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New approach to natural ventilation in public buildings inspired by iranian’s traditional windcatcher

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Abstract

Concern about global warming has resulted in a resurgence of interest in naturally ventilated buildings. Natural ventilation is increasingly being used in modern public buildings to minimize the consumption of non-renewable energy. It is an effective measure to improve indoor air quality. This paper explores the potential of using natural ventilation as a passive cooling system for public buildings like shopping malls. The characteristics of present public buildings are analyzed in terms of climate and technology. Based on the thermal comfort requirements for the people and the climate conditions in these spaces, the study found that it is possible to use natural ventilation to create a thermally comfortable indoor environment. Openings can, most of the time, be enough to cool the buildings. Even though use of an opening for ventilation of a space seems very simple, the flow that occurs in this situation is rather complicated. The amount of air going through the openings will depend on several items like size, type and location of the opening. This paper reviews wind driven ventilation designs with respect to traditional Iranian’s Windcatcher. The windcatcher systems found to be an efficient way channel fresh air into the space. The context of the work was to improve the use of natural ventilation systems in buildings. The aim of this article is to find which should be the type, size and location of the opening to reach sufficient ventilation rates in modern spaces by use of methods that works in traditional Windcatcher.

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INTRODUCTION

Increased consciousness of the environmental problems has aroused people’s interest of renewable
energy systems, especially the application of green features in buildings [1]. Natural ventilation has gained prominence in recent times as a bespoke method of ventilating buildings. The two fundamental principles of natural ventilation are stack effect and wind driven ventilation. Stack effects are caused by temperature differences between the inside and outside of buildings. When the inside building temperature is greater than the outside, warm indoor air will rise and exit thus being replaced by cooler, denser air from below. The stack effect is dominant during periods of low wind speed and reduces in summer periods when temperature differences are minimal [2]. Green features are architectural features used to mitigate migration of various air-borne pollutants and to moderate the transport of heat, air and transmission of daylight from outside to indoor environment in an advantageous way [1].

In the past, without modern facilities, it was only the intelligent architecture of the buildings that enabled people to tolerate the hot summer [3]. Examples are sometimes better than definitions in explaining concepts [4]. The windcatcher system is one of the green features for providing good natural ventilation. They were employed in buildings in the Middle East for more than three thousands years. They have different names in different parts of region [1]. In some areas, where there is no prevailing wind direction, such as Dubai on the Persian Gulf, windcatcher with many openings are used. These rectangular towers are divided by diagonal walls, which create four separate airwalls facing four different directions. Windcatchers have shuttered to keep out unwanted ventilation. In dry climates, they also have a means of evaporating water to cool the incoming air. Some of them have porous jugs of water at their base. While others use fountains or trickling water [4]. In the modern design, the principles of wind effect in windcatchers and passive stack effect can be considered in the design process.

The success of a natural ventilation system relies heavily upon the design and performance of the facade openings that allow outdoor air to flow in and stale air to flow out of a building. These openings can take the form of simple holes, openable windows, trickle ventilators or throughwall ventilators [5]. Air movement within a building is affected by the orientation size, placement, ratio, and types of openings, which alter the inertia, pressure differentials, and buoyancy characteristics of airflow. Window openings are acceptable in dwellings due to their low-tech nature and manual operability. However they are somewhat limiting for larger buildings and on their own are not considered to be a primary ventilation method [2].

1. VENTILATION

1.1. Introduction

Any building, even with all windows and doors shut, will have a degree of ventilation [6]. Natural ventilation uses the natural forces of wind pressure and stacks effect to aid and direct the movement of air through buildings [2]. Differences in wind pressure along the facade and differences between indoor and outdoor temperatures create a natural air exchange between indoor and outdoor air. The ventilation rate depends on the strength and direction of these forces and the resistance of the flow path [7]. Wind incident on a building face will produce appositive pressure on the windward side and a relative negative pressure on the leeward side. This pressure difference as well as the pressure differences inside the building will drive airflow [2].

Ventilation is used to maintain a satisfactory environment within enclosed spaces. The environmental criteria controlled may be:

- Temperature: Relief from overheating
- Humidity: Prevention of condensation or fogging
- Odor: Dilution of odor from smoking, body odor, processes, etc.
- Contamination: Dilution or removal of dangerous or unpleasant fumes and dust [6].
challenging to control natural ventilation in order to obtain the required indoor environment conditions [7].

