An Introduction to Natural Ventilation for Buildings

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J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

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J. Paul Guyer, P.E., R.A.

Paul Guyer is a registered mechanical engineer, civil engineer, fire protection engineer and architect with over 35 years experience in the design of buildings and related infrastructure. For an additional 9 years he was a principal advisor to the California Legislature on infrastructure and capital outlay issues. He is a graduate of Stanford University and has held numerous national, state and local offices with the American Society of Civil Engineers, Architectural Engineering Institute, and National Society of Professional Engineers.

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1. INTRODUCTION. This publication contains information on design features and practices affecting natural ventilation in buildings. Guidelines based on the best available data are provided. Conflicts between differing guidelines will arise in some cases. Resolution of these conflicts is left to the designer's discretion, since each must be handled on a case-by-case basis. Comfort, life-cycle costs, maintenance concerns and functional efficiency should be the primary criteria for such decisions, and designers should draw on their previous experience as well as on the guidelines presented here. In most cases, there are several alternative approaches to achieving a desired effect.

2. SITE SELECTION AND PLANNING.

2.1 GENERAL PRINCIPLES. The siting of a building(s) will have major impacts on the comfort of the building's occupants and on the functioning of the building and its systems. In fact, the feasibility of using natural ventilation for cooling may depend on proper siting. Consideration of the wind and thermal implications of site planning and selection must be given the highest priority for any building project in the earliest stages of the planning and design process. The first task of the planner or designer is to identify the most suitable site for the building(s) to take advantage of the favorable, and to mitigate the adverse, characteristics of the site and its microclimate. For buildings using natural ventilation, this includes avoiding enclosed valleys and sheltered locations, maintaining adequate building spacing (avoiding wind shadows and wakes) and organizing the site layout to increase interior air velocities and minimize interior heat gain. Design of the buildings should not only be related to conditions in the building interior, but also to the external spaces between and around them. Comfortable outdoor spaces can provide valuable additional or alternative living area in many types of projects.

2.2 VENTILATIVE CONSIDERATIONS. The major site factors affecting ventilation are described below. Figure 2 is a flowchart for the design and analysis of factors.

2.2.1 TOPOGRAPHIC FEATURES. If maximum ventilation is desired, avoid enclosed valleys and very sheltered locations. Sites near the crest of hills or ridges may provide increased exposure to winds for ventilation. Ridge crests can receive wind speeds higher than those on flat ground; an increase of 20 percent is an average rule of thumb. In very windy locations, sites at the crest of hills or mountains may receive too much wind with potential for problems with structure and driving rain. If continuous ventilation is desired, sites on or near the top of a slope (for increased wind exposure), and facing south (to southeast for decreased afternoon solar exposure) are recommended. If night ventilation is desired, recommended sites are those near the bottom of a slope (to catch the nighttime downslope winds), and facing south to southeast for decreased exposure to afternoon sun. In cooler temperate climates, sites in the middle to upper part of the slope facing south are recommended for access to sun and wind.

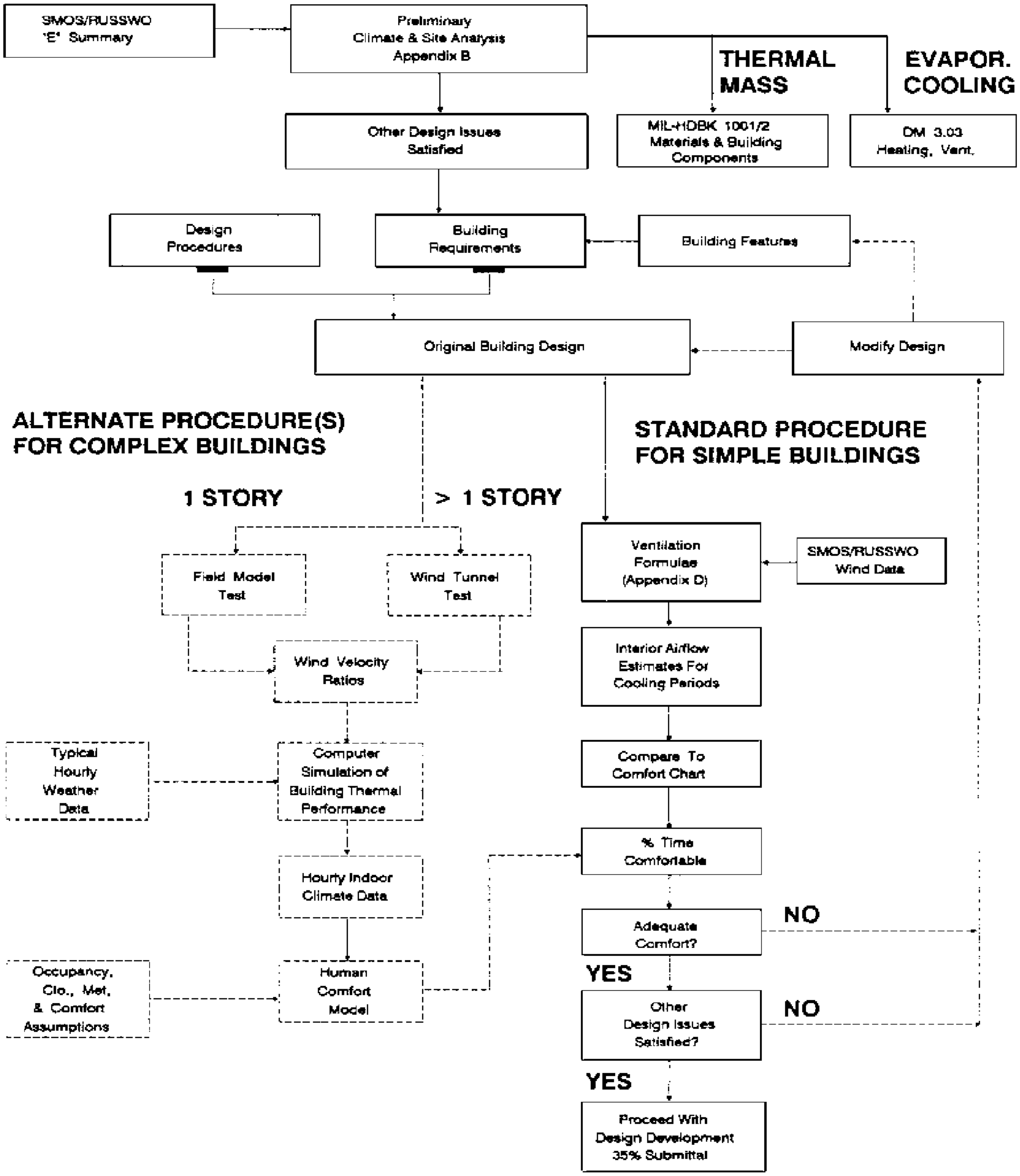


Figure 1

Natural ventilation design and analysis flow chart

2.2.2 OBSTRUCTIONS. Obstructions include elements such as buildings, fences, trees and other landscaping. They affect both the wind and sun impinging on the building. Important wind effects of obstructions include airflow at: flows on the windward face, corner flows, and wakes. Figures 2 and 3 show wake effects of complex building shapes. To maximize ventilation, buildings should not be sited within the wake of any obstruction and should be placed sufficiently far apart that each acts in isolation. To achieve this, a clear spacing of at least 5H (five times the height of the upwind building) is required. If the spacing is closer, the downwind building is placed within the wake of the upwind building resulting in lowered local air velocities and the possible establishment of a vortex or roller of trapped air. Such rollers are stable at clear spacings of less than 1.5H (one and one-half times the height of the upwind building) and ventilation through the downwind building can be quite weak. For spacings between 1.5 and 5H, the airflow oscillates between the two patterns shown in Figure 3 and ventilation in the downwind building(s) will be sporadic and much less effective than if properly spaced.

2.2.3 POLLUTION SOURCES. Because it is too difficult to filter pollutants from the air entering naturally ventilated buildings, the building(s) should be upwind of pollution sources. When this is not possible, it is desirable to position them as far as possible from upwind pollution sources, such as kitchen exhausts or major roads, so that the pollution has space to disperse in the atmosphere before reaching the building.

2.2.4 PLACING A NEW BUILDING IN A DEVELOPED AREA. In positioning more than one building, or a new building in an already developed area, provision for air movement must be one of the most important considerations. New buildings are not only affected by the existing buildings around them but they can also affect the ventilation in the existing buildings and the air movement in surrounding open spaces. Buildings and open spaces can be organized to preserve each building's access to prevailing breezes. For the same density, high buildings surrounded by large open spaces have better ventilation than more closely spaced low-rise buildings. The important influences on urban winds are:

a) dimensions of obstructions,
b) spacing between obstructions,
c) homogeneity or variability of building height,
d) orientation of streets with regard to prevailing winds, and
e) distribution, size, density, and details of planted and open areas.

2.2.5 DIMENSIONS OF THE OBSTRUCTIONS. The dimensions of the obstructions affect the size and extent of the wake zones. In general, the larger and taller the obstruction, the longer the wake. The spacing between the obstructions determines whether the leeward obstruction will be within the recirculating wake of the upwind obstruction. As described above, a minimum clear spacing of five heights of the upwind obstruction is required.

2.2.6 HOMOGENEITY OR VARIABILITY OF BUILDING HEIGHT. Placing a high-rise building in an area of low-rise development may create strong air currents at ground level. If the upwind building is higher than the downwind one, the lee roller of the high-rise may sufficiently engulf the downwind building to cause ventilation in the downwind building to reverse direction. If the building is taller than six stories, a wind tunnel test is required to determine the pedestrian-level winds.

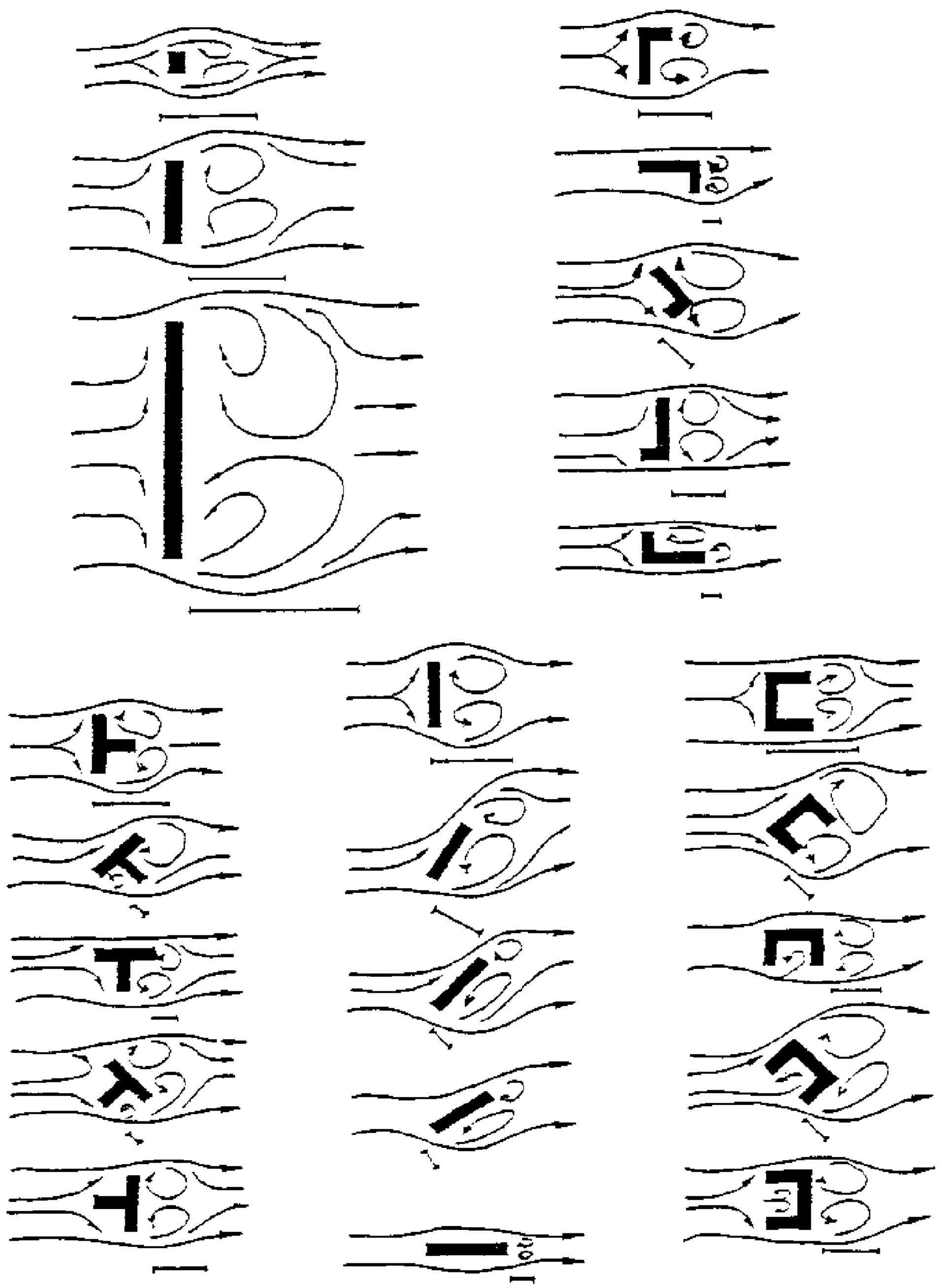
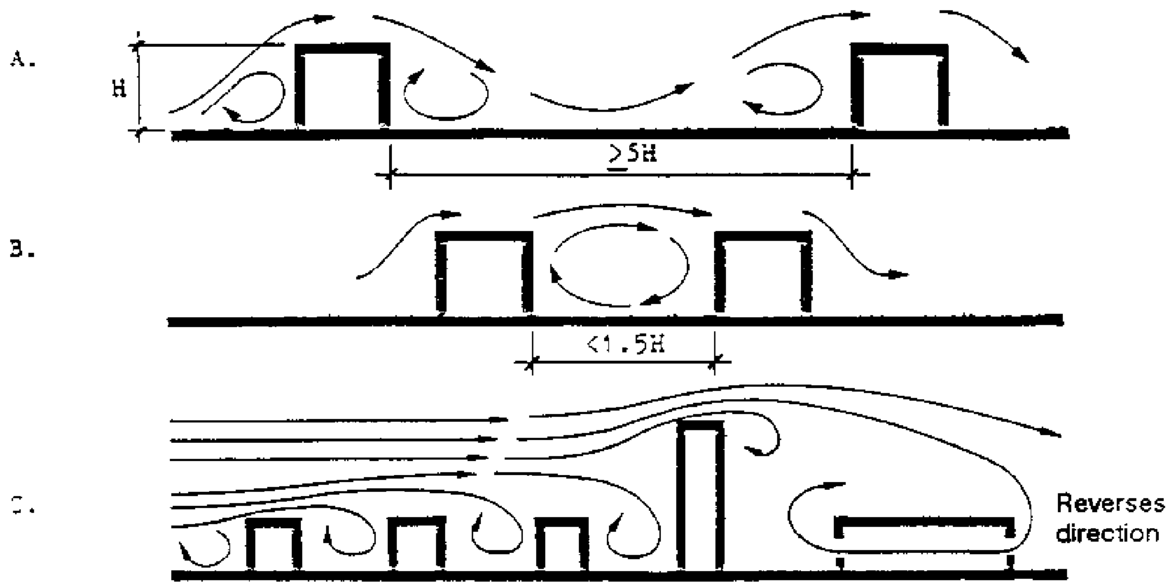


Figure 2

Effect of wind incidence angle, and the length and shape of obstructions on downwind wake



Building wakes
A. Minimum clear spacing to minimize wake effects on subsequent buildings
B. A stable vortex can form if buildings are placed too close together
C. Wind effects of a highrise on other buildings upwind and downwind

Figure 3

Building wakes and interbuilding spacing

2.2.7 ORIENTATION OF STREETS WITH REGARD TO PREVAILING WINDS. If streets are laid out parallel to the prevailing winds, the wind will be funneled into the streets. This funneling will be more pronounced if no major gaps occur between the buildings lining the streets. If streets are laid perpendicular to the prevailing winds and buildings are continuous, the flow will depend on street width as described above. As in the case of single buildings, a clear spacing (street width) of at least five heights of the upwind building is required for the downwind building to have unobstructed ventilation. Grid patterns of buildings require larger building-to-building spacing to maintain ventilation due to the shapes of the building wakes. If the buildings are staggered in a checkerboard pattern perpendicular to the wind (Figure 4), ventilation can be maintained with closer spacing and wake effects are somewhat reduced.

