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Natural Ventilation Approach in Designing UrbanTropical Houses in Port Harcourt Metropolis

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Abstract
Building ventilation is necessary and natural ventilation systems rely on pressure differences to move fresh air through buildings.Natural ventilation systems are usually integrated into building systems where there is some mechanical support; these are called mixed mode or hybrid ventilation buildings. It is a processof supplying fresh air and removing or diluting indoor pollution concentration. Buildings with well-designed natural ventilation systems often provide very comfortable and pleasant environments for the occupants. In general, the advantage of natural ventilation is its ability to provide a very high air change rate at low cost, with a very simple system. However, due to not much of air movement viawind driven in high density urban area, stack effect is seeming to be more reliable than cross ventilation. The stack-effect is based on the fact that warmer air rises as cooler air falls. This is due to differing densities; when air is heated, it becomes less dense, allowing it to rise, pushing cooler air downwards. Creating an upward air stream, this concept is very important in the stack-driven method of ventilation. Stack effect performance is very much related to the temperature difference between indoor and outdoor environment, understanding the climate characteristic is essential. The process by which building heats up or cools down itself naturally without the use of mechanical driven devices is called passive cooling. Controlling the neutral plane level in the house by the sizes of the openings isessential in driving the air in and out. On the other hand, cooling process for human though is not only relied on the airtemperature as it also involves the sensible heat cooling which very much related to theactivities held in the room. Different setting and location of the building may also requiredifferent approach in providing a good thermal condition of the building, thus opening anample room of researches and studies in this field. While in tropicalarea, maintaining the indoor temperature lower than the outdoor temperature is also important tokeep the pressure difference for wind flow besides providing indoor thermal comfort to theoccupants.
***Keyword**: Natural Ventilation, Stack effect, Tropical Housing.*

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I. Introduction

Ventilation is the intentional movement of air from outside a building to the inside. Natural ventilation occurs when the air in a space is changed with outdoor air without the use of mechanical systems, such as a fan. Most often natural ventilation is assured through operable windows but it can also be achieved through temperature and pressure differences between spaces.

Natural ventilation systems rely on pressure differences to move fresh air through buildings. Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or differences in humidity. In either case, the amount of ventilation will depend critically on the size and placement of openings in the building. It is useful to think of a natural ventilation system as a circuit, with equal consideration given to supply and exhaust. Openings between rooms such as transom windows, louvers, grills, or open plans are techniques to complete the airflow circuit through a building. Natural Ventilation systems rely on natural driving forces, such as wind and temperature difference between a building and its environment, to drive the flow of fresh air through a building. Both work on the principle of air moving from a high pressure to a low-pressure zone.

Natural ventilation systems are usually integrated into building systems where there is some mechanical support; these are called mixed mode or hybrid ventilation buildings. The main benefit of some augmentation by mechanical systems is that there is less unpredictability with indoor environment conditions, though it will result in greater energy use. Almost all historic buildings were ventilated naturally, although many of these have been compromised by the addition of partition walls and mechanical systems. With an increased awareness of the cost and environmental impacts of energy use, natural ventilation has become an increasingly attractive method for reducing energy use and cost and for providing acceptable indoor environmental quality and maintaining a healthy, comfortable, and productive indoor climate rather than the more prevailing approach of using mechanical ventilation. In favorable climates and buildings types, natural ventilation can be used as an alternative to air-conditioning plants, saving 10%-30% of total energy consumption.

Natural ventilation can be an appropriate choice when compared to air conditioning in the tropic climate of Nigeria, particularly as the nights are cool and this can be used to pre-cool the building. It can save substantial amounts of energy by decreasing or eliminating the need for mechanical cooling. It may also improve the building 's indoor air quality. Buildings with well-designed natural ventilation systems often provide very comfortable and pleasant environments for the occupants.

Natural ventilation

Natural forces (e.g. winds and thermal buoyancy force due to indoor and outdoor air density differences) drive outdoor air through purpose-built, building envelope openings. Purposebuilt openings include windows, doors, solar chimneys, wind towers and trickle ventilators. This natural ventilation of buildings depends on climate, building design and human behaviour.

If well installed and maintained, there are several advantages of a natural ventilation system, compared with mechanical ventilation system (Edward2005):

➢ Natural ventilation can generally provide a high ventilation rate more economically, due to the use of natural forces and large openings.

