EVALUATION OF PARAMETRICS FOR THE DEVELOPMENT OF VERTICAL SOLAR CHIMNEY VENTILATION IN HOT AND HUMID CLIMATE

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Abstract: In terms of housing passive cooling design, tropical climatic regions present the most difficult problem to solve. A good dwelling design can keep the indoor environment favorable and comfortable during most of the year without the use of any mechanical devices. This can be accomplished by various techniques such as the use of radiant barrier, insulation materials, and natural ventilation. Depending on ambient conditions, natural ventilation may lead to indoor thermal comfort without mechanical cooling. However, in cases where the wind effect is not well captured especially in single side ventilation, then solar–induced ventilation may be a viable alternative. Solar induced ventilation standing involved temperature difference experiments which can be done using both physical modeling and computer simulation (Computational Fluid Dynamics). Solar induced, especially vertical solar chimney ventilation combined air movement and solar radiation simulation. They have different input data which depend on the climatic data of the selected location. This paper evaluates the parametric study strategies in pilot testing, terrace house model and previous research model by simulation and experiment for solar induced ventilation in tropical condition. Comparison of the results of simulations and experiments illustrate a good agreement between numerical and experimental results. These results encourage further research to develop the vertical solar chimney suitable for tropical condition.

Key word: tropical climate, parametric study and vertical solar chimney

1. Introduction

In tropical climatic regions passive cooling is one of the most difficult problems to solve. The simplest and the most effective solution for active cooling is to introduce air conditioning. However, such equipment involves high initial and operational costs for installation, energy and maintenance. Therefore air conditioners are unlikely to be applied widely, particularly in residential building. Thus, passive cooling system is more desirable. Although in Malaysia, passive cooling is a popular cooling strategy adopted in residential buildings researcher (Pan, 1997; Tan, 1997; Jones, 1993; Zulkifli, 1991; Hui, 1998; Abdul Razak, 2004) have shown that its natural ventilation performance could not provide internal thermal comfort. Climate conscious design in the equatorial tropic assumes that air movement is one of the main cure for thermal comfort ills. According to Hui (1998), the indoor air velocity in low rise building range between 0.04m/s – 0.47 m/s. The reasons may be due to inappropriate design solutions for indoor air movement or low outdoor air velocity. However, recent data from the Malaysian Meteorogical Service Department showed that mean outdoor air velocity is between 1 m/s to 1.5 m/s.

One of the more promising passive cooling methods for tropical climatic regions is the stack ventilation strategies. Stack ventilation is caused by stack pressure or buoyancy at an opening due to variation in air density as a result of difference in temperature across the opening. The same principle can be applied for opening at different height, where the difference in pressure between them is due to the vertical gradient (Awbi, 2004). It utilizes solar radiation, which is abundant in these regions, to generate the buoyant flow. However, as currently applied, the induced air movement is insufficient to create physiological cooling. More studies are needed to improve the ventilation performance of this cooling method. Velocities associated with natural convection are relatively small, usually not more than 2 m/s (Mills, 1992). Stack induced ventilation can be improve by solar induced ventilation. However, in cases where the wind effect is not well captured then solar–induced ventilation may be a viable alternative. This strategy relies on heating of the building fabric by solar radiation resulting into a greater temperature difference. There are three building elements commonly used for this purpose: Tromble Wall, Solar Chimney, and Solar roof (Awbi, 2004).

