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Original Article/Research

Analysis of thermal comfort and indoor air flow characteristics for a residential building room under generalized window opening position at the adjacent walls

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Abstract

Thermal comfort is an imperative factor that determines the health and productivity of the occupants living in residential buildings. The growing health related symptoms and demand for the electrical energy encourage the occupants to switch over to natural ventilation. Thermal comfort for naturally ventilated buildings mainly depends on the size and orientation of window openings. Even though most research works include the study on indoor thermal comfort for various positions of window opening it was limited to single sided and cross ventilated buildings. In real situation most of the rooms attached to the residential buildings are having window openings at their adjacent wall and hence this paper was focused to study the occupants' thermal comfort and indoor air flow characteristics for a room with adjacent window openings under generalized approach. Computational fluid dynamics (CFD) technique is employed to study the indoor air flow for a three-dimensional room model. The CFD simulation is checked for grid independence and having good validation with experimental measurements on the reduced scale model at wind tunnel and with the network model with the k–ε turbulence model. Air temperatures along various midlines, planes, areas occupied by low temperature zone and predicted mean vote (PMV) contours are presented in this paper. From this study a new set of strategies are identified to locate the window openings and the best location improves percentage of low temperature by 50%, reduces the PMV and PPD by 0.12% and 3.51%, respectively with reference to the worst window opening position.

Keywords: Thermal comfort; CFD; Ventilation; Network model; Wind tunnel

1. Introduction

People living in hot and arid climatic zones have been affected by many building related health symptoms like head ache, heat stroke, dehydration, frostbite, lung diseases etc due to lack of thermal comfort. These health symptoms ultimately reduce the productivity level of the occupants and hence occupants are paying more attention

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to keep their indoor environment under good thermal comfort. Thermal comfort is the state of mind that expresses the satisfaction with the thermal environment. Thermal comfort can be maintained by dissipating the heat generated by the body due to metabolic activity to the environment and thereby the thermal equilibrium was maintained with the surrounding. The indoor thermal comfort can be maintained by providing proper ventilation which in turn depends on many factors like wind force, outdoor temperature, surrounding building topography, height, shape, orientation, window opening type, size and its position. Among the above factors, window opening can be designed easily by the engineer for good ventilation and thermal comfort and rest of the factors could not be easily controlled.

In this context, Gao and Lee (2011) evaluated the influence of opening configuration on natural ventilation performance of residential unit at Honk Kong and stated that relative position of the two window opening groups (bed room windows and living room windows) was the most affecting parameter. Also better natural ventilation performance can be achieved when the two openings are positioned in opposite direction or perpendicular to each other. Hassana et al. (2007) investigates the effect of window combinations on ventilation characteristics for thermal comfort in buildings. The author also stated that for single sided ventilation with two non adjacent openings gives better ventilation than adjacent openings. Seifert et al. (2006) studied the airflow for the building envelop having window opening nearer to the roof and floor level, windward opening nearer to the roof and leeward opening starts from the mid height of the building and both the window openings nearer to the roof level. Stavrakakis et al. (2012) optimized the window opening design for thermal comfort in naturally ventilated building by the artificial neural network method. Ramponi and Bloken (2012) studied the physical diffusion of indoor air for the building envelope with both openings near to the floor and at the mid height of the building under 5% and 10% of wall porosity. Favarolo and Manz (2005) also analyzed the influence of opening configuration on natural ventilation performance by flow visualization and CFD technique and identified that ventilation performance is mainly affected by its vertical position and width of the opening. However, all the above studies are focused to investigate the effect of window opening orientation and its size for the building envelope with single sided ventilation or cross ventilation. Similarly other studies on building ventilation performance are also made on sided ventilation or cross ventilation. Allocca et al. (2003) analysed the single sided natural ventilation to study the effect of buoyancy on the ventilation rate. Straw et al. (2000) presented the results of experimental, theoretical and computational investigations of the wind driven ventilation with openings on the opposite walls of the room. Caciolo et al. (2012) developed a new set of empirical relations in leeward conditions based on the CFD simulation and full scale experiments. These correlations have been set up to assess the airflow rate due to the combination of stack and wind effects. Kato et al. (1992) investigated the mechanism of cross ventilation by the LES model in a room with opening at their opposite walls. Karava et al. (2011) made an experimental study of basic cross ventilation flow characteristics that are essential for accurate natural ventilation modeling and design. The authors also mentioned that the airflow pattern in room with cross ventilation is complex and cannot be predicted by simplified macroscopic models such as orifice equation. Liang ji et al. (2011) investigated the influence of fluctuating wind direction on cross ventilation using wind tunnel experiments with the aim of improving the evaluation accuracy for natural ventilation. Similarly, the recent research works are also pertained to study the air flow in a room with single sided ventilation (Zhen and Kato, 2011; Caciolo et al., 2011) and cross ventilation (windows at the opposite walls) (Hu et al., 2008; Lo and Novoselac, 2013; Nikolopoulos et al., 2012; Lo and Novoselac, 2012; Lo et al., 2013).

But, in real case, the rooms attached with residential buildings have their openings at the adjacent walls and not at their opposite walls. The air flow for the room with window openings at their adjacent walls is entirely different from single sided and cross ventilated buildings. The air enters through the window openings at the windward side wall and turns 90°, travels along the wall and leaves through the window opening at the adjacent wall. The path of air travel depends upon the relative position of window opening at the adjacent walls. Ravikumar and Prakash (2009) studied the effect of window opening size and its aspect ratio on indoor airflow characteristics for the room with window openings at adjacent walls and the importance of investigating such a type of window orientation is also pointed out. The air flow pattern inside a room is complex and is characterized by multi-flow features such as laminar boundary layers, highly turbulent diffuser jets and low turbulence flow.

Air flow analysis can be performed by methods like theoretical models, experimental testing and Computation Fluid Dynamics (CFD) technique. In order to obtain reliable information concerning the air flow and the pressure distribution around and inside a naturally ventilated building, full-scale measurements can be performed (Straw et al., 2000; Koinakis, 2005). However, wind tunnel tests on small-scale models are usually preferred, as they allow the control of wind speed and direction, as well as the study on different configurations (Eftekhari et al., 2003; Wong and Heryanto, 2004). Walker and White (1992), Nielsen and Olsen (1993), Dascalaki et al. (1995), Zeidler and Fitzner (1997) used the tracer gas measurement technique for their air flow studies. The study of complex flow patterns by experimental approach is highly infeasible and it provides the flow pattern details only at the specified locations. An alternative approach is to rely on CFD, based on