Numerical Simulation of Natural Ventilation of a Bedroom in Warm Climate

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ABSTRACT

This study utilizes the two-chamber model to simulate naturally ventilated airflow through a window opening in a common-type bedroom in Taiwan. Standard k-epsilon turbulence model is implemented to account for such a natural convection flow pattern. The driving force in this space is mainly the heat flux generated by occupant's skin. The result shows that under normal operation indoor, carbon dioxide (indicator air contaminant for IAQ) is less than 1000 ppm, ASHRAE Standard recommended.

KEYWORDS

CFD, Natural Ventilation, Two-chamber model

INTRODUCTION

RECENTLY, further efforts on the natural ventilation system have been made, due to the environmental benefit and energy saving aspect of the building for residence (1-4) . It is important to perform the ventilation of the space efficiently in consideration of health and thermal comfort. Natural ventilation may be defined as ventilation strategies, which are driven by the natural forces of external wind and indoor/outdoor temperature difference. These force induce pressure difference between inside and outside of the building openings resulting air movement and thermal exchanges, according to principles of the conservation of mass, momentum and energy. The pressure difference between indoor and outdoor environments which define the rate of ventilation are dependent on several parameters (5-7), e.g. The wind e.g. The wind speed and orientation relative to the building, the external temperature ...etc. There are three types of natural ventilation strategies whose performances are directly influenced by variations in the above parameters. These are (8) :

- i Ventilation through windows;
- ii Ventilation through trickle vents;
- iii Passive stack ventilation systems.

From the above, only the first strategy is the focus of this content.

However it is very difficult to simulate naturally ventilated airflow phenomena through the opened area, because of its complexity and uncertainties. In order to present such a natural phenomenon under some reasonable assumption, we construct the two-chamber model to achieve it. As illustrated in figure 1, this model consisted of two chambers : an climate chamber, simulating the typical domestic climate in Taiwan and an indoor chamber, representing the common-type bedroom layout where all the field-variable estimating (temperature, velocities...) were carried out . According to the statistical survey of climate data, parameters concerned with air in climate chamber are then specified. It represents the usual still-air properties in warm climate in Taiwan. The air in the indoor chamber move through the opening window (in and out) as a result of buoyancy force, generated by the body lay down on the bed and the conservation of mass, momentum and energy .

A number of studies have been undertaken for natural convection heat transfer within a enclosure (9-12). The citations listed in these representative studies provide further references for this problem. It has been established that natural convection heat transfer from inner heating elements is significantly affected by the plume-rise effect. However it appears that most of this literature dealt with fundamental physics. In practice, a lack of knowledge remains on the phenomena of natural ventilation through window openings in a residential bedroom.

The objective of the president study was to provide physical insight into the nature of buoyancy-driven air flow and natural ventilation phenomena pertinent to the common-type bedroom layout in Taiwan considered for which little or no information is available .In doing so, The standard k-epsilon turbulence model is employed to simulate turbulent natural ventilation in the bedroom. Of particular emphasis in this study was influence of the opened window location on the flow phenomena. It's expected to identify a suitable location of opening toward the outdoor environment that makes ventilation strategy effective and assure achievement of comfort level.

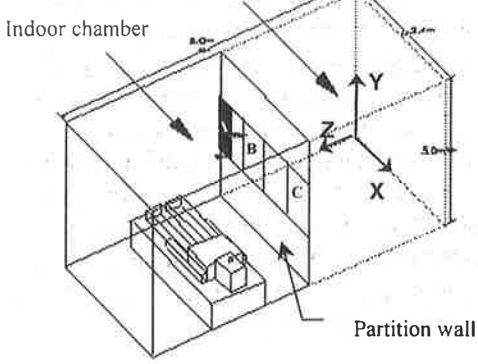

Figure1 Schematic Diagram of the physical configuration investigated.

METHODS

• Physical Problem and Mathematical Formulation

Figure1 illustrate schematically the physical problem of air undergoing natural ventilation process through window opening in a residential bedroom. Initially air is at its domestic temperature T_i in Taiwan. Suddenly the heat flux generated by occupant's skin (face and breast) raise temperature of air adjacent to these regions. The buoyancy-driven airflow resulting from temperature difference between occupant's skin and ambient air is assumed to be three-dimensional and turbulent.

Further the thermophysical properties of the air are temperature independent, except for the density, for which the Boussinesq approximation is valid. The other dimensional parameters specified in this study are shown in Table 1.

Table 1 dimensional parameters specified in numerical calculation

parameter	value specified	remarks
size of indoor chamber (m)	3 x 2.4 x 3	length-scale of common-type bedroom in Taiwan
size of window opening (m)	0.3 x 1.2	ratio of opening area to floor area . 0.05 (min. opening value in Building Code in Taiwan)
size of climate chamber (m)	3 x 2.4 x 3	
initial temperature, T_i	26℃	statistically average temperature in summer in Taiwan
wall of the climate chamber	26℃	
wall of the indoor chamber	adiabatic	
partition wall between climate chamber and indoor chamber	adiabatic	
heat flux generated from occupant's skin (face and breast)	58.2 (W/m^2)	1 met.
carbon dioxide emission rate from occupant	0.35 l/min	Under 1 met. activities

● Numerical Method

Numerical simulation of the physical problem under consideration has been performed via a finite volume method for solving the governing equations and boundary conditions mentioned above. This study applies the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm (13) to solve those equations . The " two equation " model of turbulence, the k-epsilon model (14) was adopted . To bridge the steep dependent variable gradients close to the solid surface, the " general wall function " is employed. The iteration calculation was continued until a prescribe relative convergence of 10^{-4} was satisfied for all field variables of this problem. 30 x 30 x 30 grid system were employed for the president calculations.

