

# Innovation in Natural Ventilation in Buildings' Design and Application

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*ABSTRACT: In a world of dwindling resources and "zero energy" efficiency; mechanical ventilation systems are still a key contributor to thermal comfort in buildings. It is even worse that natural ventilation design is ignored in buildings design because of the availability of cheap HVAC systems. HVAC systems in new builds as well as in energy audits are focused on as an important element because of their high rates of energy consumption. Passive design of buildings comes as a strategic synergy that achieve thermal comfort, saves valuable energy and leads to healthier indoor environment. Amongst passive design techniques in buildings is the use of natural ventilation in buildings. Natural ventilation is important for all types of climates, yet more important in hot climates as they lead not only to good indoor-environmental-quality but also are main component in achieving thermal comfort, this paper reviews the latest in natural ventilation design principles generally, giving special focus to a sample of the cutting edge passive ventilation systems created for both hot arid and hot humid climates; specifically Dwindraught Cooling and Wind Channels systems. The paper investigates the general rules of thumb to designing the systems and using them in buildings design.*

*Keywords: Natural Ventilation, Wind Channels, PDEC*

## INTRODUCTION

Buildings present very high energy consumption compared to the other economic sectors. Although percentages vary from country to country, buildings are responsible for about 30–45% of the global energy demand; and because of the increasing standards of life, the affordability of air conditioning, the universalisation of modern architecture and also the temperature increase in the urban environment and the global climatic change, the energy needs for cooling have increased in a rather dramatic way. [1,2,3,4]

In 2003 electricity black-outs occurred in Europe and the west coast of USA, a problem that alerted many to the link between air-conditioning use and peak load demand (in the US as a whole, air conditioning represents 40% of the peak

load). While developed countries have found a way out of the problem (such as the increase of capacities of power stations), some developing countries till recently are still struggling with blackouts; in 2012 electricity blackouts stormed Egypt due to severe shortage in fossil fuels. In 2011 a prestigious newspaper in the same country quoted El Shark El Awatat radio; 4.5 Million A.C units in Egypt consume twice as much energy as that produced by the high dam.

Apart from the energy consumption, air conditioning may be an important source of indoor air quality problems. Condensate trays and cooling coils may be contaminated by organic dust; which might cause fungal and mould growth in fans. Also, dirty filters may cause important contamination problems, while cooling

towers may cause spread of Legionella. [5,6]

The passive driving of air flow internally could help replacing mechanical ventilation especially when coupled with reductions in the buildings heat gains. Passive ventilation could be either wind driven or buoyancy driven; wind driven ventilation develops as wind strikes a building causing relatively high pressure differential across the ventilated space — which might lead to the very successful cross ventilation if two opposite windows are available or might lead to the modest single sided ventilation if opening(s) are available only on one side of the ventilated space — while for buoyancy driven ventilation, air moves due to temperature differential across some height. Both systems use the natural laws of physics and aim at achieving internal comfort without or with very little use of energy. The choice of the natural ventilation system depends mainly on its climatic potentiality and applicability.

### **WIND DRIVEN CROSS VENTILATION**

For moderate climates of temperatures not exceeding 28–32°C, and high relative humidity; the flow of outdoor air at a given speed (1.5 – 2m/s; a very light breeze) through a building extends the upper limit of the comfort zone beyond the limit for still air conditions, and it may provide a direct physiological cooling effect. This is because at high humidity; higher air speed increases the rate of sweat evaporation from the skin. However, when a building is cross-ventilated the temperature of indoor air and surfaces closely follow the ambient temperature; hence the temperature limit of 32°C. [7]

An important example on utilising pressure driven cross ventilation in buildings is the Menara Umno office building by the architect Ken Yeang; a tall building in a hot humid region that was initially designed to be non air conditioned. The building utilises tall wind wing wall

along with balconies and full height operable windows to cross ventilate the building. Yeang describes the cross ventilation strategy indicating that for good natural cross-ventilation to be effective as a substitute for air conditioning, then the best arrangement for windows is full wall-openings on both the windward and leeward sides with adjustable or closing devices which can assist in channelling the air flow in the required direction following the change of wind. Ideally, openings should be as large as possible however the high velocity of winds at the upper floors of the tall building could make this impractical. A recessed window with means of adjusting the through-flow of wind and wind-swept rain would provide an alternative to air-conditioning when desired. [10, 11]