1.2. Reasons for Ventilation

The required values for these criteria will depend upon the reason the space is being ventilated. It may be for the benefit of people, processes, equipment, materials, livestock, horticulture, building preservation or any combination of these. CIBSE and ASHRAE. Provide guidance on selection of these values [6].

1.3. Why Should We Use Natural Ventilation in Public Buildings?

The recent advent of computers and other public equipments increased the internal heat gains in most public buildings. Highly glazed facade, often with poor shading, have become very common. This, together with the extra heat gains from the electric lighting made necessary by deep floor plans, and the wider use of false ceilings, increased the overheating risk. On the other hand, there is an increasing demand for higher quality public buildings. Occupants and developers of public buildings ask for a healthy and stimulating environment. [8] Mostly, that is provided by an air conditioning system. But in many cases, with some efforts to reduce internal gains (equipment well chosen and solar protections), natural ventilation may be sufficient to ensure good comfort levels in occupied buildings. Peak cooling loads in commercial buildings are generally in the range 30–100 W m

In that case, air conditioning system will not be necessary. This will result in considerable energy and cost savings and also indirectly in a reduced burden on the environment, since the use of energy is always associated with the production of waste materials. Some aspects of comfort can even be considered as better with natural ventilation:

- In a mechanically ventilated building, air movement is likely to be associated with noise while natural ventilation, in a quiet environment, is silent.
- Openable windows for natural ventilation under user control are appreciated by most people. Moreover, studies of sick building syndrome (SBS) have indicated that perception of greater control over ventilation, lighting and temperature is associated with decreased symptom prevalence. In many recreational and public buildings the users would not expect to have control over the environment.
- Control over ventilation is most easily seen in relation to opening of windows, individual variability and different distances from the window make it quite difficult to satisfy everybody.
- What do we exactly mean by “natural ventilation”? We will first distinguish “hygienic ventilation” from “ventilation for cooling”. We will talk about “hygienic ventilation” when the aim is to provide a clean, healthy and comfortable atmosphere in a building for the people who use it and work there. We will talk about “ventilation for cooling” when the aim is to refresh the building; that type of ventilation can occur when the building is not occupied as well as during occupation hours. Ventilation is qualified as “natural” if it has no energy consumption for fans.
- In this paper, we will talk about natural ventilation for cooling. It is used to “help” the cooling system and lower its energy consumption, and is achieved by window openings. A mechanic system assures a hygienic ventilation.

1.4. Which Effect on the Building Conception?

We must note that if natural ventilation is apparently the simplest and cheapest option to cool the building, it is also the most difficult to control, since the driving forces, and thus the air flow rates, vary constantly with the weather.

To be successful, the ventilation must be planned and not “just happen”. Its importance must be
recognized at the initial stages of the design process, before decisions are made which might make it unworkable.

The building envelope itself is a critical component of the ventilation system.

Orientation can influence the cooling load. For example, east facing glazing (morning sun) is likely to give rise to overheating only if the building is of very lightweight construction. Solar shading can save on the cooling load. And feasibility of natural ventilation for cooling will depend on internal gains!

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The shape of a building influences the ventilation characteristics by its height, influencing stack effect ventilation, and its shape in relation to the prevailing wind speed and direction which affects wind-induced ventilation. Wind pressures may oppose or assist buoyancy forces resulting, at times, in reversal of intended flows. More, the relation of the new building to surrounding buildings affects the wind pressure distribution over the building shell and therefore the ventilation rate.

So the type, size and location of the window apertures have to be well studied.

In this sense the design of the ventilation system begins as soon as the architect decides what shape the building will be. These are decisions which are very difficult to change once the building is built.

We have tried here to give some information on the relation between window apertures and air change rate in a certain type of building, to help designer to design the building envelope [8].

