PAPER 11: THE IMPACT OF SOLAR CHIMNEY GEOMETRY FOR STACK VENTILATION IN MALAYSIA'S SINGLE STOREY TERRACED HOUSE

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ABSTRACT

In terms of passive cooling design in housing, tropical climates present the most difficult problem to solve. The climatic conditions of the tropical regions are characterized by high air temperatures, high relative humidity and very low wind speeds. These make the environmental conditions uncomfortable. This situation arises from the low air velocity and high temperature experienced during day time. The wind effect is also not well utilized especially in the usual single sided ventilation. The field measurement study on an existing house indicated that the basic design of single storey terraced house is not effective in providing natural ventilation for achieving thermal comfort. It is hypothesized that solar–induced ventilation may be a viable alternative. Therefore this paper discusses the impact of solar chimney geometry for stack induced ventilation strategies on a single storey terraced house model under Malaysian conditions. The solar induced ventilation study involved computer simulation using Computational Fluid Dynamics where air movement and solar radiation simulation are the major variables. Validation of CFD FloVent was done by comparing the results with field measurements and it showed a good agreement. Further development of the solar induced ventilation designs have been made and evaluated to attain solar chimney geometry. The simulations were performed on a selected day of one year. The result showed that the solar chimney geometry of 3 x 1 m area and 3.5 m vertical height provided continuous air movement where highest velocity could reach 0.6 m/s (on 21st March, on north-south orientation).
Keywords: stack ventilation, vertical solar chimney geometry

INTRODUCTION

Ventilation is one of the important options in providing thermal comfort in buildings (Bansal, 1994). Thus, as a passive cooling system it is highly desirable. To reduce the mechanical cooling energy cost of new building in a hot and humid region, the design should maximize the natural ventilation and minimize the fraction of sun energy absorbed by a dwelling (Khedari J, 1997). Two major goals in natural ventilation include provision of sufficient fresh air and satisfactory temperature. At temperatures below 34°C, which is the average temperature in many hot and humid conditions, air movement might be one of the most useful and least expensive methods to provide a comfortable indoor climate. The movement of air across human skin creates a cooling sensation caused by heat leaving the skin through convection and by the operation of perspiration. The most common way to create air movement without mechanical power is to open a window and allow breezes to blow into a building (Khedari J, 2000). Under Malaysian conditions, passive cooling is a popular cooling strategy adopted in residential buildings. Abdul Razak (2004) have shown that cross ventilation performance could provide internal thermal comfort. According to Hui (1998), the range of indoor air velocity in low rise buildings is between 0.04m/s and 0.47 m/s. This is inadequate, and may be due to inappropriate design solutions for indoor air movement or low outdoor air velocity.

One way of producing natural ventilation is through stack effect. In order to increase stack effect ventilation in buildings and, as a consequence, to improve indoor air movement, is to rely upon the use of solar energy, namely through solar induced ventilation. Ventilation provides cooling by using moving air to carry away heat from the building when the indoor temperature is above the outdoor temperature (Hirunlabh, 1999). Solar chimney is one of the several available options for achieving solar-induced ventilation (N.K. Bansal, 1994). This paper highlights the ongoing research on the possibility of using solar chimney to induce air movement in the Malaysian terraced house.

Malaysia's Climate Conditions

Malaysia's climate is characterized by relatively high levels of humidity and temperature. Malaysia lies between 1° and 7° North latitude and 100° and 120° East Longitude. It has two main land areas which is the Peninsular Malaysia and East Malaysia. Since the peninsular has the major population (76%), the present study is aimed on this area. Towns in the Penisula experience a seasonal climatic change which is dominated by the monsoons. Johor Bahru is the second largest town after Kuala Lumpur and located at the southernmost part of Peninsula. The seasonal pattern of wind and rainfall is a dominant climatic characteristic in tropical climates. Monsoon winds occur twice a year; the Northeast and Southwest monsoon. The southwest monsoon originates from Australia and blows across the Sumatra Island and the Straits of Malacca during the months of May to September. The Northeast monsoon originates from the central Asia and blows across the South China sea through Malaysia to Australia during the months of November to March. During months of April and October inter-monsoon winds occur. According to the meteorological data in Senai, Johor Bahru, the mean monthly temperature remains constant. This varies by only 2°C, from 25°C in January to 27°C in April 2005. The average of daily temperature is about 26.5°C throughout the year. Relative humidity varies from 75 to 85 percent. Solar irradiation is 400 MJ/m^2 to 600 MJ/m^2 monthly total, and higher during northeast monsoon and lower during the southwest monsoon. Figure 1 and figure 2. show a combination of high global radiation with decreasing wind speed from February to June that causes an extremely over heated period with high mean air temperature.

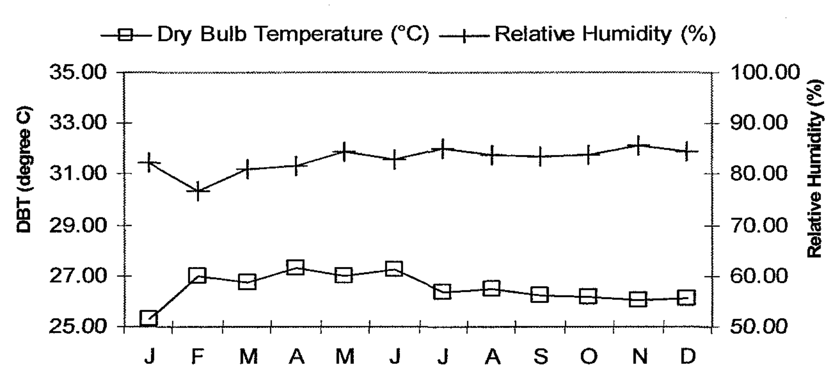

Figure.1. Seasonal pattern of an average dry bulb temperature and relative humidity for each month (data obtained 17.4 m high from sea level Senai Meteorological Station, 2005)

