

Thermal comfort investigation on a naturally ventilated two-storey residential house in Malaysia

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Abstract. This paper presents a case study to investigate the human thermal comfort on a naturally ventilated two-storey residential house in Malaysia. Three parameters were investigated in this study, namely the air temperature, air velocity and air humidity. These parameters were measured using the appropriate measuring device to obtain the actual data and compared with simulation results. The level of thermal comfort in the house was found to be poor as the parameters measured are over the limits specified by ASHRAE standards. Simulation on the model of the house was performed using the Computational Fluid Dynamics (CFD) commercial code, FLUENT to visualize the temperature distribution and air flow pattern and velocity in the house. The error between these two sets of data was acceptable and thus the simulation used in this study was validated. Comparison was also made in the CFD simulation to see the effects of using a ceiling fan installed in the house and without ceiling fan. The level of thermal comfort was poor in both cases as it did not satisfy the standards set by ASHRAE but more uniform temperature distribution inside the house was found when the ceiling fan was turned on. The thermal comfort level became critical in the afternoon as during this period, the house receives direct sunlight which causes the temperature inside the house to increase. Although the mechanical ventilation devices did not help to improve the thermal comfort in the house being studied, the CFD simulation results can be used by building designers to further improve the level of thermal comfort in naturally ventilated residential houses.

1. Introduction

Due to Malaysian climate that is hot and humid throughout the year, the weather is not consistent and changing. High temperature with high humidity causes discomfort to the human and it affects the thermal comfort of the occupants in a house. Most residential buildings in Malaysia are not equipped with air-conditioning systems, but relies on natural ventilation, passive cooling system and mechanical ventilation devices such as ceiling and extractor fans to achieve certain level of thermal comfort. To optimize the thermal comfort effects, special attention must be given to the design and installation of these devices. Mechanical ventilation is more convenient compared to natural ventilation, but there is

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a downside for it. As the mechanical ventilation consumes electricity, it is costly while natural ventilation is free.

This study was conducted to investigate the thermal comfort of a naturally ventilated double-storey terrace house in Bangi, Selangor, Malaysia. The aim of this study is to investigate the house ventilation with the thermal comfort of the occupants in the house. Data measurements were taken and some parameters such as air temperature, air velocity and air humidity were studied. Simulation of the house using a CFD software, FLUENT was also done. When the results from each method were obtained and recorded, analysis of data was made by comparing these results together. The simulation was also done to compare the thermal comfort of the house with the fan turned on and off. All the results obtained were then compared with the standard set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for human thermal comfort. On top of that, the objective of this study is also to find out the best improvement method to enhance the human thermal comfort.

2. Literature Review

To assess the thermal comfort, it is necessary to determine the air velocity, temperature distribution, and relative humidity of the air in the residential building. Numerical methods such as computational fluid dynamics (CFD) can be utilized to assist in the analysis of thermal comfort. FLUENT is a useful tool that can be used to create a virtual model of the interior of the residential building and simulate air flow and temperature distribution which are directly related to thermal comfort. Many researchers have used CFD to analyze thermal comfort in building spaces and investigated the effects of natural and stratified ventilations on the thermal comfort. This includes Bastide et.al. [1], who has utilized CFD to predict building energy efficiency, Serra & Semiao [2] who evaluated and compared between two different ventilation strategies. Stravarakakis et.al. [3] also evaluated the effect of window sizes to thermal comfort and hygiene in buildings using CFD. Modifications to any existing residential building can also be simulated using CFD prior to any physical renovations.

3. Methodology

3.1 Actual Data

Data collection and analysis were performed for the parameters investigated which are the air temperature, air velocity and air humidity. Standard values set by ASHRAE were compared with the data measured to determine the thermal comfort of the house occupants. The measurement of the parameters investigated was carried out when the house is ventilated naturally. The source of natural ventilation is from windows and doors which are open to allow the air from outside the house to enter the house and vice versa. The readings were taken periodically at 12am, 6am, 8am, 12pm, 2pm, 6pm, 8pm and 10pm for each day in two weeks. The measuring devices were placed in the hall, dining room, kitchen, master bedroom, room 1 and room 2. The air temperature was measured using anemometer and hygrometer.