The first type incorporates glazed element in the wall to absorb solar irradiation into the wall structure. This building has double walls which are combined into a shaft at their upper end. The south facing shaft wall was made from glass. The solar radiation that penetrates the glass heats the inner wall. Eventually, this inner wall heats the air which will rise and induce a flow of fresh air from the openings below (Watson, 1979). Two examples of stack induced ventilation concepts is solar collector and stack height. The former shows one way to amplify stack effect by utilizing solar collectors and increasing the height of the hot air column (stack height). Critical parameters of this design are the stack height and cross sectional area of its inlet and outlet. A massive and high version of this type is needed to generate indoor air velocity as high as 1.0 to 2.0 m/s, which can be achieved easily in an ordinary shallow buildings (with no obstruction at all). The second, form is the solar chimney which has long been known, and applied in vernacular architectural design. In general, the induced air movement is not used directly to suck indoor air. Instead, it is used for ventilating the building (such as in the double skin building). A stack chimney is usually designed in combination with a wind tower in hot arid climatic regions. In many types of ventilated building, winds are considered to be more important than buoyancy. This is because wind induced ventilation flow is commonly stronger than stack induced flow, in particular, low rise buildings. A milk house that was built in 1800s is a historical example of a stack chimney application (Satwiko, 1993). The other method is used in areas with large solar altitude. In this case a large sloping roof is used effectively to collect the solar energy (Awbi, 2004). Another solar roof design called *the Nigerian Solar* Roof was studied by Barozzi, using physical and numerical (Computational Fluid Dynamics Codes) modeling and data from Ife, Nigeria. Two findings were noticeable from these experiments. Firstly, both physical and numerical experiments gave almost identical results. Thus, it showed the potential of CFD Codes to simulate air flow. Secondly, both types of modeling indicated the presence of buoyancy driven ventilation within the model. However, the air speed within the occupant's zone was too low to create physiological cooling. The term *Solar chimney* is used extensively in Barozzi's experiment as the *chimney* shape is quite obvious. In his study the term *Solar chimney* seems to be more suitable as the chimney takes the form of a roof (Barozzi, 1992).

2. Objectives

Air movement created by the stack effect is usually not adequate to achieve physiological cooling. It is less than the recommended air speed range for cooling of 0.15 to 1.5 m/s in tropical condition (Satwiko, 1994). It can be seen that two means are available for improving air movement: firstly, by increasing the air volume (stack height) and secondly, by increasing the air temperature difference. The indoor air temperature has to be kept low. All the above designs involve stack effect. However, in terms of construction (complexity, technology, etc.) and material (cost, durability, availability, etc.) these designs are not suitable for wide application in low cost housing in tropical countries. Studies of solar chimney ventilation involve temperature difference experiments which can be done using both physical modeling and computer simulation (Computational Fluid Dynamics). Solar induced, especially vertical solar chimney combined air movement and solar radiation simulation. They have different input data which depend on the climatic data of the selected location. This paper evaluates the parametric study in initial test, field measurement and terrace house model by simulation and experiment for solar induced ventilation in tropical condition. These results encourage further research to develop the vertical solar chimney suitable for tropical condition. The objective of this study is to:

- Evaluate the possibility and limitation of solar chimney ventilation parametric design in initial test and terrace house model under Malaysia’s climate condition
- Evaluate the optimum performance of solar chimney ventilation parametric design to increase indoor air velocity.

3. Methodology

3.1. Climate data and simulation program

Climatic data for Malaysia’s condition, in particular, Johor Bahru, was collected from Senai Weather Station. Wind speed calculation using Power law concept obtained by using this technique was done by Ismail (1996), Kin (1998) and Hamid (2001), and will be used as an illustration for the calculation of Malaysia’s proposed wind profile. Solar radiation, temperature and humidity were obtained from DOE weather file data (Ossen 2005). The simulations for this study are done using a general three dimensional computational fluid dynamics model. For the stack effect prediction, density variation caused by temperature rise, which takes air density as constant and considers the buoyancy on air movement by the difference between the local air density and the pressure gradient. The upwind scheme has been used in the calculation (Hunt, 1999). The simulation tool used to simulate the temperature and air velocity distribution is the CFD Flo Vent. Flovent is the most widely used software for modeling engineering fluid flows due to its robustness, accuracy, and user friendliness (Flomerics, 2000).

3.2. Pilot testing model

A pilot testing using one model was measured and simulated for solar induced ventilation study. Figure 1 shows the pilot testing model and the simulation model. The chimney pvc pipe in the pilot testing was 12 feet high and 0.5 feet in diameter, supported structurally by timber framework. The models were black surface colors respectively. Data loggers were positioned at three different points on each pipe and another at outdoor (figure 1). In the CFD simulation, the following boundary condition area used: the material and thickness of the chimney are based on the base model, while the climatic condition is set similar to the site climatic conditions (Nugroho, 2005).