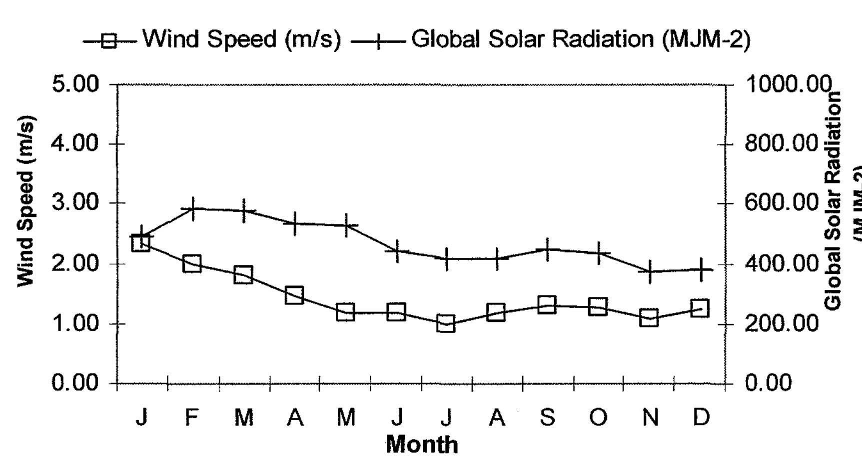

Figure.2. Seasonal pattern of total global solar radiation and average wind speed (data obtained 17.4 m high from sea level Senai Meteorological Station, 2005)

Terraced Houses in Malaysia

The property market report indicated that terraced houses accounted for approximately 57% of the total Malaysian housing stock in the year 2002 (Kubota, T. *et al* 2006). The majority of terraced house population is concentrated in Johor Bahru. Further, more than 50% of these terraced houses are single storey. Therefore, this study has focused especially on single storey terraced houses. In order to assess the thermal environment and thermal comfort conditions, a preliminary investigation was conducted in March 2006 (Nugroho, A.M *et al.* 2006). A single storey terraced house was used for the investigation in Johor Bahru, Malaysia (Fig.3).

Figure.3. A single storey terrace house in Johor Bahru, used for field measurements

Study of Solar Chimney Geometry

In the past decade, solar chimneys have attracted much attention in various investigations. Studies on impact of geometry variable on solar chimney have been expressed in terms of height, length and width. Several studies were concerned with height variable of solar chimney design ventilation. Hirunlabh (1999) found the temperatures increased with increased Metal Solar Wall (MSW) heights. In addition, temperature along the metallic wall height is at a maximum at the middle of the MSW and at minimum near the opening due to the incoming room air at the bottom of the MSW and to the contact with ambient air a the top. Experimental investigations of the performance of the MSW showed that with 1 m height and 0.34 m gap the MSW would produce optimum natural ventilation. Alfonso (2000) evaluated height parameters of solar chimney for satisfying the needed average flow rate. To evaluate the effect of chimney height on ventilation flow rate, several dimensions of chimney height between 0.5 and 3 m were simulated. Air flow rate increases for higher values of height.

The impact of solar chimney length variable was done by Khedari (1998) and Alfonso (2000). Khedari (1998) showed the impact of length variable for solar chimney ventilation. The air velocity could be increased by increasing the surface area of solar chimney or the number of units of solar chimneys on roof, eastern and western walls. Alfonso (2000) changed the length of solar chimney to evaluate the effect of air flow rate in the room. Variation of chimney length between 1 and 5 m, which correspond to chimney sections between 0.2 and 1 m^2 were used. Airflow rate increases linearly with the increase in length. Also, the amplitude in air flow rate increases with chimney length. One can also conclude that the increase in chimney length is more effective than the increase in chimney height, when one seeks to increase solar collection area in order to favour air flow rate.

Previous research (Bouchair, 1994; Hirunlabh, 1999 and Ong, 2003) considering the width (air gap) of solar chimney variable was carried out. Bouchair (1994) completed an important study of a solar chimney for cooling ventilation. The chimney had a fixed height of 2 m with both walls maintained at the same temperature. The influence of the chimney width was investigated. It was found that in the chimney width range 0.1 m – 1 m, there was an optimum chimney width between 0.2 and 0.3 m, which gives maximum ventilation rate. It was also found that this optimum chimney gap is essentially independent on the chimney wall temperature. However, it may be seen that the optimum gap is slightly wider when the chimney inlet becomes higher from 0.1m to 0.4 m. The optimum chimney width was approximately one-tenth of the chimney height, or an aspect ratio (H/w) of 10. Hirunlabh (1999) investigated the relation between air gap and air mass rate in metallic solar wall. The hourly variations of the experimental air mass flow rate produces by the MSW for two different gaps (0.1-0.145 m). It can be seen that the mass flow rate increased with increased gap. The maximum average of air mass flow rate during the hot period (10:00-16:00 h) was about 0.015 kg/s. Ong (2003) investigated the effects of air gap and solar radiation intensity on the performance of different chimneys. In order to verify the theoretical model, experiments were conducted on a 2 m high physical model with air gaps of 0.1, 0.2 and 0.3 m. A solar chimney with a 0.3 m air gap was able to provide 56% more ventilation than one with a 0.1 m air gap.

The estimated effect of the solar chimney was shown to be substantial in promoting natural ventilation for low wind speeds. Thus, the above reviews suggest that solar chimney strategy to increase air velocity and decrease air temperature has been treated as separate issues. There is no specific research done to study the relationship between solar chimney geometry (height, width, length) and comfort ventilation. Therefore this research attempts to focus on the impact of solar chimney geometry to improve stack ventilation for comfort ventilation in tropical condition.

METHODS

Solar Chimney Pilot Testing Measurement and Simulation

A pilot testing using one model was measured in Universiti Teknologi Malaysia (UTM), Johor Bahru on seven days from March 17th to 24th 2005. The chimney PVC pipe in the pilot testing was 3.5 meter high, 1meter above the ground and 0.15 meter in diameter. They are supported structurally by timber framework. The model was black in colour. Data loggers were positioned at three different points and another the outdoors. The instrumentation consisted of sensors with a data logger system. The sensors were set up to monitor outdoor and indoor air temperature and humidity conditions. Figure 4 shows the positions of the instrument installation within and outside of the PVC pipe. The time step is 15 minutes for all automatic measurement during the daytime 00.00 h to 23.00 h. Outdoor climatic conditions (solar radiation, wind speed, wind direction, air temperature and humidity) were also obtained from Senai Meteorological Station, 2005.