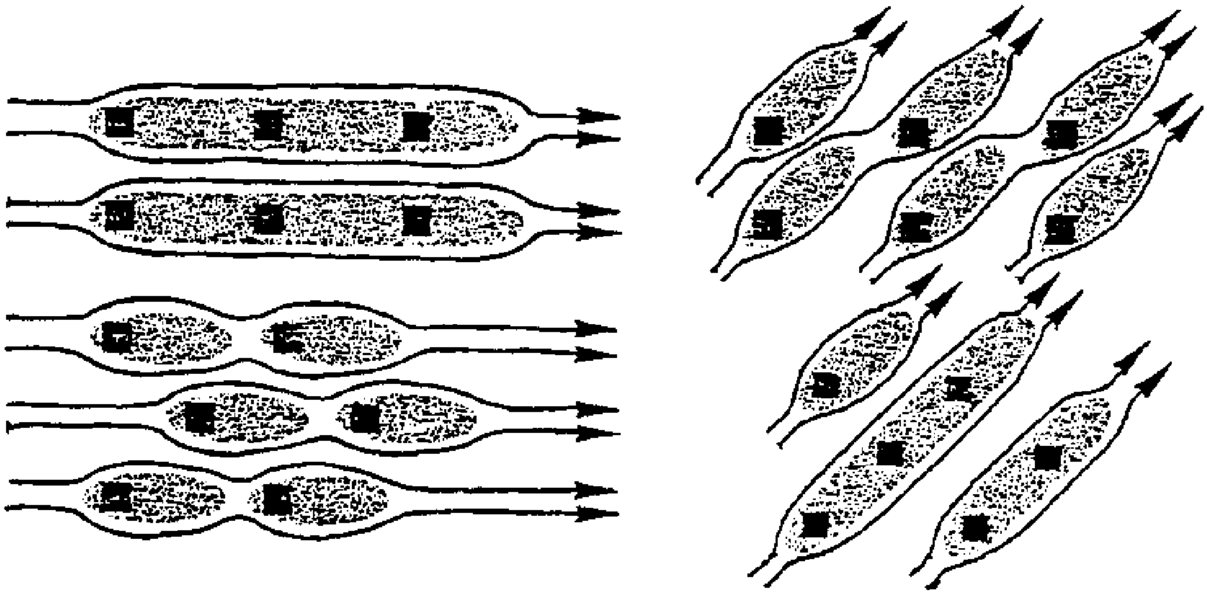


Figure 4

Building spacing configuration and ventilation availability

2.2.8 DISTRIBUTION, SIZE AND DETAILS OF PLANTED AND OPEN AREAS. Planted areas can have a pronounced effect on airflow patterns and speeds. In general, grassy open areas without dense trees or bushes allow the air close to the ground to be cooled and to return to its unobstructed velocity. Sunlit open areas with manmade surfaces may heat the air above them and should be minimized on the windward sides of naturally ventilated buildings. Trees can provide shade but may also block wind if their understory is too dense.

2.3 THERMAL AND OTHER CONSIDERATIONS. Other major factors to be considered in assessing the local features as they affect site planning are presented below.

2.3.1 SOLAR SHADING. Topographic features and obstructions may provide shade and reduce solar gains. Buildings can be arranged to provide shade for adjacent structures and exterior spaces. The extent and timing of shading due to nearby obstructions can be determined using a sun path diagram.

Close building spacing may decrease natural daylight and adversely affect ventilation. Daylighting is not usually a problem for residential types of buildings in hot climates. Whether the ventilation is affected depends largely on the direction of the prevailing wind.

2.3.2 REFLECTANCE. The reflectance of nearby surfaces, especially obstructions and ground surfaces near openings, can have a large effect on the interior temperatures of the building. Reflected light and local heat sources, such as nearby asphalt pavement, can substantially increase internal temperatures of naturally ventilated buildings and should be avoided, especially on the windward side.

2.3.3 SLOPE. A sloping site may affect the heat gain of the buildings if it restricts the orientation of the building and its windows. The optimal orientation for the long face of a building and for windows is north-south facing. Sloping sites which require placement of windows to the east or west should be avoided because they are more difficult to shade.

2.3.4 ELEVATION/ALTITUDE. With increasing altitude, temperature and pollution decrease; precipitation (rainfall, snow, and fog), insolation and daily temperature ranges increase.

2.3.5 PROXIMITY TO WATER. Proximity to large bodies of water may serve to moderate temperature extremes because water stores more and radiates less solar energy than soil. On a smaller scale, ponds or sprays may be used to provide cooling when located near interior spaces if the climate is not too humid.

3. LANDSCAPING.

3.1 GENERAL PRINCIPLES. Landscaping may affect the microclimate of the building site and the air movement in and around buildings. For naturally ventilated building sites, landscaping may be effectively used to provide shade for both the building and for the surrounding outdoor spaces. Landscaping may also be used to increase ventilative potential or provide shelter from excessive wind.

3.2 THE SHELTER EFFECT. Windbreaks can protect both buildings and open spaces from hot or cold winds. A windbreak of vegetation creates areas of lower wind velocity in its lee by:

a) deflecting some of the wind over the windbreak and the zone immediately to the leeward of the barrier,
b) absorbing some of the air's momentum, and
c) dissipating some of the air's directed momentum into random turbulent eddies.

Vegetation is more effective at absorbing wind energy than solid objects, such as buildings, which primarily deflect the wind.

3.2.1 EFFECT OF THE PHYSICAL DIMENSION OF WINDBREAK ON SHELTERED AREAS. The leeward sheltered area varies with the length, height, depth and density of the windbreak. As the height and length of the windbreak increase, so does the depth of the sheltered area. The sheltered area also increases with windbreak depth, up to a depth of two windbreak heights (2H). If the windbreak depth is increased beyond 2H, then the flow "reattaches" to the top of the windbreak and the length of the sheltered area decreases (see Figure 5). An area of slightly lowered velocity also exists for 10H in front of the shelterbelt or windbreak (see Figure 6).

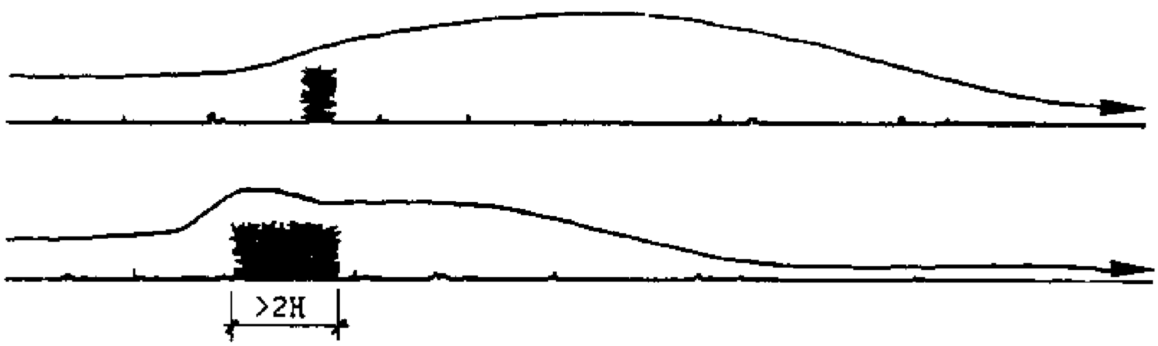


Figure 5

Effect of the along-wind depth of windbreaks on the sheltered area

3.2.2 EFFECT OF POROSITY OF THE WINDBREAK ON SHELTERED AREA. The extent of the sheltered area produced also varies with the porosity of the barrier. Porous barriers cause less turbulence and can create a greater area of total shelter (reduced speeds) than solid barriers. The more solid the barrier, the shorter the distance to the point of minimum wind velocity and the greater the reduction in velocity at that point. The velocity, however, increases more rapidly downwind of the minimum point providing less sheltered area than behind a more porous barrier (see Figure 6).

3.2.3 WIND INCIDENCE. The incidence angle of the wind also affects the length of the sheltered area. Tree and hedge windbreaks are most effective when the wind is normal to the windbreak. If the wind approaches a windbreak at an oblique angle, the sheltered area is reduced (see Figure 7).

3.2.4 TYPE OF VEGETATION. Hedges provide a more pronounced sheltering effect than trees because they have foliage extending to the ground level. In fact, the flow beneath the branches (around the trunks) of trees can actually be accelerated above the free wind speed upwind of the tree (see Figure 8).

3.2.5 RECOMMENDATIONS FOR WINDBREAKS. If a sheltered area is desired for a zoned or seasonally adjustable building, it is recommended that the landscaping be designed to allow for reduced velocities without large scale turbulence. To achieve this, windbreaks should be at least 35 percent porous. The windbreak is most effective when the building it is to protect is located within 1.5 to 5 heights of the windbreak.

3.2.6 RECOMMENDATIONS TO AVOID SHELTERED AREAS. If shelter is not desired, plant trees far apart. Shade trees can be used around buildings without too much ventilation interference if 1) the trees are tall, 2) the trunks are kept bare, and 3) the trees are kept close to the building (see Figure 8). Dense hedges should not be placed so that they affect the airflow through building openings.

3.3 CHANGE IN THE DIRECTION AND VELOCITY OF AIRFLOW.

3.3.1 DEFLECTING AIRFLOW. Rows of trees and hedges can direct air towards or away from a building (see Figure 8). For ventilation, it is generally best to orient rows perpendicular to the window walls to channel airflow towards openings, provided that solar control is maintained. Dense hedges can be used in a manner similar to solid building wingwalls to deflect air into the building openings. Vegetation may be used to create positive and negative pressure zones for ventilation or to increase the windward area of the building. Per unit area, vegetation will not be as efficient as solid wingwalls in producing these effects, but it can be more cost effective than wingwalls because it can be much larger at a lower cost.

3.3.2 INCREASING WIND VELOCITIES. Vegetation can create areas of higher wind velocities by deflecting winds or by funneling air through a narrow opening. See Figure 10. Narrowing the spacing of the trees used to funnel air can increase the airflow 25 percent above that of the upwind velocity. A similar effect occurs at the side edge of a windbreak.

