The Impact of Balconies on Natural Ventilation Performance of the Building. A case study in Phuentsholing, Bhutan.

Chimi[1], Phurba Lhamo[1], Sonam Yangchen[1], Tshering Cheki[1,2]

[1] CEAD, College of Science and Technology, Royal University of Bhutan
[2] Department of Civil Engineering, Indian Institute of Technology, Roorkee

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Abstract- Due to the presence of high temperature and humidity in the sub-tropical climate like Phuentsholing, residents are forced to use electro mechanical ventilation increasing the energy consumption by a building. Due to this cooling energy demand in buildings represent about 10% of the total energy consumed by the world. Phenomena such as global warming, population growth and longing for luxury living are the key reasons for an increase in energy demand. Particularly, due to the impact of global warming, many people have started to use mechanical system like HVAC for cooling spaces. However, these energy demands can be reduced by 5% to 6% by using natural ventilating mechanism. This paper investigates the impacts of the various type of natural ventilation in building and present the effectiveness of the balconies to induce natural ventilation in building employing Computational Fluid Dynamics.

Index Terms- Natural ventilation, Computational Fluid Dynamics (CFD), balcony; hot climate

I. Introduction

The consumption of energy by the world has increased by more than 50% in the last few decades [1] [2] due to increase in population and economic growth [3]. The increase in use of non-renewable energy has resulted with huge negative impact on the environment, causing global warming, climate change, etc. apart from incurring huge expenditures. Thus, the shift to natural energy resources, has gained more attention.

Globally, it was observed that the energy demand for heating and cooling of indoor air in a building is accountable about 50% of the total building's energy consumption [4]. In Australia, buildings are considered as the third largest energy consumer following the transport and manufacturing sectors [5]. Due to high consumption of energy with huge negative environmental effects, many governments and agencies have made Energy efficiency policies and approaches a priority in building construction industries in the form of guidelines and regulation [6] [7]. Adopting and implementing passive cooling strategies in hot climate and passive heating in cold climate are considered as one of the energy efficient strategies which can significantly reduce energy demands from the building [8].

One of the effective passive cooling strategies in reducing buildings' energy foot print in hot climatic zones in natural ventilation. According to Nazari (2014) [9], natural ventilation is much more effective in mild climates with temperature ranging from 18 to 28 degree Celsius. Natural ventilation also provide thermal comfort with a healthier indoor environment with minimum expenditure. It is observed that 30% to 40% less energy is consumed by naturally ventilated buildings compared to mechanically ventilated buildings [10] [11]. Natural ventilation in the building can be achieved by various methods and balconies are one the most commonly used strategy to induce natural ventilation in tropical climate buildings [12].

This paper reviews different types opening and their contribution on the performance of natural ventilation in a building and study the effect of balconies on the natural ventilation of the building by using Computational Fluid Dynamic (CFD).

II. Natural ventilation

Dynamic pressure and static pressure differences in an environment are considered as the driving forces of natural ventilation. Therefore, higher pressure differences result in higher ventilation rate. This dynamic pressure difference is due incident wind whereas the static pressure difference is the result of a temperature gradient known as buoyancy or stack effect. It can also be driven by a combination of both static and dynamic pressure differences [13]

When the wind strikes the surface of a wall, it creates the positive pressure on the windward side and negative pressure on the leeward side causing huge pressure difference. Therefore, having openings at the external walls, directs the external air to flow through the internal spaces from positive pressured zones to the zone with negative pressure [14]. With increase in pressure difference, the indoor airflow rate increases. Moreover, parameters like building shape and orientation, wind speed, wind direction and surrounding environments also affect the pressure distribution on the building façade [15].

