Ventilation in a Mosque—an Additional Purpose the Minarets May Serve

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ABSTRACT

A minaret of a mosque, traditionally used as a high platform to deliver *adhan* (the call for prayer), has greatly lost its functional significance with the invention of loudspeakers. Despite of being a functionally redundant element, people still like to erect a minaret as a traditional symbol, identity and beauty of a mosque. In this context, a minaret could be more meaningful if it could serve further practical purposes.

As a densely occupied congregational space, a mosque deserves adequate ventilation. Efficiency of cross ventilation through windows is limited to certain plan depths and many of the community mosques with huge capacity, exceeds that limit. This paper is intended to explore the scopes of using the minarets to facilitate ventilation in warm-humid climate, placed in a dense urban set-up, having huge plan depths, with a special reference to those of Dhaka City. Possibilities are explored to use a minaret for up-draft, downdraft and to enhance the motive force of stack effect basing on principles of thermo-fluid mechanics.

INDEX TERMS

Ventilation, Mosque, Minaret, Warm-Humid Climate, Dhaka City

INTRODUCTION

Historical evidences indicate that wind towers were used in vernacular architecture of various civilizations in different ages. The 'malqaf', literally 'wind catcher', was used in ancient Egypt as early as 1300 BC. 'Badgir', a refinement of 'malqaf', was profusely used in Iran and other gulf countries. Wind scoops have been in use for at least 500 years, in the region of Hyderabad in Pakistan and in some regions of Arabian Gulf. In tropical climate, traditional Malay house facilitates ventilation through a short tower on the inclined roof [Battle, 1999].

There are also many instances in modern buildings, e.g.; Ostratonskolan (a school), Lund, Sweden; Blue Water Shopping Centre, Dartfort, Kent, UK; Nairobi Tower, Kenya; Ecotower, Kowloon, Hong Kong; Armory Tower, Shanghai, China; Umno Tower, Penang, Malaysia etc. All these practical evidences along with the scientific theories are the basis and inspiration for exploring the possibility of using the minarets for ventilation in a mosque in warm-humid climate, with a special reference to Dhaka City.

METHODS

The study refers to the warm-humid climate and other contextual aspects of Dhaka City. Issues of thermal comfort base on available data and users responses. Theoretical knowledge and practical experiences check the feasibility of using minarets as an aid for ventilation. To validate the idea, analyses are done using the principles of thermo-fluid mechanics basing on practical data of average cases. Following are some examples of data used in this paper for a mosque in Dhaka City of an average size, type and average climatic features.

Mosque (main hall): Capacity = 200 persons; volume (20m x 10m x 4m) = $800m^3$; average minaret height = 20m, average internal cross-sectional area of a minaret = $4m^2$; openings (in terms of windows, doors, perforations etc.) = $12m^2$ on south and north facade, while no opening on west facade and $8m^2$ on east facade [Imam, 2000].

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Climate (average data for the months of April to September, which are critical for thermal comfort): Daily max. air temperature = 32.4^{o}C; daily min. air temperature = 25.5^{o}C; daily average air temperature = 29^{o}C; relative humidity = 82%; wind speed (at 10 m height from the ground) = 2.35 m/s, direction: south and southeast [Meteorological data, Dhaka City].

VENTILATION IN A MOSQUE: CASE OF DHAKA CITY

Significant Features of a Mosque for Ventilation

Clarity and transparency of space is a general characteristic feature of a mosque in Dhaka City. The *qibla* wall (approximately towards the west for Dhaka City) demands opacity, which also conforms to the climatic consideration for ventilation and lighting. Total openness and transparency may be allowed for other walls; especially the south and north one, to facilitate the most desired wind flow from the south and southeast direction during the months of April-September, when the climatic condition becomes crucial for thermal comfort. By functional nature, a mosque is an assembly place, where a significant amount of anthropogenic heat, moisture, carbon dioxide gas, malodour and even germs may accumulate resulting discomfort and health hazards.

For Dhaka City, usual practice is to erect one minaret, while two is seldom found and four is almost absent, preferably on right hand side (if facing the *Qibla,* the direction of the Holy Kaba, approximately towards west from Dhaka) [Figure 2 & 3].