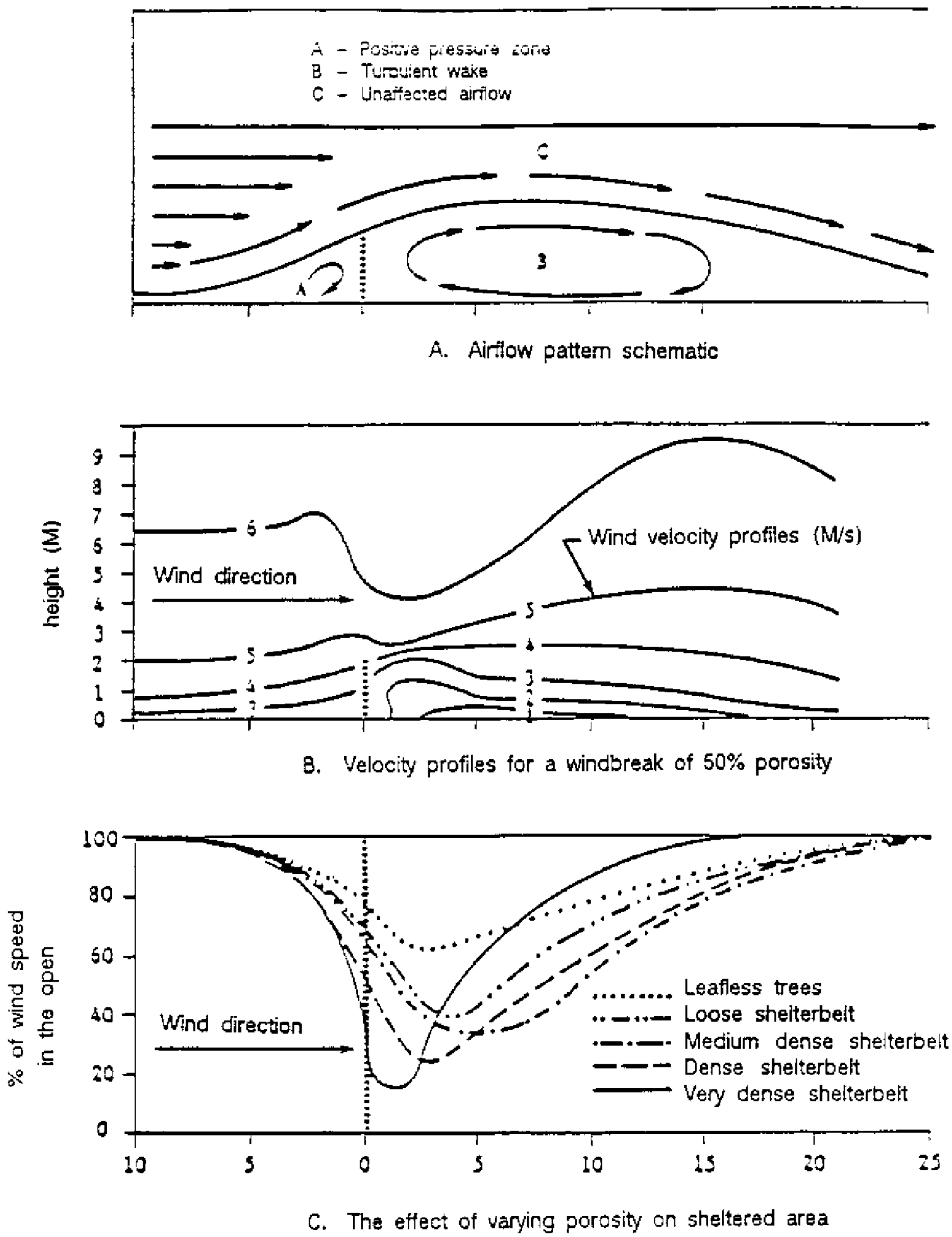


Figure 6

Shelter ground windbreaks

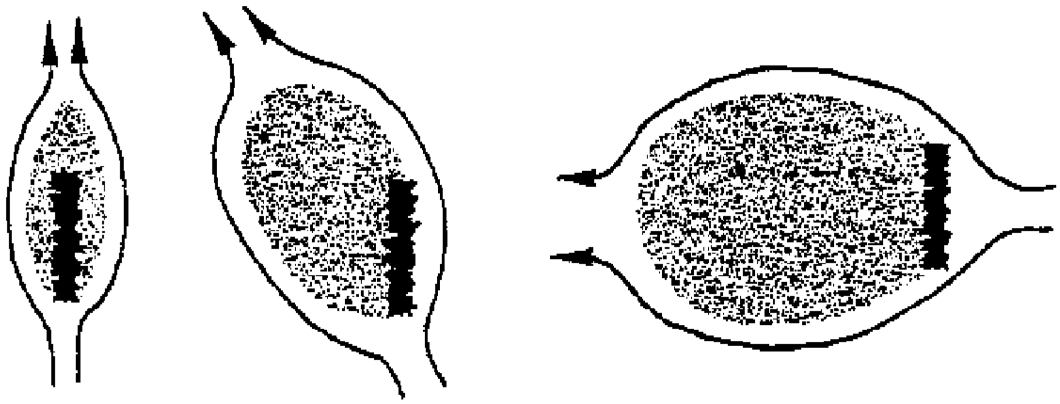


Figure 7

Effect of wind incidence angle on sheltered area

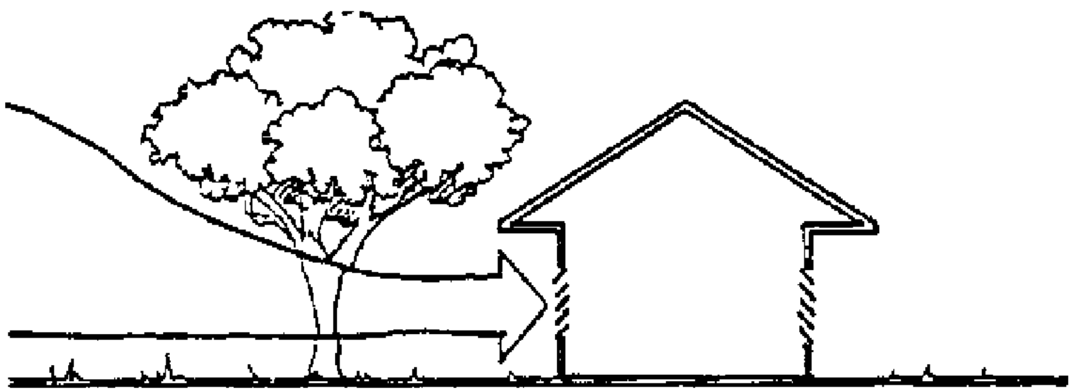


Figure 8

Acceleration of wind under trees

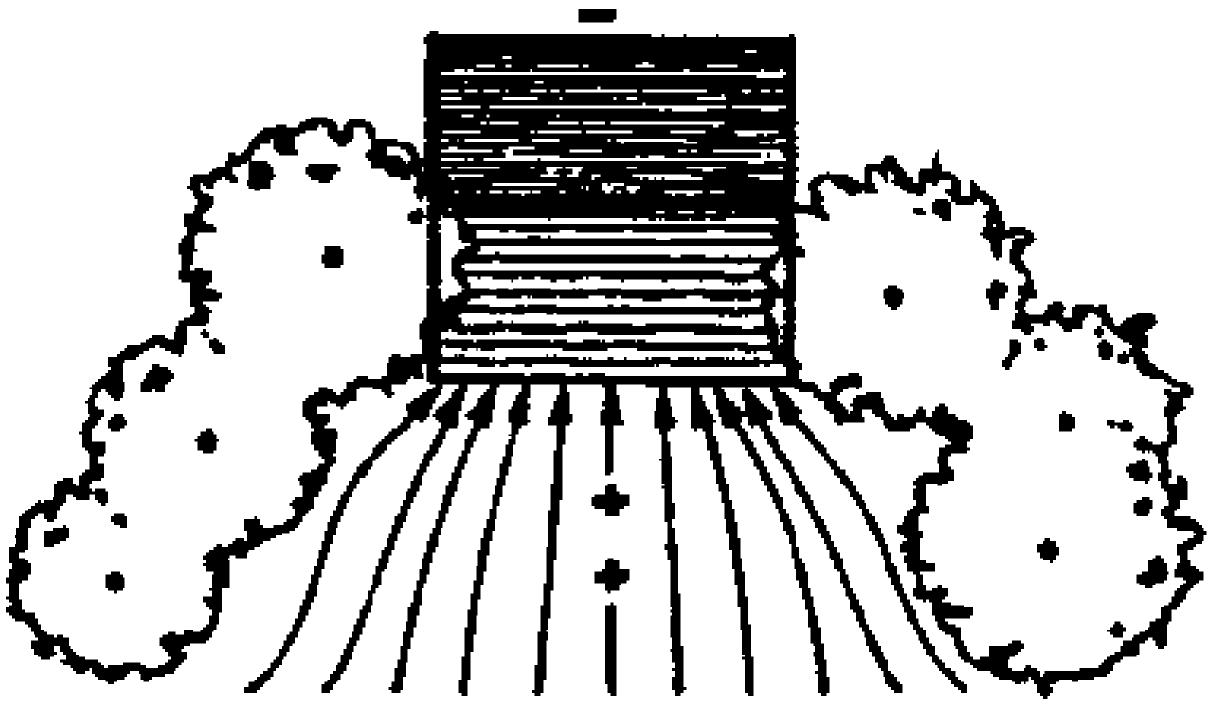


Figure 9

Funneling of air by landscaping

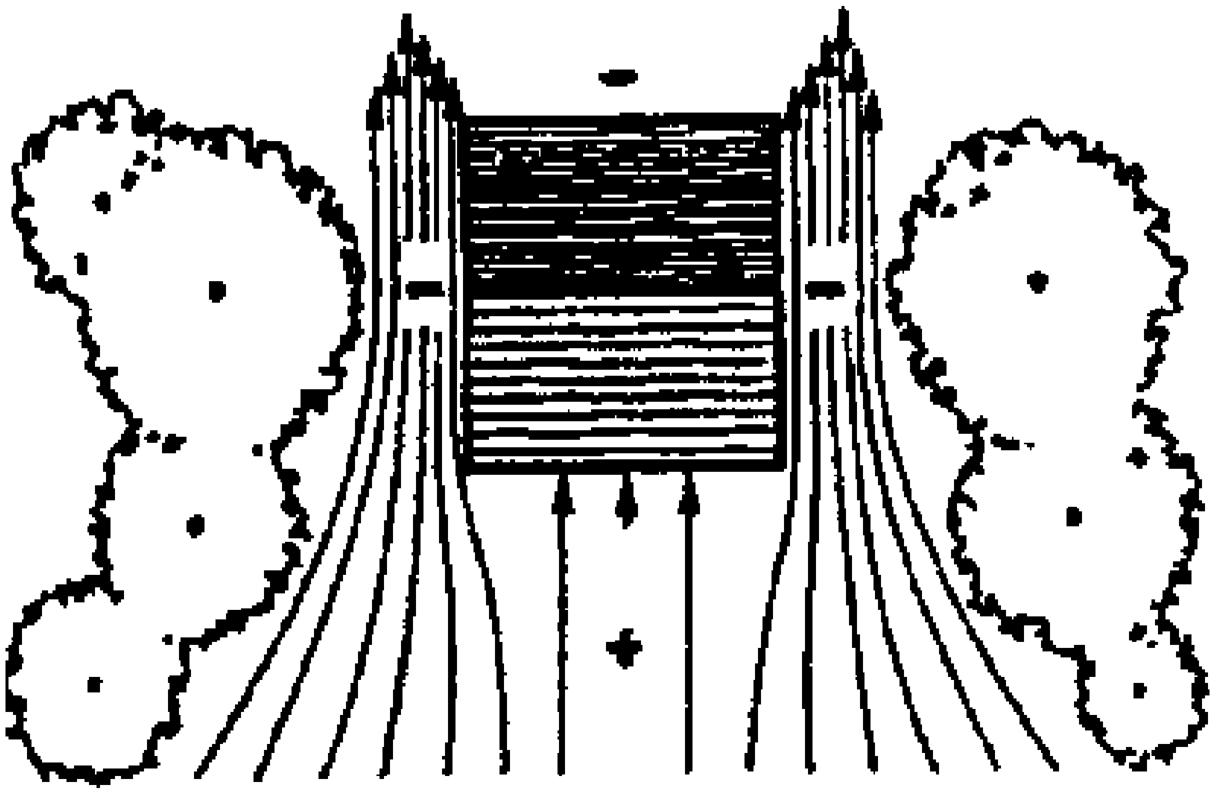


Figure 10
Air accelerated by landscaping

3.4 THERMAL CONSIDERATIONS.

3.4.1 BLOCKING SOLAR RADIATION. Large-scale landscaping, such as trees and vines on trellises, are used to shade buildings and the surrounding ground surfaces. This reduces direct solar gain to the building and indirect radiation reflected upward into the building from the ground. Trees can block up to 70 percent of the direct solar radiation, and also filter and cool surrounding air through transpiration.

Material	Reflectance (%)
Light sand dunes	30-60
Soil, sandy	15-40
Soil, dark cultivated	7-10
Green grass, meadow	20-30
Dry grass	32
Woods, bushes	5-20
Bark	23-48
Water surfaces, sea	3-10
Concrete	30-50
Brick, various colors	23-48
Blacktop	10-15

Table 1

Reflectance values of various ground covers

3.4.2 GROUND REFLECTANCE. Natural ground covers tend to be less reflective than bare soil or man-made surfaces, thereby reducing ground-reflected radiation.

Ground-reflected light represents 10 to 15 percent of the total solar radiation transmitted to the first floor of a building on the sunlit side and may account for greater than 50 percent of total radiation transmitted on the shaded side. Some portions of this radiation can provide desirable daylighting within the building, but glare and total solar gain are usually greater problems in hot climates. In general, trees, shrubs and other irregular vegetation have lower reflectivity than planar vegetated surfaces such as grass.

3.5 OTHER CONSIDERATIONS.

3.5.1 REDUCING AIRBORNE DUST. Vegetation filters the air and minimizes lifting of dust from the ground. It is most useful on the windward side of buildings especially when highways, open lots, or parking lots are located nearby.

3.5.2 REDUCING SOUND LEVELS. Mixtures of deciduous plants and evergreens reduce sound more effectively than deciduous plantings alone; however, vegetation has a relatively small effect on sound levels.

3.5.3 VISUAL SCREENING. Vegetation can also be planned to provide visual screening for privacy requirements as long as it does not interfere with the design for effective ventilation.

4. BUILDING FORM.

4.1 GENERAL PRINCIPLES. Building orientation will determine the intensity of solar radiation falling on the walls and roof of the building, and the ventilative effectiveness of the building openings. Building shape determines the amount of exterior surface area for a given enclosed volume and the length of the interior path of the ventilation air. Together, these factors determine the relative amount of thermal transfer through the building envelope and the potential effectiveness of a design to provide cooling by natural ventilation. Although building shape and orientation are important in minimizing unwanted solar gain, it is possible to counteract some of this gain or partially compensate for improper orientation and shape with the design of the building envelope. Such design measures include light-colored wall surfaces, locally shaded windows, extra insulation, wingwalls, etc. Likewise, it may be possible to somewhat compensate for poor orientation to the wind by detailed design of the facade and windows, and for poor building shape by the arrangement of the building's interior plan.

4.2 OPTIMAL SHAPE AND ORIENTATION.

4.2.1 THERMAL CONSIDERATIONS. In nearly all climates, the optimum shape for solar control is roughly elongated along the east-west axis. See Figure 11. To minimize solar gains, elongate the north and south walls creating an east-west axis. East and west exposures (walls and especially glazing) should be minimized since they are difficult to shade and receive longer periods of direct radiation. South and north exposures are less difficult to shade, especially with roof overhangs. A variation of 15 to 20 degrees from true south has little effect on the thermal performance of small buildings.

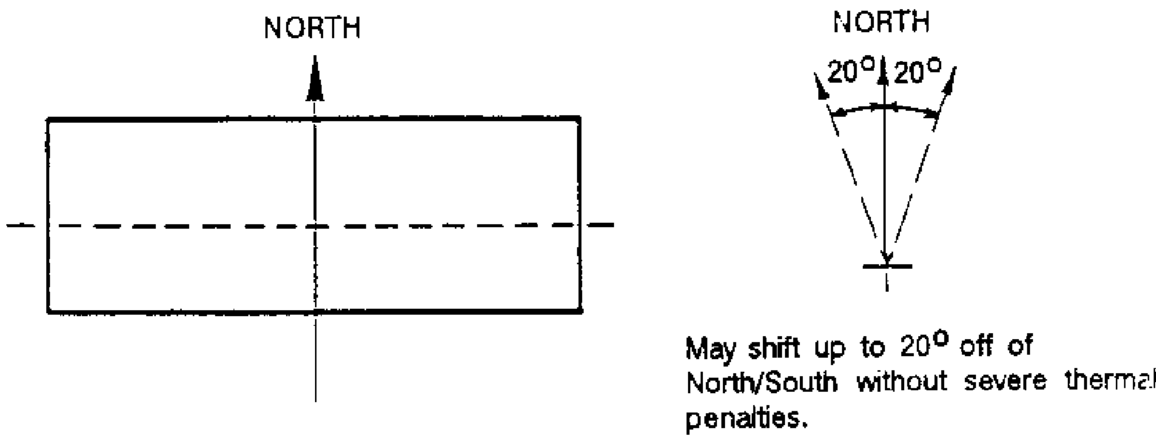


Figure 11

Building orientation and solar heat gain

The optimal elongation depends on climatic conditions. In severe hot-humid climates, extreme elongation (2.5 to 1 ratio) creates a narrow building with a large wind-exposed face for ease of ventilation. In temperate climates, more freedom in building shape and orientation is allowable.

4.2.2 VENTILATION CONSIDERATIONS. For an elongated building without openings, the largest pressure differences (which drive cross-ventilation) occur when the building is perpendicular to the prevailing wind. However, this orientation does not necessarily result in the best average interior velocity rates or airflow distribution. For bodily cooling, the goal is to achieve the highest average room velocity in which air movement occurs in all occupied parts of the room. When windows are in adjacent walls, the optimum ventilation occurs with the long building face perpendicular to the wind, but a shift of 20 to 30 degrees from perpendicular will not seriously impair the building's interior ventilation. This allows a range of orientations for resolving possible conflicts with the optimum solar orientation.

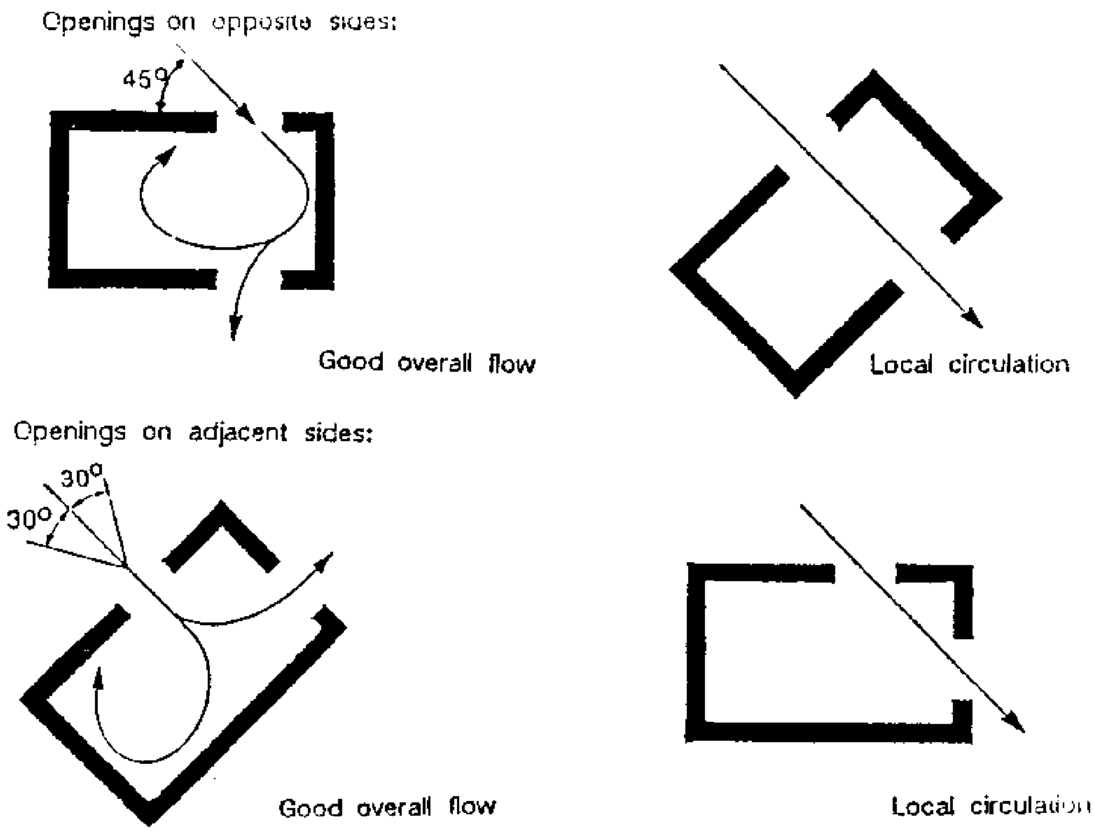


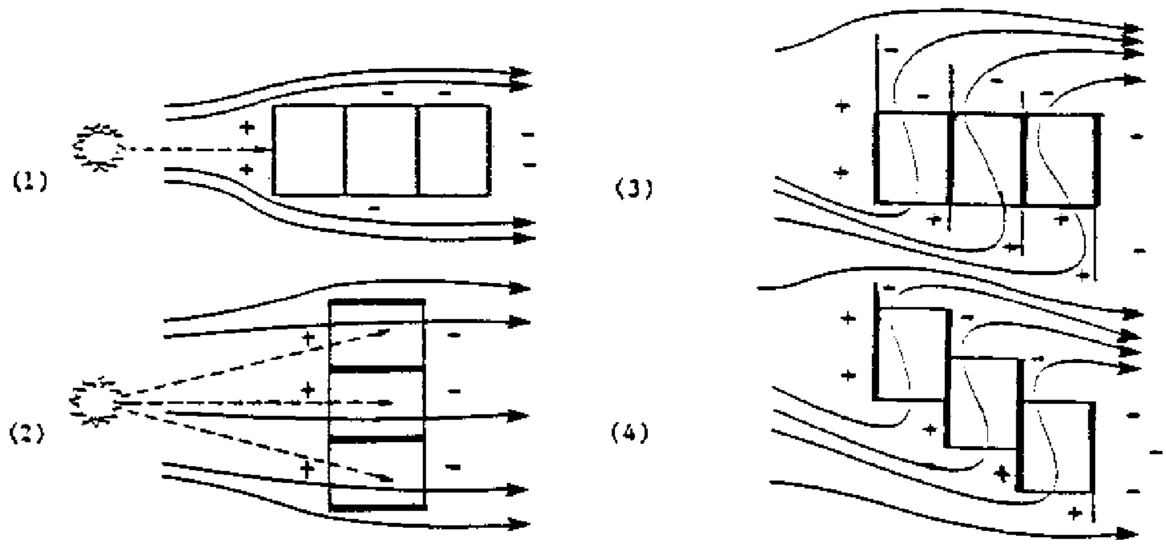
Figure 12

Effect of wind incidence angle on interior air flow

Wind approaching at an incidence angle of 45 degrees results in interior velocities that are 15 to 20 percent lower than when the wind approaches perpendicular to the face (see Figure 12). When windows are in opposite walls, a 45-degree incidence angle gives the maximum average indoor air velocity and provides better distribution of indoor air movement. Wind approaching at 90 degrees is 15 to 20 percent less effective. Wind parallel to the ventilation face produces ventilation depending entirely on fluctuations in the wind and is therefore very uncertain (see Figure 12).

