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# DESIGN OF BUILDINGS FOR THERMAL COMFORT

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It took several hundred thousand years for the world's population to reach it's First Billion ($10^9$) around 1800, but only 130 years were needed to add the Second Billion, and less than 30 more for the Third around 1960. In mid-seventies the Fourth Billion was reached and the last quarter of the century, 2 more Billions have been added, totaling to well over 6 Billions.

Our planet has evolved, for eons, with a fixed arrival rate of renewable energy from the sun. Suddenly, in geological time, our planet is experiencing population growth, non-renewable energy resource depletion, air and water pollution, environmental degradation and apparent global warming.

The expansion of urban areas is accelerating throughout the world, and each of the inhabitants of this area is consuming more resources than did his / her grand parents.

These changes and modifications of earlier situations are giving rise to many socio-economic, eco-environmental and meteorological problems. In some areas of change once local problems are now regional or even global in extent. Eventually, our planet must live within a fixed budget of renewable energy and material resources. The question is how we can best move towards this sustainable goal with our present attitude of consumerism and over use.

Architecture and Urban Planning in their widest sense consume energy, modify environment and manipulate ecology. It seems that these issues should be of professional concern to all the stake holders whose main goal is to improve the quality of life. It is therefore imperative that we produce design solutions that are sustainable, eco-sensitive, energy-efficient, climate-responsive, user-friendly and cost-effective.

Our buildings are, after all, temporary occupants of the site. The arrival of a building usually produces rapid and dramatic changes to the biological and climatic systems that evolved on the site. Buildings are guests, Sites are hosts; how might they most productively co-exist?

The site offers the building, earth for support, for a potential heat source and heat sink, and for the growth of plants, if permissible. At some level an eco-system of life is already established. Sounds on site depend on the context, urban or rural. Water is some where below the site, flows across it, falls on it as rain, and perhaps collects on its surface. Wind moves erratically across the site. Solar energy arrives in diurnal and seasonal cycles. The over all arrival rate of sun, wind and water is steady, although great variation can occur over shorter time spans.

The building arrives, bringing with it people and vehicles, a flow of material in to and out of the building, sounds generated by activity and imported utility services such as electricity, water and natural gas. The building offers the site electric light by night as also a changed micro-climate in the immediate vicinity of it's envelop. It also offers a continuous flow of heat and water containing waste or nutrients, depending on one's view point. In our society this water outflow is more often whisked off, for treatment elsewhere.

**"Architecture occurs at the meeting place of interior and exterior forces of use and space. These interior and environmental forces are general and particular, generic and circumstantial. Architecture as a wall between the interior and the outside becomes the spatial record of this resolution and its drama." - Robert Venturi, Complexity and Contradiction in Architecture**

On a more general level, the definition of the role of Building Design and Urban Planning in Energy Conservation has to be redefined. Energy and environment have emerged as crucial issues, as a result of such crises as the Chernobyl disaster, Superfund toxic waste dump sites, Draught in one part of the world and flooding in the other, Global warming. This long list of symptoms points to a larger illness.

**"He will manage the cure best, who foresees what, is to happen from the present condition of the patient." - Hippocrates**

Energy is costly, pure energy like electricity is inherently costlier. Energy demand is outstripping the supply and increased energy generation is depleting the exhaustible natural resources and degrading the environment. In the long run, energy costs would equal or exceed the environmental costs, which our society will have to pay dearly.

On the other hand, energy is vital for economic development which forms the foundation of social well being and political stability. In this scenario, energy conservation becomes not only imperative but also an obligation dictated by the basic human instinct of self- preservation.

This can be done only by applying scientific methodology, which will enable us to make quantitative assessment of qualitative performance of materials, systems and resources.

Our responsibility to improve the quality of life also beacons us to develop scientifically and mathematically based methods of responding to Thermal, Luminous, Acoustics and Aqueous environments. The procedure can be described in the following way:

**a.** Analysis Techniques – to understand the problem and its context. This would characterize the important variables and establish their relative importance

**b.** Design Strategies – which are form generating and which also concentrate on revealing the relationships between the architectural form, space and energy

**c.** Evaluation Procedures – to evaluate the performance of the design

Since we are focusing on Design of Green Cities, we will zoom in on Design Strategies for Building Group Scale, which deal with a range of scale that extends beyond a single building to a cluster, block, town or city.

