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PASSIVE BUILDING DESIGN: OPENINGS APPROACH FOR NATURAL VENTILATION TO CONTROL INDOORS ENVIRONMENT

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Abstract: This study was inspired by a contemporary trend in architecture, which is the interest of passive and low energy applications in buildings. Where a natural cross ventilation can be a promising passive solution for summer thermal comfort in buildings especially in hot country like Libya. It takes advantage of the night temperature of the air to cool the walls at the buildings, although this technique is well–known in hot climate, its use in new buildings requires being able to predict the quantity of heat that can be dissipated. There is indeed a lack of experimental and research data either to build design rules for engineers or to validate numerical code dedicated to the design. This paper concentrates on the area of cross ventilation and Highlights the opportunity of using this passive low energy cooling method here in Libya.
Keywords: Cross ventilation, windows types, opining orientation, nocturnal cooling

1. INTRODUCTION

Tow– sided or cross ventilation occurs when air enters the room or buildings from one or more opening on one side and room air leaves through one or more opening on another side of the room or buildings, the flow of air in this case is mainly due to wind pressure, and buoyancy pressure becomes important only if there is a significate difference in height between the inflow and outflow openings.

As well as, ventilation is the process by which fresh air is introduced and ventilated air is removed from an occupied space. The primary aim of ventilation is to preserve the qualities of air. Sometimes, ventilation may also be used to lower the temperature inside an occupied area. Without ventilation, a building's occupants will first be troubled by odors and other possible contaminants and heat. Humidity will rise, thus enhancing moisture hazards (e.g. mold growth and condensation). Oxygen will not be missed until much later. The purpose of ventilation is to eliminate airborne contaminants, which are generated both by human activity and by the building itself. Therefore, designers should not only care about the design of the window aesthetically, but they should also care about reducing the thermal transmission of the window through the load to achieve the thermal comfort required for the users of the space.

Natural ventilation also, is the process of supplying and removing air by means of purpose–provided aperture (such as openable windows, ventilators and shafts) and the natural forces of wind and temperature–difference pressures. Natural ventilation may be divided into two categories:

- Controlled natural ventilation is intentional displacement of air through specified openings such as windows, doors, and ventilations by using natural forces (usually by pressures from wind and/or indoor–outdoor temperature differences). It is usually controlled to some extent by the occupant.
- Infiltration is the uncontrolled random flow of air through unintentional openings driven by wind, temperature–difference pressures and/or appliance–induced pressures across the building envelope. In contrast to controlled natural ventilation, infiltration cannot be so controlled and is less desirable than other ventilation strategies, but it is a main source of ventilation in envelope–dominated buildings.

2. CONTROLLING THE AIR MOVEMENT THROUGH THE OPINING ZONES

The movement of air inside the space is controlled through ventilation holes, to achieve several main functions, namely:

— Health Ventilation

Replacing clean air with unpleasant air, i.e. providing the building with the oxygen necessary for breathing to prevent the increase in carbon dioxide, as well as getting rid of unpleasant and harmful odors and fumes. The rate of renewal of the air of the space occupied by a person varies according to his job, in the living room, for example, the air needs to be renewed from 1 to 1.5 times per hour, while in the kitchen, where odors and high carbon dioxide levels increase, this rate increases to 4 or 5 times per hour. (Al–Zafaranim,2000)

— Thermal Comfort Ventilation

Cooling the human body when needed by controlling the air speed and its movement, because with the increase in air speed, the rate of heat transfer from the body to the surrounding environment increases, as well

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as the increase in the evaporation capacity of the air, that is, the amount of water vapor or moisture absorbed by the air, and then the cooling effect caused by sweat evaporation increases on the skin. (Al–Zafaranim,2000)

— Structural Cooling Ventilation

Cooling the origin, as the outside air entering through the opening's mixes with the internal air, and heat is transferred between them according to the difference between their two temperatures. Experiments have proven that the cooling effect caused by ventilation inside buildings increases with the decrease in the thickness of the external walls and their darkening in color, and it decreases with the increase in the thickness of the wall and its resistance to heat penetration, because the air temperature in this case increases its dependence on the temperature of the internal surfaces. (Al–Zafaranim, 2000).