4.2.3 RESOLVING CONFLICTS BETWEEN THERMAL AND WIND ORIENTATIONS. Where optimal solar orientation and wind orientation are opposed, solar considerations usually take precedence. In general, inlets for natural ventilation can more easily be designed to accommodate for less than optimal wind orientations than solar control devices (see Figure 12). This is especially true in high-rise buildings where orientation to reduce solar gains is most important. However, if the building is a low-rise, well-insulated, has a light external color, and has effectively shaded windows, then the change in internal temperature with respect to orientation may be negligible. In such cases, ventilation has a greater effect on the internal conditions, and orientation with respect to winds should take precedence.

4.3 ELEVATED BUILDINGS. Buildings elevated on columns or lateral walls can have an increased ventilative potential of up to 30 percent over that of buildings on grade. Wind velocity increases with increasing height above the ground; elevating the building raises it to an area of greater free wind speeds. Elevated buildings also allow for inlets in the floor of the structure which can permit cool, shaded air to enter the building from below. This design is common in hot, humid climates where floors are elevated to reduce structural rot. When situated next to water, elevated buildings can allow cooler air that has passed over the body of water to enter the building from below. Elevating the building may also be worthwhile if the ground is continually damp or when the building is located in a flood plain. Airflow beneath a high-rise elevated building may be accelerated beyond a level which is comfortable or safe for pedestrians.



Alternative solutions to the problem created when sun and wind both come from the west in hot climates where cross ventilation is required for comfort.

(1) With wind and sun from the west, rooms with two external walls facing north and south will have little air movement, but protection from solar radiation

(2) Rooms facing east and west will have breeze and solar radiation, a less desirable combination

(3) The careful placing of external walls can be used to create high and low pressure zones to achieve cross ventilation 'turning' the air movement through 90°

(4) The staggering of rooms can be used to achieve the same result, obtaining the benefit of cross ventilation and protection from solar radiation at the same time

Figure 13

Resolving conflicts between thermal and wind considerations

5. BUILDING ENVELOPE AND STRUCTURE.

5.1 GENERAL PRINCIPLES. The building materials and type of construction used will have a significant effect on the heat gain and heat loss characteristics of the building. For naturally ventilated buildings, lightweight materials with light-colored, heat-reflecting outer surfaces are desirable. The major building components of the structure are the roof, which provides shade and protection from the rain, and the fenestration system, which determines the volume, velocity and distribution of interior ventilation.

5.2 ROOF AND ROOF VENTILATORS.

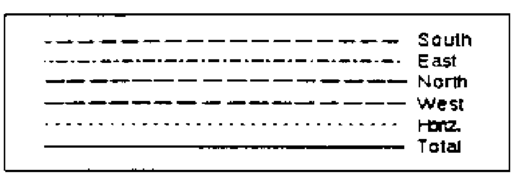
5.2.1 ROOF OVERHANG EFFECTS ON ROOM VENTILATION. Roof overhangs can enhance ventilation by damming the air stream in a pocket at the wall; thereby, increasing the positive pressure outside the window and consequently the airflow through the opening.

5.2.2 ROOFS—THERMAL CONSIDERATIONS. Roofs receive the most solar radiation of any building surface and are the primary protection from direct radiation in low-rise buildings. The amount of solar radiation falling on the surfaces of a building varies with latitude, season, time of day and building orientation. Use light coloring on the roof to reflect solar gain. Effective insulation, including the use of radiant barriers above resistive insulation, is critical to ensure comfort in spaces below the roof (see Figure 15). Attics above living spaces need to be independently ventilated. As roof pitch decreases, the temperature of the ceiling below can be expected to rise.

26° NORTH LATITUDE						June 21
Time		: Btu/sq.ft–hr				
a m	p m :	South	East	North	West	Horizontal
6	6 :		98	38	96	19
7	5 :		180	52	180	79
8	4 :		193	38	193	143
9	3 :		171	19	171	199
10	2 :		126	3	126	243
11	1 :	9	66		66	271
12		13				281

26° NORTH LATITUDE						March/September 21
Time		: Btu/sq.ft–hr				
a m	p m :	South	East	North	West	Horizontal
6	6 :					
7	5 :	21	175		175	42
8	4 :	56	222		222	115
9	3 :	88	202		202	181
10	2 :	114	150		150	233
11	1 :	130	79		79	266
12		135				277

26° NORTH LATITUDE						December 21
Time		: Btu/sq.ft–hr				
a m	p m :	South	East	North	West	Horizontal
6	6 :					
7	5 :	5	9		9	
8	4 :	120	171		171	51
9	3 :	177	179		179	113
10	2 :	212	138		138	162
11	1 :	232	74		74	194
12		239				204



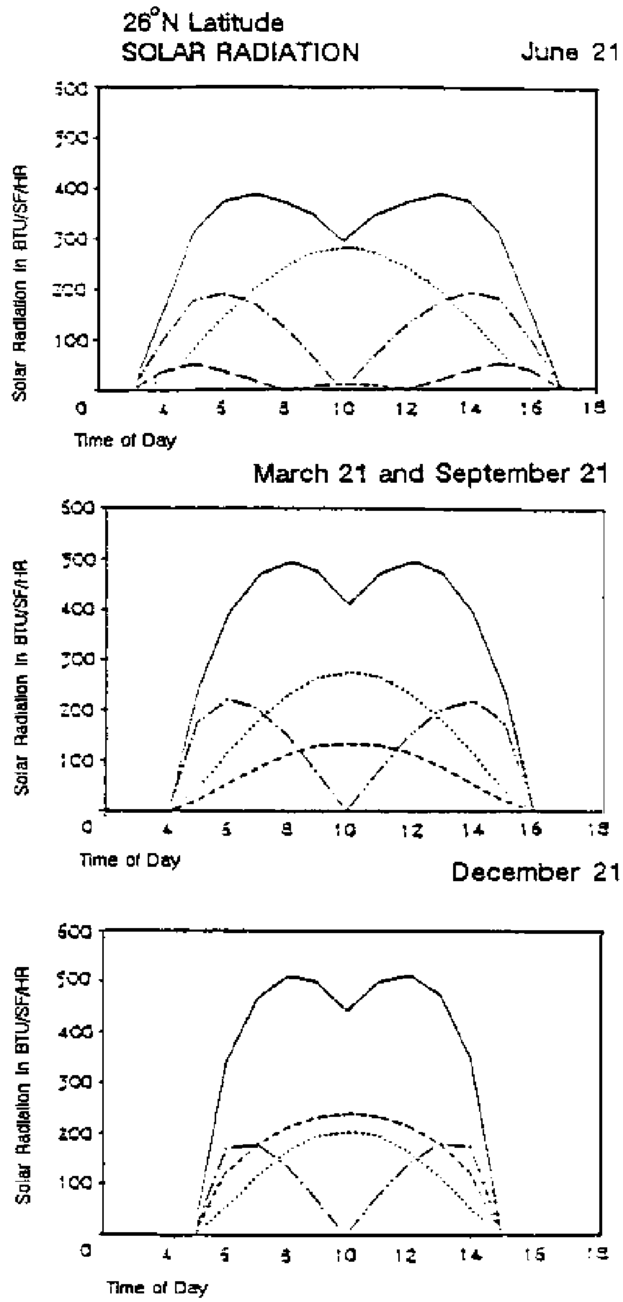


Figure 14

Direct irradiation values in Btu/ft^2/hr for 26 deg north latitude

Also, ventilation of the attic space becomes progressively more difficult. Attic ventilation should be designed so that openings are provided in both positive and negative pressure areas to provide proper cross-ventilation. When venting attic spaces, be careful to place exhaust outlets so that hot air is not blown into occupied spaces or near air inlets. Overhanging eaves may provide necessary solar shading for windows and building surfaces.

5.2.3 VENTILATORS. Higher indoor air movement can be obtained with proper cross-ventilation than with roof openings. Therefore, roof ventilators should not be considered as alternatives to proper wall openings but should be used in conjunction with proper wall openings to obtain well ventilated interior spaces. Only part of the windward slope of a steeply pitched roof is under positive pressure. Low pitched and flat roofs are subject to suction over their entire areas when:

X = 1.2 x length (feet)

where:

length = Length of the building in the windward direction
X = Area of the windward face

Under these conditions a stagnant zone exists over the entire roof due to flow separation occurring at the windward eave. The result is that the entire roof is more or less under suction and is a good location for exhaust outlets. With high pitched roofs and when the building length is greater than 1.2 times the area of the windward face, the stagnant zone exists mainly downstream from the ridge while a portion of the windward side of the roof is under positive pressure. The critical roof pitch at which the point of flow separation is displaced from the windward eave to the ridge depends, to a large extent, on the wall height, but may be taken between 18 and 25 degrees for wall heights between 12 and 15 ft (3.6 and 4.6 m), respectively (see Figure 16).

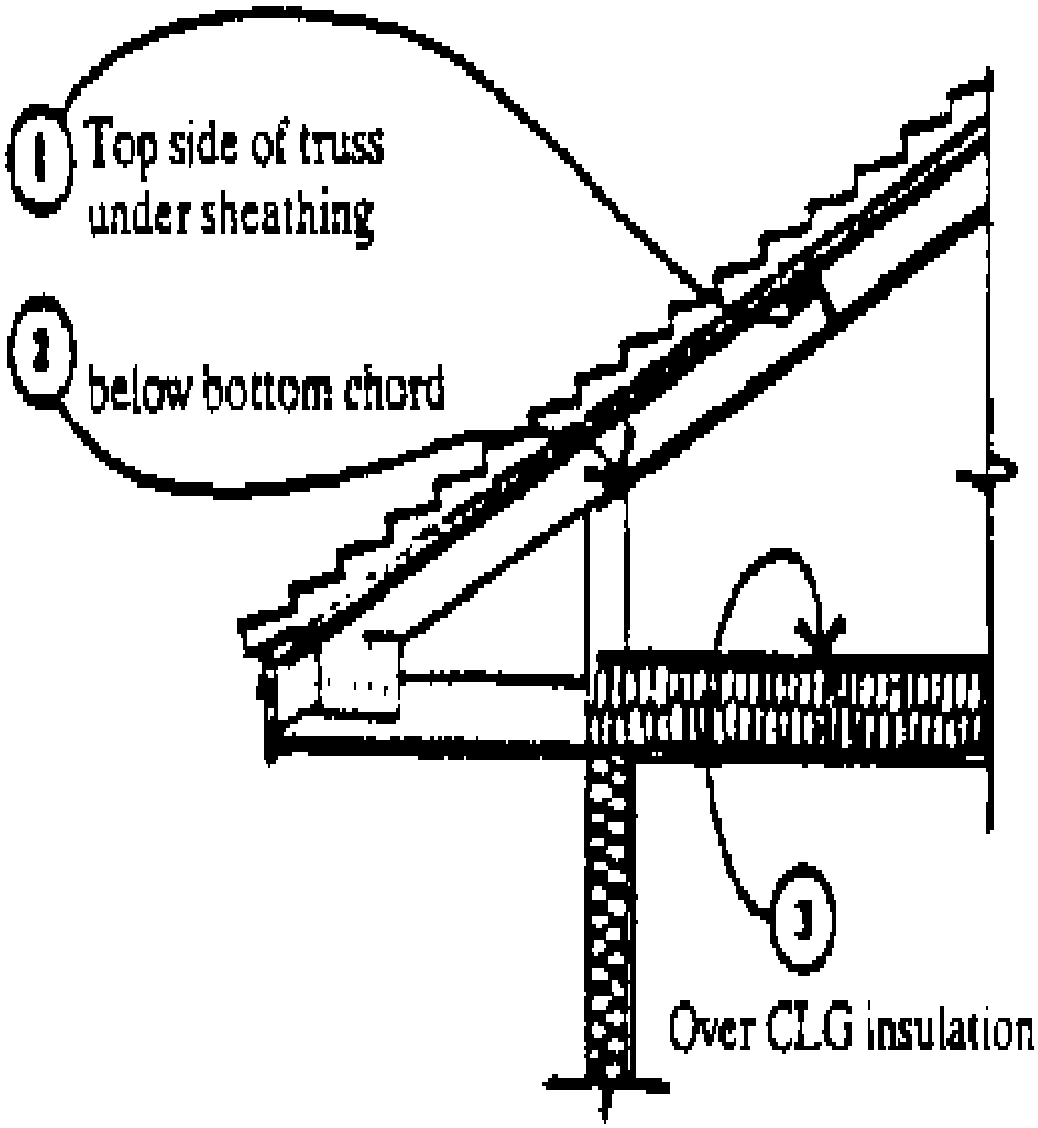


Figure 15

Attic section with three possible locations for a radiant barrier

5.2.4 VENTILATOR PLACEMENT. Use the strong negative pressure areas near the ridge as exhaust locations. Placement of exhaust openings on high pitched roofs is more critical because of possible positive pressure zones, which should be avoided. Ventilators or wind scoops with openings facing the wind can act as effective inlets but water infiltration must be considered in their design and location. Possible problems with privacy, rain, and noise from ventilators must be identified and resolved.

5.2.5 VENTILATOR PERFORMANCE. Wind tunnel studies have shown that the performance of common turbine roof ventilators is only slightly better than that of an uncapped pipe. All other tested pipe designs proved more effective than the turbine type. The highest performance for a simple ventilator was produced by placing a canted flat plate over the pipe (see Figure 17).