### **BUOYANCY DRIVEN VENTILATION**

At higher temperatures the driving of outdoor air would cause severe discomfort; thus outdoor air should be treated to reduce its temperature. Evaporative cooling is a method of treating air and is extensively used as a passive cooling technique in traditional built environment. The air movement over a wetted surface causes some of the water to evaporate. This evaporation results in a reduced temperature and an increased vapour content in the air (the same criterion defines the climatic limit of evaporative cooling potential which is the wet bulb temperature of the air to be cooled). The increase of the wetted surface area increases the evaporation, resulting in a significant cooling effect.

There are two basic types of evaporative air cooling techniques: one; direct evaporative cooling (DEC) (in which the reduction of temperature is followed by an increase of moisture content), two; indirect evaporative cooling (IEC) where cooling is delivered across a heat exchanger, which keeps the cool moist air separated from the room (this system does

not cause an increase of the air humidity). [8]

## WIND CHANNELS SYSTEM

Wind channels system is an attempt to find means for cross ventilating high-rise deep-plan residential buildings passively. Deep-plan buildings especially residential ones; might be designed as an economic scheme in high value land; in which the building layout fits the maximum footprint allowed and in each floor plate more than one flat are fitted. Flats are separated with party walls that run from floor to ceiling. This proprietary plan organisation means that cross ventilation is highly improbable.

In a simple estimate of the economic side of poor natural ventilation in deep-plan residential towers in the Mediterranean city of Alexandria (Egypt); it is found that in a typical residential block of 12 floors there are 72 apartments; in a moderate case 2 air conditioning units might be installed per apartment; and even with the low subsidised domestic electricity prices in Egypt (\$0.045 per KWh), the A.C share of the energy bill for the whole building is estimated to be \$6529 per year. [13]

The wind channels concept is an evolution on the wind towers idea, yet the towers are substituted with horizontal channels to capture the wind from the building facade and deliver it horizontally into deep plan. The system is a set of horizontal overhead and under floor ducts repeated each floor and designed to create the connections between high or positive pressure facades and low or negative pressure sides of the building to enable cross ventilation indoors.

Cross ventilation in a room is only guaranteed when the room has two (preferably) opposite windows with high pressure difference across them. In traditional deep plan high-rise residential buildings; each room has only one opening and all rooms are separated by floor-to-ceiling walls that allow only weak single

sided ventilation and forcing the wind to flow around the building rather than through the rooms. The wind channels system is to provide each room with an extra opening of contradicting pressure to the room's window's (i.e. windward rooms are connected with low pressure zones, and leeward rooms are linked to high pressure areas around the building). The wind channels system works separately in each story of the building; it is split into two separate channels working in parallel; first a straight ceiling void opened at one end to the windward facade and terminates over leeward rooms through large controllable ceiling grill in each room. Second a similar channel running underfloor to connects windward rooms with low pressure facade. In either case the large pressure difference between the two ends of the channel(s) causes air to flow at relatively high speeds passing by the rooms and replacing their hot air and promoting occupants' thermal comfort [12]. (Fig. 1)

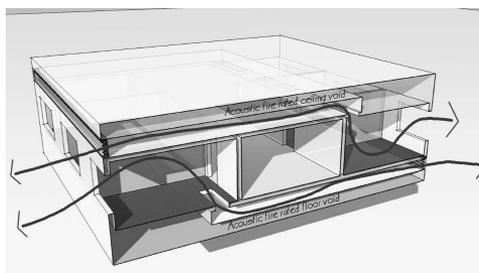


Figure 1: A schematic diagram showing the configuration of wind channels system in a sample storey of the building. Source [13]

The system sizing is a critical element in which the air change rate required in each room and the number of rooms served by each channel is the major indicator of the size of the channel. The first step in the calculations is to find the air flow rate required through the facade opening of each channel; depending on the regulations of the country on which the system is used; air flow rate required could be dictated alternatively air change rate might be required. In such case Equation 1 could be used to identify the air flow rate required

for each room based on the room's volume and required air change rate.