The major Architectural and Planning elements they address are buildings, streets and open spaces which are primary components of the design process. The strategies are mostly concerned with the relationships between these components. These strategies are among the most neglected by Architects and Planners.

These strategies reveal at least one of the five criteria given bellow -

**1.** They must deal with energy.

**2.** They must, primarily, be passive in nature.

**3.** They must reveal major form and organizational relationship.

**4.** They should have potentially major impact on the appearance of the building.

**5.** Some strategies, if ignored at this stage, would require redesign at later.

Each strategy contains a strategy statement, an explanation of the phenomenon related to the strategy, a sizing rule of thumb or tool, and an illustration of the strategy in an architectural application.

The strategy statements are not directives; they do not say that one must do this to conserve energy. They do say that if one does this that will probably be the result. The strategy that fits the designer's other concerns should be selected. There is no single right way to do something without the agreement of the people involved and affected; therefore, the strategies are stated as possibilities, not as absolutes.

**RADIAL ORGANIZATIONS: (Streets, Open Spaces and Buildings.)**

**STRATEGY NO 1: RADIAL VENTILATION CORRIDORS**

**Radial Ventilation Corridors of streets or open spaces can take advantage of cool air drainage and night thermal currents. (Cooling)**

Cities have significant impact on wind patterns in two ways. First, when regional winds are calm, the urban heat island effect causes centripetal wind patterns moving from areas of low density to areas of high density, with strong currents. Second, because areas of higher development density produce and store more heat during the day and retain it longer than low density areas, the temperature differential between high density areas and the surrounding country side increases causing warmer polluted city air to rise and creating a negative pressure that sucks cooler air from city perimeter towards the centre.

Both of these effects are particularly pronounced on calm summer nights and can be used to help flush dense areas of heat and pollutants. Two main urban design elements are required:

**1.** A band of undeveloped, preferably vegetated land at the perimeter that can serve as cool air source and

**2.** Wide corridors to provide a pathway for the cool air to move from perimeter to centre.

**ELONGATED ORGANIZATIONS**

**(Streets, Open Spaces and Buildings.)**

**STRATEGY NO 2: EAST-WEST ORIENTED SETTLEMENT FORM.**

**East-West elongated building groups spaced in the North-South Direction maximize solar gain while insuring solar access to each building. (Heating)**

The placement of a building, such that it has access to the sun without shading other buildings, has important implications for the form and arrangement of groups of buildings. Individual dwelling units at Pueblo Acoma, New Mexico, are arranged in long thin east-west elongated clusters, each having a south facing terrace. **(Knowles, 1974, p. 27)**

The appropriate spacing between buildings is determined by the profile angle of the low altitude winter sun. Multiply the height of the building, H, by the value X, form the table to determine the spacing, S, that will provide optimum winter exposure for a cluster of buildings. **(Ref. Table)** The table is based on sun position on Dec. 21 and Jan/Nov 21 for northern hemisphere latitudes of the Indian peninsula from 8 $^{0}$ to 36 $^{0}$. The most intense solar radiation falls between the hours of 10 AM and 2 PM **(Solar time).**

Spacing will change substantially if the site is sloped, increasing for north-facing slopes and decreasing for south-facing slopes. The rows are much closer together than they could be on a flat site, allowing more compact development without sacrificing southern exposure. **Figure B.** The ideal massing to collect sun on site can be in conflict with the ideal massing to protect solar access to neighboring sites. To achieve both solar collection and protect solar access, massing for on- site collection should be within the solar envelope. **Figure C.**