3.2 CFD Simulation

The simulation was performed using CFD software, FLUENT for house with natural ventilation and fan turned off and when the fan is turned on. The house was drawn and meshed using Gambit software and analyzed using FLUENT to investigate the behaviour of the air temperature and air velocity inside the house. The software was unable to simulate the air humidity. Thus, only air temperature and air velocity were simulated and investigated in both simulations. The boundary conditions were set the same with the value measured during the data collection. Other physical values were also measured such as the wall temperature, glass temperature, velocity inlet (wind speed), size of openings (window and door) and other. Some parts of the house were neglected as it does not affect the parameters investigated. Figures 1 (a) and (b) show the floor plan with dimension for ground floor and first floor.



Figure 1. (a) Ground Floor Plan (b) First Floor Plan

The measured physical value used in the simulation is the opening and fan dimensions. The openings are windows and doors, which is the source of natural ventilation. The dimensions of doors, windows and fans were considered to be standard in size for all residential houses in Malaysia. The dimension of the fan is described as span. Span means the diameter of the fan or the distance between one ends of the fan to another end. 52" span of fan was chosen as it is in standard size that applicable for all room dimensions. This size is usually used for standard bedroom and dining room [4]. Table 1 shows the boundary conditions set in the simulation. The velocity inlet is the front door which is the source of the natural ventilation and the back door is the pressure outlet for the air to flow out which is shown in Figure 2. Wall will be set by default automatically for faces that are not set with boundary condition.

Table 1. Boundary Conditions

Boundary Condition/ Air Temperature Characteristic	Wall Thickness (t), m	Wall Temperature (T_w), K	Air Velocity (v), m/s	(T_a), K
Outer Wall	0.125	303	N/A	N/A
Inner Wall	0.125	300	N/A	N/A
Glass Sliding Door	0.005	303	N/A	N/A
Velocity Inlet	N/A	N/A	0.2	300
Fan	N/A	N/A	12.7	300
Pressure Outlet	N/A	N/A	N/A	N/A

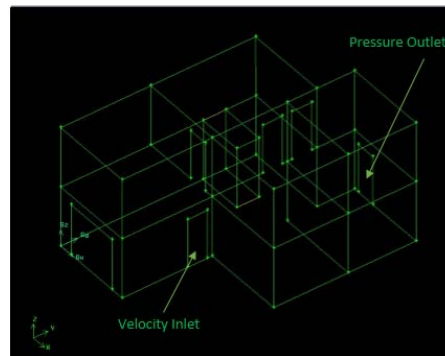


Figure 2. Gambit House Drawing with Boundary Condition

4. Results, Analysis and Discussions

After the simulation data was obtained, validation of the data was performed with the actual data. Comparisons were made in both cases and represented in Figure 3 (a) and (b). The percentage error for air temperature and air velocity is 0.24% and 13.11% respectively. These errors are acceptable and thus the simulation results are valid and acceptable.