In the CFD simulation, the following boundary condition area is 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 and Hamdan, 2006). Using the FloVent version 5.1 program, the simulation models are created directly using the drawing board window provided with this software. This is to give more accurate representation of the buildings. The sizes and the dimensions of the models involved in this simulation are similar to the pilot testing measurement. The difference between the simulation model and pilot testing is the sectional shape. The simulation consists of rectangular section while the pilot testing model consists of cylindrical shape. Like CAD software, the building created in this CFD software using 1:1 scale. The model was placed inside an overall domain solution size of 40 m x 40 m x 20 m high. The position of the model inside the overall domain solution was at 20 m from x-plane, 20 m from z-plane and 1 m from y-plane. Figure 4 shows the overall domain solution and the position of the model inside the overall domain solution. The main objective of the simulation is to estimate the air temperature inside the solar chimney model. Therefore, temperature tapping points were placed at the mid point of inlet, middle of model and outlet openings. The exact location of the monitor point determines the accuracy of the predicted internal air temperature. In this research, the major climatic variables are site, wind data or reference wind speed, wind profile, solar radiation and atmospheric boundary layer characteristics. The summary of the suburban site conditions for Johor Bahru's hot and humid climate is used in the simulation. The location of the study is UTM. The latitude is 1° 08' N and the longitude is 104° 42' E of Greenwich. The height above sea level is 37.8 m. The nearest meteorological station is located at Sultan Ismail (SI) airport known as Senai meteorological station, approximately 20 km from Johor Bahru. The average ground characteristics of the site weather station area are considered as a combination of flat terrain and low-rise buildings. This gives the empirical exponent (a) value of 0.22, the roughness length (Z0) value of 0.25 m and the gradient height (Zg) value of 370 m.

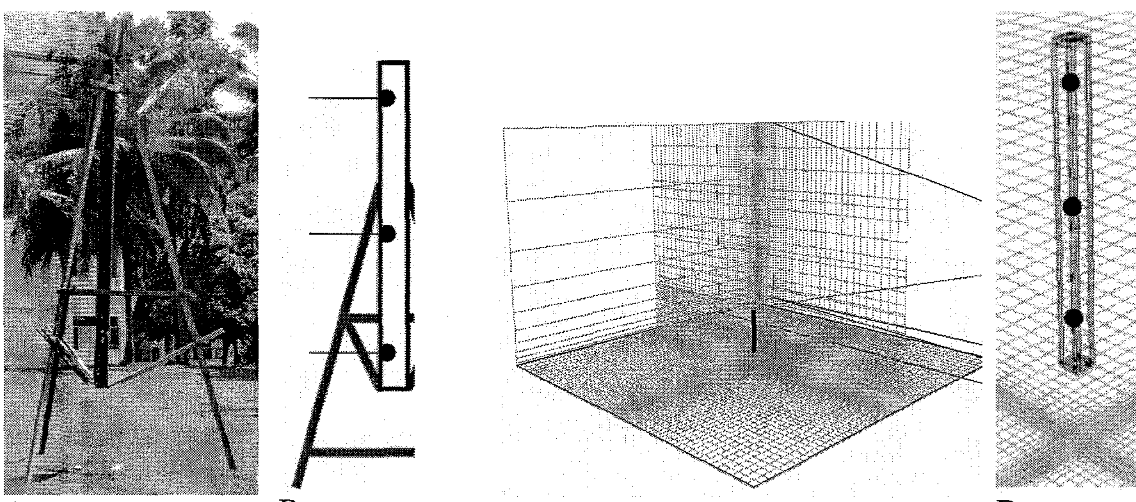

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Figure.4. The solar chimney pilot testing (a), the position of data logger inside pipe (b), overall simulation modeling setting up for solar chimney model (c) and the position of monitor point in relation to the position field measurement and size of model (d)

Terraced House Measurement and Simulation

The authors carried out a survey of a typical single storey terraced house in Taman Sri Pulai, Johor Bahru on two consecutive dates from March 20th to 21st, 2006. The house was kept empty without furniture to reduce the thermal exchange between objects. The house comprised 5 rooms. The windows of the living and master bedroom are facing towards the east. Windows of the kitchen and two bedrooms are facing toward the west. A room received ventilation with single side opening. The windows have double sashes, which were retrofitted by the occupants. Two sashed windows are fixed in the kitchen and the bedrooms and the living room had a sliding window. In a typical Malaysian dwelling, the windows are usually kept opened during the day and closed at night in both present and traditional practice (for security). During the measurement all doors remained closed and all windows of the house remained opened. The walls and roofs are not insulated for heat transmission. The building structure consists of, 0.15 m thick brick walls (including cement and lime plaster). Thickness of the outside and inside walls are 0.2 m and 0.15 m, respectively. Figure 5 shows the positions of the instrument installation within and outside of the investigated house. Outdoor climatic data were collected with one global weather station. The immediate surrounding environmental conditions were measured at 2 m above the ground. The global weather station measured solar radiation, wind speed, wind direction, air temperature and humidity. Indoor climatic conditions were collected with thermal data logger and compact data loggers. The Inova thermal data logger measurement was aimed to collect data on environmental parameters (air temperature, mean radiant temperature, relative humidity and wind speed), which were necessary for further thermal comfort analysis. The Dickson compact humidity loggers measured dry bulb temperature and relative humidity, which were carefully calibrated with the thermal data logger beforehand to give reliable results. In this study, the temperature, humidity and air velocity was measured at 1.10 m (human body level) above the floor where indoor temperatures and humidity were observed on the four rooms (living room, bedroom 1, bedroom 2 and kitchen) and complete measurement in one room (master bedroom) of single storey building. The time step is 15 minutes for all automatic measurement.

The initial conditions for simulation have been set using the climatic data from the field measurement obtained between 08.00 h to 19.00 h on 21 March 2006 (Table 1). All of the tests on five rooms were carried out by using CFD FloVent. Figure 5b show the CFD model and boundary condition. The CFD program requires inputs representing problem type, flow domain (material, type of flow, etc.), boundary conditions (walls, inlet, outlet, symmetric wall), and calculation method. The problem type is used to activate calculation modules; in this case, flow, heat transfer, and turbulence modules. The flow domain was set as (air density: 1.149 kg/m^3, viscosity: 1.872E-5, specific heat: 1007 J/kg. K, conductivity: 0.02643 W/m. K, temperature: 27.6°C-32.2°C). The wind flow set at steady state, subjected to gravity of 9.8 m/s^2, and is turbulent. Roughness Height of the ground was set as 0.03. Initial wind was defined at the inlet using an atmospheric boundary layer to obtain a realistic wind profile based on the exponent law (Ansley, R.M *et al.* 1999). The wind speed at 2 m above ground is 0-0.2 m/s based on site Globe Weather data. The turbulent kinetic energy and energy dissipation rate were set to 0.33 and 0.48 respectively. The calculation used the standard k-e epsilon turbulent model with 1500 iterations. To avoid convergence problems, fan relaxation 1 was applied. The solar radiation calculation was set to the following details (latitude: 1.8 degree, day: 21 March, solar times: 08.00 h-19.00 h).