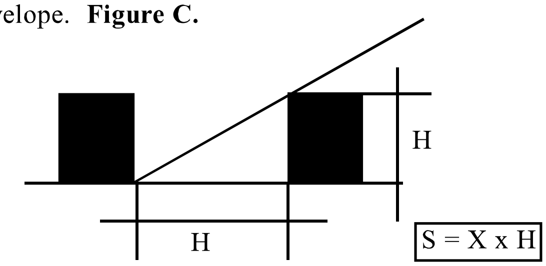


**Table no. 1. Values Of “X” For Building Spacing**

| Lat. $^0$N. | 9 AM Dec | Ja/N | 10 AM Dec | Ja/N | 11 AM Dec | Ja/N | 12 NOON Dec | Ja/N Dec | 1 PM Dec | Ja/N Dec | 2 PM Dec | Ja/N | 3 PM Dec | Ja/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.6 | 0.5 | 0.6 | 0.5 | 0.7 | 0.6 | 0.8 | 0.7 |
| 12 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.7 | 0.6 | 0.7 | 0.6 | 0.8 | 0.7 | 0.9 | 0.8 |
| 16 | 1.1 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.9 | 0.8 | 1.1 | 0.9 |
| 20 | 1.3 | 1.1 | 1.1 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 | 1.0 | 0.9 | 1.1 | 0.9 | 1.3 | 1.1 |
| 24 | 1.5 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 1.1 | 1.0 | 1.1 | 1.0 | 1.2 | 1.1 | 1.5 | 1.2 |
| 28 | 1.7 | 1.4 | 1.4 | 1.2 | 1.3 | 1.1 | 1.3 | 1.1 | 1.3 | 1.1 | 1.4 | 1.2 | 1.7 | 1.4 |
| 32 | 2.0 | 1.7 | 1.6 | 1.4 | 1.5 | 1.3 | 1.5 | 1.3 | 1.5 | 1.3 | 1.6 | 1.4 | 2.0 | 1.7 |
| 36 | 2.4 | 2.0 | 1.9 | 1.7 | 1.7 | 1.5 | 1.7 | 1.5 | 1.7 | 1.5 | 1.9 | 1.7 | 2.4 | 2.0 |

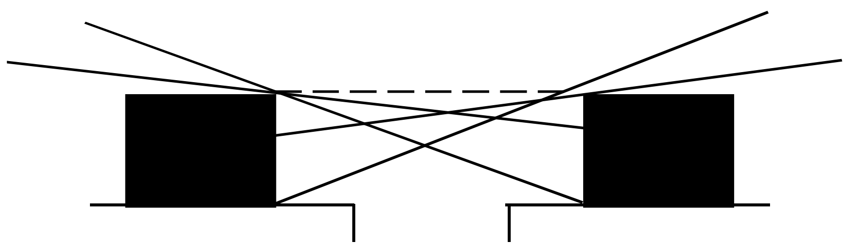
COMPACT ORGANIZATIONS: (Streets, Open Spaces and Buildings)

**STRATEGY NO 3: MUTUAL SHADING**

**Shared shade: Buildings can be arranged to shade each other and adjacent exterior spaces (Cooling).**

Narrow streets with tall buildings are characteristic of vernacular layouts of hot- arid cities. They create more shade than wide streets, and are useful for shading East and West facade on North-South oriented streets. At mid-day, unless the ratio of building height to street width is 4:1 or greater, it is difficult to achieve shade. When the sun is high, horizontal elements like roofs, pergolas, or tree canopies are extremely effective.

The space formed by the streets and building walls on either side is often called an “Urban Canyon”. The amount of shade cast by a building on to the street and the opposite building is a function of the street orientation, and width, the building height and the sun angle.



Profile Angle “P” For North-South Canyons.

| **Profile Angles ( degrees ) for Shading Design in Section of N-S Streets** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Lat $^0$ N** | **6am / 6pm** | **7am / 5pm** | **8am / 4pm** | **9am / 3pm** | **10am / 2pm** | **11am / 1pm** | **12noon** |
| 8 | 3 | 18 | 33 | 47 | 61 | 76 | 90 |
| 12 | 5 | 20 | 34 | 48 | 62 | 76 | 90 |
| 16 | 7 | 21 | 35 | 49 | 62 | 76 | 90 |
| 20 | 8 | 22 | 36 | 49 | 63 | 76 | 90 |
| 24 | 10 | 23 | 36 | 49 | 63 | 76 | 90 |
| 28 | 12 | 24 | 37 | 50 | 63 | 76 | 90 |
| 32 | 13 | 25 | 37 | 50 | 63 | 76 | 90 |
| 36 | 14 | 26 | 37 | 49 | 62 | 76 | 90 |

In hot climates narrow shaded North-South streets are more appropriate for pedestrian circulation, outdoor living areas and shopping. East-West streets, difficult to shade, may be wider and thus appropriate to vehicular traffic, while being shaded by arcades, awnings or other element scale shading devises.