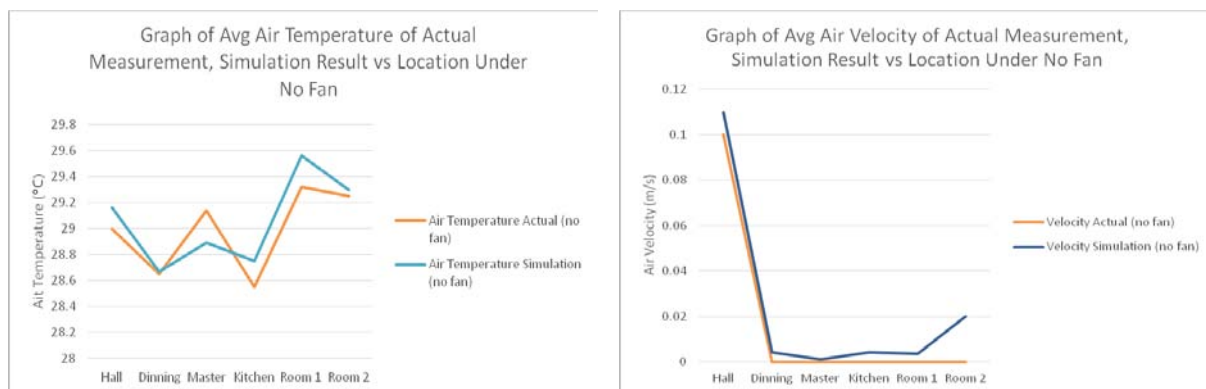


Figure 3. Data Comparisons for: (a) Air Temperature and (b) Air Velocity

The velocity vector of the internal house was obtained to investigate the pattern of air flow inside the house with the fan turned on and off (see Figure 4 (a) and (b)). When there is only natural ventilation, the air flow is only existed on the ground floor because at the ground floor, there is a source of natural ventilation which is the front door. The back door which acts as the outlet for the wind flow also helps in encouraging the air flow at the ground floor. Small or no air flow at the first floor cause the temperature distribution at the first floor for the case of fan off is higher compared to temperature distribution for case of fan turned on. From the results obtained, it shows that the natural ventilation only exists on the ground floor because the source of the wind is located at the hall and the outlet is at the kitchen. The air velocity at the first floor is approximately zero. The results for both actual and simulations were then compared in a graph together with the ASHRAE set of standards in Figure 5. As the velocity for the actual and simulation when the fan turned off are almost the same, both values are overlapped in the graph. Due to the very small value, the graph plotted for the velocity when fan turned off shows straight line near to zero. The velocity is below the limit set by the ASHRAE. When the fan is turned on, the magnitude of velocity is very large and exceeds the limit set by ASHRAE. With the presence of mechanical ventilation, the temperature distribution of the house is able to be regulated and maintained.

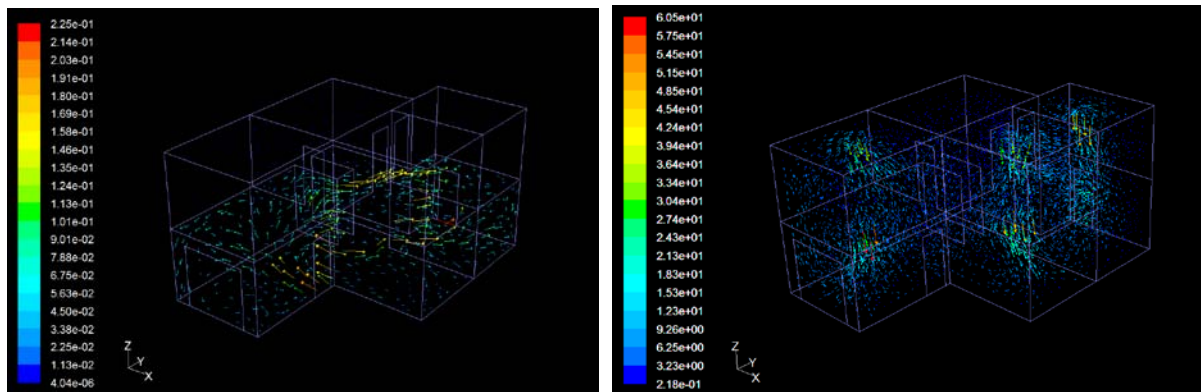


Figure 4. Velocity Vector of the House (a) When Fan Turned Off (b) When Fan Turned On

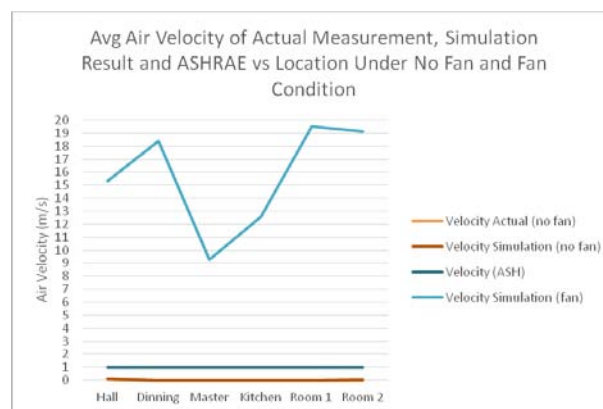


Figure 5. Comparison of Average Air Velocity for All Cases

The heat absorbed by the wall is one of the factors that cause the temperature inside the house to increase. With natural ventilation available at the ground floor, the temperature distribution inside the house is maintained to 302 K compared to the temperature of the wall which is 303 K (see Figures 6 (a) and (b)).