➢ Natural ventilation can be more energy efficient, particularly if heating is not required.

➢ Well-designed natural ventilation could be used to access higher levels of daylight.

From a technology point of view, natural ventilation may be classified into simple natural ventilation systems and high-tech natural ventilation systems. The latter are computer controlled, and may be assisted by mechanical ventilation systems (i.e. hybrid or mixed mode systems). High-tech natural ventilation may have the same limitations as mechanical ventilation systems; however, it also has the benefits of both mechanical and natural ventilation systems.

In general, the advantage of natural ventilation is its ability to provide a very high air change rate at low cost, with a very simple system. Although the air-change rate can vary significantly, buildings with modern natural ventilation systems (that are designed and operated properly) can achieve very high air-change rates by natural forces, which can greatly exceed minimum ventilation requirements.

There are a number of drawbacks to a natural ventilation system:

• Natural ventilation is variable and depends on outside climatic conditions relative to the indoor environment. The two driving forces that generate the airflow rate (i.e. wind and temperature difference) vary stochastically. Natural ventilation may be difficult to control, with airflow being uncomfortably high in some locations and stagnant in others (Davis &Nordin, 2002). There is a possibility of having a low air-change rate during certain unfavourable climate conditions.

• There can be difficulty in controlling the airflow direction due to the absence of a well-sustained negative pressure; contamination of corridors and adjacent rooms is therefore a risk.

• Natural ventilation precludes the use of particulate filters. Climate, security and cultural criteria may dictate that windows and vents remain closed; in these circumstances, ventilation rates may be much lower.

• Natural ventilation only works when natural forces are available; when a high ventilation rate is required, the requirement for the availability of natural forces is also correspondingly high.

• Natural ventilation systems often do not work as expected, and normal operation may be interrupted for numerous reasons, including windows or doors not open, equipment failure (if it is a high-tech system), utility service interruption (if it is a high-tech system), poor design, poor maintenance or incorrect management.

• Although the maintenance cost of simple natural ventilation systems can be very low, if a natural ventilation system cannot be installed properly or maintained due to a shortage of funds, its performance can be compromised, causing an increase in the risk of the transmission of airborne pathogens. These difficulties can be overcome, for example, by using a better design or hybrid (mixed-mode) ventilation. Other possible drawbacks, such as noise, air pollution, insect vectors and security, also need to be considered. Because of these problems, natural ventilation systems may result in the spread of infectious diseases through health-care facilities, instead of being an important tool for infection control (Baker &Steemers, 2000).

STACK EFFECT VENTILATION

The stack-effect (Bahadori, Dehghani-Sanij&Sayigh, 2014) is based on the fact that warmer air rises as cooler air falls. This is due to differing densities; when air is heated, it becomes less dense, allowing it to rise, pushing cooler air downwards. Creating an upward air stream, this concept is very important in the stack-driven method of ventilation.

In order for this method to work, the climate must be right, meaning the interior of the building should contain warmer air than the air outside. With openings at the lower levels and top of the building, the warm air inside would rise and leave the building through the openings at the top, while cooler air from outside would flow in through the openings near the bottom. A greater temperature difference would make this system very effective. Once again, Fig 2.2 below shows this phenomenon in action in conjunction with a wind-driven system; the cool air enters the building at the lower level of the building as the warmer air from inside is forced out through the skylight.

Furthermore, pressure is also involved in the stack effect. At the point in between the warm and cool air is the area of neutral pressure; any point below this would be at a lower pressure, thus drawing in the air from the outside. Above the neutral pressure line, the pressure is higher, forcing air out through openings near the top into lower pressure areas outside.

Advantages (Ezema, Olotuah& Fagbenle, 2016)

i. Does not require wind; can work even when the surrounding air is completely still. ii. Relies on natural force (pressure and temperature differences)

iii. More control with regards to where the openings in the building are.

iv. Uses almost no energy compared to conventional methods, saving money and the environment

Disadvantages (Wikipedia, 2010)

i. Cannot control exterior temperature ii. Can bring polluted air into buildings

ENHANCING THE STACK EFFECT PERFORMANCE

Climatic Characteristic

As stack effect performance is very much related to the temperature difference between indoor and outdoor environment, understanding the climate characteristic is essential. The tropical climate of Port Harcourt can be classified as warm-humid equatorial, having high temperature andhumidity throughout the year, obtains intense sunshine, high temperature, strong glare, high radiation levels and rainfall. The average temperature and humidity is relatively high and consistent throughout the year. The monthly averages are almost constant though.