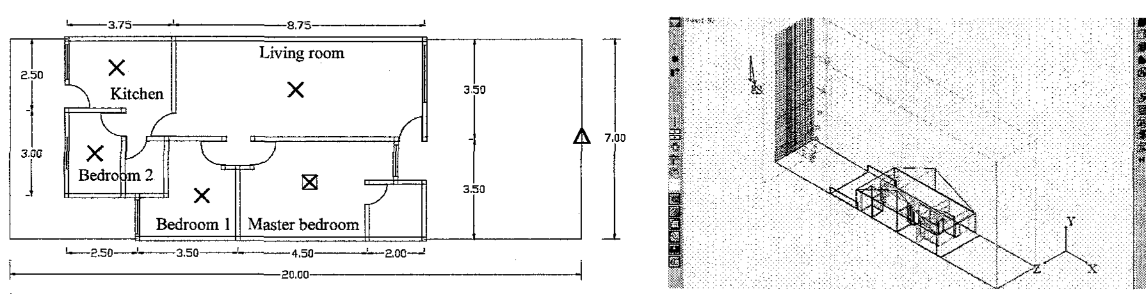

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Figure.5. The positions of global weather data (?), compact data logger (×), thermal data logger (?) for the measurement and terrace house model in CFD

Table 1. Field Measurement Input Data for CFD simulation

Time	Air temp. (°C)	Humidity (%)	Wind speed (m/s)	Solar irradiance (Wm-2)	Wind direction (°)
8	26.56	89.2	0	4.09	0
9	28.89	79	0.03	16.65	0
10	29.56	76.7	0	20.76	0
11	27.50	78.6	0.1	80.00	178
12	31.67	65.6	0.1	118.57	182
13	29.67	72.8	0.3	71.37	180
14	29.67	72.5	0.15	35.88	168
15	28.11	78.6	0.1	15.55	176
16	27.22	82.7	0.2	19.65	161
17	27.22	82.5	0.05	44.24	178
18	27.2	82.5	0.1	31.54	167
19	26.8	89.2	0	6.23	0

Development of Solar Chimney Prototype

Development of the proposed solar chimney prototype had been undertaken for the selected climate condition (on 21 March at 12:00 h). It was simplified to provide a comparison between pilot testing and the different geometry configuration in the same climatic conditions. However, general and subjective conclusions were formulated. Predictions of the impact of geometry configuration of the solar chimney were performed for variety of geometry configurations (height, width, length) and another configuration (thickness and material). The ability of the solar chimney to offer induced ventilation is expressed by the air velocity and air flow rate inside the solar chimney. Higher air flow rate of the ventilation means higher air velocity.

The basic simplified pilot testing shown in figure 4 is a typical configuration with overall size of 0.15m x 0.15 m x 3.5m high. This size is to represent 1 cylindrical PVC pipe on pilot testing. The diameter of pipe is 0.15 m and the height of pipe is 3.5 m. The modified solar chimney configurations are extension of the pilot testing model. The modification is by introducing geometry and material configuration. In this stage, the basic solar chimney models are modified physically into five alternative forms. First, several sizes of height were simulated between 1 m, 3.5 m, 6 m and 9 m, Second, the size of the width are 0.05m, 0.15m, 0.3m, 0.6m and 1m. Third, the length of the solar chimney are as follows 0.05 m, 0.15 m, 0.5 m, 1 m, 1.5 m, 3m, Fourth, the thickness are 0.002m, 0.005m, 0.01m, 0.05m, 0.15m. Last, the material of solar chimney as brick wall, aluminum, glass and brick-glass.

The discussion of the results in this simulation section referred to the basic solar chimney configuration which are model A1 (0.15 width, 0.15 m length same as with simplification of pilot testing pipe with 0.15 m diameter), A2 (0.3 m width, 0.15 m length), A3 (1 m width, 0.15 m length), A4 (0.15 m width, 1.5 m length), A5 (0.3 m width, 1.5 m length), A6 (1 m width, 1.5 m length), A7 (0.15 m width, 3 m length), A8 (0.3 m width, 3 m length) and A9 (1 m width, 3 m length). All models used aluminum as material and 3 m height with 0.005 m thickness. For the purpose of comparative analysis on the effect of the width and length, the basic model (A1) air velocity (v) and air flow rate (Q) values were used to determine the deviation of v and Q values at the proposed solar chimney configurations. The study indicated that the width and length of the solar chimney model are the main modification factors to achieve the maximum air velocity and air flow rate. Thus, the finding suggested several solar chimney geometry models for respective width (0.15 m, 0.3 m and 1 m) and length (0.15 m, 1.5m and 3 m) variables. The selected model for performance on different conditions was determined by the air velocity and air flow rate induction. The results obtained for model A1 showed the maximum air velocity and model A9 illustrated the maximum air flow rate. Hence, it can be concluded, that for a solar chimney model, the model A1, A7 and A9 can be used to determine the appropriate chimney geometry configurations at early design stage.

RESULTS AND DISCUSSION

Pilot Testing validation

Validation of the program was performed by comparing the measurement of pilot testing with the CFD simulation. Figure 6 shows the comparison of measurement and simulation result. It shows that the agreement between the measurement and simulation is generally good. The average difference between the measurement and simulation for ambient temperature was 0%; for black bottom was about 3%; the maximum difference was 8% at 10:00 h in the black top pipe. This gives confidence in using the computer code to study the air flow and temperature.