**GRID ORGANISATIONS: (Streets and Buildings)**

**STRATEGY NO 4: Balanced Urban Patterns of Streets and Blocks.**

**Streets and blocks can be oriented and sized to integrate concerns for light, sun and shade according to the priorities of the climate. (Heating, Cooling)**

The orientation and layout of streets has a significant effect on the micro-climate around buildings and on the access to the sun and wind for use in building.

Depending on the climate and heat load of buildings, different combinations of strategies may be appropriate. The diagrams show potential generic solutions for a range of climates. Refer to the table of **Street Orientation and Layout by Climatic Priority** for specific recommendations by climates.

**Street Orientation and Layout by Climate Priority**

| Building Type IDL Bldgs | SDL Bldgs. | Response 1ST Priority | 2nd Priority | Comments |
|---|---|---|---|---|
| - | Cold | Lee | Sun | Strict cardinal orientation for sun. Discontinuous streets in direction of winter winds. Space E/W streets for solar access for spring and fall |
| Cold | Cool | Sun | Lee | Cardinal orientation for sun. Discontinuous streets in direction of winter winds. Space E/W streets for solar access at solstice. |
| Cool | Temperate | Winter sun, Summer wind | Winter Lee, Summer shade | Orient + / - 30$^0$ from cardinal for sun. Adjust orientation 20-30$^0$ oblique to summer wind. Space E/W streets for solar access, if needed. Elongate blocks E/W. |
| Temp. Arid | Hot - Arid | Summer shade Winter sun | Summer wind Summer wind, | Narrow N/S streets for shade. Rotate from cardinal to increase street shading. Space E/W streets for solar access, if needed. Elongate blocks E/W. |
| Temp. Humid | Hot Humid | Summer Wind | Summer shade, Winter sun | Orient streets 20-30$^0$ oblique to summer wind. Modify orientation by rotating from cardinal to increase street shading. Space E/W streets for solar access, if needed. Elongate blocks E/W. Wide streets for wind flow. |
| Hot Arid, Tropical Arid | Tropical Arid | Shade all | Night wind Day Lee | Narrow N/S streets for shade. Elongate block N/S, if E/W facades shaded. Wider auto streets run E/W. |
| Hot Humid, Tropical Humid | Tropical Humid | seasons all seasons | Shade | Orient streets 20-30$^0$ oblique to predominant wind. Respond to secondary wind direction. Maximize street widths for wind flow, but not paving. |

The diagrams of **Summer Solstice Shadows (Figure B)** show the effect of different street orientation on summer solstice sun shading patterns at different latitudes. They represent four story buildings on 18.0 m wide right of way streets. Cardinal orientations give more sun to south facades in winter, whereas rotated organizations tend to reduce winter gains and increase summer gain, especially on Easterly and Westerly facade. How ever, for buildings that do not require winter sun for heating, rotated organization give more evenly distributed sun to more facades.

A cardinal orientation will generally cast more shadow on buildings facing N/S streets than rotated organization and thus does a better job at shading buildings. In contrast rotated organizations provide more shade on the streets during more of the day. A cardinal orientation will have one shady street, while cross streets will be sunny. In contrast, rotated organizations will provide shade on at least one side of the street for most of the day. The 22.5$^0$ rotation plans show increase street shading while meeting solar orientation criteria and may be appropriate for temperate climate.

**DISPERSED AND COMPACT ORGANIZATIONS**

**(Streets and Buildings)**

**STRATEGY NO 5: Loose and Dense Urban Patterns**

**Loose urban patterns maximize cooling breezes in hot climates (Cooling), while dense urban patterns minimize winter winds in cool climates (Heating).**

Air movement in streets can be either an asset or liability, depending on season and climate. Wind is desirable in the streets of hot climates to cool people and remove excess heat from the streets; it also becomes a potential resource to cool buildings by cross ventilation. This is important all the time in humid climates and at night in arid climates. On the other hand, wind reduces pedestrian comfort in cool season and increases infiltration heat losses of buildings.

For summer cooling, streets oriented 20 - 30$^0$ / to summer winds maximizes air flow through an urban area to reduce wind flows in streets, wind breaks can be used to block undesirable cold winter winds or hot dusty desert winds. For regular organizations of buildings in an urban pattern, tall buildings on narrow streets yield the most wind protection, while shorter buildings on wider streets promote more air movement.

