Potentials of Window Design in Inducing Airchange in Still Air Condition

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ABSTRACT: One of the major problems that has evolved as a result of rapid urbanisation marked by increased density in Asian cities is a drastic reduction of surface wind speed. This has given rise to almost still air conditions between buildings affecting indoor comfort. This phenomenon has affected wind driven heat and pollution removal potentials in naturally ventilated buildings. It has been observed that in Dhaka, a city in the Tropics, even after having multiple windows on opposing facades cross ventilation is not taking place most of the day. Commonly used ceiling fans are not contributing much in the way of achieving required air change. This paper presents the findings of a study where significant air change in still outdoor conditions with regard to rooms having single window have been observed. The study focuses on the design aspects of windows as a function of indoor airflow pattern generated by ceiling fans. Field results from full scale study and simulation studies using Computational Fluid Dynamic Software (CFD) are corroborated to develop design options for windows that potentially increase indoor comfort and air change rate. It is expected that the findings will immensely help design professionals practicing all climatic contexts where ventilation particularly in summer is an important design consideration.

Keywords: Windows, Ventilation, Tropics

1. INTRODUCTION

Within Asian cities, not based on bioclimatic considerations, streets and open spaces are progressively ending up as still spaces. Not a favourable outcome for cities in the Tropics. Natural airflow bypass these spaces as the urban canopy layer is pushed further upwards with the increasing height of the urban fabric, particularly in high density areas. In such urban contexts, buildings designed for natural ventilation does not always perform to desired levels- surface roughness created by the urban fabric dampens air velocities within and between building reducing ventilation potentials of naturally ventilated buildings. Dhaka is such a city where with rapid urbanization users are moving towards mechanically ventilated buildings. However, other than air cooling commonly used air-conditioners used in residential buildings does little in the way of ensuring health ventilation while putting ever increasing demand on the dwindling energy resources. With regard to apartments, currently one of the fastest growing building type in Dhaka, rooms having two exposed surfaces are not ensured cross ventilation not to mention of rooms having single walls exposed to outdoors due to wind shadows created by windward buildings. So the potential for air change driven by natural wind movement is significantly lowered. Furthermore, based on climatological observations it is known that natural wind flow is not a constant phenomenon, there are still periods at different times of the day even in open areas, reported in [2]. Thus as a reliable alternative ceiling fans have been commonly used for thermal comfort. Air flow across the skin is an effective means of keeping oneself cool as at high humidity where comfort zone is extended at higher temperatures by increased air velocities [1] [2] [3]. Studies have been conducted with ceiling fans where complex ceiling systems have been suggested [4] and also on the design of windows for natural ventilation [5]. This paper presents in its subsequent sections demonstrates the limitations of a ceiling fan in ensuring much studied health ventilation [6] in such contexts and potentials for using the same in generating air change without increasing the energy budget by looking at the design of windows.

2. METHODOLOGY

In conditions described above whole house fans can ensure required air change [7], however installation of such a fan would add to household energy expenditure in addition to installation costs. Hence by studying the airflow pattern inside rooms strategic opening may be suggested in order to ensure displacement ventilation. Furthermore displacement ventilation would also assist in maintaining indoor air temperature much close to comfortable outside conditions while enhancing cooling potential of fan driven air movement indoors.

The climatic context where the studies were done is in the city of Dhaka (Fig.1), in the warm-humid tropics at 24^{o} N latitude, with very little diurnal temperature variation, marked by high humidity (Mean Annual RH: 77%). The monthly mean maximum (Summer) Temperature is 35.4°C, monthly mean minimum (winter) Temperature is 11.0°C and average wind speed is 4.1m/sec.

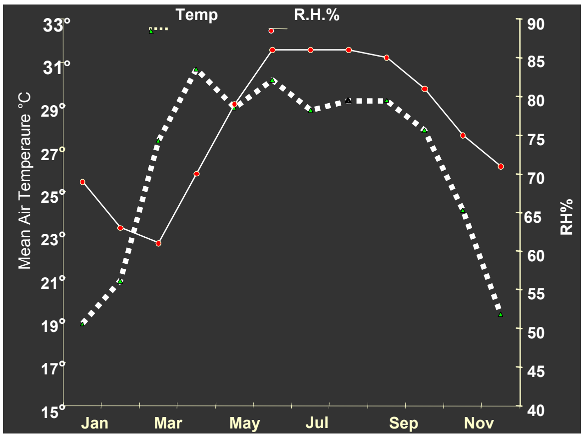


Figure 1: Mean air temperature and Relative humidity of Dhaka city (source: Met Office Dhaka, Bangladesh)

It has been observed that airflow increases the tolerance to high humidities without much increment in the upper limit of the comfort zone. However with airflow as little as 0.5m/sec the upper limit of zone is pushed to 32.7°C from 32.0°C and the tolerance to high humidity is pushed to 91%RH .[3]

3. REAL SCALE STUDIES

Real scale study was conducted to test the hypothesis and to observe airflow characteristics in real time using various window configurations. The real scale study further facilitated in deriving input data for the Computational Fluid Dynamic (CFD) studies done at a later stage of this work.