It was also found that the temperature difference affects the air density that produces buoyancy forces and makes the air flow from

high-density regions (lower temperature) to low-density regions (higher temperature). Buoyancy driven ventilation is categorised into two main groups: mixing ventilation and displacement ventilation [16]. In mixing ventilation, the single opening acts as both supply and exhaust, in which fresh cool air enters the enclosure from the lower part and the warm stale air escapes from the upper part of the same opening. Whereas, in displacement ventilation, it has two openings located at different heights, where fresh air enters from the lower opening and warm air exits from the upper one which is usually located near the ceiling [17] as shown in figure 1.
The buoyancy forces and the stack effect are created due to the location of openings at different heights with indoor and outdoor temperature differences in a room. The pressure difference is also created by wind forces depending on the direction of the incident wind. It can either reinforce (Figure 2-left) or oppose (Figure 2-right) the buoyancy forces.

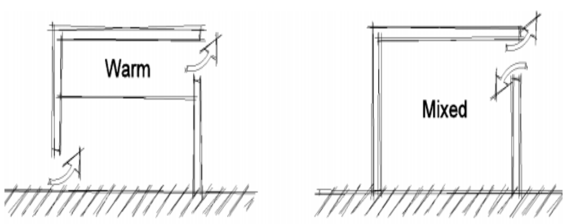

Figure 1: Buoyancy-driven ventilation: displacement ventilation (left) and mixing ventilation (right)

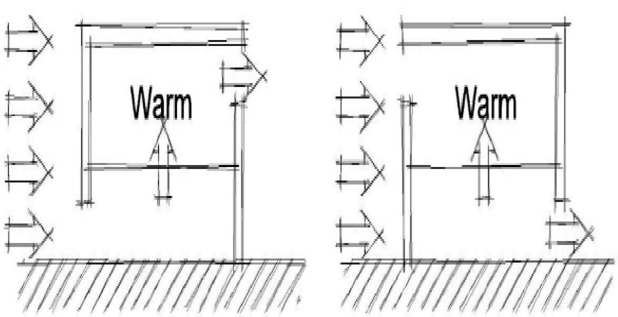

Figure 2: Buoyancy-driven ventilation: displacement ventilation (left) and mixing ventilation (right)

III. Advantages and Disadvantages of Natural Ventilation

Natural ventilation is one of the main determinants of indoor thermal comfort conditions and quality especially in hot climates [18] replacing hot air inside a space with cooler air from outside by a natural means reducing energy demands and environment pollution. It was also found that about 30% of the energy used by the building sector is used for space conditioning [19]. Furthermore, a study has found out that natural ventilation decreases the chance of airborne infection by 6-28% compare mechanical ventilation in hospitals [20]. In terms of installation and maintenance costs, natural ventilation is much more cost-effective than mechanical ventilation, especially for residential buildings [21].
Regardless of the aforementioned advantages, there are limitations during the application of natural ventilation in buildings such as: limited control and noise pollution from outside. In contrast to mechanical ventilation, it is highly depended on natural forces such as wind speed and direction [22]. Thus, ventilation rate cannot be easily adjusted by the occupants as per requirement by users. Therefore, in extreme hot climates, overheating in some days will be unavoidable [21]
Moreover, the dependence of building ventilation performance on the wind requires adequate consideration of building location, orientation and designs to facilitate natural ventilation which adds additional challenges to the building designers. Furthermore, open windows used for natural ventilation make the enclosed spaces prone to outside noise and pollution, especially in high-traffic areas and regions close to pollution sources [23]. Despite all the limitations of natural ventilation in buildings, passive cooling system still remains an attractive solution for space cooling.

IV. Types of Ventilation

Researchers have observed that two openings opposite or perpendicular to each other would enhance the ventilation performance [24]. The arrangement of openings' here refers to their form, size, and location on the façade. According to [25] the placing of two openings far apart improves the ventilation performance compared to the case with two adjacent openings. Similarly, Yin and his group in 2010 [26] have pointed out that relative openings' heights also contribute to the performance of natural ventilation. They have also found that the same level of inlet and outlet results in better ventilation in most of the cases.