To predict wind velocity in streets refer graph **(Figure A),** which shows wind speed in the streets as a function of the Blockage Ratio **(Rb)** of a given building group **(Wu, 1994, pp. 103-107).** The Blockage Ratio is defined as:

$$R_b = \frac{(W \times H)}{(W + L)^2}$$

To determine the wind speed in streets oriented parallel to the wind, first find the blockage ratio using either the formula above or from the calculated ratios from one of the building groups shown in the matrix in **Figure B.** Enter the graph on the horizontal axis with blockage ratio, move vertically to intersect the curve, and then move horizontally to read on the vertical axis the predicted average wind speed in the street as a fraction of the open prevailing unobstructed wind speed. High fractions are desirable for cooling and low fractions for heating.

In cool climates, major streets should be oriented perpendicular to winter winds and street net work should use discontinuous organizations, with many T intersections to slow and block wind flow in the streets.

**INTERWOVEN ORGANIZATIONS (Open Spaces and Buildings)**

**STRATEGY NO 6: INTERWOVEN BUILDINGS AND PLANTING.**

**Organizations of interwoven buildings and planting can be used to reduce the ambient air temperature (Cooling).**

The temperature in densely built up areas is frequently several degrees higher than in the surrounding rural areas due to heat generation from fuels, increase absorption and storage of solar radiation, poorer radiant sky cooling and reduced wind speed due to surface roughness. Planted areas can be as much as 6 - 8$^0$C lower than built up areas due to a combination of evapo-transpiration, reflection, shading and storage of cold.

When parks are located in dense areas, localize air circulation patterns are created as heated air rises over dense areas of heat island peaks, which is replaced by cooler air from the vegetated areas **(Chandler, 1976, p. 43).**

The studies show that, smaller open spaces, evenly distributed will have a greater cooling effect than a few large parks. Streets should be oriented to carry cooler air away from parks. For a city of one million, urban temperature do not start decreasing until the evaporating surfaces, i. e, planting, are 10-20 % of the city area. As the evaporating area grows from 20 to 50 % the minimum air temperature decreases by 3.3 - 3.9$^0$C and the maximum air temperature decreases from 5 to 5.6$^0$C. The graph of cooling rates due to vegetation cover shows temperature drop as a function of area **(Oke, et al, 1972).** The curves suggest a non- linear performance, where 30% of the surface area covered with vegetation produces 66% of the possible cooling achieved by evapo-transpiration.

Increased water use to irrigate landscaped areas is an issue in some cities; how ever since trees use less water and provide more cooling than turf, replacing turf with trees is an improvement on both accounts. **(Akbari et al., 1992, p. 55)**

**INTERWOVEN ORGANIZATIONS (Open Spaces and Buildings)**

**STRATEGY NO 7: Interwoven Buildings and Water.**

**Organizations of interwoven buildings and water can be used to reduce the ambient air temperature (Cooling).**

In hot-arid climates, water evaporating in to the air can cool the air temperature. The evaporation rate in an enclosed space such as a courtyard depends on the surface area of the water, the relative humidity of the air and the water temperature.

The Iranian alluvial fan villages of Muhiabad and Kousar Riz **( Figure A ),** are organized around the flow of water that has been brought to the surface through the use of "Qanats", horizontal channels cut deep, some times miles into the up hill alluvial soils to drain ground water. The emerging stream passes in and out of houses and court yards in surface and sub-surfaces channels. Garden and orchards, surrounded by walls to block wind blown sand, are irrigated to provide cool, shaded, food producing compounds filled with trees, vines, vegetables, herbs and pools. The courtyard level of houses is set near the water's elevation, at times sunken 6 m or more below grade **(English, 1966, pp. 52 - 55; Ardalan and Bakhtiar, 1973, p. 82).**

The water bodies cool the enclosure surfaces particularly the ceiling, by radiation. Because radiant cooling is a function of the area and the angle of heat sink "Seem" by a warmer body. A shaded pond will be cooler than an unshaded one. Horizontal surfaces containing water in the sun should be light in colour.