2. WINDCATCHER

Windcatcher have been used over centuries in the hot arid regions of Iran and the countries of the Persian Gulf to provide natural ventilation and passive cooling. The windcatcher maintain natural ventilation through living spaces due to wind as well as buoyancy effects [9]. It is one to the special masterpieces of Iran's architecture and it is also the signs of predecessors' intelligence in agreement with the climate, you can consider it the most specific examples of clean energy [3]. Windcatcher is normally a tall structure with the height between 5 and 33 m mounted on the roof of a building (Fig. 1). The design of these systems has been traditionally based on the personal experience of architects as well as the dignity, wealth and social position of the house owners and differed in the height of tower, cross-section of the air passages, placement and the number of openings as well as placement of the tower with respect to the structure it cools [9]. The primary attraction of windcatchers is that they are passive in nature, requiring no energy to operate [2].

![Fig 1. Ancient windcatcher in the city of Yazd.](image)

2.1. How to Perform and the Functions

Iranian windcatchers work on the principles of natural ventilation, employing both wind driven and stack effect ventilation. There are actually two kinds of main functions about windcatchers:

The function according to the principle of traction of opening facing the wind and the suction of
The way a windcatcher works is mainly based on taking the fresh air into the building and sending the hot and polluted air out or "the suction functions" perhaps it is not so necessary to explain that when the wind hits against the walls of internal blades of the windcatcher it necessarily falls down, but it is necessary to refer to this point that the other holes of the windcatcher turning back to the wind direction, gives the hot and polluted air into the wind and so works like a ventilation and a sucked machine.

The function of this kind of a windcatcher is actually performed according to this fact that when the wind hits an obstacle, and since the density of the air is thick on the side of the wind direction, so in this direction there is a positive pressure, but a negative pressure on the other side. Therefore, when the ventilation is open on the sided of the wind there will be a positive pressure to a negative pressure. In the windcatchers, according to this principal, the opening facing the wind takes the air into the porch and the air in the porch with its negative pressure on the opening back of the wind is drawn out (Fig. 2). Sometimes according to the superficial evaporation the windcatcher supplies the necessary moisture by conveying the wind over the weather and the cold-storage [3].

![Fig 2. Traction and suction in windcatcher](image)

![Fig 3. Windcatcher function during the day and night.](image)

### 2.1.1. The function according to temperature difference.

It seems that there is a little attention of technicians about the function of a windcatcher regarding the temperature difference. In fact when there is not a windy blast sensibly, the windcatcher acts according to this action. During the day, since the sun hits on the southern face of the wind catcher, the air heats in the southern face of the windcatcher, and goes up. This air taken above through the inner air of the porch is compensated and in fact it makes a kind of proportional vacuum inside the porch, and takes the cool air of the inner court into itself, so the existing air in the northern opening is pulled down too (Fig. 3).

During the night it becomes cold outside, and the cold air moves down. This air is saved by the heat and becomes warm on parapets and then goes up. This circle continues till the temperature of the walls and outside temperature become equal. But before it usually arrives at this situation the night ends and once again the windcatcher acts its function as mentioned above. In general, in most time, windcatcher does as we explained it, in order to the traction, suction, and the effect of temperature difference [3].

### 2.2. Location of Windcatcher
Windcatchers are generally used in two kinds of building: water-reservoirs and houses. In houses the windcatcher is usually made in the summer-sitting part of the house. Windcatchers are often related to halls, pools and basements.

They cause the air circulation to circulate in the building. They also relate with the moisturizing elements such as: 1) pool, 2) garden, 3) trees, 4) basement walls, 5) Payab and compensate the shortage of ground moisture and therefore provide a fresh and suitable place for living during the hot and intolerable summer for the residents and people. Windcatchers materials are always of mud brick, brick, mud, and "shoruneh" wood. It is one of the woods which resists against natural factors and termite attacks.

The temperature difference between the inside and outside of the building and different parts of it which causes the pressure difference and at last move the air. For example since the moisture is very low in Yazd (The average moisture: 30.33%), windcatchers not only makes the air circulate, but they provide comfort for the residents by evaporating the air as following: The dry and warm wind passes over a small stone pond with a fountain gets cool and wet through evaporation. Then the cool and wet air flows in the rooms.

Sometimes they put mat, pantile, or thorns over the windcatcher opening, and they sprinkled water on them, and as a result they increased the moisture and the arrivery cool air [3].

2.3. Windcatcher Elements

Each elements of a windcatcher form is affective in its final formation. A windcatcher in order from down to upward is formed of following parts: 1) chimney, 2) stalk, 3) catgut and chain, 4) shelf.