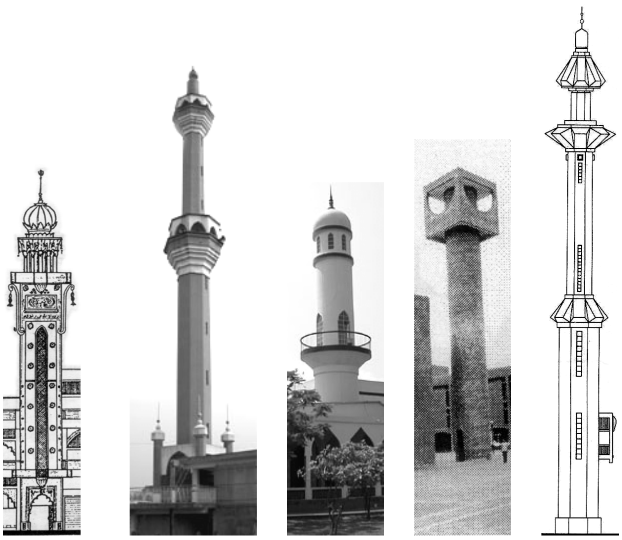

Figure 1 Some examples of minarets of Dhaka City (last one is a proposal for a project, not yet constructed)

Ventilation: Type and Requirements

Ventilation can be categorized in three types according to its objectives to serve: (a) Health ventilation, (b) Thermal comfort ventilation and (c) Ventilation for structural cooling [Givoni, 1976]. The relative importance of each of these functions depends on the climatic conditions prevailing in different seasons and regions.

Considering a mosque as a place of assembly for almost sedentary activities, ASHRAE suggests for typical minimum ventilation, 33.8 to 59.4 m^3/h (9.4 to 16.5 L/s or 20 to 35 cfm) per person, for a threshold of CO_2 concentration 1000 ppm [ASHRAE, 1985]. Bangladesh National Building Code (BNBC) recommends 36 to 45 m^3/h (10 to 12.5 L/s) per person with a minimum of 27 m^3/h (7.5 L/s) per person for an assembly space [BNBC, 1993]. ASHRAE allows somewhat reduced rates for facilities used for short periods and where it can be *flushed out* between performances. Since a mosque conforms to these conditions, the reasonable rate for health ventilation is considered as 36 m^3/h (10 L/s) throughout this paper.

In warm-humid condition of Bangladesh, the main function of ventilation is to provide thermal comfort through air motion past the body, sufficient for cooling through rapid sweat evaporation. Volumetric airflow is not suitable criterion under such condition and requirements should be expressed in terms of air velocity within the occupied area. To achieve thermal comfort in a mosque of Dhaka City during critical months from April to September, for the type of activity (1.0 met) and clothing of occupants (0.6 clo), the required minimum air velocity is 2 m/s [Markus, 1980].

Means of Ventilation

The size of windows has considerable influence for air velocity within a mosque. For security reason, the main prayer hall of most of the mosques of Dhaka City is usually confined with walls, doors and windows. Generally, buildings that are naturally ventilated through windows are restricted to certain plan depths, i.e., cross ventilation is effective to 15 m depth [Battle, 1999]. For example, a mosque of average size in Dhaka City with a capacity of 200 persons in the main prayer hall requires an area of about (20m x 10m) = 200 m^2 (for a 'good' standard) [Imam, 2000]. Since, longer side is usually oriented towards north south direction, the average plan depth is greater than the limit of effectiveness for cross ventilation (i.e., 15 m).

Ceiling fans are commonly used to achieve thermal comfort through enhanced evaporative cooling by increasing air velocity. These ceiling fans generate localised and re-cyclic turbulence, which practically acts as an *air-curtain* and hinders cross ventilation. It becomes worse in high RH, particularly during months from June to September with an average RH of 84.43%. This RH sometimes goes as high as 95%, when the occupants add some more anthropogenic moisture to the indoor air. For prolonged use of the space, some more negative elements are accumulated like, excessive carbon dioxide gas, malodour, pathogenic elements etc. As a matter of fact, a veranda of a mosque with smaller plan depth, usually open on three sides, is found to be more comfortable than the main prayer hall, since it enjoys the natural ventilation by dint of its type of configuration and minimum level of enclosure.