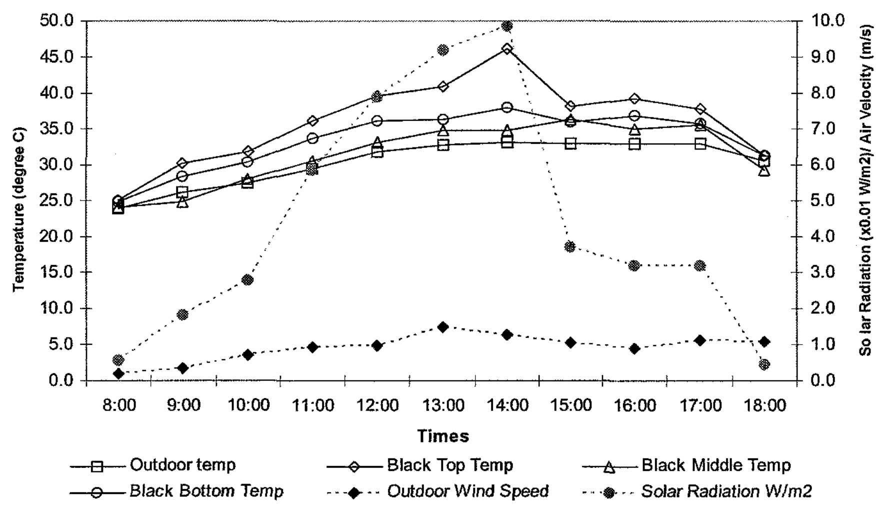


Figure.6. Comparing measurement and CFD simulation of pilot testing

Terraced House Simulation Validation

Validation of the CFD model with the field measurement results was carried out in two steps. The first step was the validation of temperatures at consecutive times and the second one was the validation of the air velocity. The purpose of this two-step validation was to find the cause of deviation between the two results. Figure7 emphasises a good agreement between CFD simulations with the field measurement results. The difference was less than 5% for most of the calculated points on the temperature. The relative errors were less than 2% and with no difference for the ambient temperature. In those cases, the absolute differences were less than 0.4°C. In conclusion, the outdoor/ambient and indoor air temperature calculated by the CFD simulation showed a good agreement with the results of the field measurement. Figure 8 shows the plot of points for field measurement and CFD simulation airflow velocity under outdoor and indoor conditions. The figure 8 shows close agreement between measured and simulation values. Deviations are within range of 10% of the calculated air velocity. In most observations, this difference is less than 5% of the calculated values. Although there are slight differences between the results of CFD and field measurement, it can be inferred that the CFD modeling is appropriate to reproduce the phenomena occurring in the measurements. The use of the CFD model to investigate the performance of the thermal comfort ventilation thereby is validated.

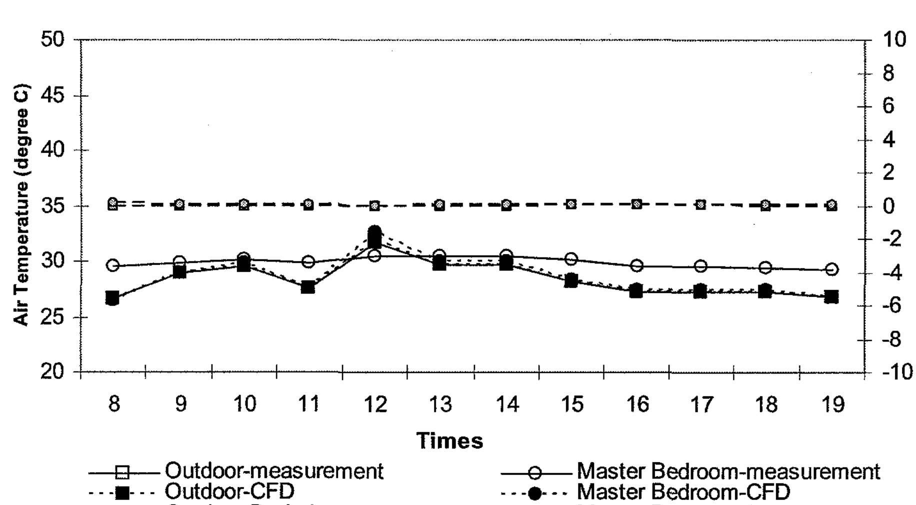


Figure.7. Comparison of the temperature result between field measurement and simulation

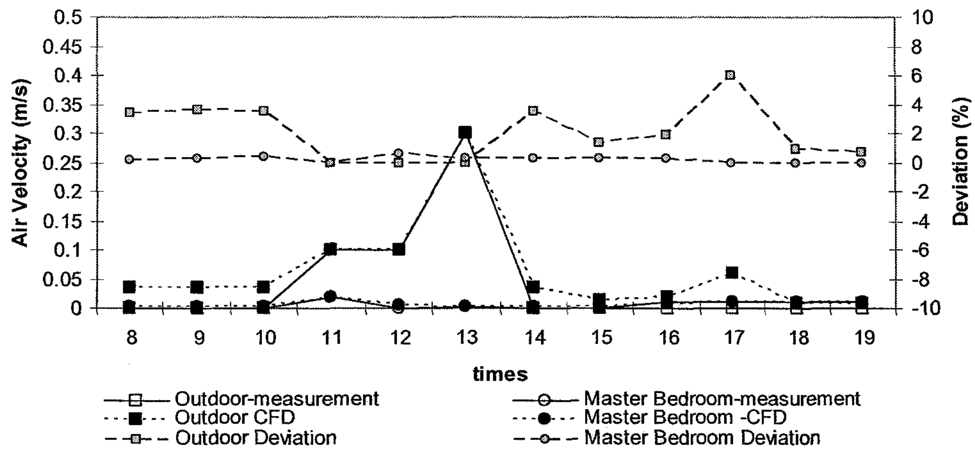


Figure.8. Comparison of the air flow velocity result between field measurement and simulation

Development of Solar chimney

The primary purpose of the solar chimney models is to use the solar radiation received by the chimney for improvement of the stack induced ventilation. The direct solar radiation incident on solar chimney were obtained at five times within general activities day hours (8:00 , 10:00, 12:00, 14:00 and 16:00 h). The average air velocity of model A1, A7 and A9 are higher at 12:00 h than at other times on 21 March. The reason can be explained as at 12:00 h the solar irradiance is maximum (916 W/m2) even though the air velocity inside the chimney suggests a higher value. The average air velocity inside the model A1 indicated a higher value than in the model A7 and model A9, on north-south orientation. The profile pattern of air velocity reduction with the increase of chimney width had a similar pattern during all three hours considered. However, the maximum amount of air velocity was received during 12:00 h. This is a clear evidence that higher amount of air velocity is produced when the sun is at higher altitudes and when the solar irradiance is the highest.

The results of the average air flow rate into the chimney showed that higher air flow rate obtained during the noon hour than in the morning and afternoon. Lower values of air flow rate in all models were indicated at 08:00 h and 16:00 h which were caused by the lower solar intensity. Figure 9 exhibits a higher gradient curve with the increase in the width and length of chimney. This indicates that by increasing chimney section from basic model (pilot testing), it increases the total air flow rate into the chimney significantly. The average air velocity pattern on the model A1, A7 and A9 has similar profile. However, the model A7 indicated a lower gradient profile than the model A1 and model A9. The maximum air velocity was obtained during 12:00 h for model A1 (0.8 m/s). These patterns are mainly due to the effects of highest solar radiation produces maximum air velocity in all models. The results indicated that the maximum average air flow rate (2.5 m3/s) through the model A9 occurs at noon time, when the sun is at higher altitude. Model A9 illustrated different profiles of air flow rate compared to the model A1 and A7. The average air flow rate pattern on the model A1 and A7 have similar profile. The model A1 and model A7 obtained a constant amount of air flow rate for considerable number of hours; 8:00 h to 16:00 h (for width between 0.15 m and 0.3 m). This profile was maintained even when different chimney widths were applied. Also, the air flow rate is increased with the increase of width ratio. The chimney width of 1 m for the north-south orientation indicated 1.5 m3/s of air flow rate induction respectively compared to 0.05 m3/s of air flow rate through the chimney width of 0.15 m.

