SIMULATION OF AIR MOVEMENT IN TERRACE HOUSE USING CONVECTION VENTILATOR

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ABSTRACT

This paper presents the simulation of air flow in naturally ventilated house using Computational Fluid Dynamics (CFD) technique. This study is to verify the effectiveness of using convection ventilator in reducing indoor air temperature and improving air movement in naturally ventilated building. The air distribution parameter address in this study are air temperature, relative humidity, air velocity, CO_2 gas, CO gas, and comfort index (PMV and PPD). Measurements were done in six major areas in the house after installing the ventilator turbine. The simulations were performed by using FLOVENT software with involving occupants inside the house with two types of turbulence model before and after installing the ventilator. All the data obtained ware analyzed and compared with the ASHRAE standard 62-1989, ASHRAE standard 62-1999, EPA- National Ambient Air Quality Standard and relevant previous study. Result obtained for actual measurements were, 31.26 °C – 32.08 °C for air temperature, 61% - 73.6% for relative humidity, 347 ppm – 442.8 ppm for CO_2 gas, 0.8 ppm – 1.04 ppm for CO gas and 0.026 m/s – 0.088 m/s for air velocity. Compared to CFD simulation, results obtained were in the range of 32.79 °C – 34.82 °C for air temperature, 52% - 69% for relative humidity, 399 ppm for CO_2 gas, 0.97 ppm for CO gas and 0.032 m/s – 0.0866 m/s for air velocity. As a conclusion, the CFD simulation using FLOVENT software is a useful tool for thermal comfort and indoor air quality prediction in a naturally ventilated house.

1.0 INTRODUCTION

The purpose of a ventilation system is to provide acceptable microclimate in the space being ventilated. In this context, microclimate refers to thermal environment as well as indoor air quality. These two factors must be considered in the design of a built in environment or a building as they are fundamental to the comfort and well-being of its occupants or the performance of industrial processes within these spaces. These require knowledge of the heat balance between the human body and the internal environment, the factors that influence thermal comfort and discomfort as well as the indoor pollution concentrations that can be tolerated by the occupant.

The essence of this study is to simulate the air movement in terrace house fitted with convections a ventilator. The experimental house and its layout is an shown in Figure 1 and Figure 3. This effect plus the occupancy behavior and the effects of building orientation, altitude and surrounding terrains can account for significant differences in ventilation characteristics, and hence the indoor climate and energy needs in the house. The main objective of this research project is:

(a) To identified and obtain important modeling parameters for valid CFD room modeling.
(b) To evaluate air distribution performance in natural ventilation house through measurements and CFD technique.
(c) To compare and validate results obtained from both the measurements and CFD simulation technique.
(d) To predict the thermal comfort criterion (PMV and PPD index) by using FLOVENT Software and determine the subjective assessments of occupants' sensation of thermal comfort and occupancy odors or freshness.
(e) To verify the possibility of using convection ventilator in reducing indoor air temperature and improving air movement in naturally ventilated building.

2.0 LITERATURE REVIEW

There have been numbers studies relating thermal comfort, ventilation requirement and indoor air quality (IAQ) in buildings [Zainal (1996), Donnini (1996), Tham (1993), Kim (1999), Yoon (1996), and Thariq (2003)]. Important results from these studies were; temperature range from 20.6 – 29.0 ^oC, himidity range from 24 – 68%, air velocity from 0.04 – 0.24 ms^{-1}, CO range from 0.05 – 7 ppm and air change rate of 0.6 – 11.6 h^{-1}. CO_2 gas inside building varies from 280 to 1460 ppm {Kim el.at (1999) and Dongles (1996)]. The variation in the CO_2 level is due to various variables such as activity levels and effectiveness of the HVAC system. Besides that, the CO_2 concentration has been used as an indictor for the fresh air requirement and ventilation rate of buildings. Results of the above studies are summarized in Table 1.

3.0 METHODOLOGY

The scope of this study includes measurements of the important air distribution parameters, simulation performed of air flow and thermal temperature distribution patterns using a FLOVENT Software and comparing results with actual measurement. The effectiveness of using Convection Ventilator in controlling indoor environment by reducing air temperature and increasing air movement of naturally ventilated buildings is investigated. The main procedures of this study are as follows:

(a) CFD Simulation – Simulation of air flow pattern in a terraced house before and after installing Convection Ventilator using FLOVENT software.