Figure 2: View of the courtyard from the test room

A test room was selected (Fig. 2) at the top floor apartment of a three storey apartment building. To prevent the effect of natural wind flow on indoor air motion the test room selected had an open to sky courtyard coupled with it. The courtyard was deep enough to preclude any effect of natural wind flow and furthermore studies were conducted in still air conditions. Digital rotating vane anemometer was used to record air velocities at discrete locations within the room (Fig.4), foam spray was used to visualize flow pattern and photo records were made.

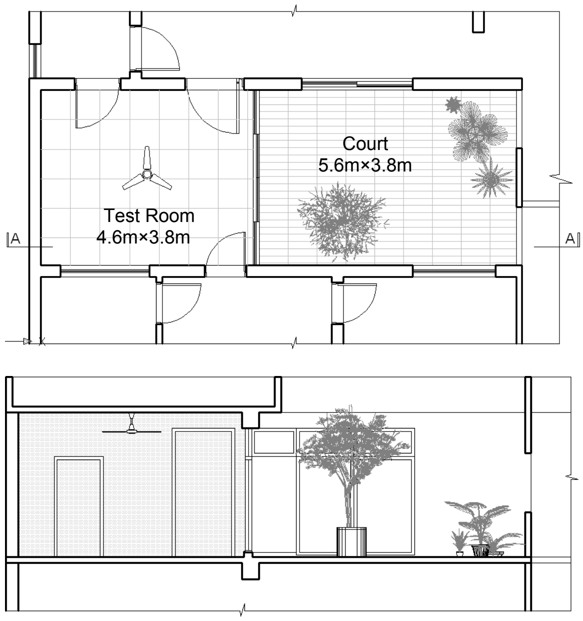
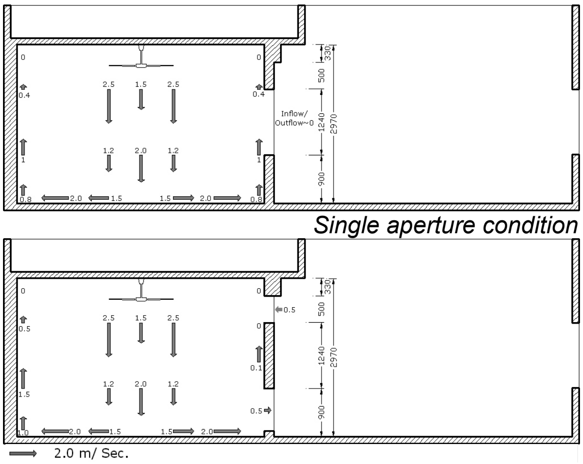


Figure 3: Plan and section of the test room

During the study all doors and openings were kept closed except for the openings in question.

Major findings:

- When the fan speed was set at its maximum, highest air velocity was been recorded (2.0 m/sec), at an height 2.1 m above the floor below the edge of rotating fan blades.
- Air velocity at floor level was found to be relatively higher at floor level in comparison to wall and ceiling level measurements. The direction of the flow was towards the wall and away from the centre of the room.
- No significant change in the airflow profile was found in situations having aperture representing commonly used window location in comparison to a closed room situation with the ceiling fan on. There was no measurable inflow or outflow through the opening indicating very low potential for air change.
- With two openings-one at skirting level and one at lintel level (2.14m), where inflow and outflow velocities were 0.5m/sec respectively. This finding indicates potential for significant air change.



Single aperture condition

Dual aperture condition

Figure 4: Measured velocities within the test room.

4. IMMERSION STUDIES

During real scale studies it was observed that vortexes were generated at different locations within the room effectuated by the ceiling fan and the overall flow pattern within the room was one of spiralling motion. Following real scale studies immersion studies were conducted to further profile complex flow characteristics observed in the real room and to further assist understanding of CFD results done at a later stage. The study facilitated qualitative assessment of the flow characteristics generated by the fan.