The air temperature average is consistent between 26°C and 32°C with high relative humidity ranging from 80% to 90% and never falling below 60%. The annual mean temperature is about 27°C (80°F) with the average monthly temperature ranging from 1 - 3°C (2 - 5.5°F). Average maximum temperatures are about 30°C (86°F) and sometimes may reach 38°C (100°F) on clear days; The monthly average daily solar radiation in Port Harcourt is 4000 - 5000 Whr/m2, with themonthly average daily sunshine duration ranging from 4 hr to 8 hr (Mohammad, 2010).

Rainfall is also high over the year and sometimes comes with strong wind, averaging 2500mm to 3000mm annually and is more intense with the monsoons (Mohammad, 2012). Other sources quote Port Harcourt ashaving a yearly mean temperature of between 26°C and 27°C and relative humidity (RH) of 70%to 90% throughout the year. The mean maximum daytime temperatures between 29°C and 32°Cwhile the mean minimum temperature is between 22°C and 24°C (Nwofe, 2014).

As the daytime temperature is considered quite high, a building in Port Harcourt has to be able to insulate the indoor surrounding in providing a good thermal comfort for the users. This can be achieved by using proper building materials combined with good design. Maintaining a significant lower temperature inside compared to the outdoor temperature may help in enhancing the air flow into the house via stack effect ventilation process. However, encouraging rapid air flow into the building during daytime in Port Harcourt may also bring the heat into the building. Thus,proper consideration on how to slightly cool the air before entering the building is important.

Passive Design Strategies in Traditional Houses

The process by which building heats up or cools down itself naturally without the use of mechanical driven devices is called passive cooling. Unlike active cooling which ensures the use of energy to maintain a balanced interior condition, Passive cooling takes full advantage of the micro climate, using climate responsive design parameters such as Orientation, shape, fenestration, landscape etc. (Urge-Vorsatz, Cabeza, Serrano, Barreneche&Petrichenko, 2015). Irimiya, Humphery and Aondover (2013) referred passive cooling techniques (Climate responsive designs) to design technologies or features used to cool buildings without power consumption i.e., without the use of mechanical and electrical driven devices. Climate responsive design according to Uzuegbunam (2012) is relatively unknown in Nigeria due to factors which include poverty, lack of awareness, Illiteracy and poor governmental policies.

A. Poverty According to the report released by the National Bureau of statistics (NBS) reported by Vanguard Newspaper (2016), approximately 67.1% (112 million) of Nigeria's total population of 167 million live below the poverty line. This means that the Nigeria poverty rate is becoming very high compared to the

54% reported by the same body in 2010. Poverty is a strong limiting factor to energy efficient buildings as money is needed to procure the materials and human resources needed to execute such Climate responsive buildings. (Akadiri, 2015).

B. Lack of awareness:Ogunsote et al (2011) noted that buildings in Nigeria rather than being designed to take full advantage of its bioclimatic factors are becoming a show of owners profligacy i.e., attention of building designers is concentrated on aesthetic values which in turn calls for an abusive use of mechanical driven devices to achieve desirable thermal comfort by users without knowledge of the severe negative implications of the devices. The need for awareness both by designers and owners of buildings on the influence of climate responsive design is essential.

C. Illiteracy: With the adult illiteracy rate standing at 56.9% in 2010 (National Bureau of Statistics, 2010) and reported to reach 59.6% by 2017, Almhafdy, Ibrahim, Ahmad and Yahya (2013) opined that the level of knowledge the illiterates have as regards passive designs and energy efficient buildings is very low hence, they need to be educated on the merits of passive designs (climate responsive designs).

D. Poor governmental policies: The government rather than concentrating attention on making policies that will ensure that energy efficiency is achieved in buildings has concentrated attention on how to generate more non-renewable energy sources which will subsequently increase global warming and climate change. KPMG (2013) reported that 82% of energy use in Nigeria come from non-renewable energy sources and Nigeria has further plan to increase energy generation by 2020 (Husin& Harith, 2012)

In their opinion, Yahia and Johansson (2014) blamed the rising increase in energy use to maintain indoor comfort (Active cooling) as against passive techniques in Nigeria on the rising standard of living, the proliferation of new work profiles and equipment that requires air conditioning, 'peer' pressure from other modern cities and unfaithfulness on the part of the political elites and scientists who condemn voracious energy use (Active cooling) from the comfort of their fully fitted air conditioned offices.