Figure (1). Structural Cooling Ventilation.
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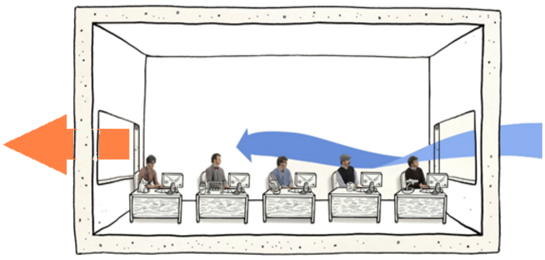
Figure (2) Cooling Ventilation
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The assessment of ventilation inside the space depends on two main components,

- The first is that it is easy to achieve, as ventilation must meet the rates necessary to achieve its hygienic function.
- The second is the extent of achieving thermal comfort for users within the space by achieving appropriate air velocities inside the space. It is considered a variable element according to the type of activity within the space.

3. DESIGN FOR NATURAL VENTILATION

The design of controlled natural ventilation systems requires identification of the prevailing wind direction, the strategic orientations and positions of openings on the building envelope. These openings include windows, doors, roof ventilators, skylights, vent shafts, and so forth.

— Ventilation rates

When designing a ventilation system, the ventilation rates are required to determine the sizes of fans, openings, and air ducts. The methods that can be used to determine the ventilation rates include:

(a) Maximum allowable concentration of contaminants

A decay equation can be used to describe the steady–state conditions of contaminant concentrations and ventilation rate, like this:

$$C_i = C_o + F / Q \quad (1)$$

where C_i = maximum allowable concentration of contaminants;
C_o = concentration of contaminants in outdoor air
F = rate of generation of contaminants inside the occupied space (l/s)
Q = ventilation rate (l/s)

(b) Heat generation

The ventilation rate required to remove heat from an occupied space is given by:

$$Q = \frac{H}{c_p \cdot \rho \cdot (T_i - T_o)} \quad (2)$$

where H = heat generation inside the space (W)
Q = ventilation rate (l/s)
c_p = specific heat capacity of air (J/kg. K)
ρ = density of air (kg/m^3)
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

(c) Air change rates

Most related professional institutes and authorities have set up recommended ventilation rates, expressed in air change per hour, for various situations. The ventilation rate is related to the air change rate by the following equation:

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$$Q = \frac{V*ACH}{3600} * 1000 \quad (3)$$

where: Q = ventilation rate (l/s)
V = concentration of contaminants in outdoor air
ACH = air change per hour

Table 1 gives some recommended air change rates for typical spaces. Table 2 provides some examples of outdoor air requirements for ventilation.

Table 1. Recommended air change rates

Space	Air change rates per hour
Garage	6
Kitchen	20 – 60
Bathrooms	6

Table 2. Outdoor air requirements for ventilation

Application	Estimated maximum occupancy (persons per 100 m² floor area)	Outdoor air requirements (l/s/person)
Offices		
– office space	7	10
– conference room	50	10
Education		
– classroom	50	8
– auditorium	150	8
– library	20	8
Hospitals		
– patient rooms	10	13
– operating rooms	20	15

Note: Data source: ASHRAE Standard 62–1989, Ventilation for Acceptable Indoor Air Quality.

— Flow caused by wind

Major factors affecting ventilation wind forces include:
- average wind speed;
- prevailing wind direction;
- seasonal and daily variation in wind speed and direction;
- local obstructing objects, such as nearby buildings and trees;
- position and characteristics of openings through which air flows; and
- distribution of surface pressure coefficients for the wind.

Natural ventilation systems are often designed for wind speeds of half the average seasonal velocity because from climatic analysis there are very few places where wind speed falls below half the average velocity for many hours in a year.

The following equation shows the air flow rate through ventilation inlet opening forced by wind:

$$Q = C_v \cdot A \cdot v \quad (4)$$

where Q = air flow rate (m^3/s)
A = free area of inlet openings (m^2)
v = wind velocity (m/s)
C_v = effectiveness of the openings (assumed to be 0.5 to 0.6 for perpendicular winds and 0.25 to 0.36 for diagonal winds)

— Flow caused by thermal forces

If the building's internal resistance is not significant, the flow caused by stack effect may be estimated by:

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$
$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i \quad (5)$$

where Q = air flow rate (m^3/s)
K = discharge coefficient for the opening (usually assumed to be 0.65)
A = free area of inlet openings (m^2)
Δh = height from lower opening (mid–point) to neutral pressure level (m)
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

— Guidelines for natural ventilation

The following guidelines are important for planning and designing natural ventilation systems in buildings:

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- a natural ventilation system should be effective regardless of wind direction and there must be adequate ventilation even when the wind does not blow from the prevailing direction;
- inlet and outlet openings should not be obstructed by nearby objects;
- windows should be located in opposing pressure zones since this usually will increase ventilation rate;
- a certain vertical distance should be kept between openings for temperature to produce stack effect;
- openings at the same level and near the ceiling should be avoided since much of the air flow may bypass the occupied zone;
- architectural elements like wingwalls, parapets and overhangs may be used to promote air flow into the building;
- topography, landscaping, and surrounding buildings should be used to redirect airflow and give maximum exposure to breezes;
- in hot, humid climates, air velocities should be maximized in the occupied zones for bodily cooling;
- to admit wind air flow, the long façade of the building and the door and window openings should be oriented with respect to the prevailing wind direction;
- if possible, window openings should be accessible to and operable by occupants;
- vertical shafts and open staircases may be used to increase and generate stack effect;
- openings in the vicinity of the neutral pressure level may be reduced since they are less effective for thermally induced ventilation;
- if inlet and outlet openings are of nearly equal areas, a balanced and greater ventilation can be obtained.

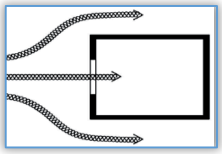
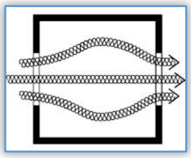
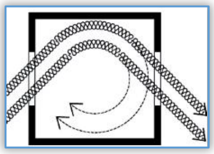
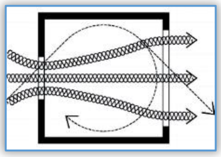
— Air movement inside the space and position of windows in the horizontal plan

To obtain ventilation inside the space, several factors must be present in the external openings, the most important of these factors are the following (Al–Zafaranim,2000):

- Availability of at least one air inlet and at least one air outlet for a single space, or defining a field for wind movement that helps direct the air into the space.
- The pressure difference between the internal and external voids should be large in a way that helps to draw air and move it within the void.
- Putting the wind–receiving window in the direction of the preferred wind.

It is possible to summarize the effect of these factors as shown in Table (3), which shows several different cases of the external openings and the possibilities of their different patterns and the prevailing form of the wind direction inside the void at the level of the horizontal projection (Source: Al–Esawy, 2003):

Table 3. The relationship between the location of windows in the horizontal position and the direction of wind movement within the space. (Al–Esawy, 2003)

Wind direction	Elevation	Placement of windows and wind direction
Ventilation inside the space is somewhat weak, And not enough for the entire void		single window blank
The air flows directly from these openings to the opposite opening, forming an air stream that causes a kind of inconvenience to the users of the space, and the ventilation is not homogeneous in the space		Two opposite windows have the same width, and the direction of the wind is perpendicular to them
Most of the air volume passes and moves through the space of the room and increases its flow at the corners, thus achieving a more homogeneous ventilation inside the space		Two opposite windows of the same width, and the direction of the wind is tilted on them
Air flows inside the space, whether at a slope or perpendicular to the outer opening, and the highest wind speed inside the space is at the smaller opening, whether air enters or exits from it.		Two opposite windows (the width of the entrance is smaller) and the direction of the wind is perpendicular or inclined to them

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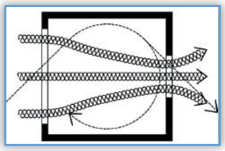
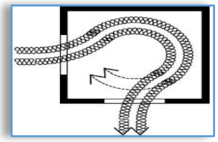
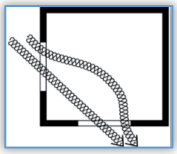
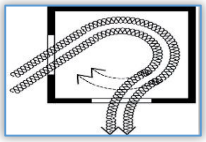
Air flows inside the space, whether at a slope or perpendicular to the outer opening, and the highest wind speed inside the space is at the smaller opening, whether air enters or exits from it.		Two opposite windows (The width of the entrance is greater), and the direction of the wind is perpendicular or inclined to them
Homogeneous ventilation can be obtained within the space.		Two adjacent windows, and the direction of the wind is perpendicular to the entrance
Air passes from the entrance window to the exit window without achieving homogeneous ventilation of the void, especially at the other corners		Two adjacent windows and the direction of the wind is tilted on the entrance towards the other window
Homogeneous ventilation can be obtained within the space.		Two adjacent windows, and the direction of the wind is tilted against the entrance The direction of the other window

— Air velocity in inner space:
To achieve the movement of the wind inside the space, the window does not have to be opposite to the direction of the wind, but the wind can enter the void in the event that the direction of the window is parallel to the direction of the wind, and if the movement of the wind inside the void in this case is few, and the designer in this case must use the auxiliary plant elements in Directing the wind inside the space to get the required wind movement inside it. (Givoni, Baruch, 1992)