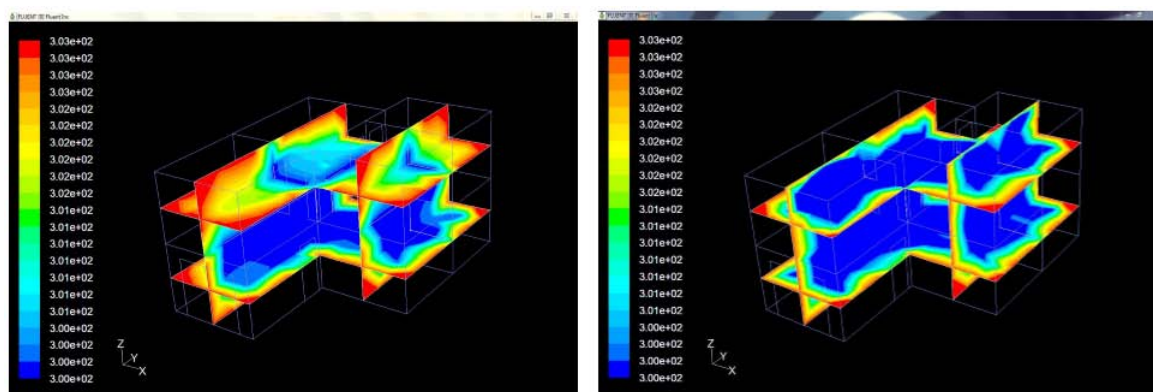


Figure 6. Temperature Contour (a) Fan Turned Off (left) (b) Fan Turned On (right)

Some part of the house at the first floor has temperature of 303 K, which is almost the same with the wall temperature. This causes discomfort to the occupant due to the high temperature. The results obtained show that mechanical ventilation which is the fan, helps a lot in maintaining the temperature distribution inside the house. The results for both actual and simulations were then compared in a

graph together with the ASHRAE set of standards in Figure 7. It is shown in the figure that the air temperature for case when fan is turned on is close to the ASHRAE standard, while the other results are farther away from the ASHRAE standard. Natural ventilation is not enough to maintain the temperature as it is changing throughout the time and not consistence.

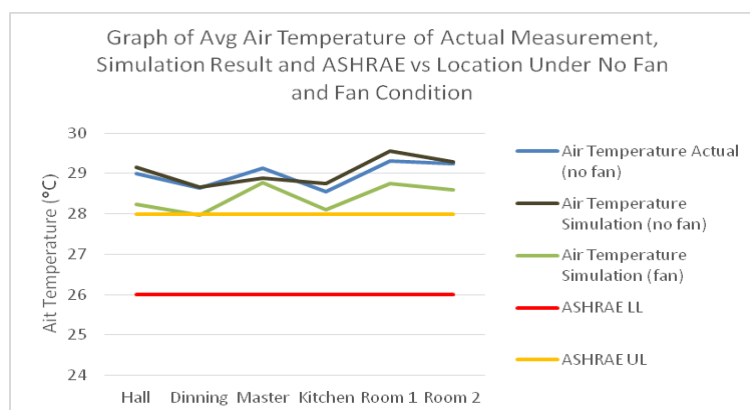


Figure 7. Comparison of Average Air Temperature for All Cases

5. Conclusion

As conclusions, the thermal comfort of the house is generally poor and does not satisfy the standards set by ASHRAE. However, the level of thermal comfort for the house with fan turned on is considered good compared to that of with fan turned off. Both cases show that the thermal comfort level becomes critical during afternoon as during this period, the house receives direct sunlight which causes the temperature inside the house to increase. With the fan turned on, the temperature inside the house is able to be maintained and regulated. Improvement is needed in order to achieve the thermal comfort. For air velocity, mechanical ventilation such as fan can be used to encourage the air flow inside the house. As the house design is fixed and house modification is restricted, other improvement should be considered for example, installing the latest mechanical ventilation system that is more effective and energy saving. Glass doors and windows are tinted with protective film to block direct sunlight from penetrating the house. Planting shade trees is also another method in reducing the direct sunlight and reduce the temperature distribution around the house. Others opening available such as small windows can be opened to encourage natural ventilation flowing from outside to inside house.

6. References

- [1] P. L. F. G. a. H. B. A. Bastide, "Building energy efficiency and thermal comfort in tropical climates," Presentation of a numerical approach for predicting the percentage of well-ventilated living spaces in buildings using natural ventilation, vol. 38, pp. 1093-1103, 2006.
- [2] A. V. S. N. Serra, "Comparing displacement ventilation and mixing ventilation as HVAC strategies through CFD," Engineering Computation: International Journal for Computer-Aided Engineering and Software, vol. 26, no. 8, pp. 950-971, 2009.
- [3] D. K. P. Z. H. S. N. M. G.M. Stavrakakis, "Selection of window sizes for optimizing occupational comfort and hygiene based on computational fluid dynamics and neural networks," Building and Environment, vol. 46, pp. 298-314, 2011.
- [4] D. Mar, "What Size Ceiling Fan Do I Need?," 2013. [Online]. Available: <http://www.delmarfans.com/educate/basics/what-size-ceiling-fan-do-i-need/> . [Accessed 8 November 2013].