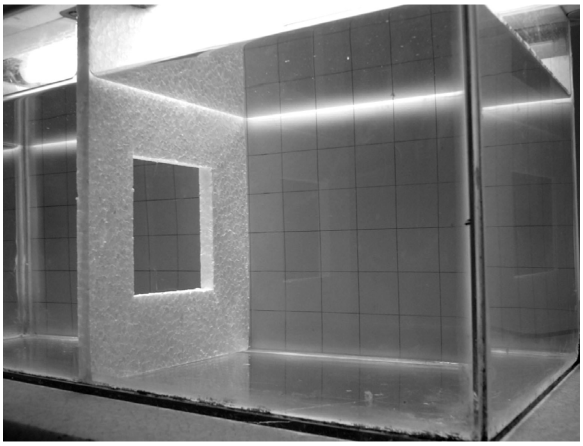


Figure 5: Scaled immersion model of the room with single opening.

Immersion studies were conducted using scale model (1:16) of the test room (Fig 5). The model consisted of a clear glass tank (457mm×216mm×228mm), filled with water, to allow visual assessment of the flow characteristics. A partition was placed inside the tank to create ‘indoor’ (216mm×216mm) with a ceiling height 177mm created by the water surface, coupled with an outdoor situation. Apertures were made on the partition to represent windows (Fig.5) (Fig 6). A scale model of the ceiling fan with slanted blades made of metal, powered by an electric motor was immersed inside the chamber representing ‘indoor’. The model fan was dropped to the standard level below the water surface, here indicating the ceiling plane. Dye was released at intervals with the fan in motion to visualize streams and submersible particles were released to observe flow pattern. Video recordings were made of the varying study situations.

3.2.1 Flow Study in Base Condition: Single window

With the base condition, i.e. standard window opening at the usual sill height, immersion studies indicated that almost no fluid stream crossed the opening within a given time frame. Thus dye released ‘inside’ resulted in relatively high saturation inside in comparison to ‘outside’ indicating little or no prospect of air change with the fan in motion. This finding corroborates with the initial observations in the real scale studies.

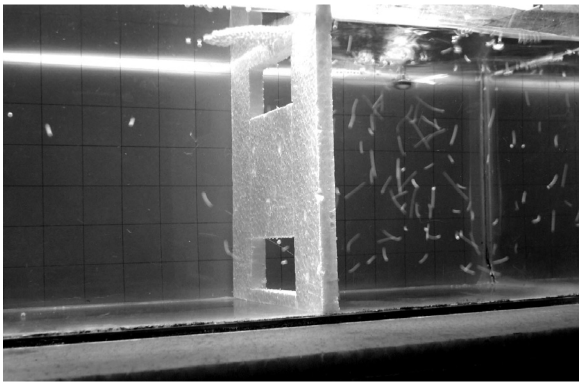


Figure 6: Particle flowing out through the lower opening (indicated by motion blurs).

3.2.2 Flow Study with Two Apertures:

With two openings, one at sill level and the other above lintel level, the released dye immediately streamed ‘outside’ through the bottom opening and flowed in through the opening above. Where the usual window was closed, no representative aperture in the partition (Fig. 6), the in and outflows were clearly visualized within an identical time frame as in case of base condition. This phenomenon was further visualized with submersible particles driven my fluid motion (Fig. 6). The study indicated that with two apertures the prospect of fan induced air change is significantly increased.

Major Findings:

- The floor could be regarded as the primary plane of resistance (PR) while walls acted as secondary plane of resistance and the ceiling as the tertiary plane of resistance with regard to the perpendicular angle of attack of airflow. With every change of fluid flow direction against the successive planes velocities dropped. It was further observed that across apertures close to the Primary Plane of Resistance (PR) generated outflow velocities were highest.
- It was evident from the immersion studies that fluid motion close to the floor was relatively higher at maximum fan speed compared to fluid motions along the walls or the ceiling.
- However, in case of the base condition, fan at a slower rpm the PR was virtually raised well above the

sill level rendering discernable outflow through the opening. In real terms such a condition may never happen as fan speed in summer conditions is kept at its maximum hence the prospect of such a flow pattern is low.

- The overall fluid pattern generated by the fan was spiral. Hence particle deposits in the corners of the modelled room indicated weak corner vortex. This corroborates with the real scale studies where such corner phenomenon was observed.