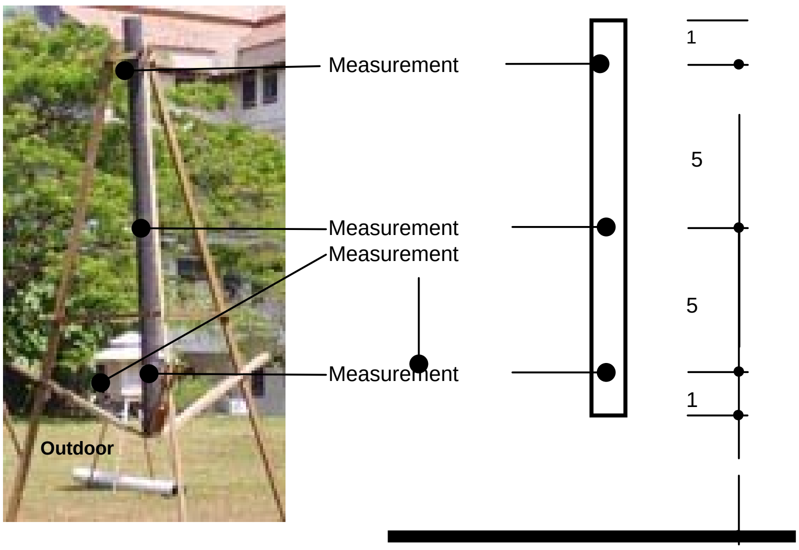


Figure 1: Pilot testing model

3.3. Terrace house model

A field study of terrace house has been carried out by Moh Najib Ibrahim (1989). The field study is located in Taman Tun Aminah, 15 km from Johor Bahru and surrounded by housing estates. The layout of terrace house is similar to the typical low cost housing. They consist of 2 bedrooms and 1 living room. The bed room dimension is 3 m (height), 3.5 m (depth), 3 m (length) and has single side window. Under the same prescribed experiment conditions, the results have been validated by experimental and simulation models. The purpose of the experiment and simulation is to evaluate of the room parametric study.

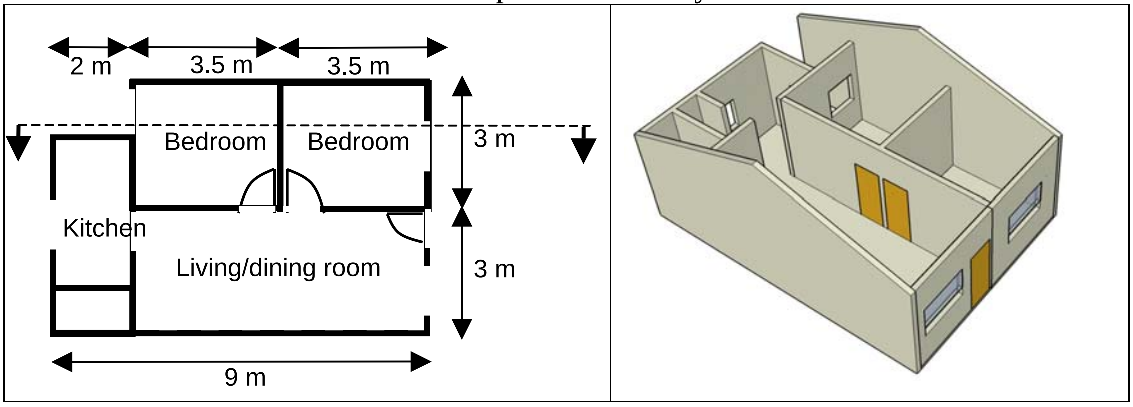
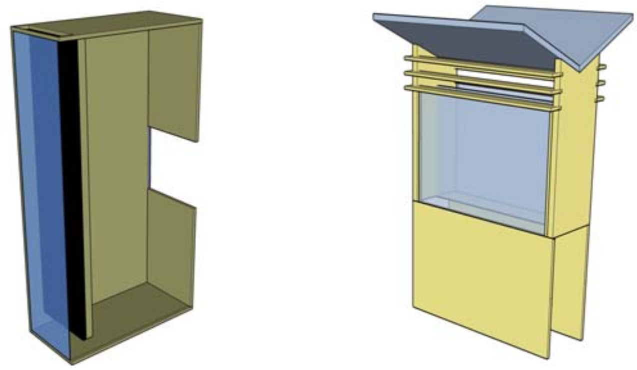


Figure 2: Terrace house model

3.4. K.S. Ong Experiment and Optimum Vertical Solar Chimney Model

The simulation is based on KS Ong's experimental results and previous research conducted for evaluating solar chimney design parameters. The additional purpose of conducting this study was to explore the optimum design parameter of vertical solar chimney in hot and humid climatic conditions. Ong (2003) has presented a mathematical model of solar chimney using the matrix method for solving simultaneous equations for heat transfer and experimental results on a 2-m-high solar chimney in Malaysia.