RESULTS AND DISCUSSION

Numerical simulation have been undertaken for the naturally-ventilated flow through different kinds of window location (A, B and C)in a residential bedroom with the relevant dimensional parameters listed in Table 1. Window openings A, B and C are located on the left hand side, the middle and right hand side of partition wall respectively, as shown in figure 1.

The numerical results will therefore be presented with primary focus on the influence of the opened window location on turbulent flow structure and carbon dioxide distribution in a common-type bedroom in Taiwan.

• Natural Ventilation Phenomena

First of all, flow structure developed within a naturally ventilated room under average heat flux (58.2w/m^2)are presented by means of velocity vector diagram, as illustrated in figure 2. This plot display vector in the cross-section plane through the center of the window opening in the middle of partition wall. Convective thermal-plume from internal heat source generated from occupant's skin cause an upwind air movement. The warm air forms a temperature-stratification region under the ceiling which is then exhausted at high part of window opening, then the " cooler " air flow through lower part of window opening, due to conservation of air mass. This convective plume also entrains air from lower level into the higher level and large circulation forms in the left region of this bedroom illustrated in figure 2.

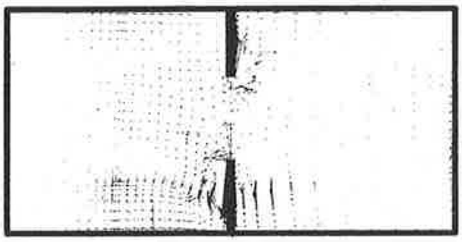

Figure2 naturally ventilated airflow through the window located at left hand-side of the partition wall.

• Flow Pattern and Carbon Dioxide Distribution

It is of significance to reveal relationship between the location of window opening and heat source and estimate influence of variation in those parameters on indoor air environment.

There are three kinds of window locations (at the left, middle and right portion of the partition wall) connected to the climate chamber. Figure 3 shows that the characteristics of flows pattern are similar to each other and indoor carbon dioxide concentration is less than 1000 ppm, ASHRAE 62-89 Standard recommended. It is expected to show that the minimum opening area(5% of floor area) in the Building Code in Taiwan is reasonable.

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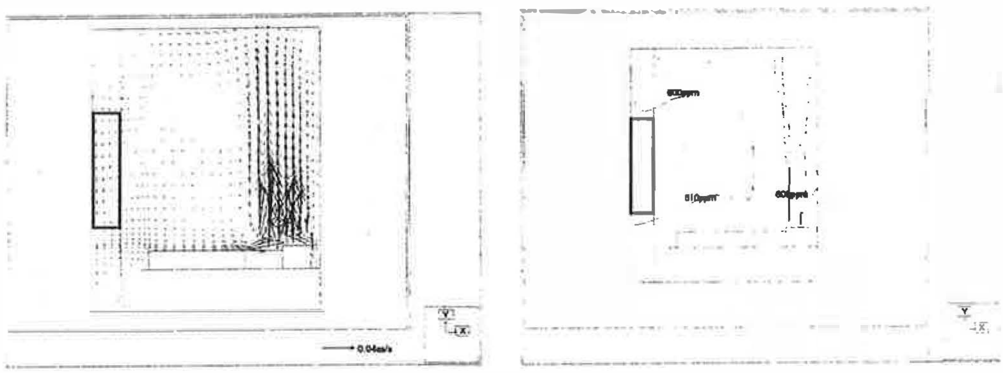
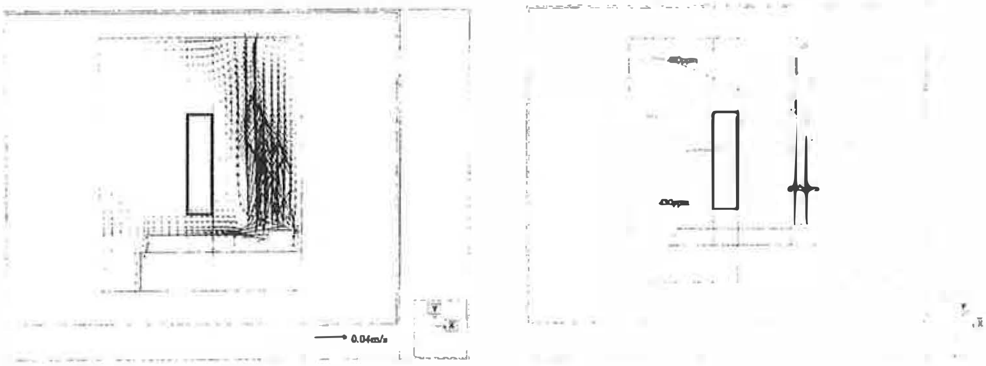


(a) window opening located on the left-hand side of the partition wall



(b) window opening located in the middle of the partition wall

(c) window opening located on the right-hand side of the partition wall

Figure 3 Velocity vector diagram (left) and CO_2 concentration profile (right)