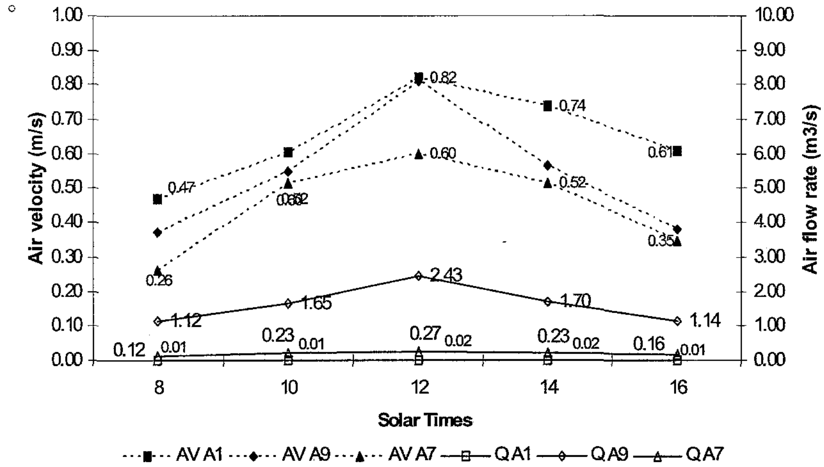


Figure.9. The air velocity and flow rate in the top, middle, bottom position of model A1, A7 and A9 for solar times at 8:00, 10:00, 12:00, 14:00 and 16:00 h on 21 March 2005 on north-south orientation

Terraced House Simulation without Solar Chimney

The correspondence simulation is 3.5 x 5.5 m master bedroom with activity plane height of 1.1 meter (Figure 10). The evaluation of natural ventilation quantity is based on the target absolute work plane air velocity at 0.25 m/s-1.5 m/s. The correspondence average air velocity, air flow rate and air temperature on reference point area were also presented. The analysis is based on the average values calculated for air movement and temperature at the reference points area (3.5 m length x 5.5 m deep at 1.1 m high position).

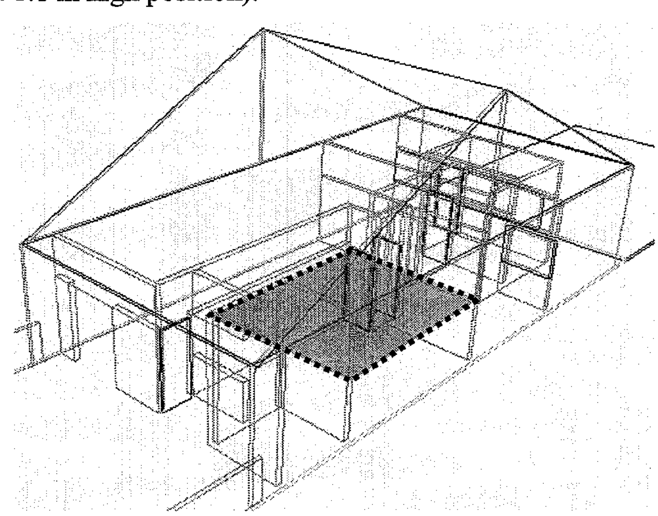


Figure.10. The reference area in field study

The respective days of sun path affect significantly on the air velocity and air temperature levels for different hours during the day. The maximum air velocity and air temperature values were achieved at noon (12:00 h) and the minimum was in the morning (8:00 h) with exception on field study measurement (21 March 2006). Figure 11 shows the average air velocity for field study is lower than on other days. The air velocity on that day ranged from 0.001 m/s until 0.1 m/s. Similarly the air velocity profile was obtained on 21 March, 22 June, 24 September and 21 December 2005 are the same. The low air velocity level indicated that indoor air velocity is insufficient for thermal ventilation (0.25m/s-1.5 m/s). The results also indicated that different days of the year received different air velocity levels with respect to the outdoor climate conditions. Figure 11 illustrates that the temperature profile showed a similar gradient on all days. The field study on 21 March 2006 has a low value at 12:00 h and at 16:00 h compared to other respective days. The maximum indoor air temperature value of 35.5°C was on 21 March 2005 at 12:00 h. The high air temperature level indicated that the indoor temperature needs maximum air velocity to provide thermal ventilation (1.5 m/s).

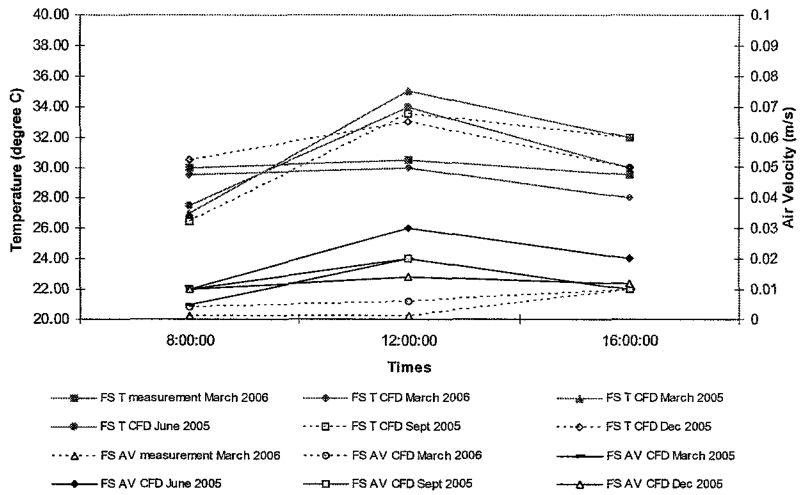


Figure.11. The indoor average air velocity and temperature at 8:00, 12:00 and 16:00 h solar times of field study measurement on 21 March 2006 and simulation on 21 March 2006, 21 March 2005, 22 June 2005, 24 September 2005 and 21 December 2005

Terraced House Simulation with Solar Chimney

The solar chimney is used to induce the air movement into the building and increase the cooling factor of the room. This may provide psychological cooling, which may promote the use of natural ventilation. The maximum air movements (air velocity and air flow rate) are then calculated when solar chimney is put on the roof. The results are obtained at five times a day (08:00, 10:00, 12:00, 14:00 and 16:00 h), with different house orientations (north-south and east-west) and on four different days (21 March, 22 June, 24 September and 21 December).