KS Ong Experiment Optimum VSC Model

Figure 3: K.S. Ong experiment model and optimum vertical solar chimney model

3.5. Vertical solar chimney model in terrace house

In order to achieve optimum vertical solar chimney, a basic terrace house model was modified. The vertical solar chimney model was placed in between two bedrooms, at a height of 2 m above floor level (figure.4). Climatic data for simulation model under the same field experiment.

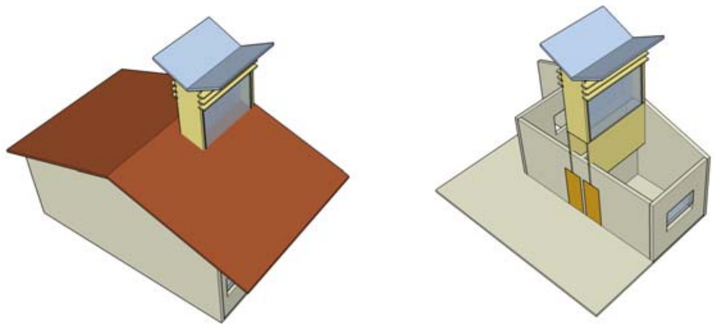


Figure 4: Application of vertical solar chimney model in terrace house

4. Result and Discussion

4.1. Pilot testing experimental and simulation.

The experiment tool used to measure the temperature and humidity is the Dickson temperature and humidity data logger. Dickson data logger has dual channel sensors which can record and store humidity and temperature data for two months, accurately and it is also lightweight. Dickson data logger can store thousand of sample points and specifications requirement. In the pilot testing the data logger is set for every 5 minutes from 10.00 am to 18.00 pm. Evaluation of the pilot testing and simulation design parameter was performed by comparing the measurement of pilot testing with the CFD simulation. Figure 5 shows the comparison of the results from the measurement and simulation. It shows that the agreement between the measurement and simulation is generally good. The average difference between the measurement and simulation for black bottom was about 3%; the maximum difference was 8%, which is recorded at 10 hr for black top pipe, while there are no differences for ambient temperature (Nugroho, 2005). Base on the simulation result, the average air velocity inside the pipe until 0.1 m/s. Figure 6 shows the distribution of air velocity in the time of day. Maximum air velocity is recorded at 13 hr and this shows the possibility of using stack effect in Malaysia's climate condition.