Chimney

The chimney part of the windcatcher is usually an incomplete pyramid form. The different proportions of upper part of the windcatcher are arranged with this part. In some samples, its height is as high as a person's height and in some other it is some meters high.

Stalk

That part of the windcatcher which is located between shelf and the room is called the "stalk"; the higher is the windcatcher the higher is its stalk too. The higher of the stalk in Yazd windcatchers according to the climatic reasons and the height of the windcatcher is for taking suitable wind which blows in heights, the beauty of this part is mostly dependent on the brick working decoration.

Catgut and chain

The catgut and chain is located between the stalk and the shelf. This element would be made and the shelf, this element would be made in different shapes.

Shelf

The head of the windcatcher is the shelf which includes the blades, the channel of air passing. The common types of geometric figure of the shelf include: a lengthened, vertical rectangle, horizontal and a square. Shelves are usually front open or front closed. And this feature would be changed according to the wind blast, on the other hand two shelves would be usually considered for each ways of air channel towards the room.

3. CONTEMPRARY OPENINGS IN LINE WITH OLD WINDCATCHERS

The proficiency of Iranian traditional windcatcher demonstrates the accurate principles according which it has been designed and constructed. These principles can be recognized and followed in new buildings, to make the natural ventilation occur properly. Openings are the key elements of ventilation in contemporary buildings. If the characteristics of openings (such as size and location) are defined in line with those of windcatchers, sufficient ventilation rate can be expected as it has happened to traditional
In following, different operation methods of an Iranian traditional windcather and the appliance of these patterns in arrangement of a new building’s openings are explained.

3.1. The windcather operates according to positive and negative pressure created by wind

Window Orientation and Wind Direction

Air is deflected over and around building forms and thereby creates the zones of pressure differential known as calm areas or eddies. They are positive and negative pressure zones (Fig. 4). Positive pressure is exerted on the windward side of a building as the air piles up. This zone causes the airflow to slow down until a new path is found around the obstacle. Once a new release is located, the air speeds around the obstacle at a velocity greater than that of the initial airflow. Likewise, negative pressure is formed on the leeward face and sides of the building because of lower air density. These zones are potentially optimum locations for openings in the building’s skin to encourage air movement through the structure.

![Fig 4. The movement of air over a structure creates a positive and negative pressure zones.](image)

Inlet openings should be located in positive pressure zones and outlet openings in negative pressure zones. That provides the best conditions for maximum air movement through the building (Fig. 5) [10].

Window Locations

Cross ventilation is so effective because air is both pushed and pulled through the building by a positive pressure on the windward side and by a negative pressure on the leeward side (Fig. 6) [4].

![Fig 5. Air flows from positive to negative pressure zones through a building.](image)  
![Fig 6. Cross ventilation between on opposite walls is the ideal condition.](image)

When the single openings are on opposite sides of an interior space and the air movement is perpendicular to the inlet opening, the main airflow travels from inlet opening to outlet opening. The remainder of the interior space receives no significant air movement (Fig. 7). When air movement is skewed to the inlet opening but the inlet and outlet openings are in alignment with the exterior direction of the air movement, the flow of air will pass through the interior space in a narrow stream. When the air movement is perpendicular to the inlet opening and the outlet opening is in an adjacent wall, the flow of
air will circulate throughout the entire interior space (Fig. 8) [10].

Fig 7. (a) Air movement is perpendicular to the inlet opening and is aligned with both openings. (b) Air movement is oblique to aligned inlet and outlet openings.

Fig 8. (a) Air movement is skewed to the inlet opening but the inlet and outlet openings are in alignment with the exterior direction of the air movement. (b) Air movement is perpendicular to the inlet opening and the outlet openings in an adjacent wall.

If a room can have windows on only one side, use two widely spaced windows instead of one window (Fig. 9).

3.1.1. e. Inlet and Outlet Sizes and Locations

Generally, the inlet and outlet size should be about the same, since the amount of ventilation is mainly a function of the smaller opening. However, if one opening is smaller, it should usually be the inlet because that maximizes the velocity of the indoor airstream, and it is the velocity that has the greatest effect on comfort. Although velocities higher than the wind can be achieved indoors by concentrating the air flow, the area served is, of course, decreased (Fig. 10). The inlet opening not only determines the velocity, but also determines the air flow pattern in the room. The location of the outlet, on the other hand, has little effect on the air velocity and flow pattern [4].