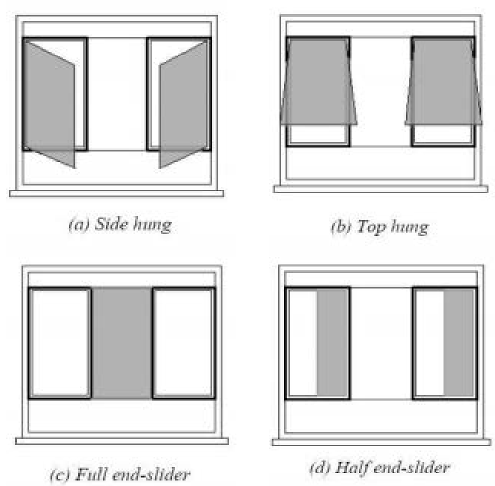

Figure 3: Window types examined by Gao and Lee

The study carried out by [27] found that a larger inlet accompanied with a smaller outlet would improve the ventilation rate. Moreover, the rectangular windows with smaller width to height ratio would enhance the efficiency of natural ventilation mechanism [28]. Heiselberg and his friends [29] have found that in winter, the bottom-hung windows are effective for both single-sided and cross ventilation configurations, whereas in summer, the full end slider and side-hung windows performed better for cross ventilation. It was also found that the side-hung windows are most appropriate for single-sided ventilation when type of windows as shown in figure 3. were analysed using CFD [24].

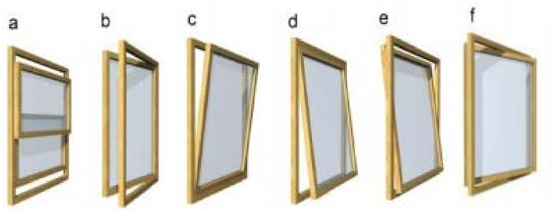

Figure 4: Window types examined by Grabe et al. (2014): a) double vertical slide window, b) turn window, c) bottom-hung window, d) awning window, e) horizontal pivot window, and f) vertical pivot window

Similarly, Grabe and his group [30] investigated the ventilation performance for buoyancy driven ventilation of six different window types as shown in figure 4 and concluded that horizontal pivot windows presented the best ventilation performance while tilt windows were proven to be the worst. This findings were supported by [31] that side-hung windows performed better for windward conditions while bottom-hung windows showed a better overall performance, when they carried out an experiment on natural ventilation by developing semi-empirical models for a ventilation performance of abovementioned window types under various wind directions.

V. Balconies and Wing Walls

Another facade design feature that affects the performance of natural ventilation in building is balconies and wing walls. Balconies of buildings located in subtropical climates not only create private outdoor space but also play a vital role in indoor air movements [32] by controlling the internal air velocity [33]. This is supported by study carried out by Chand and his group [34], where that have found that provision of a balcony increases wind pressure.

Wing walls are another building feature that affects natural ventilation by creating pressure difference. Givoni [35] has demonstrated that the addition of wing walls to single-sided ventilation would significantly improve the natural ventilation and indoor air circulation. It was found that wing wall walls at the 45˚ wind direction has a best performance in creating air movement.

VI. Simulation and Observation

For this particular experiment, a bedroom of a residential unit in Phuentsholing was identified. Phuentsholing is located in the southern part of Bhutan at 26’49’’N to 26’54’’N Latitude and 89’20’’E to 89’28’’E Longitude and at an altitude of 293m above mean sea level [36]. The external window of the room is located on a windward side and door on the opposite wall. The boundary condition for the inlet window and the outlet door is set respectively. For the inlet window the boundary condition with an average wind velocity of 1.5m/s, average temperature of 23˚C and humidity of 60% in Phuentsholing is considered. For the outlet door, the out let pressure of zero is set as its boundary condition. The figure 5 and Figure 6 shows the plan, elevations and 3D view of the model room with and without a balcony. The dimension of the room is 3.2m length X3m width X3.15m height.