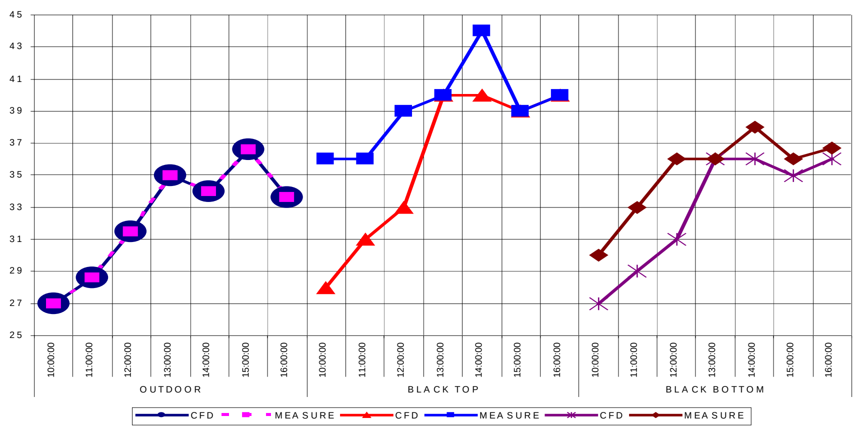


Figure 5: Comparing experiment and simulation of pilot testing

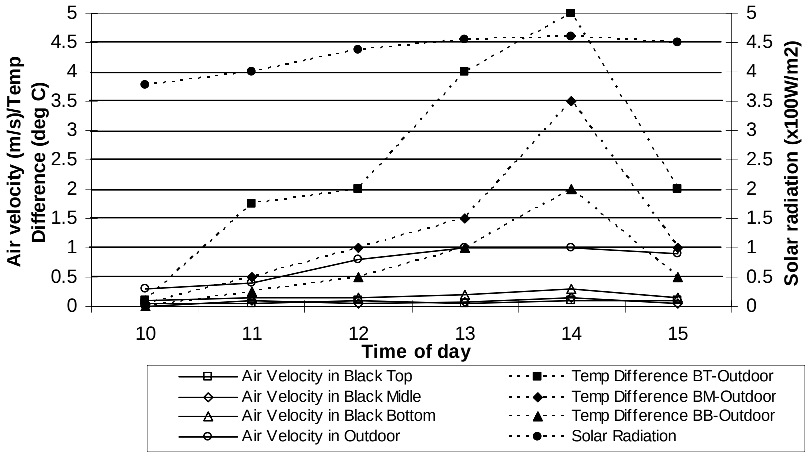


Figure 6: Air velocity and temperature difference of pilot testing simulation

4.2. Field Study Experiment and Simulation

The study is based on continuous air velocity, temperature and humidity measurements performed inside the building. Indoor climate analyzer was used for collecting the data. Data was taken at the center of the bed room, 110 cm above floor level (ASHRAE 1992). Figure 7 shows the results from experiment and simulation. They are in close agreement and deviations are within 1% of the calculated temperature and 2 % of the calculated air velocity. Figure 8 shows the effect of single side room ventilation is indicating lower air velocity than outdoor wind speed. The air velocity of less than 0.1 m/s mean insufficient for thermal comfort psychological cooling (Rajeh, 1989). The experiment and simulation results showed the limitation of field design parameters using single side ventilation.