According to Mohammad (2012), Maintaining a comfortable environment within a building in the tropics depend on how well heat gain into the building can be minimized and dissipating excess heat from the building, i.e. to prevent ingress of heat and swift removal of excess heat once it has entered is the basic technique for accomplishing thermal comfort in passive cooling concepts. These techniques are further stressed below:

1 Passive cooling through prevention of heat gains in buildings. The climate of the warm humid zone (Tropics) is characterized by high rainfall, high humidity and relatively high temperature which was put at between 300c - 350c and is fairly even throughout the day and throughout the year, the solar radiation is intense and hence should be prevented from entering into the building SKAT (1993). Mansor, Said and Mohamed (2010) further stressed that preventing heat from entering the building should be the first concern and not how to cool down the building i.e., if excessive heat can be minimized, then the problem of cooling down the building will be half solved. The important methods of reducing heat gains in buildings such as shading, vegetation (landscape), building orientation, use of high thermal mass to reduce heat absorption, insulation etc. are further discussed.

2 Shading. Among all other solar passive cooling techniques in the tropical region, shading is considered to be the most effective and should be the first line of defense if ingress of solar gain is to be minimized in buildings. Hashim, Samikon, Nasir and Ismail (2012) in their studies revealed that shading reduces the indoor temperature by about 2.50c to 6.80c more than other passive cooling techniques. Mohammad (2012) also posited that shading of buildings is cheaper, effective and easy to implement than every other passive cooling techniques. Shading can be achieved through the following:

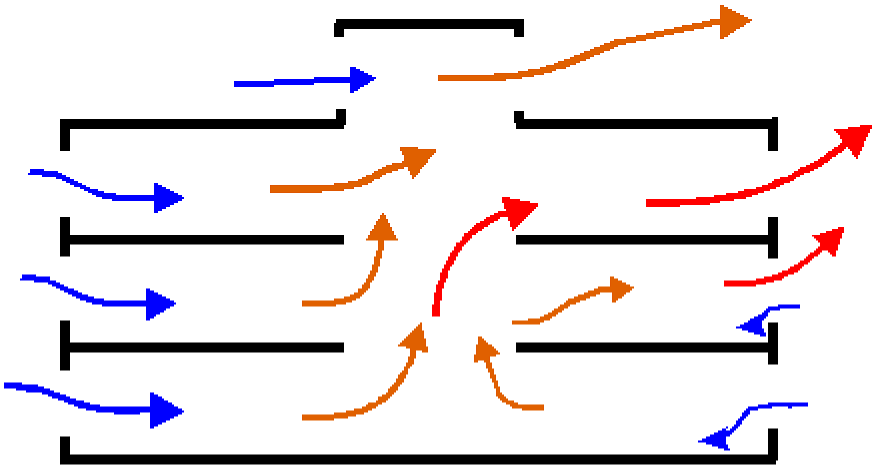
3 Shading using trees and shrubs trees and vegetation are most useful as a mitigating strategy when planted in strategic locations around buildings in the tropical regions; they lower surface and air temperatures by providing shade and through evapotranspiration (Amasyali, & El-Gohary, 2016). Evapotranspiration alone can help reduce peak summer temperatures by 2-90f (1-50c). Trees with wide shading crowns protects roofs, walls and windows from direct solar gains and can reduce surrounding air temperature significantly (SKAT, 1993).

4 Shading by overhangs and fins. Fins and overhangs act like caps and help in blocking direct sun rays. Fins and overhangs if properly designed can effectively reduce solar ingress and heat gain in buildings. Effective design of fins and overhangs depends on the solar orientation of building façade (Mohammad, 2012). Types of fins include horizontal, vertical and egg-crate fins.

5 Shading by textured surfaces. According to Mohammad (2010), surface shading should be adopted especially on walls if passive cooling of building is to be achieved in the tropics. Textured walls have parts of their surface in shade which helps in insulating the interior from solar heat gain.