(b) Comfort Evaluation – Evaluate comfort condition, temperature distribution and air movement as a result of installing the convection ventilator.

Two ventilators were fitted on the roof of the experimental house as shown in Figure 2 with vents system as shown in Figure 4. Comfort and indoor air quality (IAQ) parameters were compared with ASHREA Standards 55-1992 and 62-1989, and EPA-National Ambient Air Quality Standards.

The absolute error and average error are used to validate the simulation model.

Absolute error value, E_{ABS},

$$E_{ABS} = \frac{X^i_{CFD} - X^i_{exp}}{X^i_{exp}} \times 100\% \quad \ldots\ldots\ldots\ldots (3\text{-}1)$$

Average error value, E,

$$E = \sum_{i=1}^{n} \left| \frac{X^i_{CFD} - X^i_{exp}}{X^i_{exp}} \right| \times 100\% \quad \ldots\ldots\ldots\ldots (3\text{-}2)$$

4.0 RESULT AND DISCUSSION

The results of air movement and temperature distribution simulation in naturally ventilated terraced house fitted with convection ventilator are presented.

A total of six areas in the house have been chosen for the measurements of the environmental parameters (air temperature, ventilating, humidity, pmv and ppd). The areas chosen are living area, bedroom 1, bedroom 2, bedroom 3, formal dining and kitchen. In term of CFD simulation, two turbulence models are studied to determine the effectiveness of the ventilator in improving thermal environment in a terraced house. Results from CFD simulation are compared and validated with actual measurement. Upon validation, the study proceeds to alternative air flow analysis of the ventilation system of the experimental house. To validate all the results, the value of absolute error using Equation (3-1) and overall average error using Equation (3-2) were calculated to show the percentage of error between simulation and actual measurement. Only the comparisons of average result before and after installing the ventilator are used to validate the results of CFD simulation with actual measurement for all measurement parameters.

The results of CFD simulation showed higher values than the measured results. This is because the geometry modeling for all the represented occupants was assumed to be the same size and capacity but in reality this would not happened as the occupants were of different weights. Moreover, infiltration factor was also neglected although there were leakage partly through the doors and the windows is for temperature. The simulated results for temperature were higher than the measured values. This was due to the assumption that the occupant body was assumed at a consistent temperature of 37°C for every parts of body. But in actual, the human body as a whole parts would not have a constant temperature or the same heat transfer coefficient of 0.22529 W/m^{2}k.

Based on the study done by Bjorn, different parts of body posses their own heat transfer coefficient and its' relative temperature instead of constant temperature of 37°C. The varying temperature of the human body temperature will result in different metabolism and capacity of the occupants and not constant as assumed in the simulation. Furthermore, occupants were defined as static and with the least of activity under the category of standing and seating in the simulation model. But in actual, these assumption could not be arrived at, as every occupants were free to doing their own things including chatting, laughing, reading, landing and sleeping. By referring to the activities that had been mentioned above, it may increase a person exhalation rate and at the same time will increase the CO_2 level in the house.

The FLOVENT software is also capable to evaluate the Comfort Indices. That is the PMV **(**Predicted Mean Vote**)** and PPD (Percentage of people Dissatisfied) based on given conditions that have been used in the simulation model. We can assesses each point in the space to see whether the occupants response is likely to be hot (0<PMV<3), neutral (0) or cold (-3<PMV<0). The Table 3, shows the comparison for PMV index before and after installing the ventilator and clearly shows that PMV index has decreased after installing the ventilator. Also, as shown in Table 3, the PPD index had been decreased after installing the ventilator. However, the improvement in the PMV index was not enough for maintaining comfort in the house. The simulated air flow patterns in the house before and after installing the ventilator are shown in Figures 6 and 8.

5.0 CONCLUSION

The simulation of air flow in natural ventilated house was successfully carried out and validated with actual measurements. The overall average error percentage between simulation and actual measurement was less than 50%. The results showed small difference between the measured and simulation values in term of air velocity, relative humidity, CO_2 gas and CO gas. Besides that, the air temperature predicted by CFD simulation was higher than actual measurement. The boundary conditions for the simulation procedure were assumed fixed and not affected by other parameters. However, there were influencing factors such as the presence of fluorescent lights and leakage of the room.