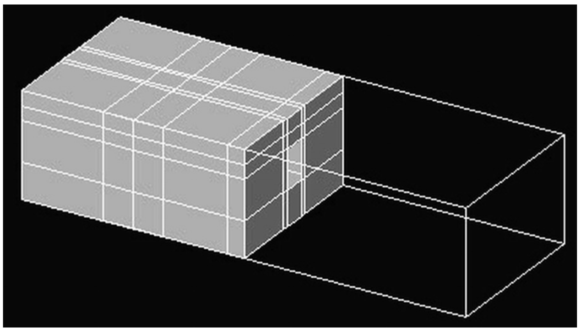


Figure 7: Three dimensional CFD model of the room coupled with the courtyard.

5. CFD STUDIES

PC based Computational Fluid Dynamics (CFD) studies were done using Easyflow version 2.0. CFD techniques facilitated greater flexibility of modelling parameters and geometry. Downward air velocity generated by the ceiling fan, recorded in the real scale study, was used to derive an appropriate input velocity in the CFD model. Given the airflow flow pattern observed in the previous studies a three dimensional CFD study with a 3D model (Fig.7) was done.

Standard K-ε model was used in the simulation study and the input parameters were:

Air temperature: 300^0K (1 Atmosphere pressure)

Density: 1.161kg/m^3

Viscosity: 1.589×10^{-05} m^2/s

Air velocity:2.58m/s at angle of 15^0 from the ceiling plane.

Air inlets: four air inlets arranged in pinwheel fashion was modelled to approximate ceiling fan.

Outlets: 4 outlet planes were modelled just above the ceiling fan blade.

The characteristic of the incoming flow was laminar. With laminar flow the fluid motion is highly ordered and identifiable with parallel stream lines. Thermal effects of the flow were not considered. The flow simulation was based on steady state condition, where the velocity at any point is same at all instants. Phoenics Reader (version 1.2.0.6, copyright Eugene Krinitsky) was used as a post processor to visualize the CFD results.

Two three dimensional models were created-one with a single opening, representing the base case condition and the other with two openings. The second model approximated a condition where the conventional window is closed and the one below and the one above is opened (having a total cross sectional area as in the base case window).

In the study of the base case condition, there were no cross flow across the conventional window as indicated in Figure 8 and Figure 10. However a significant outward flow was observed in the case of dual windows (Fig.9 & 11). x component (U1) of the velocity plots along the length of the model section showed a significant outflow velocity. This observation confirms that with dual windows cross ventilation or displacement ventilation can be achieved in such a context.

6. ANALYSIS AND RESULTS

The outflow velocity thus observed can play a significant role in ensuring displacement ventilation in a room as observed in the studies. In the case of conditions studied the following observation can be made:

For a constant outflow velocity: 1.29 m/s

Ventilation rate can be calculated from:

$Q=C_vAV$

Where Q= airflow (m^3/s), A= Area of opening (m^2), C_v=opening effectiveness coefficient (varies between 0.3 to 0.6)

In the modelled condition, A= 1m^2, V= 1.29m/s and considering C_v=0.6, Q is 0.774m^3/s.

Hence number of potential air changes per hour n will be:

n= Q/Volume=(0.774 X 3600)/58.52=47.6 Changes per hour. At this very high rate of air change, in addition to health ventilation, cooling by displacement can be achieved where outdoor air temperature is below the skin temperature.

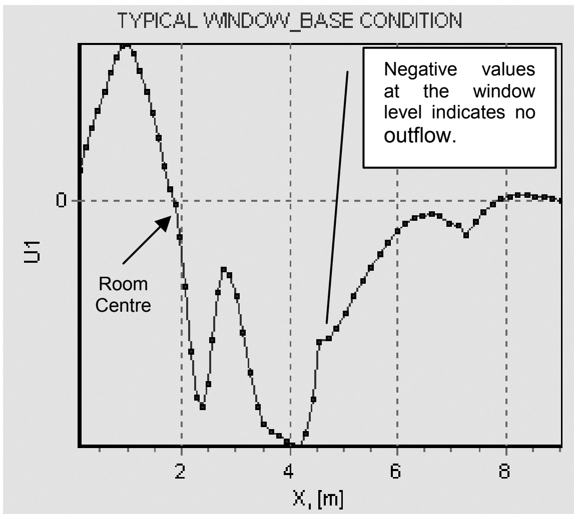


Figure 8: Velocity plots through the centre of the CFD model with single window.