After that CFD has been used to study the efficacy of the balcony on natural ventilation by simulating the model on two different cases:

1. Case I- bed room without balcony
2. Case II- bedroom with balcony

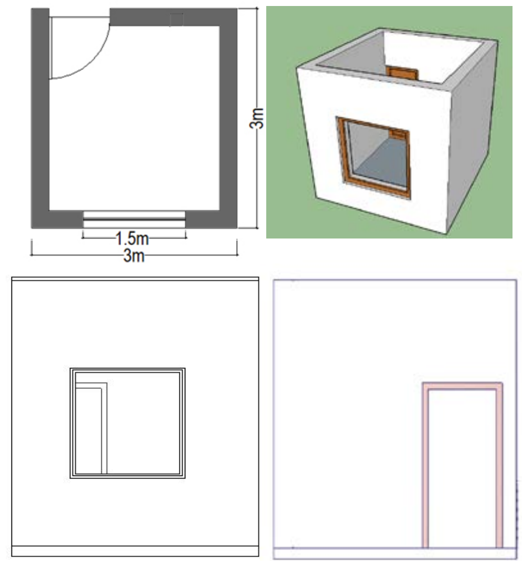

Figure 5: a) Plan, b) View, c) Front Elevation & d) Rear Elevation of case -I

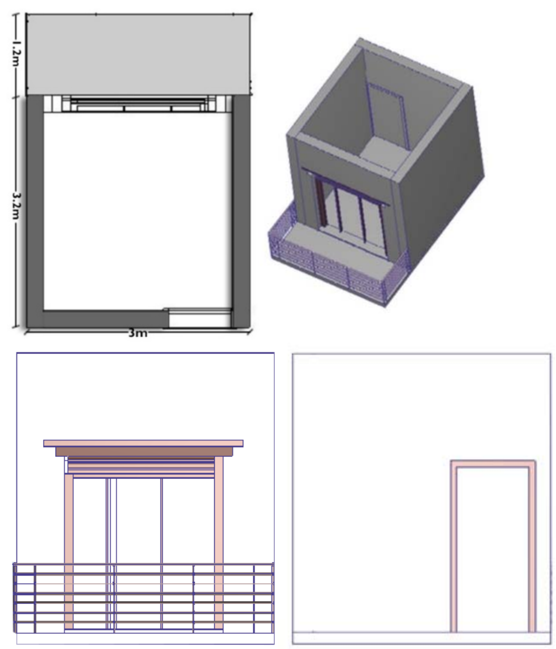

Figure 6: a) Plan, b) View, c) Front Elevation & d) Rear Elevation of case -II

The mesh was then generated in CFD and then the model was simulated for the result. Figure 6 shows the result of the CFD simulation at a different height of planes in case-I. The highest speeds recorded happened in the centre of the room from the window to the corner and the side of the door (up to 1.5 m/s). The velocity of the wind inside the room are observed to be different depending upon the height as shown in figure 7 and figure 8.

The result was recorded for three different heights; 0.5m,a height of the person in sleeping position, 1.2m, a height of person sitting on the chair and 2 m, a height of standing person.

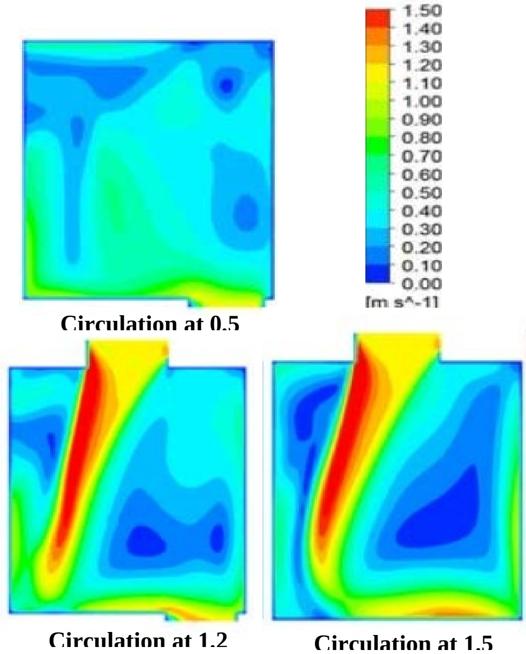

Figure 7: Velocity contour on the horizontal plane found on different heights in case -I