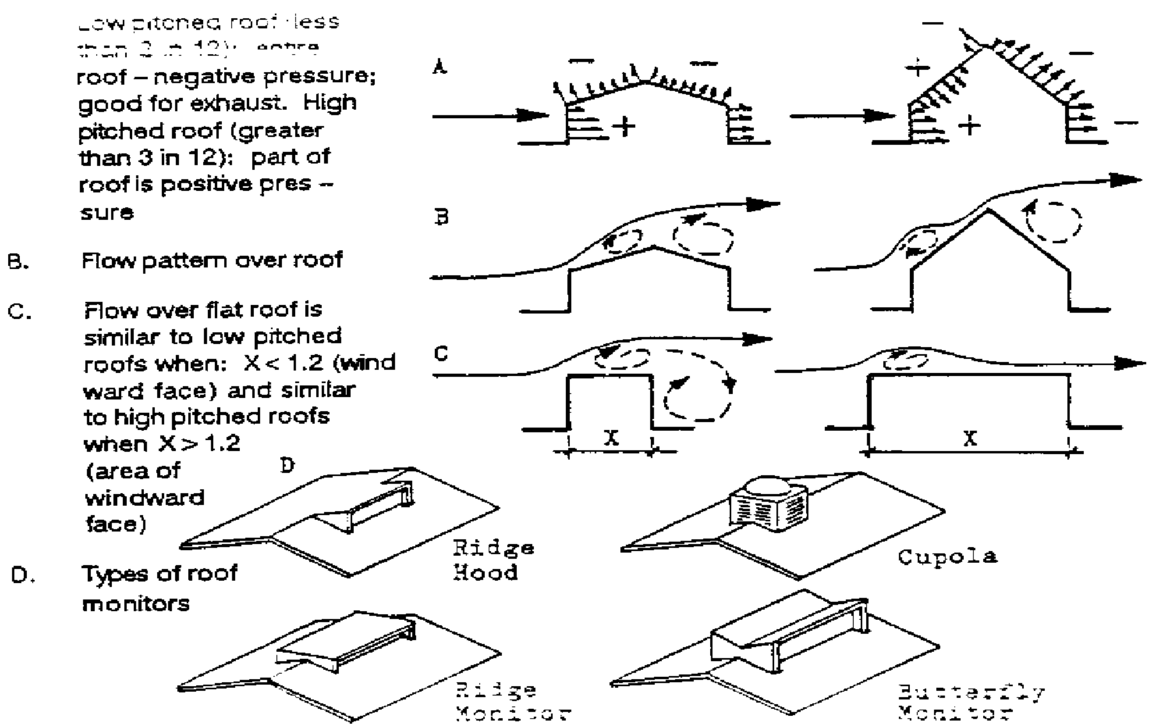


Figure 16

Effects of slope on roof pressures and ventilation characteristics

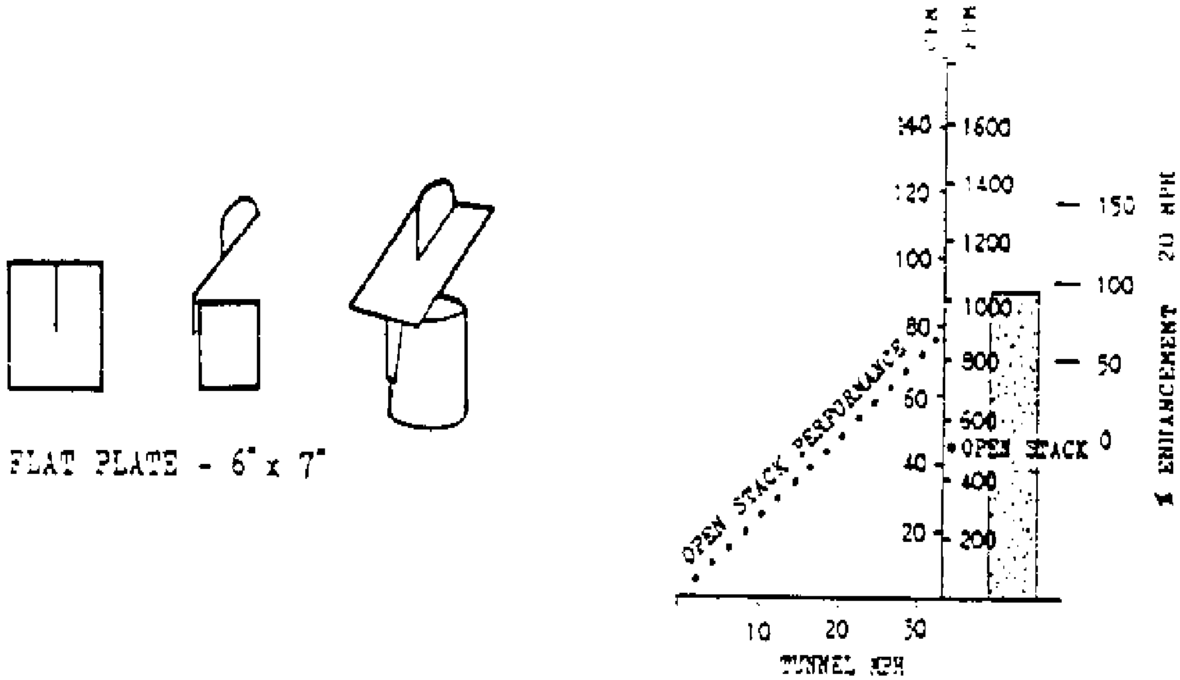


Figure 17

Roof ventilators: performance of simple flat-plate ventilators

Wingwalls can increase the elevational area of the building and increase the positive pressure build up and interior velocity. The lengths of the arrows suggest the relative pressure differences.

Figure 18

Effect of wingwalls

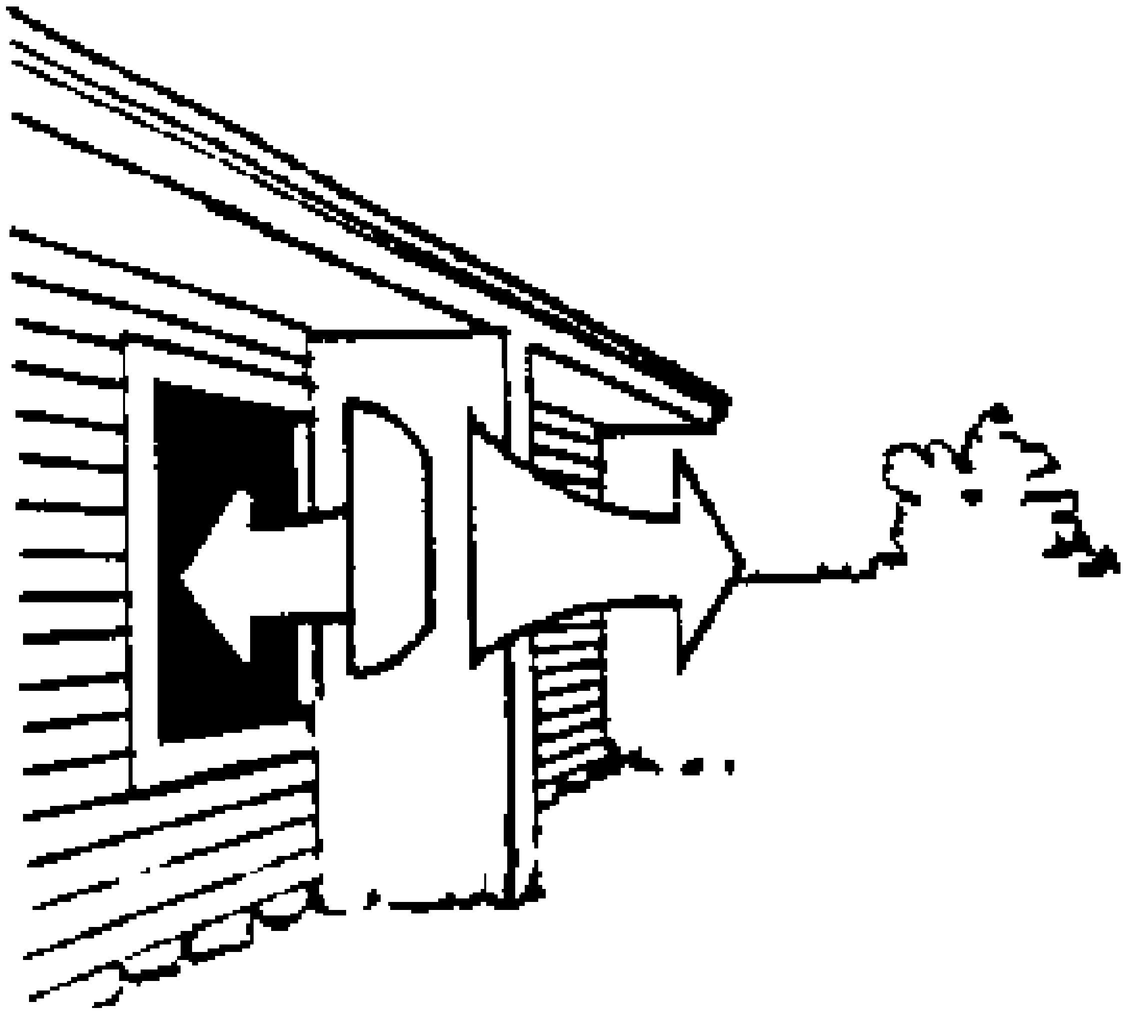


Figure 19

Wingwall acting as air flow diverter

5.3 WINGWALLS. Wingwalls or exterior vertical fins can increase a building's ventilative potential by catching and deflecting winds into the interior. Properly designed wingwalls may also provide solar shading by acting as vertical fins on east and west elevations.

5.3.1 VENTILATIVE CONSIDERATIONS. Wingwalls can increase interior ventilation rates when the wind incidence angle is perpendicular to the building face. Placement of wingwalls to the side, or parapets on top of the building, increases the area of the windward facade creating higher positive pressures and resulting in higher interior velocities (see Figure 17). Wingwalls can also be used to intercept and increase the admittance of oblique breezes into the building. Wingwalls placed perpendicular to the building facade can create air dams that "trap" and redirect air into the building (see Figure 19).

5.3.2 IMPROVING CROSS VENTILATION. One of the most useful effects of wingwalls is the creation of cross-ventilation in rooms with windows on one wall only or in rooms without positive pressure inlets and negative pressure outlets. Proper placement of wingwalls can create positive and negative pressures which drive ventilation in otherwise stagnant rooms (see Figure 20). Wingwalls can improve ventilation in rooms with openings only on the windward side, but are effective only if they create positive and negative pressure zones. They cannot improve ventilation in rooms with openings on the leeward side only. For ventilation with openings in one wall only, up to 100 percent improvement of the interior airflow and air change rate may be achieved. Wingwalls do not significantly enhance ventilation in cross-ventilated rooms with openings on opposite walls unless the wind incidence angle is oblique. For oblique wind angles (40 to 60 degrees), wingwalls can increase average interior velocity by up to 15 percent.

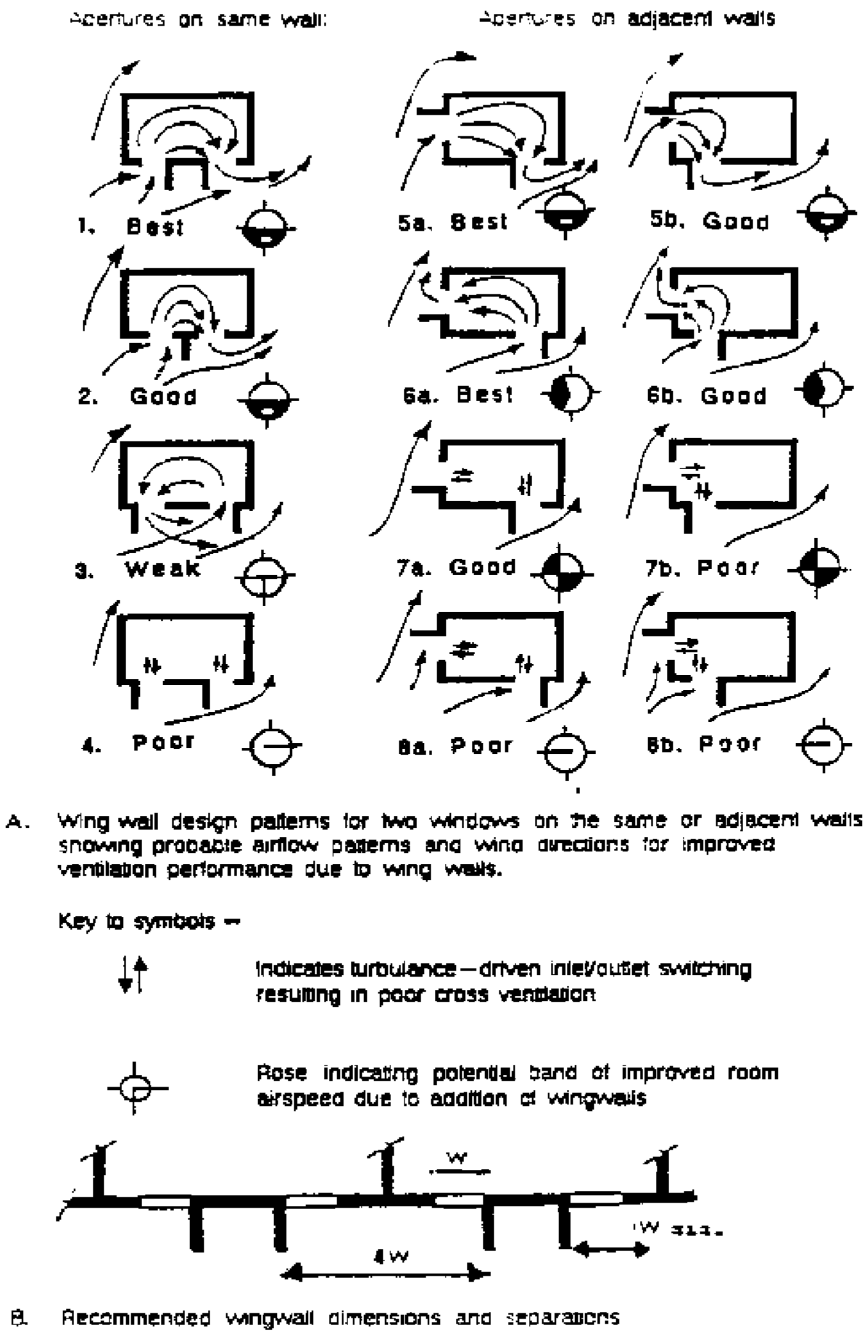


Figure 20

Wingwall designs and their effects on interior airflow patterns

5.3.3 PLACEMENT AND SIZE. Wingwalls from the ground to eave on small scale buildings are effective for wind incidence angles from 20 to 140 degrees. Wingwalls can be thicker than shown in the preceding figures. Projecting bathrooms, closets, entrances or other architectural features may serve as "wingwalls."

5.3.4 THERMAL CONSIDERATIONS. Wingwalls may also serve as solar shading devices, and are especially useful on southeast and southwest facades.

5.4 WINDOWS.

5.4.1 VENTILATION CONSIDERATIONS. As the wind blows onto and around buildings, it creates regions in which the static pressure is above or below that of the undisturbed air stream. Positive pressure on the windward side forces air into the building, and negative pressure on the leeward side pulls it out of the building. Pressures on the other sides are negative or positive depending on the wind incidence angle and the building shape. The rate of interior airflow is determined by the magnitude of the pressure difference across the building and the resistance to airflow of the openings. The size, shape, type and location of the openings, especially the inlets, determine the velocity and pattern of internal airflow. When designing and placing windows and openings for ventilation, the following factors must be considered:

a) Predominant external wind and directions when the winds occur.

b) Construction of the building envelope and landscaping may hinder or facilitate natural ventilation of the interior spaces.

c) Location and type of inlets has the largest effect on the airflow pattern through the space.

d) Location and outlets type has little effect on airflow pattern.

e) Number of air changes per hour has little to do with body cooling; the airflow velocity and distribution pattern are more important.

f) Changes in indoor airflow direction tend to retard airspeed.

5.4.2 CROSS VENTILATION. Cross ventilation provides the greatest interior velocities and the best overall air distribution pattern. Openings in both positive and negative pressure zones are required for cross ventilation (see Figure 21). For windows on adjacent walls, the overall room air distribution is best (10 to 20 percent higher average velocities) when the wind incidence angle is perpendicular to the building face. For windows on opposite walls, oblique wind incidence angles give 20 to 30 percent higher average velocities than perpendicular winds. See Figure 12.

5.4.3 WINDOWS ON ONE WALL. When windows are restricted to only one surface, ventilation will usually be weak, and is independent of the wind direction. Average internal wind speed will not change significantly with increasing window size. One-sided ventilation can be made effective when 1) two openings are placed on the windward face, 2) the wind angle is oblique (20 to 70 degrees), 3) the windows are as far apart as possible, and 4) if deflectors such as wingwalls are used (see Figures 20B and 22).

5.4.4 EXPECTED INTERIOR AIR SPEEDS. Indoor airspeeds, even under the most favorable conditions, are only 30 to 40 percent of the free exterior wind speed in cross-ventilated spaces; 5 to 15 percent of the free exterior wind speed in rooms with openings in one wall only; and only 3 to 5 percent in rooms with one opening.