Solar chimney performance against solar times

The maximum average air velocity is obtained at 12:00 h at reference area, on 21 March, when the solar chimney is facing to the east (figure 12). The results indicated a significant difference between air velocity values obtained in the morning and afternoon (8:00 h and 16:00 h) than at noon for solar chimney model A9. This is mainly due to the direct sunlight significantly induced the air velocity into the building during the respective hours. At 12:00 h, increase of solar intensity produced the amount of air velocity into the room as the sun is at a higher altitude at that particular hour. At reference area, the air flow rate profile indicated a similar pattern on all five hours on 21 March, which means that increase in air velocity produces the air flow rate at both openings. The comparative results between air velocity values and air flow rate showed a direct correlation between the two components, where maximum air velocity and air flow rate indicated similar pattern during the same hours. On 21 March, the maximum air temperature was obtained at 12:00 h at reference area. This is due to an effect on the solar intensity at that particular time. At 12:00 h, the solar radiation is highest, while at this time the solar intensity by the direct sun is dominant. Hence, the direct sunlight had higher intensity than the diffuse component of the sky. On 21 March, with solar chimney the master bedroom obtained the minimum air velocity at 8:00 h (0.08 m/s) that is below the target level (0.25 m/s). However, the maximum air velocity (0.42m/s) can be achieved at 12 h that is above the minimum requirement level. The maximum air velocity with solar chimney indicated 0.4 m/s higher if compared to the base case field study on 21 March 2005. The maximum air temperature reduction with solar chimney indicated 2.6°C lower than the base case field study at 12:00 h. The correspondence maximum air temperature indicated 7% reduction compared to the base case field study.

However, the use of solar chimney indicated 1%, 4%, 6% and 0.5% reduction of the air temperature at 8:00, 10:00, 14:00 and 16:00 h. Thus, the mean activity plane temperature in the master bedroom were reduced up to 26.5 °C, 31.2°C, 34.8°C and 32.5°C for solar chimney model A9. In general, with solar chimney model A9 on 21 March provided better internal condition compared to the base field study.

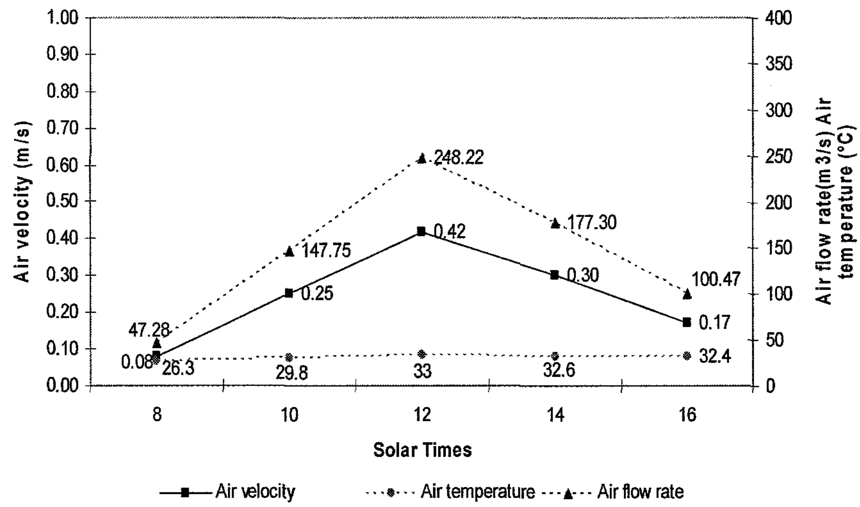


Figure.12. The indoor average air velocity, air flow rate, air temperature of field study at 8:00, 10:00, 12:00, 14:00 and 16:00 h on 21 March 2005

Sun path affects air movement (velocity and flow rate) and air temperature for different hours during the day. The maximum air velocity, air flow rate and air temperature values were experienced in the noon (12:00 h) and the minimum in the morning (8:00 h) except on 22 June. The highest air velocity and air flow rate levels were achieved at high altitude sun positions for the east-west orientation. However, on 21 March higher solar intensity received in the noon (12:00 h). Low air movement values were indicated at early morning hours (8:00 h) and late evening hours (16:00 h) when the sun is furthest from the equator, on the east-west orientation respectively. The results also indicated that different days of the year experienced different air movement and air temperature levels based on the solar times. This is best explained by the air movement values obtained at the activity plane. According to the results, the maximum value is obtained on 21 March for both air movement and air temperature, while minimum values were indicated on 21 December at reference area. On 21 March, with solar chimney, the maximum air velocity at 12:00 hour indicated 0.4 m/s higher compared to the base case field study. On 22 June and 21 December, deeper gradient air velocity profile pattern were achieved at 12:00 h and 16.00 h. However, a setter gradient happened at 8:00 h. The maximum air temperature reduction (3°C) was obtained on 22 June at 12:00 h. The minimum air temperature reduction at 16:00 h also obtained for all days. The maximum and the minimum air temperature indicated 7% and 4% reduction compared to the base case field study. The use of solar chimney also indicated 1% and 0.5% reduction of the average air temperature on all respective days. Therefore, the use of solar chimney can lower the air temperature inside the master bedroom.

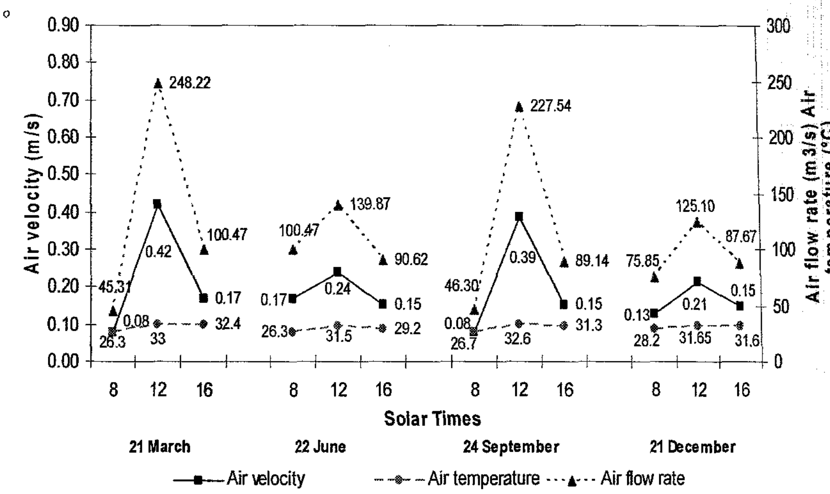


Figure.14. The indoor average air velocity, air flow rate, air temperature of field study at 8:00, 12:00 and 16:00 h on 21 March, 22 June, 24 September and 21 December