$$Ach = Q \times 3600 / \text{Volume} \quad (1)$$

Where Q is the air flow rate in cubic meters per second. Identifying the air flow rate for all rooms would give a total air flow rate required to pass through the building's

facade opening. Substituting the velocity of the prevailing wind of the locality in equation 2 is used to calculate the area of the facade opening required to supply the previously calculated air flow rate.

$$Q = A \times v \quad (2)$$

A is the area of opening in square meters while v resembles the average wind velocity passing through the opening in meters per second.

using calculated area and using 500mm high opening would indicate the width of the channel. (500mm channel is deemed to be reasonable as it is as narrow as possible to avoid wasting too much hidden voids, while not too narrow to restraint the air flow). [12]

Another factor that affects the channels size is its shape; designing the channels to the minimum required cross section would create a small channel that increases in size above the large number of rooms it serves. This should be avoided and the channel should be designed to run as straight as possible to avoid any constraint or steps that might cause turbulence in the channel leading to flow reversal, noise in the channel or disturbed internal flow. Also the rooms' ceiling diffuser design is an important factor in the wind ceiling system's success and should follow two important aspects; first sizing in which the area of each grill should be smaller than corresponding window. The area of all diffusers should be smaller than building façade's opening to ensure a single cell ventilation strategy which is explained in detail in [14, 15]. Second; the aperture of rooms' diffuser should be manually and fully controllable to allow different users to control the amount of flow in separate rooms according to

personal preference, wind availability and speed.

In a test conducted to verify the system's performance in real life situations; a storage building in the university of Nottingham (United Kingdom) is used in which a facade opening is punched through the building's external wall, and a ply wood sealed box with controllable ceiling diffuser is used internally. Only one bay of the test building is altered for the purpose of testing the wind channels system. The selected bay is the the one that would cause minimal disruption to the building's function.

Only the ceiling void is tested to be a resemblance of the performance of the entire system. This decision was made due to a number of factors; lack of resources and the impossibility of creating a 500mm channel at the base of an existing building as it would hinder the building's function in addition to creating a trip hazard for the building users.

The purpose of the test is to compare the internal wind speed driven through the system in relation to the local wind speed and direction. In order to compare the internal air flow and velocity in relation to external wind; two different measurements are taken; the wind speed and direction in the vicinity of the test building and the velocity of the air ejecting from the ceiling grill [12].

To ensure that buoyancy effect on the air flow in the system was minimal, tests were conducted in the winter season where temperature doesn't exceed 10 degrees C. Tests showed that for average wind speed of 0.74m/s; the average recorded internal air speed is 1.02m/s. The average internal air speed to wind speed reached is 1.68. (Fig. 2)

To understand the wind channels system further a detailed computational fluid dynamics simulation (CFD) is conducted for a typical high-rise deep plan residential tower to investigate the pressure

behaviour in the building. The case study building is a symmetrical 12 story building (36meters high) and is considered to be of a relatively large mass; each typical story contains 6 separate residential flats (two large 150m<sup>2</sup> flats and four medium flats 85m<sup>2</sup> each).

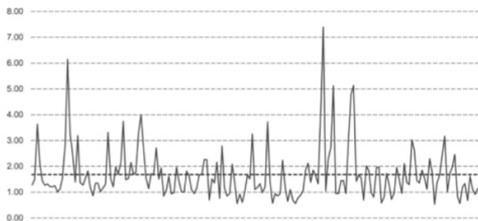


Figure 2: Results of the wind channels system tests show 1.68 average internal air speed to external wind speed ratio.

Initial CFD simulation was conducted to the building mass to identify the pressure patterns on the building; the simulation showed three different room cases; few rooms develop high-pressure, two cornered rooms are affected by both very high and very low pressure and majority of rooms are all subjected to low-pressure zone.

The channels are split into two separate voids that run across the building passing by the central core through a V-shaped treatment around the edges to avoid turbulence in the channels which run a total of 18.5 meter and have facade openings of 21.8 m. The back edge of the ceiling void is stepped to ensure a tight fitting to rooms to avoid any dead ends in which turbulence might develop. The same treatment is applied to the underfloor channel and only one detailed floor is simulated.