For evaporation to be effective, the cooled space should be isolated from ambient air to prevent mixing. Since the heat transfer, between air and a horizontal film of water, is poor **(Santa Mouris and Asimakopolous, 1996, p. 111)** the evaporating surface area of water should be increased by sprays and fountains with very fine droplets **(Yannas, 1995, p. 2.13).**

Climatic conditions when evaporative cooling is effective can be estimated from the Bio-climatic chart in **Analysis Techniques.**

**DISPERSED ORGANIZATIONS**

**(Open Spaces and Buildings)**

**STRATEGY NO 8: Dispersed Buildings.**

**Dispersed buildings with continuous and wide open spaces preserve each building's access to breezes (Cooling).**

Each building creates an area of reduced wind velocity on it's leeward side; therefore, buildings in which cross ventilation is important should be separated by a distance of 5 to 7 times the building height to assure adequate air flow, if they are directly behind one another **(M. Evans, 1980, p. 64; Koenigsberger et al., 1973, p. 129).** Compared to multistory buildings lower one story buildings cause smaller wind shadows and can be spaced close together.

Three distinct wind flow regimes can be identified between buildings, based on their spacing. "Skimming flow" is caused when buildings are organized in rows spaced closely together and oriented perpendicular to wind. When spacing is larger than that required creating a stable vortex between buildings, but smaller than the sum of the upwind and downwind eddies, "Wake Interference Flow" is induced. If spacing between buildings is larger than the sum of the upwind and downwind eddies, wind will drop between the buildings in a pattern of "Isolated Roughness", which is good for ventilation **(Lee et al., 1980, a and b). Refer Figure A, showing three flow regimes.**

To estimate the relative effectiveness of different spacing and densities of rows of buildings, enter the graph **(Figure B)** on the horizontal axis with the building height - to - spacing ratio. Move vertically to the diagonal zone, then horizontally to read the ventilation effectiveness on the vertical axis.

Percentages on the vertical axis are relative to the ventilation of an isolated building with no wind obstructions; these values are based on the decreasing pressure differentials between the windward and leeward side of buildings as spacing decreases. The graph assumes wind perpendicular to the buildings.

**(Bittencourt, 1993, p. 131)**

**SHAPE AND ORIENTATION (Streets, Open Spaces and Buildings)**

**STRATEGY NO 2: TALL BUILDINGS.**

**Tall building can be shaped in relationship to other buildings and to the wind to create favorable street and open space micro-climate. (Heating)**

Tall buildings create turbulent downward air flows towards street level, which can be either a benefit in hot-humid climates increasing comfort and cooling in the streets, or a liability in cool climates decreasing pedestrian comfort. They also are exposed to stronger wind flows because of their heights. They create several disturbances in the urban wind pattern **(Gandemer,1978;Thurow,198,pp.23 - 27).**

1. **The Down-wash Vortex Effect:** is created as faster wind speeds at the top of a building create higher pressure, while the bottom is sheltered from winds by other buildings. The wind moves down to areas of low pressure, so the flow is down the windward face of the building. When it hits the ground, it becomes turbulent and spirals, decreasing winter comfort. The speed at the street level may be four times that of the streets protected by low rise buildings. A rounded convex form facing the wind diverts more air around the building. **(Figure A - Commerzbank building, Frankfurt, Germany).**
2. **The Corner Effect:** Is an increase in wind velocity created by wind moving around the building; taller and wider buildings create ore intense corner effects. The impact extents to an area equal to the building's width. **(Fig. B)**
3. **Wake Effect:** Is a spiraling, erratic, upward flow, creating turbulence on the leeward side. These effects are strongest when there are large height differences between a tall building and it's surroundings.
4. **Gap Effect:** Passage ways under tall slab buildings create zones of higher velocity in the passage and in the open space downwind of the building. This effect depends on the building height.