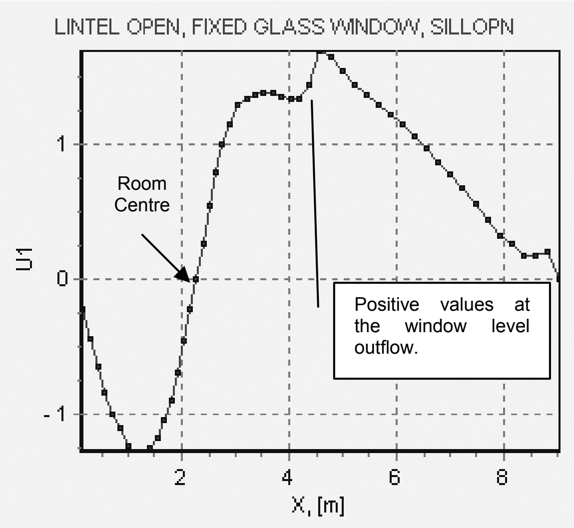


Figure 9: Velocity plots through the centre of the CFD model with dual window.

7. CONCLUSION

The investigations presented above indicates that even in the difficult situation of still condition and rooms with single sided window- displacement ventilation can be achieved with the aid of a commonly used ceiling fan. This will hopefully open up avenues for architects to design windows that facilitate such ventilation techniques. In future publications, influence of shading device on flow pattern will be presented. Also the impact of light shelves, wind breaks, installed inside the room, on the flow characteristics will be discussed.

Further studies are planned with furniture layout options will be conducted as they may affect flow pattern inside the room. Impact of and interaction with natural wind forces will also be studied to arrive at possible design solutions. Finally a design code for architects and engineers will be developed to facilitate practical application of the findings.

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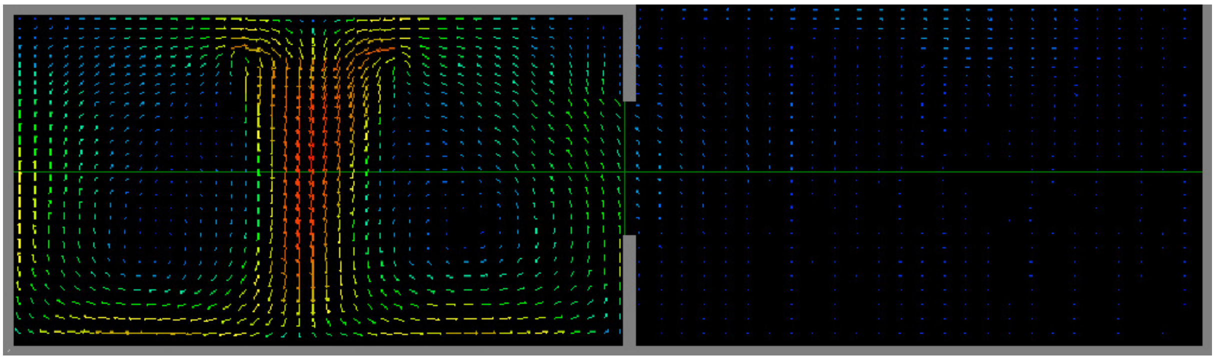

Figure 10: Velocity vectors in the upward direction along the window plane indicates no outflow

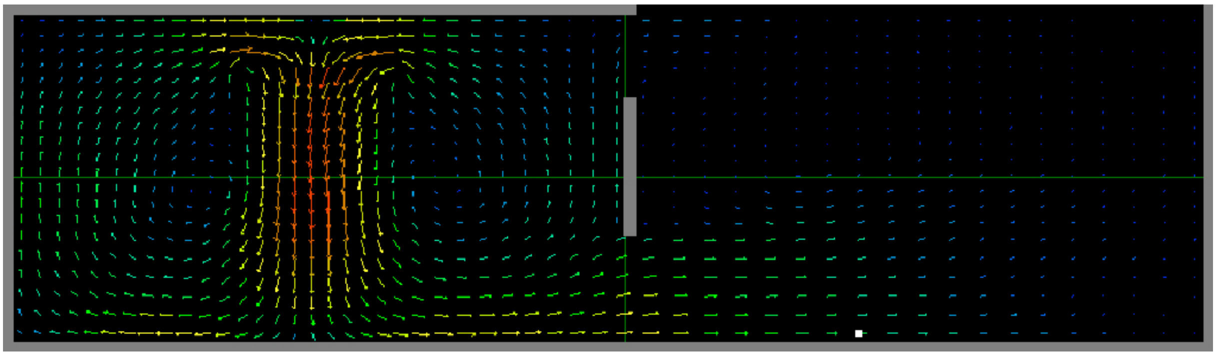

Figure 11: Velocity vectors through the bottom aperture indicating outflow.