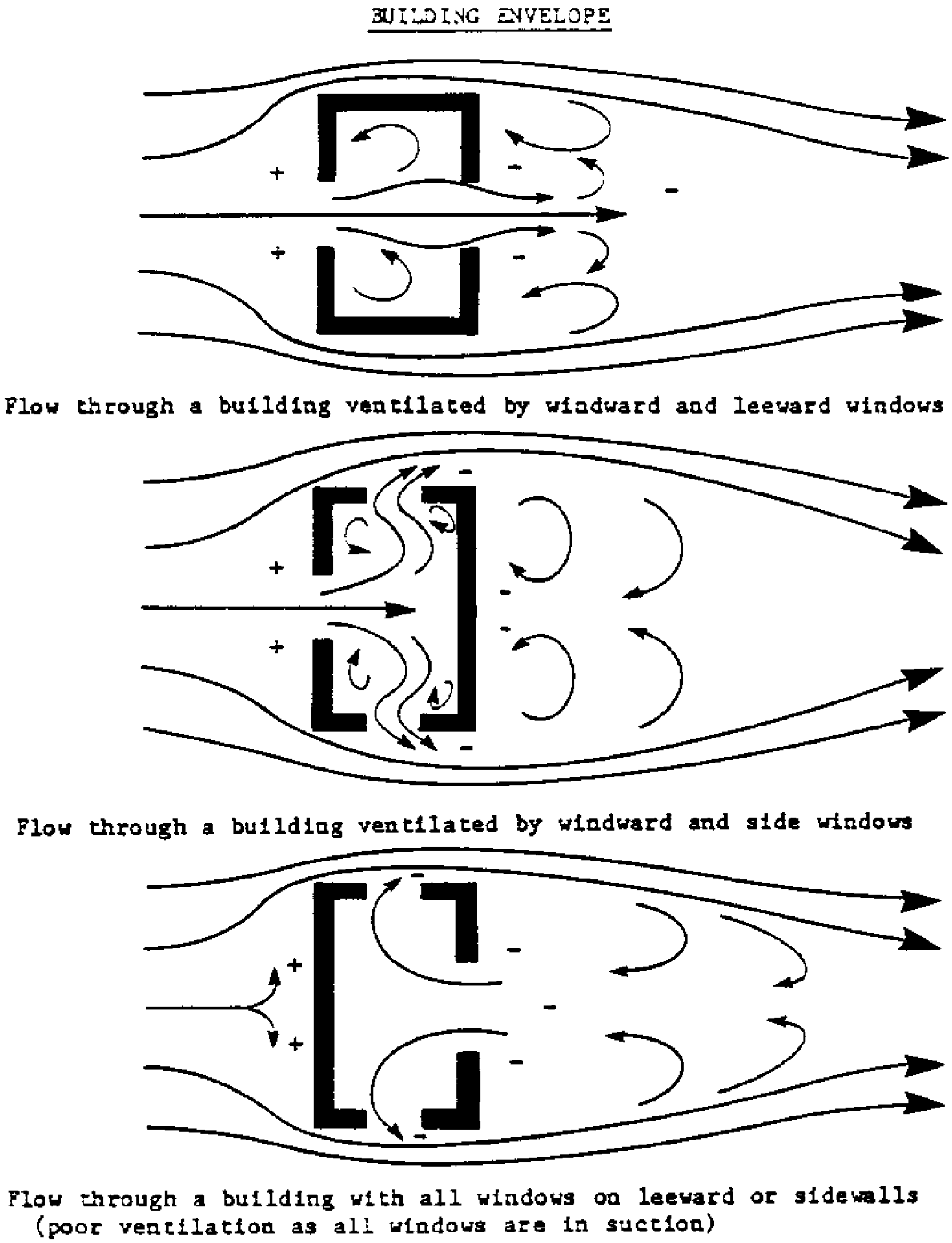
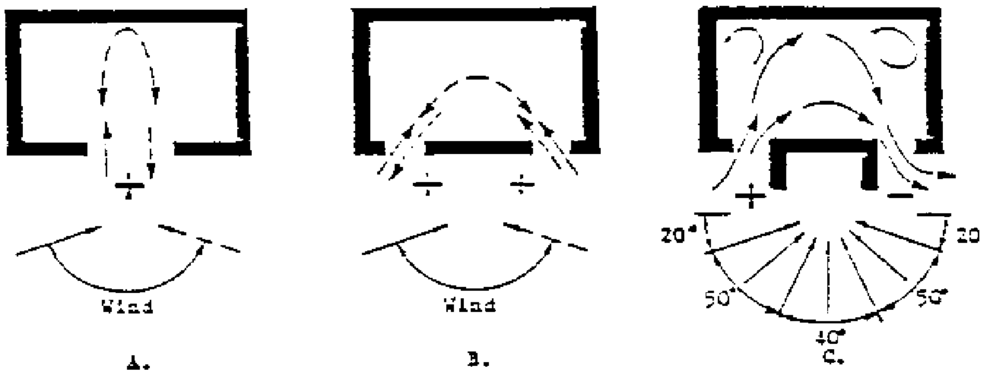


Figure 21

Flow through a building with all windows on leeward or sidewalls

(poor ventilation as all windows are in suction)



A. Worst case: one opening. Ventilation is dependent upon pulses (fluctuation) of the wind.

B. Better: Two windows placed as far apart as possible and facing obliquely into the wind. Ventilation is better becuase there is a greater difference in pressure between the two openings.

C. Best. Two openings placed far apart with apropriate located wingwalls facing obliquely into the wind. Wingwalls improve ventilation by creating positive and negative pressure zones that drive airflow.

Figure 22

Ventilation in rooms with openings in one wall

5.4.5 EFFECT OF EXTERIOR CONDITIONS. The spaces between buildings will condition the air before it enters through building openings. If possible, the airflow approaching the building inlet should not pass closely over a large hot surface (such as a sunlit asphalt parking lot) which will heat the incoming air.

5.4.6 THE VERTICAL LOCATION IN THE WALL. The stack effect in most residential buildings is negligible and completely overwhelmed by even modest wind effects. If stack ventilation is used, openings must be placed both low and high in the building. While the movement of air as a result of the stack effect may be adequate for fresh air supply, it is rarely sufficient to create the appreciable air movement required in hot zones to provide thermal comfort. Schemes that attempt to create forced stack ventilation by heating mass within the stack should not be used. For wind-driven ventilation, outlet height has little influence on interior airflow, but inlet height has a great effect on the airflow pattern in the room. Positive pressures built up on the windward face of the building can direct the airflow up to the ceiling or down to the floor of the room. These positive pressures are related to the area of the windward face. Thus, a window located high on the wall directs airflow up to the ceiling because the positive pressure built up on the building face is larger below the window than above it (see Figure 23). There is usually an abrupt drop (up to 25 percent) in air speed below the level of the inlet sill (see Figure 23). The sill height may significantly alter the air velocity at certain levels while only slightly affecting the average air speed in the whole room. Therefore, for body cooling, the best location for windows is at or below body level. Remember that body level changes with room use and that body level in bedrooms is at bed height, while body level in offices is at sitting height. Vertical placement is also affected by window type since different window types produce different airflow patterns.

5.4.7 WINDOW TYPE. Table 2, in association with Figure 25, provides data pertaining to the effects of various window types on airflow.

5.4.8 WINDOW SHAPE. Window inlet shape is the most important factor in determining the efficiency of wind cooling. The horizontal shape is the best at capturing and admitting winds for more angles of wind incidence.

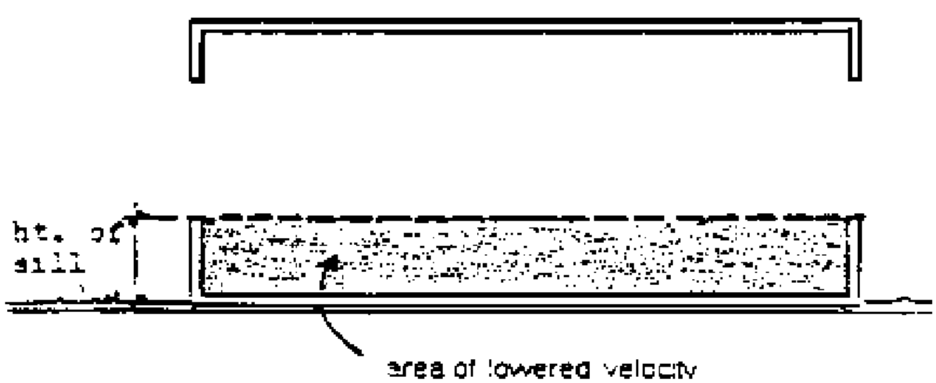


Figure 23

Effect of sill height on air flow and velocity

Window type	Interior airflow	Max. open area (%)	Recommendations for natural ventilation
Double hung/horizontal sliding	Horizontal in same direction as outside airflow. Some air leaks between panes.	50	Should be located at level and directly in front of the zone where airflow is desired.
Vertical pivot or casement	Horizontal control of airflow. Air flows between open sash and frame and over top and bottom of open sash.	50-90	Effect similar to wingwalls. Use at the level that airflow is desired.
Horizontal projection or awning	Upward unless fully open	50-90	Best placed below zone where airflow id desired
Jalousie or central pivot	Vertical control of airflow. Airfloaw at about same angle as louvers.	60-90	Good placed at any height. Cannot be fully sealed. Maximum vertical control.

Table 2

Window type and interior airflow characteristics

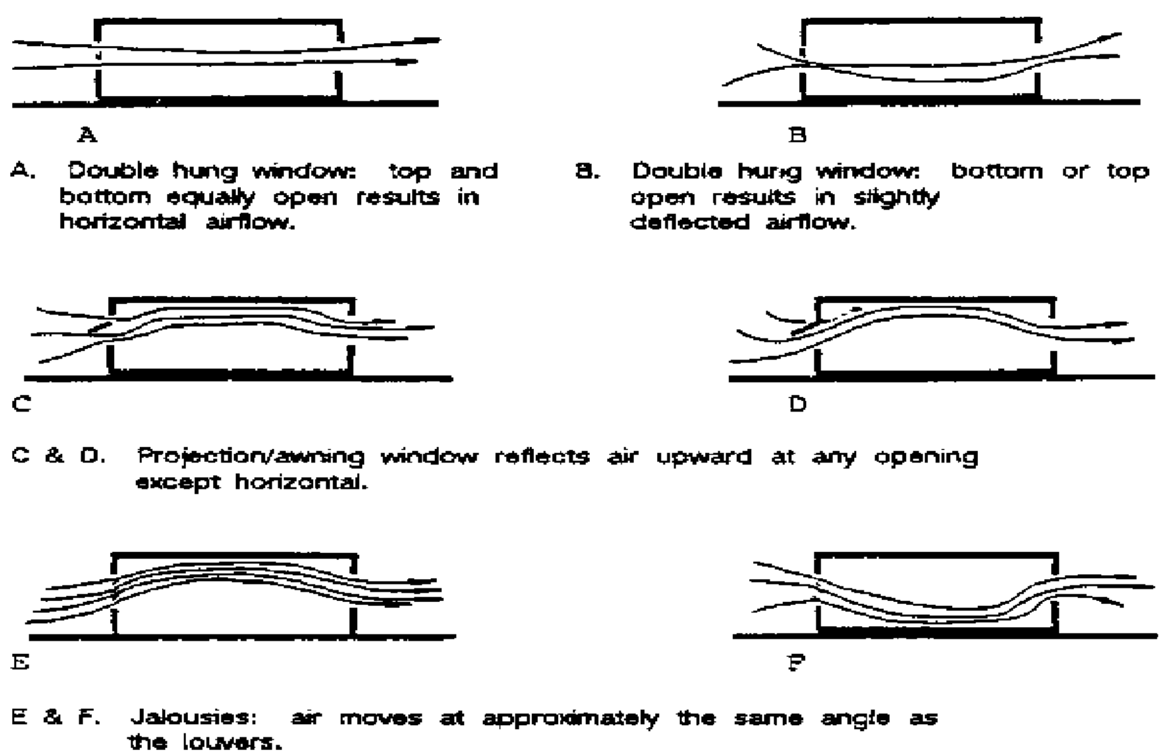


Figure 25

Air flow patterns through single banked rooms for various window types

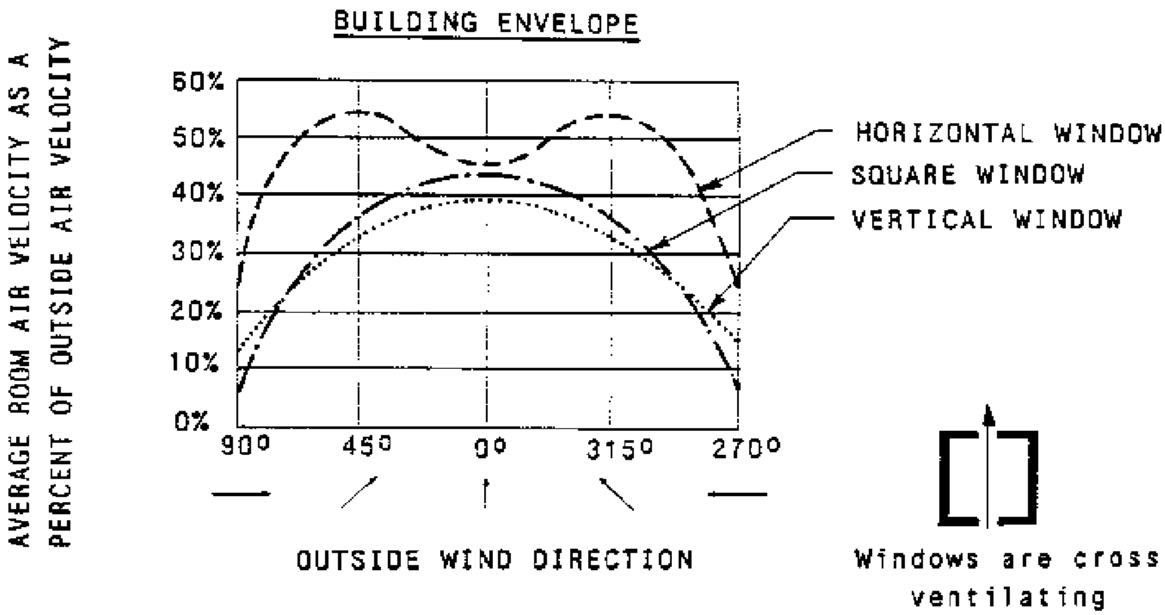


Figure 26

Window shape performance in relation to wind direction

A horizontal window performs better than both square and vertical windows in perpendicular winds, and improves its effectiveness in winds with a 45-degree incidence angle (see Figure 26). Theoretical shape has been found to be eight times as wide as tall, however smaller width-to-height ratios are also effective. Square and vertical shapes exhibit peak performance in perpendicular winds. If the wind incidence angle is confined to a narrow band and openings can be placed perpendicular to the wind, then square openings will also work effectively. However, if the wind incidence angle varies, then horizontal openings will work more effectively under a greater variety of conditions and should be used. Tall openings exhibit a lower effectiveness than both horizontal and square shapes for all wind incidences.

5.4.9 SIZE. The effect of window size depends on whether or not openings are cross ventilating. If openings are on one surface only, size has little effect on airflow. In cross ventilated rooms, airflow is determined mainly by the area of the smallest openings. Average indoor velocity and number of air changes are highest when inlet area is equal to or slightly less than outlet area as in the equation below:

Outlet area/inlet area = 1.25

Ventilation is more efficient for a greater number of incidence angles when inlets are larger than the outlets. If concentrated flow in a restricted area of the room is desired, the inlets may be sized smaller than the outlets and placed immediately adjacent to the living space to be ventilated (see Figure 27). In general, use the largest area of openings possible with inlet area equal to or slightly less than outlet area.