Solar chimney performance against house orientation

The air velocity, air flow rate and air temperature values were plotted against solar chimney orientation to determine a general distribution profile of air movement and temperature levels received in the master bedroom when solar chimney is applied (figure 13). The maximum air movement and temperature values were achieved on north-south orientation at 12:00 h and the minimum air movement and temperature values were obtained on east-west orientation at 8:00 h. The air velocity, air flow rate and air temperature values on 21 March for the north-south and east-west orientations are shown in figure 13. The maximum air velocity was obtained at 12:00 h for all orientations. The results illustrate that the minimum air velocity is obtained at different hours of the orientation; on north-south orientation at 16:00 h, while on east-west orientation at 08:00 h. The minimum air velocity on the north-south orientation (0.15 m/s) and on east-west orientation (0.08 m/s) are lower than the targeted condition (0.25 m/s). The results also showed a significant difference between air flow rate values obtained at 12:00 h and 8:00 h or 16:00 h. Initially, the air flow rate level showed sudden reduction on east-west orientation compared to north-south orientation. This is due to the increase of air velocity together with increase in the amount of air flow rate, but had little impact on the decreased of air temperature. The air flow rate profile had lesser gradient on east-west orientation compared to north-south orientation. The air temperature profiles showed similar pattern on both orientations and at each reference solar times. However, the air temperature profile at 12:00 h on 21 March indicated a pattern with higher gradients, which means that the solar irradiance is radiated into the room during this hour. On north-south orientation, the use of solar chimney provided the maximum air velocity at 12:00 h with 0.58 m/s higher than based case field study. The minimum air velocity reduction indicated 0.08 m/s at 8:00 h on the east-west orientation. Hence, on the east-south orientation it resulted in a deeper gradient air velocity profile pattern at 8:00 h and 12:00 h than at the same times on north-south orientation. The maximum and minimum air temperature reduction at 12:00 h and 16:00 h indicated 2.6°C and 0.1°C lower than the base case field study on east-west orientation. The correspondence maximum and minimum air temperature indicated 7% and 4% reduction compared to the base case field study. Further, the use of solar chimney indicated 1% and 0.5% reduction of the average air temperature on north-south and east-west orientations.

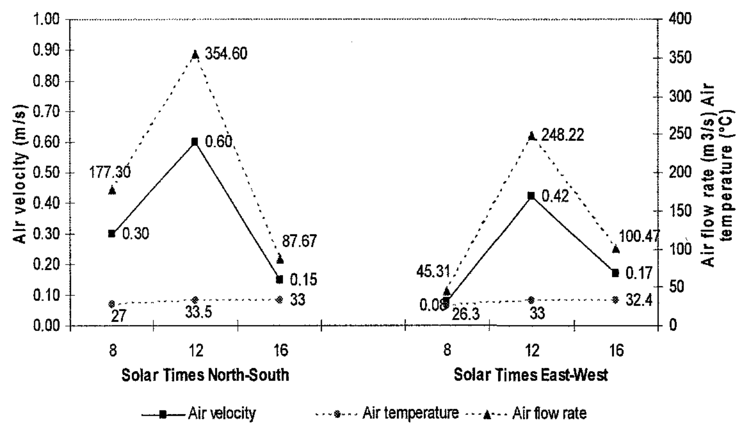
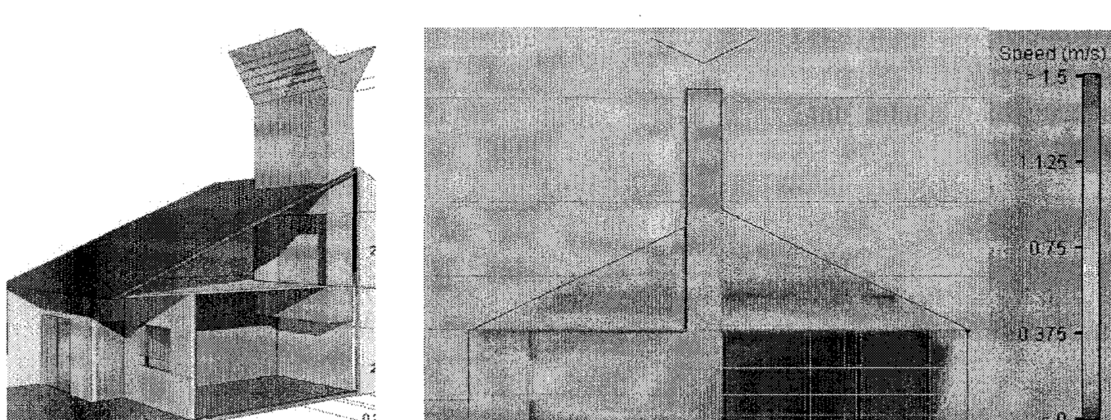


Figure.13. The indoor average air velocity, air flow rate, air temperature of field study at 8:00, 12:00 and 16:00 h on 21 March 2005 on north-south and east-west orientations

CONCLUSION

As discussed above, the proposed solar chimney geometry with the following performance variables were experimented; chimney height, chimney width and chimney length. The study indicated that the width and length of solar chimney model (or the area of solar chimney section) are the main modification factors to improve air velocity and air flow rate. The finding suggested several solar chimney geometry models with respective width (0.15 m, 0.3 m and 1 m) and length (0.15 m, 1.5m and 3 m) variables. The performance of the model on different conditions was determined by the air velocity and air flow rate induction. The results showed that model A1 had maximum air velocity and model A9 illustrated the maximum air flow rate. Hence, it can be concluded, that model A1, A7 and A9 can be used to determine the appropriate chimney geometry configurations at an early design stage. Generally, the A9 model of solar chimney performed the best as it received the maximum air velocity and air flow rate induction that flow through the chimney pipe. The increase section area of model A9 induces the maximum air velocity and air flow rate at 12:00 hours. Increase of solar radiation further also had impact an on the induction values of the air movement. Observations on the internal air movement level revealed that terraced house with solar chimney has better natural ventilation than terraced house without solar chimney for all respective conditions. The results showed that the optimum condition with the maximum air velocity was achieved at 12:00 hour solar times, on the north-south orientation and on 21 March 2005. Thus it is possible to employ solar chimney on terraced house for ventilation purposes as concluded in figure 15.



A B

Figure.15. The application of solar chimney on terraced house (a) and the air velocity contour on terraced house with solar chimney (b).

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