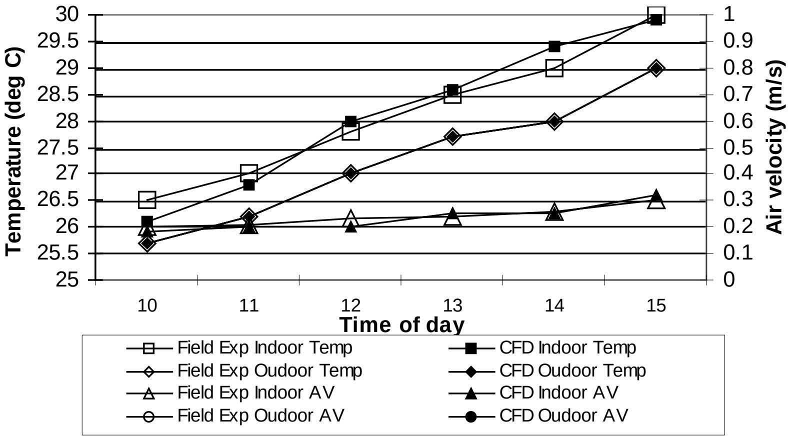


Figure 7: Comparing experiment and simulation of field study

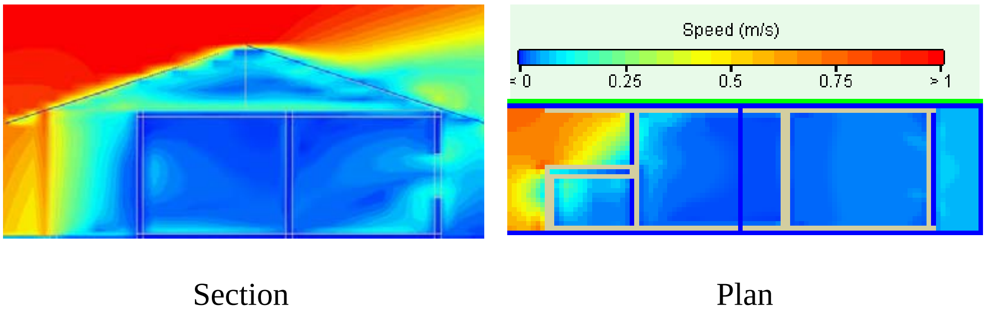


Figure 8: Air velocity pattern of Terrace House Model in Section and Plan

4.3. Previous solar chimney research and simulation

Barrozi (1992) performed flow visualization studies on Nigeria solar chimney. The prototype is of 0.25 m (height), 0.1 m (width) and 0.5 m (length), using aluminum material. The experiment result indicated a low air velocity (less than 0.1 m/s). Bouchair (1994) showed that for his 1.95 m high and 0.2 m – 1 m width chimney which was electrically heated, the optimum ratio for chimney length /gap width of 5/10 can achieve maximum air velocity. If the chimney was too big, reverse circulation occurred whereby there was a down-ward flow of air via the center of the duct. They concluded that 0.1 m/s is the average air velocity between two single glasses. Alfonso (2000) studied the performance of a thermal model and validated it with the help of the tracer gas technique for a solar chimney attached to a room of 12m2 floor areas having a brick wall and a concrete roof. They presented the solar chimney model on a 0.6 m (width), 1m (length) and different chimney height (0.5 m- 3 m). Their results showed that there was a significant increase in air velocity (0.3 m/s) with the varying solar chimney heights. Bansal (1994) developed a steady state mathematical model for a solar chimney system consisting of a solar air heater connected to a conventional chimney. The chimney model was 0.75 m high, 1 m long and having glass wall materials. Their investigation indicated that 0.15 m/s air velocity is encountered during their experiment for two different combinations of air gap (0.1 m and 0.3 m). Among others, theoretical and experimental studies on natural ventilation of buildings were also carried out by Ong (2003). The study has presented a mathematical model of solar chimney using matrix method for solving simultaneous equations for heat transfer. The experiment was carried out outdoor on a one-sided double glass-wall. The experimental models are 2 m high, 1 m wide and varying chimney gaps of 0.1 to 0.3 m. They concluded that increase in air velocity (0.3m/s) of inlet solar chimney is relative to solar chimney width. Figure 9 shows the minimum difference between KS Ong's experimental model and simulation where the minimum difference was about 1% and the maximum difference was 9%. The agreement between the measurement and simulation is generally good (Khedari, 2000). Based on previous research, simulation is conducted to evaluate solar chimney design parameters (figure10) in order to find the optimum design (3 m high, 3 m long, 0.5 m wide, glass material).