— Orientation of windows with respect to winds
It is a common belief that for good ventilation in elongated buildings the main walls should be perpendicular to the prevailing wind direction. With such an orientation the largest pressure differential is created between the windward and the leeward walls. It is assumed that this orientation provides the best ventilation. In reality, however, the situation is often different. Buildings that are exposed to oblique winds, with angles of 30^0 to 60^0 away from the normal, can provide better ventilation conditions in individual rooms and in the house as a whole. When the wind is oblique to the building, a pressure gradient is created along the windward walls. If two windows are provided in a given room along the windward walls, the upwind window is at a higher pressure than the downwind one. Thus, air enters the room through the upwind window and leaves through the downwind aperture. When the wind is perpendicular to the wall, the two openings are exposed to the same pressure and this reduces the ventilation of the room. When the wind is oblique to the wall, it is possible to greatly increase the pressure difference between the two windows by adding a single wing wall (a vertical projection on one side of the window). If such a wing wall is placed downwind of the first window, high pressure is created in front of it. A wing wall upwind of the second window creates a suction in front of it.

— Windows types and ways of opening
Different types of windows, when serving as inlets, produce different patterns of indoors airflow and provide different options for controlling the direction and level of the flow.

- Double–hung windows, by their height, determine the vertical level of airflow but not its direction and pattern. The maximum free opening is less than one–half of the total area of the sashes, a factor that limits the effective ventilation rate.
- Horizontally sliding windows also provide less than half of the free–opening area. They allow less control of the indoor flow pattern than double–hung windows because horizontal variations in the flow direction are much greater than in the vertical plane as a result of changes in wind direction.
- Casement windows opened to the outside can serve as wing walls, creating an elevated pressure when one sash, the downwind one, is opened, or creating a suction zone when the upwind sash is opened. However, when both sashes are opened, they may provide a smaller airflow than when only the downwind sash is open, because when both are open there is interference in the flow.
- Horizontal center pivot hung windows permit control of the vertical pattern of airflow (either upward or downward) if the sashes can be made to open downward on the room side, 10^0 below the horizontal.

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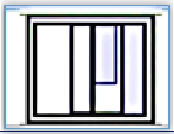
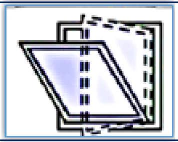
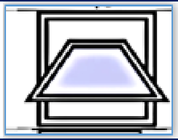
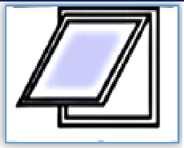
Experiments by Givoni (1976) have demonstrated that by altering the angle to which the sash is opened it is possible to modify and alter flow patterns and distribution of velocities throughout the indoor space. There are many types of windows that can be used to obtain good ventilation of which as shown in the below table.

Table 4. The types of windows and their effect on the ventilation of the space, (Givoni, 1976)

Window Shape	Window Type	Night Ventilation	Weather Protection	Ventilation Control	Air Flow
	horizontal slide	middle	middle	middle	v. good
	tilt and swivel	middle	good	good	good
	center pivot window	good	good	middle	v. good to average
	hinge at the bottom	v. good	good	Good	middle
	hinge on top	good	v. good	middle	good
	side hinge side – hung casement	weak	middle	middle	good
	upper fanlight and outward opening casement	very good	v. good	v. good	good
	vertical double sash	middle	middle	good	v. good

— Barriers to the application of natural ventilation

A successful application of natural ventilation strategies is only possible when there are no problems in many areas at various levels from the design stage to actual operating demands placed on the building users (Allard, 1998). These potential barriers include:

- Barriers during building operations
  - safety concerns
  - noise from outdoor
  - dust and air pollution
  - solar shading covering the openings
  - draught prevention
  - knowledge of the users about how to take the best advantage of natural ventilation
- Barriers during building design
  - building and fire regulations
  - need for acoustic protection

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- difficult to predict pattern of use
- devices for shading, privacy & daylighting may hamper the free flow of air
- problems with automatic controls in openings
- lack of suitable, reliable design tools

- Other barriers
  - impact on architectural & envelope design
  - fluctuation of the indoor conditions
  - design a naturally ventilated building requires more work but could reduce mechanical system (design fee on a fixed percentage of system's cost)
  - increase risk for designers
  - lack of suitable standards

— Design for natural ventilation

With the number of pleasant days provided during our fall, winter, and spring seasons we would use our air–conditioners less if our buildings were designed for natural ventilation. There are a few basic principles of airflow, based on the application of biology, meteorology, and engineering science to architecture in hot– regions. The prevailing breezes, averaging 10 mph, during the warm seasons are from the east–southeast. Sea breezes winds can reach speeds of 20 to 30 mph.