NATURAL VENTILATION THROUGH MINARETS: CONCEPT AND DESIGN

With the invention of loudspeakers, stair of a minaret is no more used for frequent climbing a high platform to deliver *adhan.* So, the internal stair can be replaced with a lighter ladder, hinged to the internal or external walls of the shaft, encased with steel-mesh for safety, which might be used for installation and maintenance of loudspeakers. Thus, a minaret can be easily converted to a ventilation tower, without loosing any of its present purposes.

Natural ventilation is achieved by using the pressure difference of wind, which is dependant on climatic factors – wind velocity, wind direction, and temperature difference [Battle, 1999].

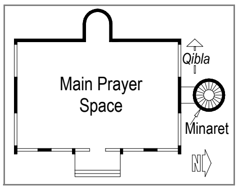

Figure 2 Schematic plan: typical mosque

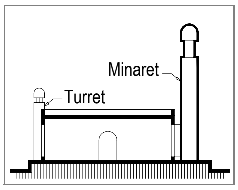

Figure 3 Section: typical mosque

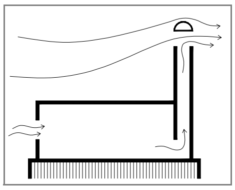
Figure 4 Wind tower as outlet

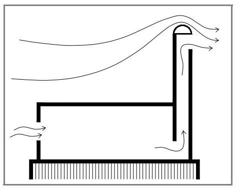
Figure 5 Oast wind tower as outlet

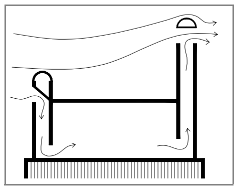
Figure 6 wind tower and scoop: combined

Wind Velocity

Wind direction and velocity over any built-form creates a pressure field – negative and positive. To maximise the pressure difference between inlet and outlet and subsequently to best utilise the natural ventilation, a minaret should be placed is such a way, so that it may effectively act as a wind tower or wind scoop or a '*badgir*' (Figure 4 to 7). Its shaft is open at the top on four (or sometimes two) sides. A pair of partitions, placed diagonally, divides the vertical shaft in to four (or some times two) to work simultaneously as a wind scoop or exhaust for any direction of wind.

For Dhaka City, during April-September, thermal comfort becomes very crucial due to relatively higher maximum daily air temperature (average 32.4°C) and high Relative Humidity (average 82%), while average wind speed (measured at 10 m height from the ground) is 2.35 m/s and blows mostly from south and southeast direction [Meteorological data, Dhaka City].

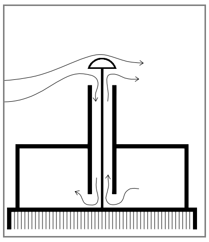

Figure 7 Badgir, inlet & outlet

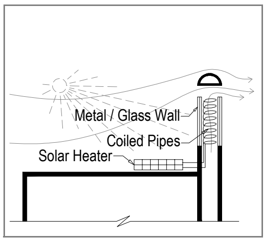

Figure 8 Minaret as a solar chimney

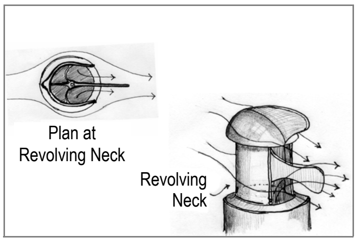

Figure 9 Revolving neck for wind tower: concept drawing

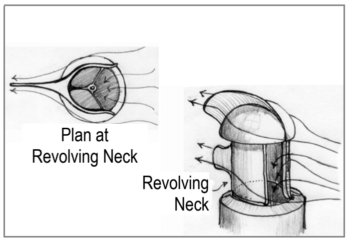

Figure 10 Revolving neck for wind scoop: concept drawing

The wind speed at higher up is always greater than that near ground. Basically, the topography affects this wind gradient [Koenigsberger, 1978]. The variation of wind velocity with the height can be expressed by the equation [Geiger, 1965]: $V_2 = V_1 \cdot Z^{\propto}$

Where, V_2 is the wind velocity (in m/s) at the height of *'Z'* (in m), V_1 the wind velocity (in m/s) at the height of 1 m and $\propto$ the exponent whose value is determined by the practical observation in a particular type of topography.

