are vertical, horizontal or a combination thereof. (One such combination is the "egg-crate" shade). Vertical shades are essential on the north side as they obstruct the morning and evening sun. However, vertical shades are ineffectual on the east and west sides and long horizontal shades are preferable. The superposition of sunpaths on the building plans can be used to determine the types of shades required and their dimensions. Shades should be separated from the building to prevent heat conduction into the building and also to allow venting of the hot air that collects below the shades. Conventional horizontal shades (as shown in Fig. 12) reflect heat onto the upper sections of the house, but this can be averted by inclining the shades (as shown in Fig. 13). Shades need not be restricted to windows, but can also be used on entire walls. An extension of this concept is a verandah extending around the house which acts both as a shading device and helps cool the air entering the house. Since shading devices have no structural function, they need not be made of concrete, and can be made from cheaper, lighter, nonstructural materials. Other ways of shading are by hollow brick facades (an extension of the "egg-crate" concept) and reflective louvres. In addition to shades, heat buildup in the house can be reduced by having reflective exterior walls. This can be easily done by whitewashing exterior walls.

DAYLIGHTING

Daylighting can be in the form of direct (or reflected) sunlight or diffused sunlight. Direct sunlight has a glare problem, i.e., if part of a room is lit by an external concentrated light (direct sunlight), then for visibility in the room, the background light (provided by artificial lighting) must be of a comparable intensity. Hence, as direct sunlight requires intense internal lighting, it is not desirable. Since most houses have external shades for sunshading and rain protection, these obstruct direct sunlight and reduce the glare problem. Luckily, due to ventilation requirements, houses in hot humid climates have large window area and the diffused light entering from these windows is adequate lighting for most rooms. Some of the internal rooms may require additional lighting through skylights or north lights. For lighting requirements in the evening and night, fluorescent lights are superior to incandescent lights as they provide "cooler" light. Light-coloured walls with a "matte" finish also help diffuse artificial lighting and make it more comfortable. It is interesting to note that individuals have inherent differences in the rods and cones of their eyes, so there can be no common universal criteria for a "comfortable" lighting level.

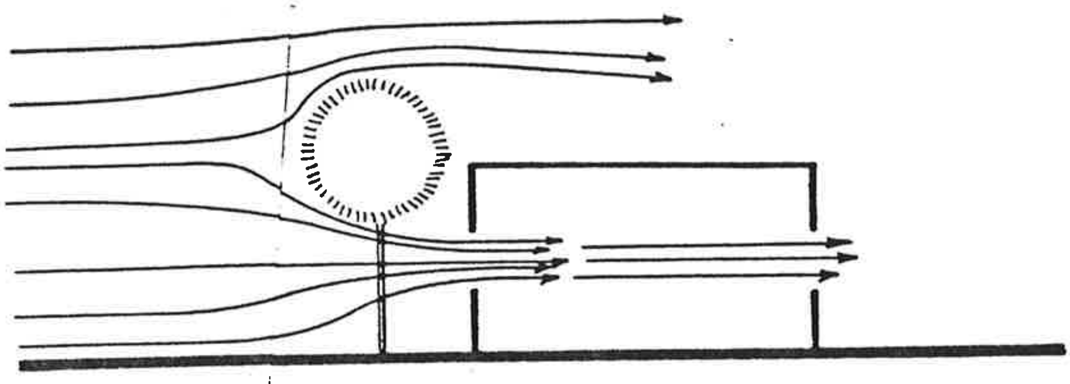


Fig. 14 Airflow control through landscaping.

LANDSCAPING

The micro-climate of a site can be greatly improved through landscaping. Landscaping can help decrease the heat buildup in the house through shading. A major advantage of natural shading is that plants constantly rearrange and reposition their leaves for maximum solar exposure and hence maximize shading, while man-made shading is inflexible. However, as ventilation is more crucial in hot humid climates, landscaping should be used for shading only if it doesn't decrease airflow into the house. Vines and creepers on pergolas and vertical trellis works provide excellent shading without decreasing airflow. Bushes and shrubs can be planted on the east and west sides to prevent insolation due to morning and evening sun. Vegetation can be used as ground cover to reduce ground reflectivity and thermal emission (dark green plants are less reflective than lighter ones). In urban areas, trees can be used to block thermal reflection and radiation from asphalt roads, sidewalks, parking lots and bare ground. Vegetation also helps reduce noise effects in urban sites.

Plants can be used to obstruct, filter and guide airflow and hence affect ventilation. They are better than man-made wind controls as they do not re-radiate heat. Plants (hedges) can be used as wing walls to deflect wind into an opening as shown in Fig. 9. Trees can help increase ventilation by acting as windcatchers over elevation as shown in Fig. 14. Plants can also be used as windbreaks to keep out undesirable hot dry summer winds and cold winter winds.

Actual plant selection for landscaping depends on the function (like short grasses for ground cover and bushy hedges for wing walls). Selection is also controlled by local site conditions and factors affecting plant survival like soil preference, growth rate and habits, life expectancy, moisture requirements, disease susceptability and leafing habits. Local site conditions like restricted water supply will affect selection. An example of site location is that deciduous trees in U.S.A. are very good landscaping material as they provide shade in summer and yet in winter, being leafless, allow the sun to heat the house. In contract, deciduous trees in India are less obliging as they are leafless in summer and provide shade in winter! It is advisable not to plant large trees very close to houses as their root systems may damage the foundation and there is the danger of falling branches during storms and strong winds. Other disadvantages of plants are that they may harbour insects or snakes and that they require maintenance (pruning and dead leaf removal).

CONCLUSION

In this paper, basic airflow principles have been used to explain and evolve design strategy. This should be supplemented and reinforced by local observation of air-flow patterns in already constructed houses in the vicinity of the site. A word of caution is required on natural ventilation, as this is based on winds and in nature there are days with little or no winds. Hence, a ventilation based design should include a back-up mechanical ventilation system consisting of suction fans (placed near the floor to suck cold air into the house) and exhaust fans (placed near the roof to push out the hot air from the house).

A well ventilated house is the only affordable design strategy to provide comfort in hot humid climates.

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