And to benefit from this breeze the height of the window has a great impact on the ventilation of the space and the movement of winds inside the space, and also affects the level at which the wind moves inside the space. It is important to achieve ventilation at the level of the users of the space according to the activity they perform inside the space, and these are different locations for the levels of ventilation entry and exit holes (Al–Wakeel, 1985).

Considerations to be consider when design for natural ventilation:

- The placement and size of inlets and outlets can affect the flow of cooling breezes through a room.

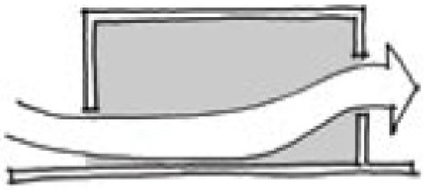

Figure 3a. Inlet placed low causes airflow to sweep the floor

- Maximum airflow can be achieved when the inlet and outlet are of equal area and placed opposite each other.

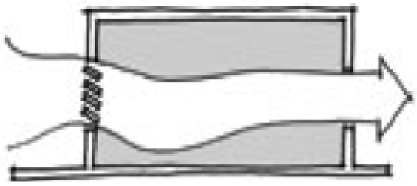

Figure 3b. Louvers placed in a downward position at the inlet diffuse airflow

- Higher velocities of air movement occur when the outlet is larger in area than the inlet.

Figure 3c. Inlet placed high directs flow upward resulting in loss of cooling effect.

- Low energy consumption can be achieved by combining this strategy with compact development, multi–use spaces in buildings, designing a privacy gradient, and providing a rain and sun screen.

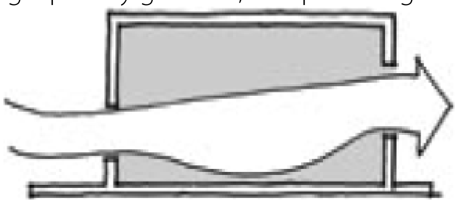

Figure 3d. Inlet placed low directs flow downward. The location of the outlet has no effect on the internal flow pattern.

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- Use shading devices to protect from the sun and also to direct cooling breezes.

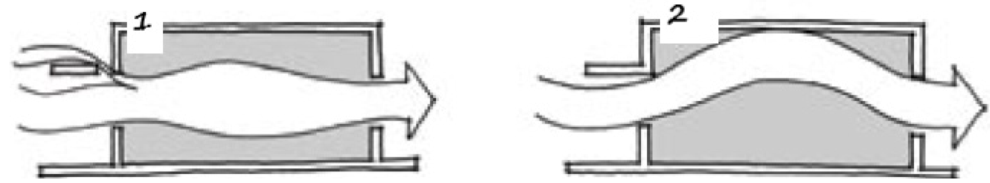

Figure 3e. 1. Providing a slot between a canopy or 'eye–brow' can increase downward pressure and result in a more comfortable air flow within a room. 2. Solid overhangs, or 'eye–brows', directly over a window can direct airflow upward away from the occupied zone of a room.

- Use rain screens to improve thermal performance of the building envelope.

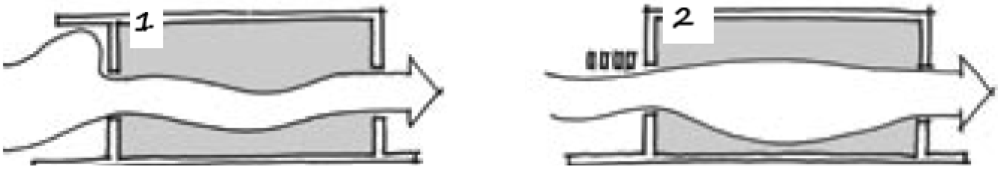

Figure 3f. 1. Overhangs collect breezes and enhance airflow to interior spaces. 2. Louvered overhangs and sunshades enhance downward pressure of airflow through a space.

4. CONCLUSIONS

It is important to conclude by emphasizing that the assessed natural ventilation potential is the potential of the site. Once a site with a good potential is found, the designer's task is to construct a building or to refurbish an existing one in a way that makes the most out of this potential. In other words, both an appropriate site and an appropriate building are necessary conditions if natural ventilation is to be applied. Moreover, in some cases, natural ventilation cannot alone provide the required airflow rate. This could be the case when the ventilation openings are too small for the wind and temperature conditions present on the site, or in rooms not directly connected to the outdoor environment. Where or when the natural ventilation can no more be ensured by either stack effect or wind, fans may be installed and switched on to ensure the necessary ventilation flow rate. Such fans may be installed either on stack ducts, or in walls or windows. What is important is that, when the fans are off, their openings are either tightly closed or part of the natural ventilation design.

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