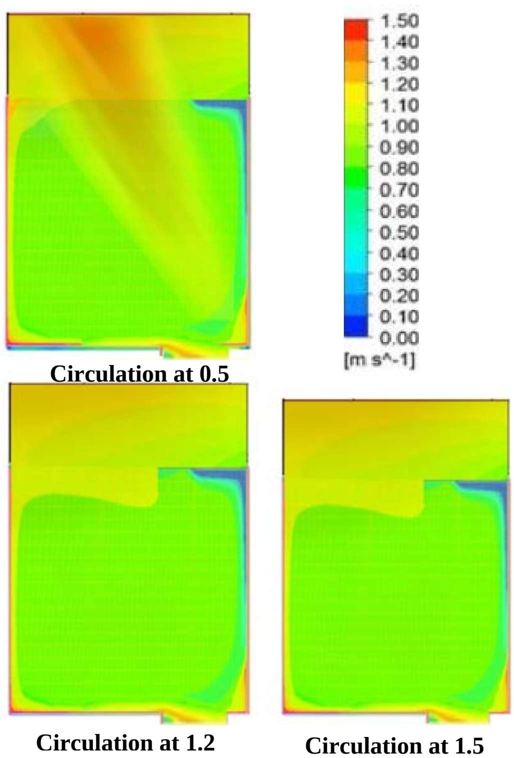

Figure 8: Velocity contour on the horizontal plane found on different heights in case -II

In case 1, the minimum air movement in bedrooms was observed at the height of 0.5m where there is opening for an inlet, as the sill height of a window was 600mm above floor level. And maximum velocity and irregular distribution of air movement at a height of 1.5m above floor level. While in case 2, the maximum air movement was observed at the height of 0.5m. It is observed that the provision of balconies changes the indoor air distribution, and it can maintain relatively better air movement in the lower part of the room compare to upper levels.

Similarly, in case 2, due to the provision of balconies, it reduces the average air velocity causing uniform distribution of air inside the room. While in case 1, it was observed that the high velocity of air movement was seen near the opening and creating an uneven distribution of air movement velocity inside the room.

VII. CONCLUSION

From this study, it is concluded that natural ventilation plays a vital role in increasing the wellness of people inside the room by replacing the stale air with fresh air from surrounding apart from reducing the initial and operation cost of the building. It also reduce the energy demand of the building reducing the negative impact on the environment by reducing the emission of greenhouse gases from mechanical ventilation equipment.

Moreover, the provision of balconies in building facades in sub-tropical climatic regions like Phuentsholing not only increase the ventilation rate of a building but also maintain the uniform distribution of air velocity in the room, providing more comfort to the dwellers by replacing the stale air with fresh air from outside with constant velocity of air movement.

VIII. ACKNOWLEDGEMENT

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X. Author

First Author – Mr. Chimi, Lecturer, Civil Engineering and Architecture Department, College of Science and Technology, Royal University of Bhutan. chimi.cst@rub.edu.bt

Second Author – Phurba Lhamo, B.Arch. student, Civil Engineering and Architecture Department, College of Science and Technology, Royal University of Bhutan. 0214608.cst@rub.edu.bt

Third Author – Sonam Yangchen, B.Arch. student, Civil Engineering and Architecture Department, College of Science and Technology, Royal University of Bhutan. 0214614.cst@rub.edu.bt

Fourth Author – Tshering Cheki, M.Tech. student, Civil Engineering Department, IIT, Roorkee, India. tsheringcheki.cst@rub.edu.bt

Corresponding Author – Tshering Cheki, M.Tech. student, Civil Engineering Department, IIT, Roorkee, India. tsheringcheki.cst@rub.edu.bt