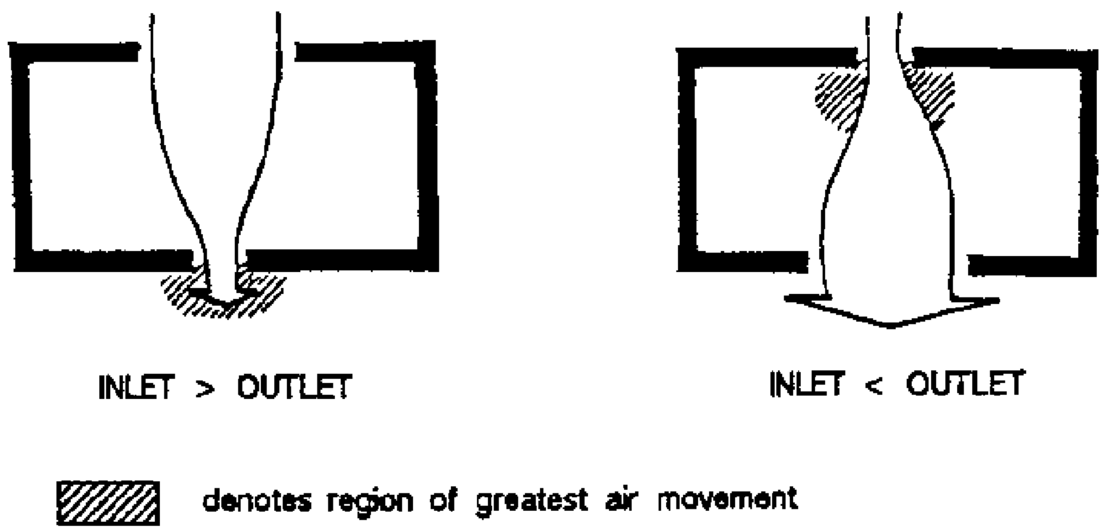


Figure 27

Effect of relative opening size on airflow

5.4.10 INSECT SCREENING. Insect screening decreases the ventilative effectiveness of openings. The amount of decrease in velocity varies with screen type, incident wind direction and velocity. Decreases in velocity are greater with lower wind speeds and oblique winds, and can be as high as 60 percent (refer to Table 4). Because insect screening lowers the effectiveness of the openings for ventilation, its presence must be factored in when sizing windows. In the window sizing procedure, a porosity factor is used to lower the opening's ventilative effectiveness when screens are used. If possible, place insect screening across the larger area at the front of the balcony rather than at each opening (see Figure 28). This creates less resistance to airflow and results in greater interior velocities.

Outside Velocity		Normal Incidence Inside Velocity Reduction			67.5 degree incidence Inside Velocity Reduction		
m/s	fpm	m/s	fpm	%	m/s	fpm	%
0.75	150	0.49	98	35	0.40	80	47
1.23	250	0.87	178	29	0.75	153	39
2.50	500	1.33	267	47	1.00	200	60
3.30	650	1.79	353	47	1.33	262	60
3.80	759	2.64	520	31	2.23	438	42

Table 3

Reduction in wind velocity due to insect screens as a function of incidence angle

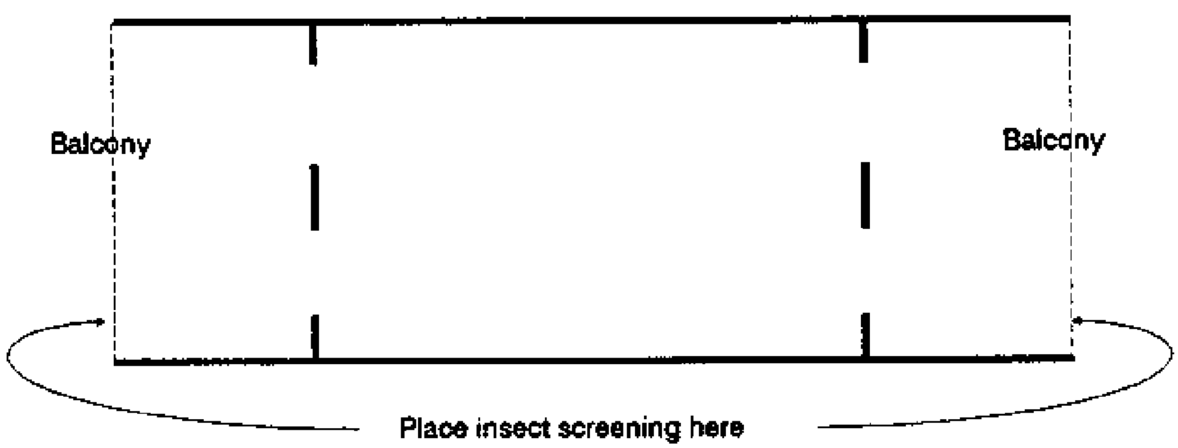


Figure 28

Best location for insect screening

Screens should be located in all areas where insects, rodents or birds could prove to be an annoyance or could damage the contents of a room. Unless the specific requirements of the local environment dictate otherwise, a 14-wire screen should be used. This allows greater interior airflow than higher density mesh and should prevent most insects from entering the building. It is possible in high-rise buildings to eliminate screens on the upper floors (above four stories) if the designer and owner mutually agree to its acceptability. When a building is located adjacent to a highway, parking lot, or other dusty area, screens may assist in reducing the infiltration of windborne dust, dirt, and other debris. The use of screens for this purpose; however, must not interfere with requirements for adequate ventilation. Screens should be maintained on a regular basis.

5.4.11 THERMAL CONSIDERATIONS. Windows usually contribute the major portion of solar heat transmission into a building. For minimum solar gain, openings should be located primarily on the north and south sides rather than the east and west sides, and all openings shall be completely shaded between 8 am and 6 pm solar time during the cooling season to minimize heat gain. Separation of the light-admitting, view, and ventilating purposes of windows may be advantageous.

5.5 SEPARATION OF FUNCTIONS. It is possible to separate the light-admitting (and therefore heat-admitting) and ventilating purposes of windows, so that there can be larger inlet and outlet areas with lower total solar gain. This separation is especially useful in tradewind areas where the predominant wind directions, from the northeast to southeast, are difficult to shade effectively. It may be preferable to use shaded, opaque openings for ventilation on the easterly exposures and separate glazed windows for view and daylight on the north and south facing exposures, which may or may not be operable as well.

5.5.1 WIND ADMITTING DEVICES. Wind-admitting devices which exclude solar light and heat include opaque or reflective louvered windows or walls, and opaque sliding or pivoting window or wall panels. A wall may also consist of a combination of window types which may be used alone or in combination to provide ventilation, view, or privacy or to provide protection from the sun or rain (Figure 29). One such combination wall might consist of:

a) a sliding glass panel which provides view and light while eliminating air, dust, insects and rain.

b) a sliding panel of opaque louvers for providing ventilation air while protecting from the sun and light rains. (Insulated opaque panels may also reduce the outward flow of heat in winter or at night when ventilation for cooling is not desired.)

c) a sliding panel of insect screening for providing air while eliminating insects.

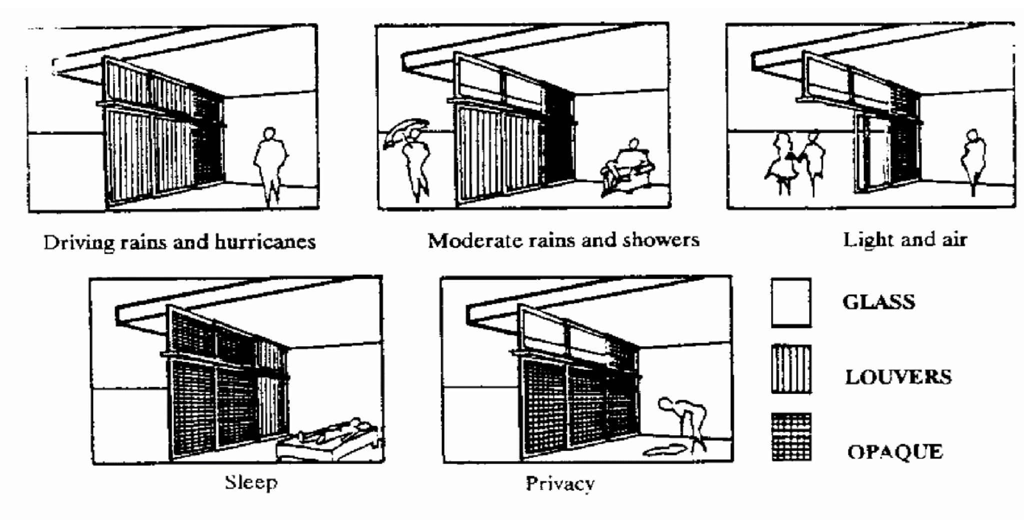


Figure 29

Possible combinations of wall systems

Fixed opaque louvers may be used on the lower part of a window wall with operable louvers above for ventilation, light and view. In warm-humid climates such as the tropics, it is important to admit wind for cooling while preventing the admittance of wind driven rain. In Window and Ventilator Openings in Warm and Humid Climates, Koenigsberger, Miller, and Costopolous, (1959), reported that only M-shaped fixed louvers satisfy the requirement of keeping the rain out and allowing the breeze to enter without deflecting it upward away from the body in the living space. The M-shaped louvers reduce the velocity of the wind by 25 to 50 percent, with the larger reductions occurring at higher wind speeds. The velocity reductions are equivalent or less than those of other louver types (see Figure 30).

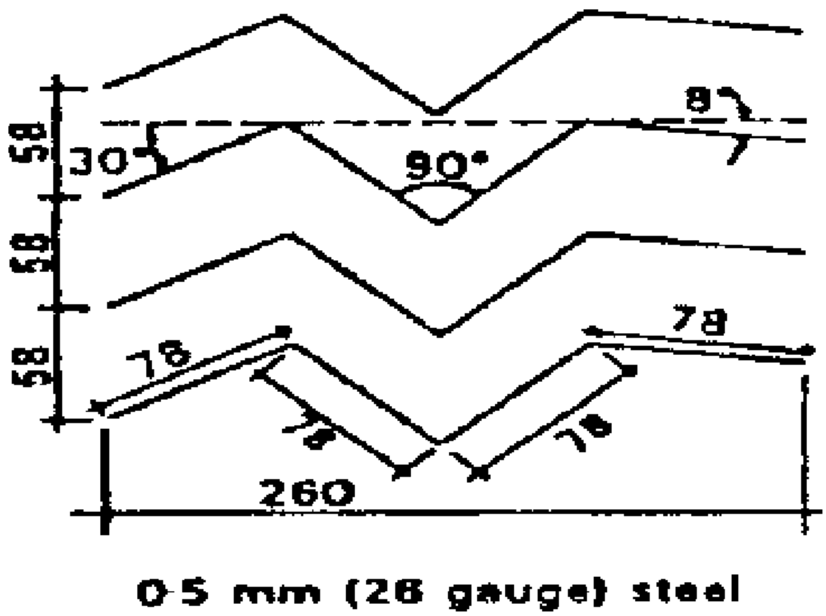


Figure 30

M-shaped louvers

5.5.2 HORIZONTAL SHADING DEVICES. A roof overhang is the simplest and most maintenance-free exterior shading device. They are most effective on the south side, but can also be used on the southwest, southeast and north facades. On east- or west-facing walls, overhangs must be very deep to be effective. The necessary depth may be achieved by the use of an attached covered porch or carport, or by adequately wide exterior balconies (see Figure 31). Careful detailing of horizontal exterior shades will maintain the ventilation efficiency of the openings. Leave a gap between the shade and the building to prevent airflow from attaching to the ceiling (see Figure 32).

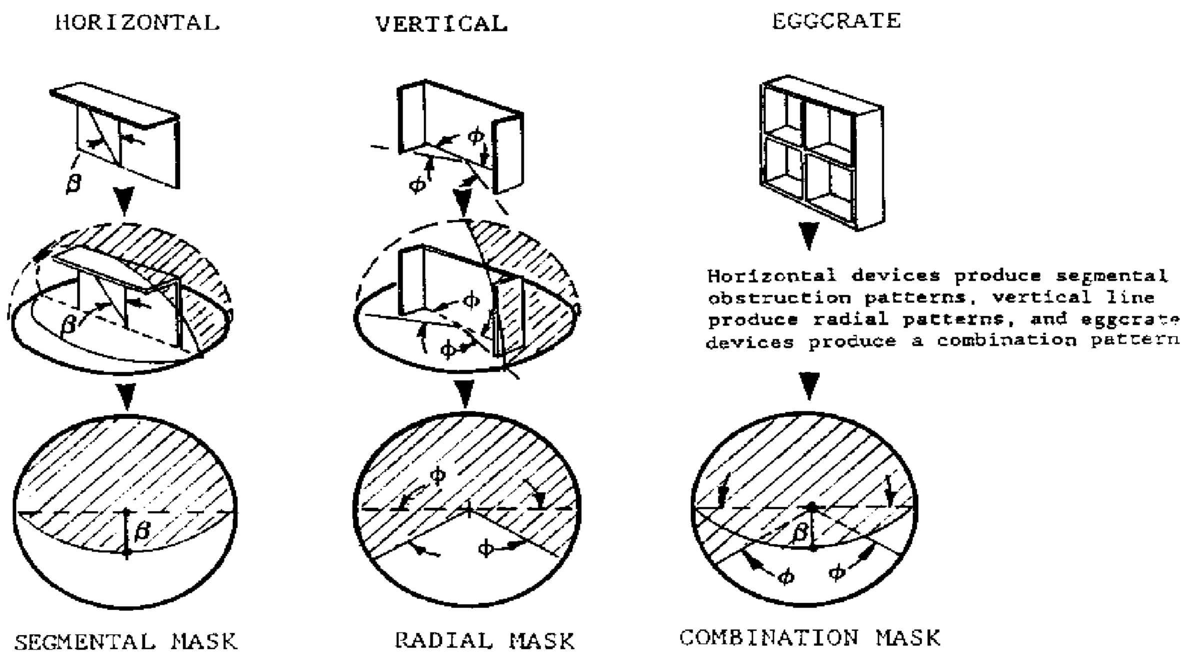
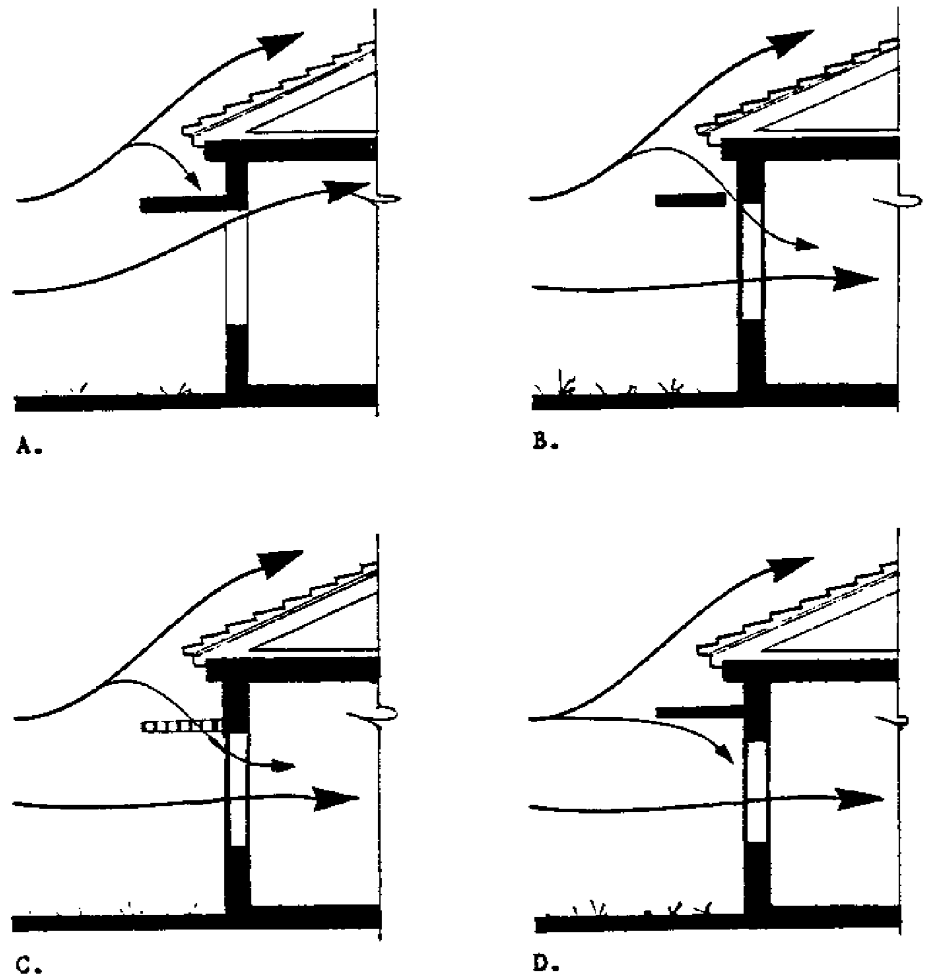


Figure 31

Solar shading masks for overhangs and side fins



A. Sunshade attached to the building face causes an upward deflection of the airflow to above the body level.

B. A gap between the sunshade and the building face maintains horizontal airflow through the live zone.

C. A louvered sunshade maintains airflow through living zone.

D. Placing the sunshade slightly above the window maintains a horizontal airflow pattern.

Figure 32

The effects of horizontal exterior shading on interior airflow

Placing the horizontal sunshade slightly above the upper edge of the window can also be used to maintain body level airflow. The exact size of the gap or placement of the overhang required depends upon the sunshade and window sizes.