The procedures of modeling include defining the geometry of the model, fluid domain, boundary conditions, initial guess, meshing of models and solver parameters. The important boundary conditions that should be defined for correct modeling is the inlet-outlet conditions of the ventilators and ceiling fan units, human exhalation either mouth or nose and the heat transfer properties by the ceiling, wall of the room model and also human body.

This study has shown the advantage of the FLOVENT software in the application CFD approach to study air flow pattern in a ventilated building space. This study is useful for future simulation where air flow analysis is involved and also crucial towards creating a better thermal environment in naturally ventilated building. Nevertheless, it is hoped that improved results will be produced from future works as compared to present study.

6.0 REFERENCE

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Figure 1: Experimental House

Figure 2: Ventilator Location at the Top of Experimental House Roof

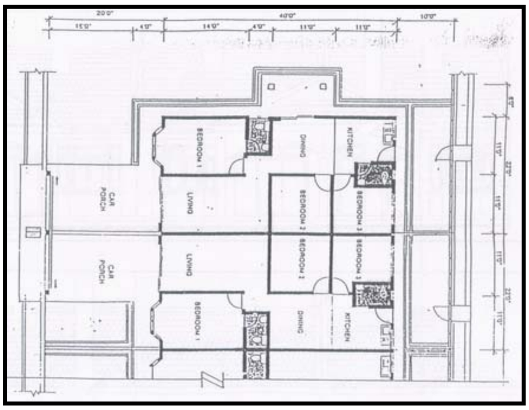

Figure 3: Plan Layout for Experiment House

Figure 4: Vents and Fan Location in the Experimental House

Table 1: Comparison of the Selected Results from the Previous Study Basically on Summer and in Naturally Ventilated Building.

Researcher	**Air Temperature (ºC)**	**Relative Humidity (%)**	**Air Change Rate per hour**	**Air Velocity (m/s)**	**CO2 gas (ppm)**	**CO gas (ppm)**
M. Zainal (1996)	20.3–23.4	80 -85	0.8–11.6	-	1160-1460	-
Donnini (1996)	21.0 – 28.0	30 - 62	-	0.04 – 0.24	280 – 960	-
Tham (1993)	24.1 – 27.7	43.2 – 68.5	-	-	300 - 800	0.05 – 0.90
Yoon (1996)	21.8 – 24.6	58 – 68	0.6 – 1.6	-	802 - 1293	-
Thariq (2003)	30.67-32.75	60.5-63.17	-	0.075-0.100	311-384	0.68-1.12

Table 2: Results Obtained From the Present Study

Researcher	Air Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	CO_2 gas (ppm)	CO gas (ppm)
Present Study	33.50-37.80	52.0-69.0	0.036-0.049	399	0.97
Thariq	31.36-31.65	61.93-72.73	0.036-0.084	352-399	0.836-0.97

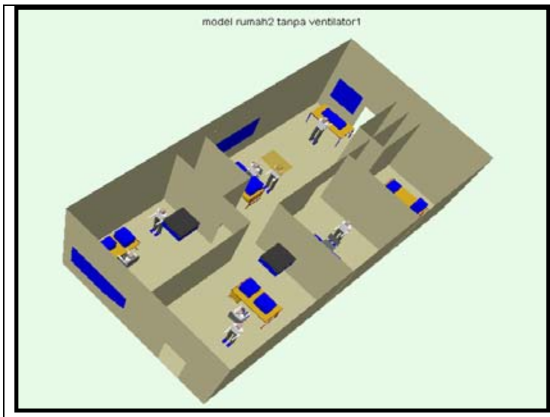

Figure 5: House Model Before Installing the Ventilator (Isometric View)

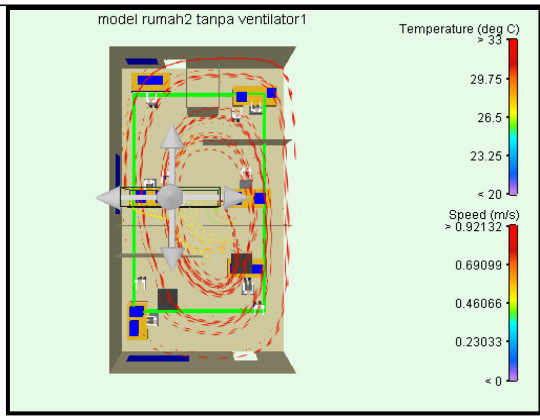

Figure 6: Air Movement Before Installing the Ventilator (Top View1)