(Fig. 3) indicates the success of the wind channels system in creating the conditions necessary for cross ventilation in all served rooms. high pressure developed in the overhead room compared to the pressure in the leeward rooms while the opposite took place in the underfloor channel. This pressure differential lead to fast air flow from the facade into the

ceiling channel then outside the building through the rooms.

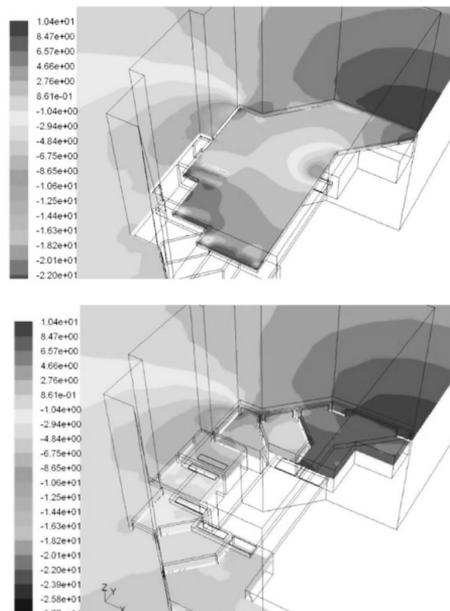


Figure 3: CFD results of the pressure patterns in the ceiling channel and the leeward rooms. High pressure difference between the channel and the rooms lead to fast air flow internally. [12]

### PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING PDEC

A simple experimental building at the University of Arizona; demonstrated that ‘passive downdraught evaporative cooling’ (PDEC) can not only achieve thermal comfort but can also achieve very high air change rates and be used to drive the air flow through the building. This building induced evaporative cooling takes place by the irrigation of a cellulose matrix at the top of a cool tower. Other porous media (such as porous ceramic) have been tried, but have the disadvantage that a large surface area is required to achieve significant cooling. The spraying of water droplets directly into the air stream has proved to be possibly the most effective technique for inducing PDEC. Downdraught cooling in various forms has now been applied in many buildings world wide, and research has advanced the

understanding of both the design implications and potential performance. [16, 17]

PDEC system is currently widely used in a large number of buildings such as Federal Courthouse in Phoenix, Kenilworth High School in Petaluma, Visitor Centre, Zion National Park, Utah, Torrent Research Centre in India, and Stock Exchange, Valletta, Malta. [18, 19]

From a total of over 100 worldwide buildings that have used PDEC, [18] explores 4 buildings intensively. Also in [9] the thermal comfort and occupants perception in some PDEC buildings has been explored. Amongst the most famous buildings to apply PDEC; is Torrent research building in Ahmedabad in India. The local climate is characterised by extremely hot dry summers (March to mid-June) when peak temperatures can regularly reach 45°C.

The first phase of the Torrent Research centre provides six linked laboratory buildings on three floors connected to a central administrative complex designed to connect with a future second phase. The whole of the first phase was completed in 2000, and the building was the first large scale application of PDEC in India.

The research centre includes 22,000m<sup>2</sup> of research laboratories and offices. Conventional wisdom would suggest that over 50% of such a new laboratory building would require refrigerant based air conditioning, in order to meet the environmental requirements within the laboratories. However, the client, aware of the compelling benefits of achieving improved efficiency in this project, sought to minimise dependence on conventional air conditioning without compromising occupant comfort. In the final complex approximately 70% of the laboratories plus all adjacent administrative areas are cooled with PDEC. [19, 20]

Typically, laboratories and offices are arranged on either side of an open concourse, which allows the circulation of people between spaces. This arrangement allows evaporatively cooled air to be introduced (via three 4m x 4m towers) to the occupied spaces at each level, and exhausted via perimeter stacks; which are designed to exhaust air at both high and low level depending on the availability of wind. In this way, the working areas are both physically and thermally buffered from the external environment.