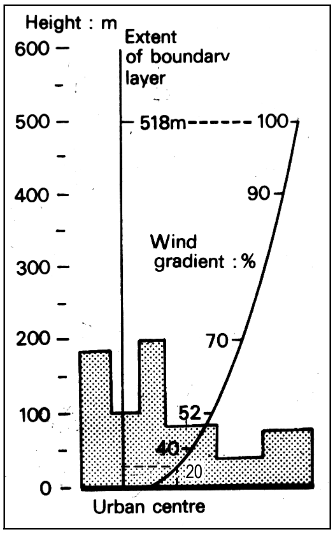

Figure 11 Wind velocity gradient in urban topography [Koenigsberger, 1978].

Analysis 1

For the months crucial for thermal comfort (April-September), the average wind velocity is 2.35 m/s at a height of 10 m from the ground. Let us find the rate of airflow, by natural draft effect, through a minaret of 20 m height with an average inner cross sectional area of 4 m^2.

From Figure 11, we get a wind velocity of 2.8 m/s at 20 m height from the ground (20% more than that at 10 m height), which will initiate ventilation, since ventilation through wind tower becomes effective when wind speed is more than 2.5 m/sec [Battle, 1999].

From Figure 12, for vertical duct height of 20m and cross sectional area of 0.05 m^2, airflow rate is 60 m^3/hr, i.e., 0.0167 m^3/s. So, for an inner cross sectional area of 4 m^2, the airflow rate should be 1.33 m^3/s ....*(1)*

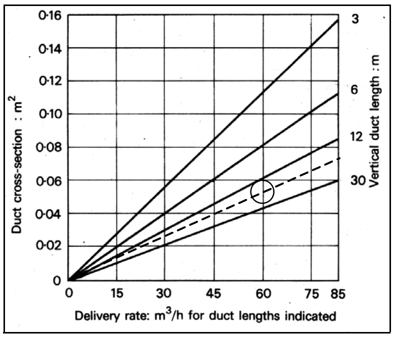

Figure 12 Duct design graph. [Koenigsberger, 1978]

Wind Direction

The manner of ventilation is fundamentally dependant on direction of wind, which varies on a seasonal and even daily basis. Due to this variation, an opening may change from a positive pressure to a negative pressure and vice versa. As a consequence, the opening may change its role as either 'inlet' or 'outlet'. So, the minaret should be placed and designed in a way to serve effectively for any direction of wind.

The concept of 'badgir' can be applied for using a minaret simultaneously as wind tower and wind scoop to work for any direction of wind. A neck, supported by single or double vanes, which may freely rotate horizontally with the change of wind direction, might be useful to orient the opening for either a wind tower or a scoop (Figure 9 & 10).

Temperature Difference

With the increase of temperature, the density of air decreases and it goes upward generating negative pressure behind, resulting suction effect for air movement. This phenomenon of air buoyancy, known as 'stack effect', can be utilised for natural ventilation through minarets. In design, wind force should be in the same direction of buoyancy force to avoid such situation, which nullifies each other and stops wind flow. The higher the minaret, the larger the internal cross sectional area and the greater the motive force for stack pressure facilitating ventilation, which can be derived from the equation [Markus, 1980]: $\Delta p = 0.043\ H\delta\ t\ Pa$ ....*(2)*

Where, Δp is the pressure difference between lower and upper section of the stack (N/m^2 or Pa), H the height of the stack (m), δt the temperature difference in ^oC.

To enhance stack pressure and thus ventilation, the temperature difference (δt) might be increased through heating the shaft of the minaret by solar radiation and using the minaret as a 'solar chimney'. Water heated from rooftop 'solar heater' and passed through metal pipes, coiled to maximise air contact, might be one good option. Upper segment of the shaft might be made of metal and painted in dark colour or constructed with 'glass blocks' or simply glass in steel frames, so that the tower absorbs solar energy to supplement the heating process [Clements-Croome, 1997].