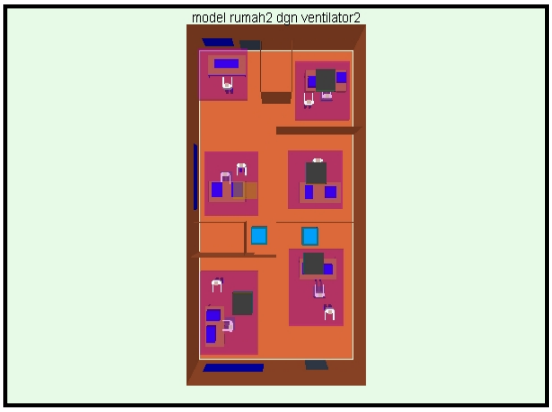

Figure 7: House Model After Installing the Ventilator (Isometric View)

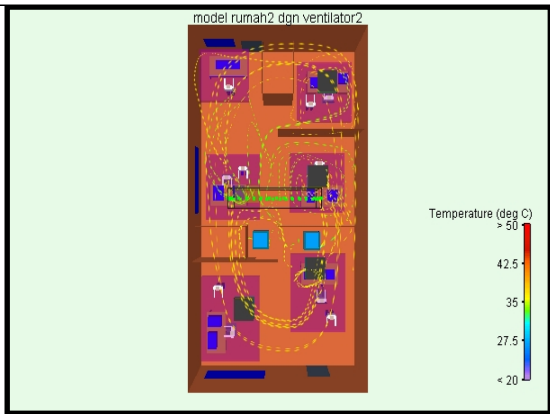

Figure 8: Air Movement After Installing the Ventilator (Top View1)

Table 3: Comparison Results for PMV Index Before and After Installing the Ventilator

Area	PMV Index (Dimensionless)	
	Before	After
Living Area	3.4	2.9
Bedroom 1	3.2	3.0
Bedroom 2	2.8	2.4
Bedroom 3	2.6	2.5
Formal Dining	2.7	2.4
Kitchen	3.3	2.3

Table 4: Comparison Results for PPD Index Before and After Installing the Ventilator

Area	PPD Index (%)	
	Before	After
Living Area	99.2	96.5
Bedroom 1	99.4	97.9
Bedroom 2	97.5	91.9
Bedroom 3	95.3	92.7
Formal Dining	96.7	91.2
Kitchen	93.9	87.8

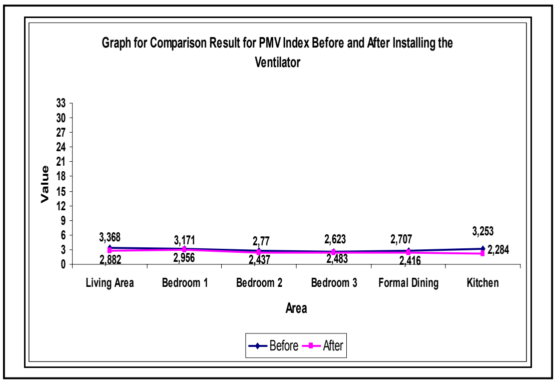

Figure 9: Graph for Comparison of PMV Index Before and After Installing the Ventilator

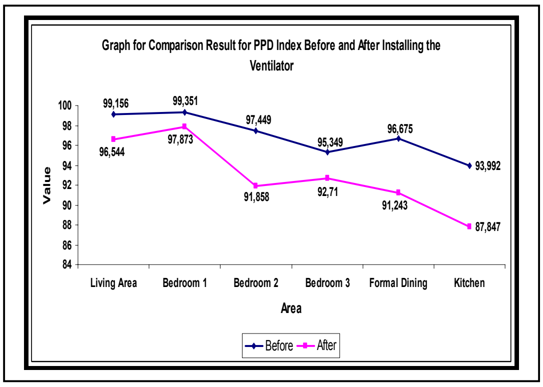

Figure 10: Graph for Comparison of PPD Index Before and After Installing the Ventilator