During the hot dry season mid-afternoon outside temperatures regularly reach above 40°C. while relative humidity is often below 20%. It is under these conditions that the PDEC system is designed to operate. Filtered water is pumped through nozzles at 50Pa to produce a fine mist at the top of the 3 large (4m x 4m) air intake towers located above the central corridors of each laboratory building. Evaporation of the fine mist serves to cool the air which then descends slowly through the central corridor space via the openings on each side of the walkway. (Fig. 4)

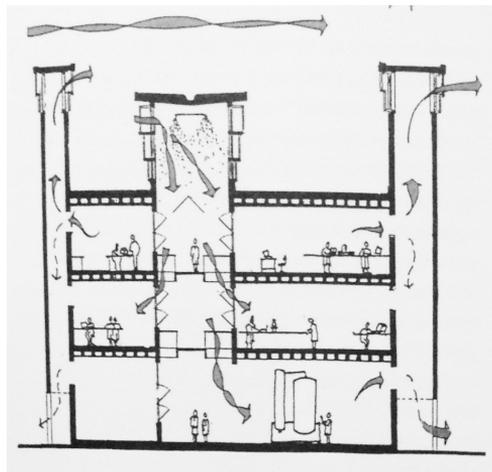


Figure 4: A section through Torrent research centre indicating the use of PDEC system; misting the air in the central atrium leads the cool air to descend pushing the hot air to stack towers on the building's parameter. Source [19]

At each level, sets of hopper windows designed to catch the descending flow. divert some of this cooled air into the adjacent space. Having passed through the space, the air may then exit via high level glass louvred openings which connect directly to the perimeter exhaust air towers. Exhaust air then either rises to the top of the stacks (in windy conditions) or falls out of the bottom of the stack (in still air conditions).

The Components of the PDEC system include a cooling tower, a top opening in which fresh air enters, misting system, and finally an internal opening that allows the cool air internally. PDEC system works when mist is sprayed in the cooling tower causing evaporative cooling, leading to cool air in the tower which then drives buoyancy flow from the tower to the rooms served by the tower.

Because the air driver in this system is buoyancy; the height of the tower is the most important aspect as per equation(3), and for that reason openings high at the top of the tower would need to be larger than those at the bottom.

$$A=q/Cd \times \sqrt{Ti+273 \div \Delta Tgh} \quad (3)$$

where A is the area of each opening, q is the air flow rate required, Cd is the coefficient of opening, Ti is the room required internal temperature,  $\Delta T$  is the difference between the internal temperature and the supply air temperature, g is the gravitational constant and h is the height between the openings.

Sizing PDEC general rule of thumb starts by identifying ambient dry bulb temperature (DB), mean wet bulb temperature for the hottest time of the year (WB), then calculate the WB depression: equation (4).

$$DB - WB \quad (4)$$

The chart in (Fig. 5) is then used to calculate the approximate temperature of the air exiting the tower as a result of the

evaporative cooling process taking place in the cooling tower.

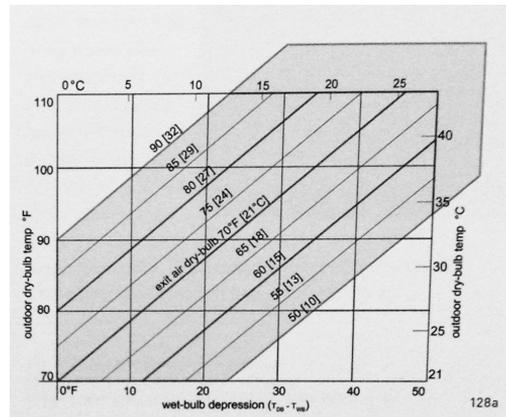


Figure 5: Chart showing the expected air temperature exiting the cooling tower as a function of the WB depression and the outdoor DB temperature. Source [19]

As with the wind channels system, the air change rate required in each room could then be identified based on the building regulations or could be calculated based on the heat gains of the room. The calculated air flow rate could then be substituted along with other variables in equation (3) to calculate the area of openings required.

## CONCLUSION

With urbanisation and development architecture moves away from traditions into new forms and new styles, and with modernity new problems arise that cause human dissatisfaction. This paper explores how innovation in design could always be built on traditions; the paper reviews the basic concepts of natural ventilation under two climatic regions hot arid and hot humid. Also two innovative natural ventilation systems are explored; wind channels that utilises the pressure difference across high-rise deep plan buildings in hot humid climates, and PDEC system that utilises low humidity and evaporative cooling to force air movement in hot arid climates. The paper also discuss the general rules of thumb for designing both systems, which would be beneficial if

understood by architects to give them more possibilities in design.

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