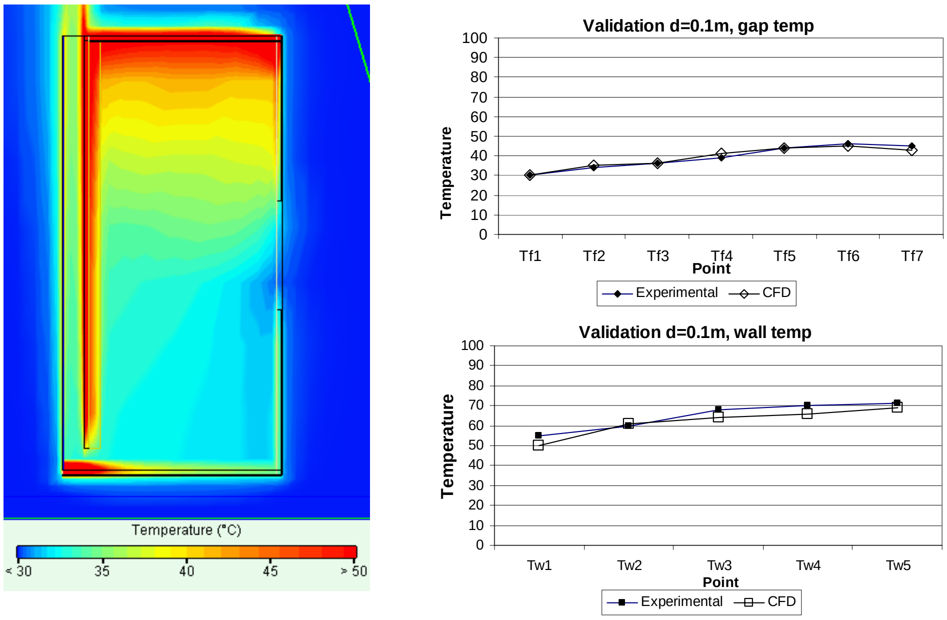


Figure 9: Comparing experiment and simulation of KS Ong model

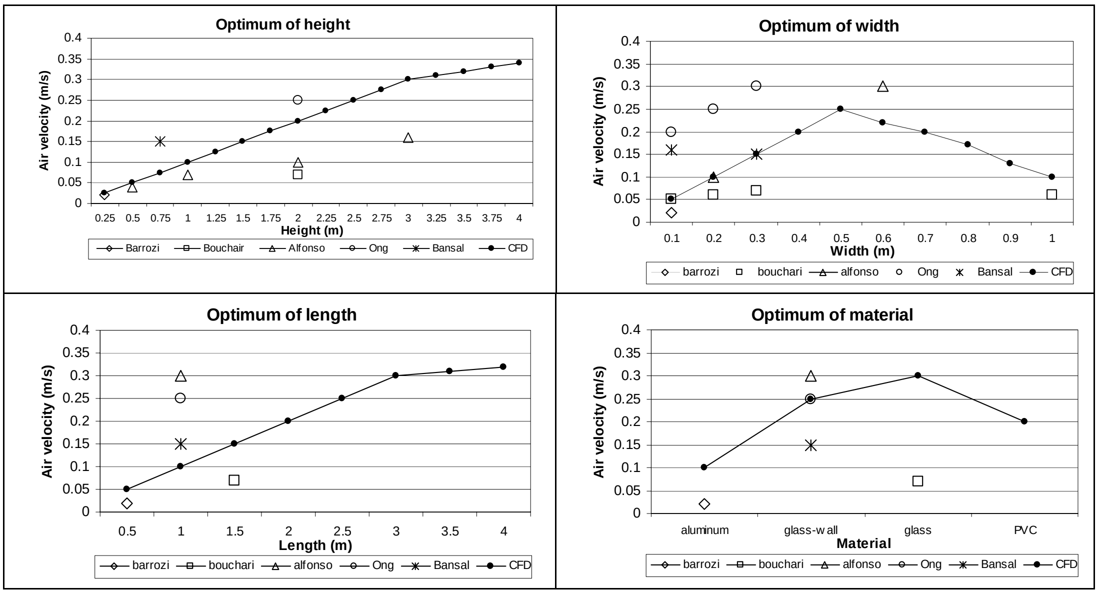
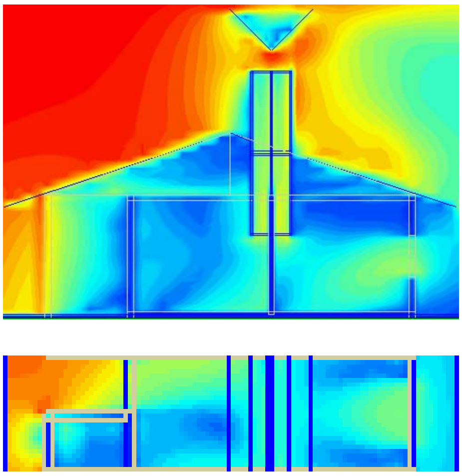
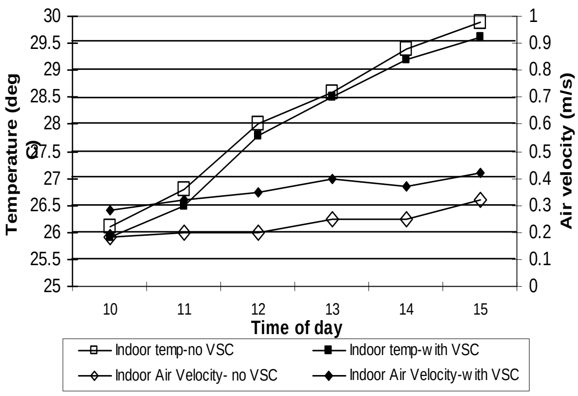


Figure 10: The optimum of vertical solar chimney base on previous research

4.4. Evaluation of Vertical Solar Chimney Parameter

It is found that in a terrace house using vertical solar chimney, air ventilation is induced by the solar chimney. Results can be more significant by increasing air velocity (0.15m/s) as well as cooling of temperature. The average temperature in the room ranges between 26˚C and 29.5˚C during 10 hr – 15 hr, which is about 0.5˚C lower than a normal terrace house without solar chimney.





Plan and Section Temperature and Air Velocity at 10 h – 15 h

Figure 11: Performances of parametric study of vertical solar chimney in terrace house model

5. Conclusion

The computational fluid dynamics simulation evaluates the solar induced ventilation in terrace house model. We have reached the following conclusions:

- Air velocity without considering the wind effect is influenced by climate parameters (solar radiation and ambient temperature). High solar radiation and temperature differences may create air flow inside the chimney pipe for pilot testing.
- Low indoor air velocity and high ambient temperature may create unwanted negative ventilation by limiting room design parameters (single side) in terrace house
- Optimum design parameters (height, width, length and material) of a vertical solar chimney can be deduced by comparing simulation results and results based on previous research.
- The performances of design parameters proposed in this study, if incorporated in terrace house model, is expected to create a reasonable indoor air velocity for human comfort, besides contribution to energy efficient and environmentally friendly options.

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