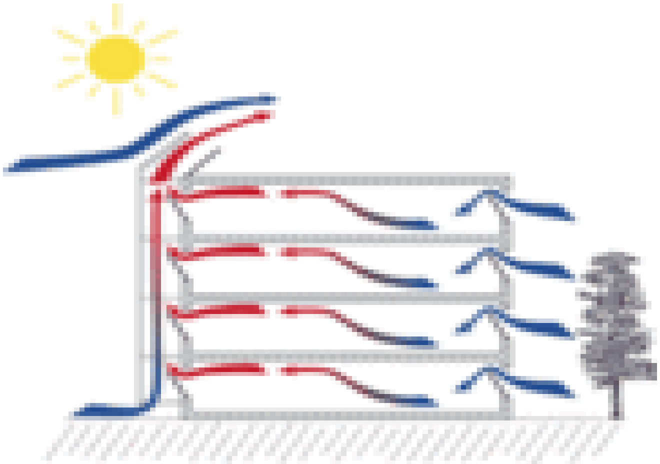
6 Proper landscaping: Incorporating shade through proper landscaping can reduce solar heat gain. Akadiri, Chinyio and Olomolaiye (2012) affirmed that proper landscaping is an effective means of protecting buildings from direct solar radiation, helps in minimizing heat gains and redirecting wind flow to enter the house for natural ventilation design. Proper landscape and vegetation create more physically comfortable and energy conscious buildings in the tropics (SKAT, 1993).

7 Building orientation is the way a building is positioned on a site. Buildings orientated for passive designs provide good natural (passive) thermal and visual comfort. Proper building orientation in the tropics can be best achieved by positioning the longer side of the building on East-West axis; it helps minimize the radiation received by building walls and hence reduces energy use in buildings (Uebersax, 2006).
8 Wind orientation or Wind flow is the movement of air in and around buildings. To achieve passive cooling and energy efficient buildings, wind orientation should be incorporated at the early state of settlement planning and building design. (SKAT 1993) suggested an open settlement pattern in the tropics to avoid wind flow from being impeded. Interior rooms should be crossly ventilated and windows should be designed along the windward sides of the site and not the leeward sides.
9 Thermal insulation, reflective roofs and wall colours. According to SKAT (1993), thermal insulation has little effect if wind orientation is properly incorporated in designs; but has a great effect in places where sun radiation is received. Reflective ceiling and roof coatings are easy ways of reducing roof overheating and heat transmission into the building through the roof. This goes a long way in reducing the need to cool down the building (Manzano-Agugliaro, Montoya, Sabio-Ortega and Garcia, 2015). Wall and surface colours also play an important role in absorbing and reflecting heat. Saidur, Masjukianf Jamaluddin (2007) stressed that walls should be in light colours to reflect heat, boundary walls and hard landscapes should be in dark colours to absorb heat and avoid reflecting heat and glare. This will mitigate against heat build-up in buildings in the tropics.



10 Heat storage and time lag. In the tropical climate, construction with materials characterised by high thermal storage capacity and long time lag should be avoided because it would cause undesirable re-radiation of heat at night thereby causing hot discomfort in buildings (Ogunsote, Prucnal-Ogunsote&Adegbie 2011).
11 Passive cooling through solar cooling systems (Induced ventilation techniques) Once heat has been built up in building, the next point of action is to find means of removing excess heat. This according to Ogunsote and Prucnal-Ogunsote (2004) can be achieved naturally through direct cooling techniques which include ventilation, infiltration, courtyard, wind tower, air vents etc.
12 Ventilation is the replacement of used air in buildings with fresh ones from outside (Nnaji, 2012). According to Lawal (2008), the amount of ventilation in buildings will depend on the size and positions of windows. To achieve good and effective exchange of air in buildings in the tropical region, Lawal (2008) stressed that windows should be located along north and south walls i.e. window positioning along east and west walls should be reduced or better still avoided. Adequate ventilation is best achieved according to Wikipedia (2010) by:

i. Cross ventilation- a situation where openings are created on two sides of the building called the inlets and outlets in order to optimize the path of air flow through the building. The sizing and placements of the openings will determine the velocity and direction of air through the building.
ii. Stack ventilation- stack effect is a situation where openings are located at ceiling and floor heights; it relies on the buoyancy of hot air to rise and exit through openings located at ceiling heights. Cooler air from outside moves to replace used warm air in buildings through inlets placed near the floor. Stack ventilation is effective in cases where cross ventilation is ineffective as a result of the unreliable movement of the wind.
13 Infiltration refers to uncontrolled air movement in and out of the building. Air is introduced in to the building accidentally or unintentionally. These often arise as a result of cracks in building envelope, gaps in openings, poor weatherization etc. Kumar, Garg, and Kaushik (2005) indicated that infiltration can contribute about 40% of heat loss in buildings in the tropics but should not be encouraged because it is also capable of bringing in uncontrolled dust, pollen and microorganisms in unfiltered air.
14 Wind Tower or wind catchers are small towers installed on top of buildings; they serve as natural ventilation systems by directing the outside air into the building. They have been used for ventilation of buildings in the tropics and arid regions for centuries (Sopian, 2005).
15 Air vents are used for passive cooling and dehumidification in the tropical regions in areas where dusty wind is severe. Air vents are protected holes provided in the apex of a dome or a tower which helps in introducing ambient air free of pollutants into the space. The introduction of ambient air will help to improve indoor comfort by providing ventilation and dissipating hot air collected at the top. Other natural means of dissipating heat from buildings include: courtyards Solar chimney, Radiative coolin, Diode roof, roof pond, rain water recycling, use of biogas etc



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II. Conclusion

There are still a lot of factors that may contribute in enhancing the natural ventilation. While at the same time, ventilation itself may not be enough to provide a good thermal condition for the interior space as it may also involve the relative humidity of the air and the temperature itself. On the other hand, cooling process for human though is not only relied on the air temperature as it also involves the sensible heat cooling which very much related to the activities held in the room. Different setting and location of the building may also require different approach in providing a good thermal condition of the building, thus opening an ample room of researches and studies in this field.

III. Recommendations

1. In warm, humid climates, like Ibadan, air velocities in the occupied zones – bedrooms and living rooms- should be maximize for bodily cooling.
2. Take advantage of topography, landscaping, and surrounding buildings to redirect airflow and give maximum exposure to breezes. Use vegetation to funnel breezes and avoid wind dams, which reduce the driving pressure differential around the building. Site objects should not obstruct inlet openings.
3. Shape the building to expose maximum surface area to breezes.
4. Use architectural elements such as wingwalls, parapets, and overhangs to promote airflow into the building interior.
5. The long facade of the building and the majority of the door and window openings should be oriented with respect to the prevailing south-west breeze. If there is no prevailing direction, openings should be sufficient to provide ventilation regardless of wind direction.
6. Windows should be located in opposing pressure zones. Two openings on opposite sides of a space increase the ventilation flow. Openings on adjacent sides force air to change direction, providing ventilation to a greater area. The benefits of the window arrangement depend on the outlet location relative to the direction of the inlet airstream.
7. If a room has only one external wall, better airflow is achieved with two widely spaced windows.
8. If the openings are at the same level and near the ceiling, much of the flow may bypass the occupied level and be ineffective in diluting contaminants there.
9. The stack effect requires vertical distance between openings to take advantage of the stack effect; the greater the vertical distance, the greater the ventilation.
10. Openings in the vicinity of the Neutral Pressure Level (NPL) are least effective for thermally induced ventilation. If the building has only one large opening, the NPL tends to move to that level, which reduces the pressure across the opening.
11. An inlet window smaller than the outlet creates higher inlet velocities. The rule of thumb is to have the outlet area 50% larger than the inlet area, assuming that they do not have a tendency to reverse roles with changes in wind direction.
12. Openings with areas much larger than calculated are sometimes desirable when anticipating increased occupancy or very hot weather.
13. Horizontal windows are generally better than square or vertical windows. They produce more airflow over a wider range of wind directions and are most beneficial in locations where prevailing wind patterns shift.

14. Window openings should be accessible to and operable by occupants.
15. Casement type windows are much less effective in comparison to sliding windows.
16. Inlet openings should not be obstructed by indoor partitions. Partitions can be placed to split and redirect airflow, but should not restrict flow between the building's inlets and outlets.
17. Vertical airshafts or open staircases can be used to increase and take advantage of stack effects. However, enclosed stair-cases intended for evacuation during a fire should not be used for ventilation. Provide equal area of operable openings on the windward and leeward side. Ensure that the windward side is well shaded to provide cool air intake.
18. Locate the openings on the windward side at the occupied level.

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