**Comfort Parameters Around Tall Buildings**

| Effect (Height) | Corner Effect | Slot Effect | Wake Effect | Downwash Effect |
|---|---|---|---|---|
| | (1) 15 m<br>(2) 15 - 35 m<br>(3) 35 - 45 m<br>(4) 100 m | (1) 15 m<br>(2) 15 - 21 m<br>(3) 21 - 50 m | (1) 48 m<br>(2) 48 - 90 m | (1) 60 m<br>(2) 60 m ( low up stream building )<br>(3) 100 m -do- |
| Comfort Parameters | (1) 1.2<br>(2) 1.2 - 1.5<br>(3) 1.4<br>(4) 2.0 | (4) Little effect<br>(5) 1.2<br>(6) 1.5 | (1) 1.4<br>(2) 2.2 | (1) 1.5<br>(2) 1.8<br>(3) 2.0 |

Comfort Parameter is an indicator of comfort in relation to wind; it is a relative reference value, by season and climate, accounting for both wind speed and turbulence and is a ratio of wind speed at a location near building to the wind speed at the same point with no building **(Melaragno, 1982).** In winter a high value means less comfort, but in summer increased comfort.

**SHAPE AND ORIENTATION (Streets and Buildings)**

**STRATEGY NO 4: BREEZY STREETS.**

**Breezy streets oriented to the prevailing wind maximize wind movement in urban environments and increase the access of buildings to cross ventilation (Cooling).**

In hot climates, especially, in humid conditions, good ventilation is necessary to remove excess heat from the streets and open spaces and to provide cross ventilation in buildings, for which sufficient wind flows is a necessary precondition. Since dense urban areas create high levels of heat gain and have less ability to loose heat by radiation, wind in streets and open spaces can be critical to cooling.

In most cases, wind speeds in the city are significantly reduced, due to friction and blockage. The configuration of buildings and streets in relation to the prevailing summer breezes can maximize air movement through the city and thus provide wind access to more buildings.

Streets parallel to the prevailing wind have the highest velocity in the streets, while streets perpendicular to the wind encourage most the wind to blow over the buildings, yielding lower velocity and more turbulent wind in the streets.

**(Yanas, 1995)** A street orientation oblique to prevailing winds will create two sides of buildings with positive pressure and two sides with negative pressure, thus maximizing cross ventilation potential in the buildings. **(Figure A - 1856 City plan, Charleston, South Carolina)**

**To maximize cross ventilation access and air movement in streets, orient primary avenues at an angle of approximately 20 - 30$^0$ from the line of the prevailing summer breeze ( Givoni, 1992 ) ( Figure B )**

In general, narrow streets will slow winds, while wider streets tend to encourage faster flow due to reduced friction. In temperate climates, winter heating is as important as summer cooling, thus east west oriented streets should be wide enough for solar access to south facades and orientation for wind should also place long block faces within 30$^0$ of south to ensure solar access.

**SHAPE AND ORIENTATION (Open Spaces and Buildings - Layers)**

**STRATEGY NO 9: OVERHEAD SHADES.**

**A layer of overhead shades can protect out door spaces and buildings from the high sun (Cooling).**

In hot climates, pedestrian streets can be quite uncomfortable unless shaded. Heat absorbing massive elements of paving and facade, high sun angle and intense solar radiation levels all contribute to the potential for extreme conditions. In many hot climates, both humid and arid, groups of buildings may be linked by shaded pedestrian streets or pedestrian may be protected by arcades at the edge of streets and open spaces. In hot arid climates day time protection from hot, possibly dust laden winds is also important, thus circulation can be mostly enclosed. Conversely, in hot humid climate, shading should not block ventilation.

**Examples: Bazar of Isfahan, (Figure A)**

**The Indian Institute of Management, Bangalore, B. V. Doshi (Figure B)**

Overhead louvers for shading can shade while admitting light. They must be sized and configured to protect space below. Louvers can be set at vary angles and orientations as long as the cut off angle is greater than the profile angle.

The profile angle is the sectional angle normal to the shading device that will provide full shade. If less than 100% shade is desired, use a cut off angle less than the profile angle. When the solar azimuth is equal to the orientation of the shading element, the profile angle is equal to the solar altitude.

For shading between 8 am and 4 pm, for horizontal louvers oriented to the south, the profile angle is 90$^0$ (straight over head) for latitudes up to 40$^0$. In this orientation the profile angle is highest in the early morning and late afternoon. For horizontal louvers oriented east-west (elongated in the north-south direction) the maximum governing profile angle is 90$^0$ for all latitudes. As a general rule, assuming full sun exposure and no shading of the louvers from obstructions:

**To provide shading by fixed over head louvers, the cut off angle of the louver design should be greater than 90$^0$.**

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