5.5.3 VERTICAL SHADING DEVICES. Vertical fins or wingwalls are the most appropriate shading devices for east and west facing openings which receive sun at low angles, and for southeast and southwest openings in combination with horizontal shading. Wingwalls which increase the ventilative potential of the building may also be utilized for shading if they are properly designed.

5.5.4 OTHER TYPES. Operable exterior shutters, rolldown shades and blinds can provide effective shading on any facade. They are most useful on east and west openings which are difficult to shade with overhangs or vertical shading devices. The thermal performance of closed exterior shutters depends on how well the heat absorbed by the shade is dissipated to the outside air. For this reason, light-colored reflective shutters are preferred in hot climates. For naturally ventilated buildings, the specification of such devices should be treated with care since air movement to the building interiors is reduced when the shutters or shades are in their closed position. If the operation of the devices is not obvious, provision should be made for mounting instructions nearby. Site obstructions such as buildings and trees may provide effective building or window shading. Analysis of the site using a sun-path diagram is recommended to determine when such shading occurs.

5.5.5 GLAZING TYPE. Each glazing type provides differing amounts of resistance to solar heat gain. Reflective and absorbing glazing types can reduce cooling loads 15 to 30 percent below that of clear glass with some reduction in transmitted light. Heat-absorbing glazing is less effective than reflective glazing because it absorbs the solar heat into the glass, thereby increasing the heat convected and radiated into the internal space. Better performance can be obtained with either reflective or heat absorbing glazing if they are used as the exterior panel of a double glazed window. In general, clear glazing with effective exterior shading shall be used unless an optional glazing/shading system can be justified in a cost-benefit analysis.

5.6 DESIGN PROCEDURE. See the latest edition of published graphic standards for details on designing exterior solar shading.

5.7 INSULATION. Insulation is used in naturally cooled buildings to reduce the amount of solar heat transmitted to occupied areas. The designer shall use the most appropriate and cost effective means of controlling heat gain through the roofs and walls of the structure with a minimum recommended composite R-value (R = thermal resistance value of the assembly) of R-20 for roofs and R-11 for walls, which are exposed to solar radiation. The insulation systems may be located inside or outside the building structure. In hot humid climates, special attention should be given to insulation systems that protect against radiant heat gain, especially through the roof, since this is the major contributor to internal heat gains. Such systems are typically composed of one to three reflective foil liners, with air spaces located between or attached to the structural members. Recent studies performed at the Florida Solar Energy Center have shown that radiant barriers in both roof and wall configurations are effective at preventing heat gain if properly used. Where heat loss is a concern, they should be supplemented with standard resistive insulation such as glass fiber, mineral wool, or rigid foams. When roof or wall insulation is not used, it is the responsibility of the designer to justify the alternate proposed wall or roof system(s). In these cases, the designer should clearly show that the internal temperatures will not be adversely affected by minimizing or eliminating insulation in the roofs and/or walls.

5.7.1 VENTILATIVE CONSIDERATIONS. Partitions and interior walls usually lower interior velocities and change airflow distributions by diverting the air from its most direct path from inlet to outlet. The closer the interior wall is to the inlet, the more abrupt the change in the airflow pattern and more of the air's velocity is dissipated. To maintain high interior velocities for natural ventilation, interior walls perpendicular to the flow should be placed close to the outlet (see Figure 33). Placement of walls or partitions can affect airflow beneficially. Walls can be used to split airflow and improve circulation creating better overall room air distribution in rooms with poor exterior orientation (see Figure 34). Naturally ventilated buildings should be single-loaded for easier cross ventilation. Corridors can be either on the upwind or downwind side, and may serve a dual function as shading devices if placed on the south, southeast, or southwest side of an elongated building facing one of these orientations. Odor-producing spaces such as toilets and kitchens, and noise producing spaces such as mechanical rooms, should be placed on the downwind side of the living spaces.

5.7.2 THERMAL CONSIDERATIONS. Locations of rooms with respect to their thermal characteristics and requirements can reduce energy consumption. Spaces which require little heating/cooling or light (closets, storage, garages, laundry rooms, mechanical chases, stairways, etc.) can be placed on the east, west, or north exposures of the building to act as buffer spaces to minimize east/west solar gains.

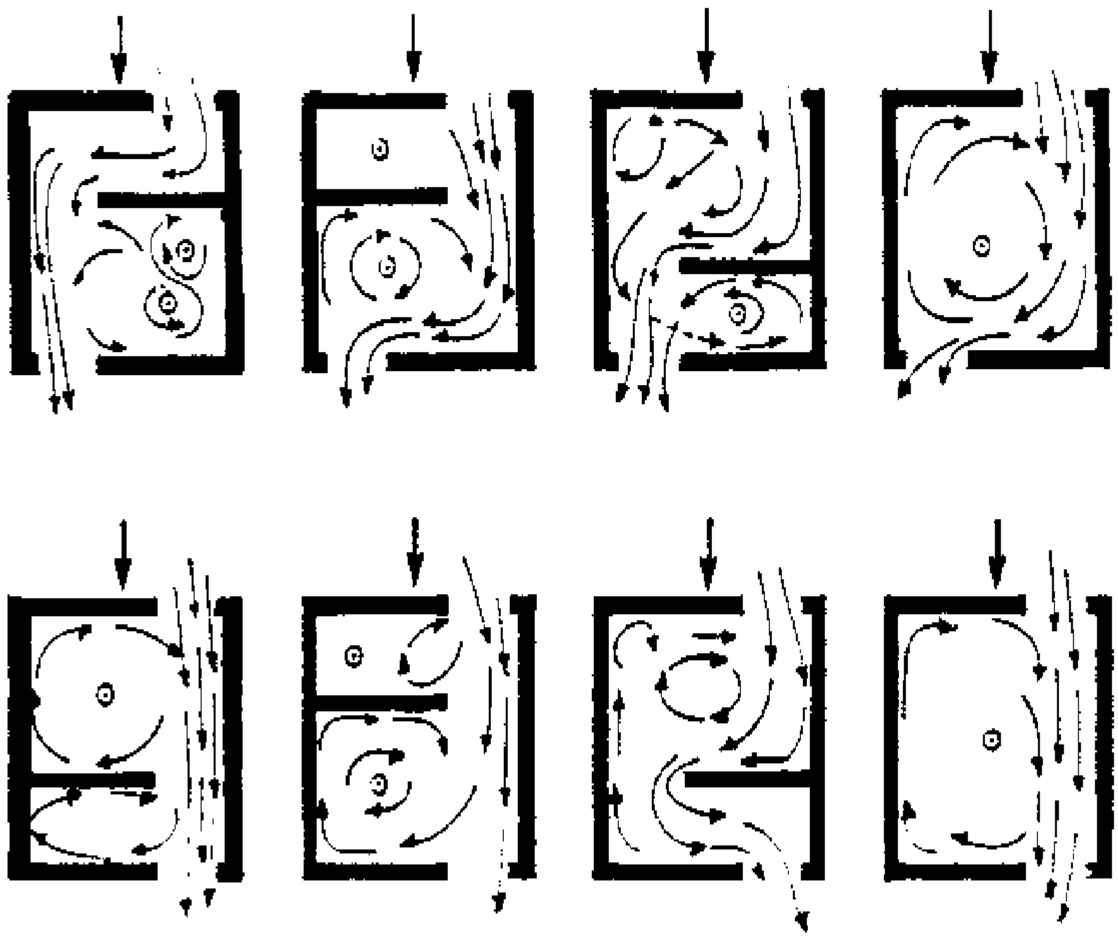


Figure 33

Effects of interior partition locations on air flow patterns

Rooms with high process heat gain (such as computer rooms) or high latent heat gain (such as laundries) should be placed near the building's ventilative outlets or be separately ventilated in order to minimize heat gain to the rest of the building. They should also be separated from other ventilated spaces by insulated walls. Rooms can also be zoned so that activities can take place in cooler areas during warm periods and warmer areas during cool periods of the day or season.

5.7.3 INTERNAL DRAPES AND BLINDS. Internal drapes and blinds are not an effective means of solar control and should not be the building's primary shading device.

Although they block solar radiation, they absorb and reradiate an appreciable amount of it within the room. This is true even for white drapes and blinds. An internal white venetian blind will reduce the daily average solar heat gain by less than 20 percent. Only exterior shading devices should be used as the primary solar control in all cases. A building with exterior solar control devices may still require drapes or blinds for privacy or to control light levels or glare. Since they block ventilative airflow, their use should be carefully considered. Drapes tend to block more air movement than blinds, but under high ventilation rates blinds may fall apart or cause excessive noise. When possible, they should be solidly connected to the floor and the ceiling to prevent blowing or rattling, and should allow air movement even when fully closed. Consider the use of systems that can be controlled at different heights to allow some portions to remain open while other portions are closed.

5.7.4 FURNITURE. Large pieces of furniture can have a major effect on room airflow patterns. Items such as desks and beds can prevent air movement below 30 inches (76 cm) or divert airflow away from occupants. These effects should be considered when selecting furniture and laying out furniture plans.

6. AUXILIARY FAN SYSTEMS. Fans are frequently used to supplement natural ventilation. Fans reduce cooling requirements by exhausting heat from the building's interior, and by increasing air movement in the living space to assist bodily cooling.

6.1 CEILING FANS. This type of fan is effective for bodily cooling on a room-by-room basis. Ceiling fans can provide inexpensive air mixing when wind driven ventilation is inadequate. Figure 34 shows the typical distribution of air velocity under a ceiling fan. When choosing ceiling fans consider control over speed variability, minimum and maximum speeds, noise level, power requirements and minimum floor to ceiling heights. For naturally ventilated buildings in which high air movement (above 98 fpm or 0.5 m/sec) is required for comfort, ceiling fans are required for each primary occupied space to maintain comfort during periods of low winds, extreme temperatures, and/or humidities, or during heavy rains when windows may be shut.

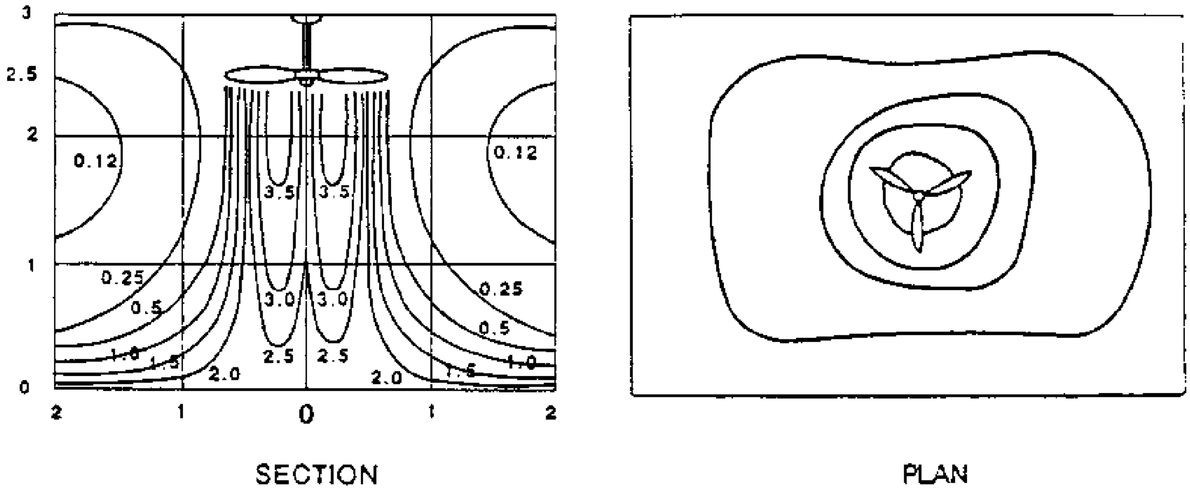


Figure 34

Air distribution patters for ceiling fans

6.2 WHOLE-HOUSE FANS. In some cases wind-driven natural ventilation through open windows may not provide sufficient ventilation to exhaust heat from the building's interior. Constrained building orientation or dense surroundings may prevent the wind from creating pressures across the building. In such cases whole-house fans, which typically induce 30 to 60 air changes per hour, may be necessary as backup units. Whole-house fans have low initial investment costs (about $400 to $600 installed) and low energy use (between 300 and 500 watts, roughly one tenth the consumption of an air conditioner). The whole-house fan operates by pulling in air through open windows and exhausting it through the attic (see Figure 35). Openings in the floor are sometimes used to draw air from the cooler, shaded underside of an elevated building. A whole-house fan should be centrally located in the building and above a public area, such as a hall or stairwell, so that it draws in air from all parts of the building.

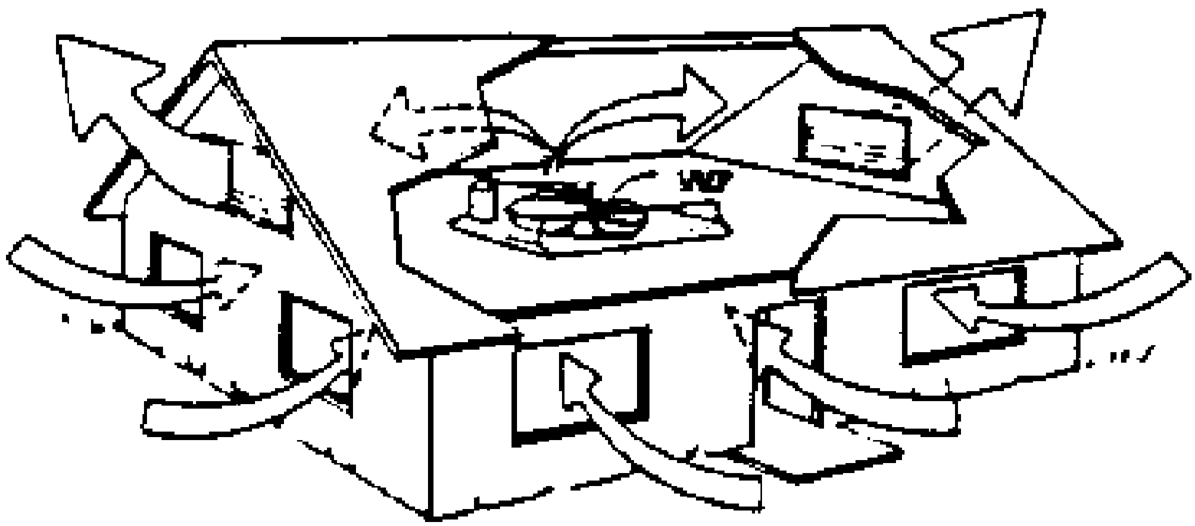


Figure 35

Air flow from a whole house fan

Whole-house fans are primarily used for cooling the building's structure, often by enhancing night ventilation. The fan is turned on when the outdoor temperatures drop in the late afternoon or early evening. In the morning, the fan should be turned off and the windows closed before the outdoor temperatures begin to rise above the interior temperature.

6.3 SIZING OF OPENINGS FOR WHOLE-HOUSE FANS. The total open window area should be approximately two times the open area of the fan. The total open window area should be three times the whole-house fan open area if there is insect screening at the windows. It is not necessary to open windows all the way to ventilate with a whole-house fan. They can be opened 4 to 6 in. (100 to 150 mm) and fixed in a secure position by stops or window locks. The attic vents need to be larger than normal for effective wholehouse fan ventilation. The free exhaust area should be approximately twice that of the area of the fan itself, and three times the area if screening is used.

Openings should be distributed throughout the attic or placed to the lee side of the building for adequate ventilation.

6.4 FANS FOR BODY COOLING. Although whole-house fans can create some air motion, especially near windows and near the fan outlet, the interior velocities created are, in general, too low for body cooling. Therefore, ceiling fans or portable oscillating fans are recommended for body cooling. It is possible to use both types of fans in combination in one building.