Fig 9. Single side ventilation

Fig 10. Inlets and outlet size should be about the same size. If they cannot be the same size, the inlet should be smaller to maximize the velocity.

3.2. Function of the Blades Inside the Windcatcher: Creating Positive and Negative Pressure

Using wing walls can help the building develop positive and negative pressure. A wing wall is usually used to aid single sided ventilation on windward facing windows. The objective is to explicitly induce positive and negative pressures on either side of two protrusions emanating from the window, thus enhancing the flow rate on an already handicapped single sided system cites results claiming that when wing walls are used the average air velocity in the room is 40% of the outside incident wind velocity.
limitation appears to be architectural integration and more specifically their use may tend to block sunlight. One way around this could be to use materials of a transparent nature which could doubly act to enhance and/or direct sunlight into the building. There is currently little research on the topic, perhaps due to the limited single sided target although they could be adapted anywhere where distinct and opposing pressures are needed (Fig. 11) [2].

![Fig 11. Airflow enhancement due to wing wall.](image1)

Note, however, that each window must have only a single wing (Fig. 12). Furthermore, wing walls will not work if they are placed on the same side of each window (Fig. 13) [4].

![Fig 12. Wing walls can significantly increase ventilation through windows on the same wall.](image2)

![Fig 13. Poor ventilation result from wing walls placed on the same side of each window or when two wings are used on each window](image3)

3.3. Stack Effect and Vertical Ventilation of Windcatcher

The vertical ventilation of windcatcher increases its proficiency as horizontal and vertical airflows occur simultaneously. By knowing and following its method and making the vertical ventilation possible, the thermal comfort situation in contemporary buildings, especially public ones, can be developed. Application of stack effect and vertical placement of windows are two ways to achieve vertical ventilation in buildings.

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Developing Stack Effect
The stack effect of the windcatcher can be followed in contemporary buildings to help vertical ventilation. In this context, there could be a channel on the reverse side of inlet openings, in which air can flow. Getting sun’s radiation on its walls, the channel makes the inside air warm and it moves upward. This warm air can get out of the channel through the holes located in the highest part of the channel. Consequently, the indoor hot air rises in the building and the vertical ventilation occurs.

Vertical placement of Windows
The purpose of the air flow will determine the vertical placement and height of windows. Additional high windows or ceiling vents should be considered for exhausting the hot air that collects near the ceiling (Fig. 14).

Fig 14. High openings vent the hot air collecting near the ceiling and are most useful for night-flush cooling.

High openings are also important for night-flush cooling where air must pass over the structure of the building. It is often advantageous to place windows high on a wall where they are too high to reach for direct manual operation [4].

Windcatchers and Evaporating Cooling
Some windcatchers have a means of evaporating water to cool the incoming air. Some of them have porous jugs of water at their base, while others use fountains or trickling water (Fig. 15) [4]. In most houses, the outgoing air of windcatcher also relates with the moisturizing elements such as pool and basement walls (Fig. 16).

Whenever the humidity is low, evaporating cooling is very effective. The results are best if the evaporation occurs indoors or in the incoming air stream. If the air coming through the inlet opening gets rather humid, evaporating cooling and ventilation will simultaneously occur and thermal comfort requirements can be met. In public buildings which usually involve courtyards or atria, evaporating cooling is effective. Evaporative cooling of courtyards and atria is especially effective when the courtyard or atria is the main source of air for the building [4].

4. CONCLUSIONS

Iranian’s windcatchers have demonstrated proficiency in natural ventilation for years of application. The principles of design and operation of these key elements can be recognized and followed in the openings of contemporary buildings. The success of a natural ventilation system relies heavily upon the design and performance of the facade openings that allow outdoor air to flow in and stale air to flow out
throughwall ventilators. Whatever the form is the appliance of the windcatchers’ principles, which have been used for thousands of years, can make it develop the natural ventilation and provide the thermal comfort requirements. In public buildings, these principles in combination with atria or courtyards can improve comfort conditions by modifying the microclimate around the building and by enhancing the airflow in it.

Fig 15. Some windcatcher in hot and dry areas cool the incoming air by evaporating.

Fig 16. Dowlatabad Garden Windcatcher: Outgoing air of the windcatcher passes the pool.

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