The rate of airflow can be obtained from the equation [Markus, 1980]:

$V = 0.827[A_1\ A_2 / (A_1^2 + A_2^2)^{0.5}](\Delta p)^{0.5}\ m^3/s$ ....(3)

Where, V is the rate of airflow (m^3/s), A_1 and A_2 the cross sectional area of lower and upper part of the stack, Δp the pressure difference between lower and upper cross section of the stack (N/m^2 or P_a).

Analysis 2

The approximate average height and internal cross sectional area of minarets of Dhaka City is 20 m and 4 m^2 respectively [Imam, 2000]. A rooftop 'solar heater' (flat plate collector) can supply hot water at an average temperature of 56 ^oc through coiled pipes in the upper segment of the shaft (Figure 8), during sunshine hours of a sample date of September in Dhaka City [Pramanik, 1999]. Let us find the rate of airflow (V), when both the hot water in the coiled pipes and the metal/glass casing heats up the air in the upper section of the stack at 49 ^oC.

From *equation 2*, pressure difference, $\Delta p = 17.2$ Pa ....*(4a)*

From *equation 3,* (applying the result of *4a*) rate of air flow, $V = 9.7\ m^3/s$ ....*(4b)*

Recommended health ventilation in a mosque is 36 m^3/h per person (see preceding section *Ventilation: Type and Requirements*). The average capacity of a mosque (main hall) in Dhaka City is 200 persons [Imam, 2000]. So, the total health ventilation requirement is 7200 m^3/h, i.e., 2 m^3/s ....*(4c)*.

From *4b* and *4c,* we may find that the rate of airflow is quite satisfactory as it is much (4.85 times) higher than the requirement of health ventilation.

When the wind and 'stack effect' act together, the resultant flow rate is derived from the equation [Markus, 1980]:

$V' = (2)^{0.5}$ x Individual flow rate = 1.4 x Flow rate of either wind or 'stack effect' ....*(5)*

Where the flow rate of either of the wind action or the stack effect is much larger than the other, then the V' will be approximately the same as the larger flow acting by itself.

DISCUSSIONS

With the invention of loudspeakers, a minaret in a mosque is no more an indispensable component for the purpose of *adhan*. Despite of this fact, people still like to erect it as an urge for tradition, identity and visual quality. Incorporation of some additional purposes may add reasons for its construction. Minarets in warm-humid climate, particularly those of Dhaka City, have mention worthy potentials to be used as an aid to natural ventilation.

Depending on the wind direction, velocity, thermal condition and other practical issues, a minaret can be used as either a wind tower or a wind scoop or a solar chimney. Even combination of two or three might be suitable in certain situation. To get benefit of wind flow from all directions, a freely rotating neck supported by vanes can be useful at the top opening of the shaft or the concept of 'badgir' can be also adopted.

The analyses through thermo-fluid equations show that a minaret of 20 m height and 4 m^2 cross sectional area can generate an airflow rate of 1.33 m^2/s by natural draft effect, which can be enhanced up to 9.7 m^3/s, if the minaret is designed as 'solar chimney'. These rate of airflow, particularly that of 'solar chimney', can serve health ventilation quite satisfactorily. Checks for effective comfort ventilation, where so many physical and technical parameters are involved, is not covered in this paper. But, from the derived results of airflow rates, it is evident that a minaret can significantly supplement other means of comfort ventilation.

The architect should identify the requirement for natural ventilation, by quality and quantity, for a particular mosque in a specific climatic and physical set-up to design a most suitable minaret. As tools, he might use thermo-fluid equations, physical modelling in wind tunnels and computer aided analysis of Computational Fluid Dynamics (CFD).

CONCLUSION AND IMPLICATIONS

This paper puts some light on the postulation how a minaret can serve an additional purpose by supplementing natural ventilation in a mosque, particularly in the warm-humid climate of Dhaka City. There remains a vast scope for further research and analysis to explore the exact magnitude and type of ventilation it may provide under various parameters. The results might inspire and guide the architects and designers for an effective design solution. This will ultimately pave at least one stone in the path towards the success of global plea for conservation of environment through energy-efficient healthy buildings.

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