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Effective solar chimney cross section ventilation performance in Malaysia terraced house

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Abstract

In hot and humid country, ventilation and thermal performance could be improved by effective natural ventilation strategies. However, the climatic conditions of the tropical countries are mainly distinguished by high air temperature and relative humidity as well as low wind velocity which are the main factors that reduce the comfort level of occupants, especially in the terrace house. The use of solar chimney in terrace house is one of alternatives to increase the thermal and ventilation performance of the indoor environment. This study initiated with field measurement in a selected case study house located in Kuching, Sarawak, Malaysia for software validation. Validation study of CFD in DesignBuilder software was done by compared with field measurement data, with the deviation ranges from 7.2% to 18%. The optimizations of solar chimney cross section were carried out. The results of CFD were observed in order to study the optimized length and width gap of solar chimney that could induce optimum air velocity and thermal performance in the indoor environment. The results show that the effective width gap for 36m³ room ranged from 0.6m to 1.0m while the length from 1.5m to 2.0m, whereby the induced air speed ranged from 0.04m/s to 0.223m/s. Based on the findings, the study has shown that the effective gap and length of solar chimney could increase the air velocity of indoor environment that creates a cooling effect on human body, especially for terrace house in Malaysia climate.

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Keywords: solar chimney; natural ventilation; thermal performance; CFD simulation

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1. Introduction

Occupied spaces in buildings need fresh air for ventilation in order to eliminate the air pollutants. There are two types of ventilation, where the fresh air could be supplied either via mechanical ventilation systems or natural ventilation strategies. Recent years, the latter strategy has become the highlight in the building industry, where most of the developers and designers have switched their direction on architectural perspective towards building performance as well as appreciation towards the environmental factors, such as daylighting and natural ventilation.(Jörn von Grabea et al., 2014) One of the reasons could be stated by the fact that the application of passive strategies in architecture could reduce carbon footprint and to reduce the urban heat island, as well as the release of carbon dioxide to the environment.

The literature stated above have researched on varies of design and configuration of solar chimney in order to refine the function. Therefore, this study is intended to investigate the influence and effectiveness of the solar chimney on thermal performance of existing terrace house without solar chimney in hot and humid climate via application of CFD simulation. In order to investigate the effectiveness of the solar chimney to the existing house, two objectives have been figured out as follows:

- To investigate the thermal performance of the bedroom in existing terrace house under hot and humid climate.
- To scrutinize the effect of introducing solar chimney on the indoor thermal performance.

The field measurement was carried out in a selected single storey terraced house, and the collected data was input into the computer simulation software as boundary condition. The CFD simulation software - 'DesignBuilder' was applied to carry out the modelling and simulation tasks in this study. The validation of the software was carried out by comparing the field measurement result and the simulation result.

1.1. Local climate condition

The case study single storey terraced house is located at Kuching, Sarawak, East Malaysia. Kuching is the capital city of Sarawak state, which is the largest state in Malaysia. Since the topography location of Malaysia is close to the equator, the hot and humid climate is emphasized with the frequent and heavy rainfall as well as long hour of solar irradiance. The yearly average air temperature falls between 32.2°C to 33.89°C while the relative humidity ranged from 57% to 100% throughout the year. The hottest season of the year lasts from early April to end of June with daily maximum temperature above 31.67°C while the coldest season of the year lasts from early December to early of February with minimum air temperature of 22.78°C. Kuching received shortest hour of daylight during 21 December and longest hour of daylight at 20 June, which are 12:03 hours and 12:13 hours respectively. In average, Kuching receives only 5 hour of sunshine per day. The wettest times of Kuching are during the North-East Monsoon season, which is started from November to February and the dry season starts from June till August. The rainfall distribution recorded from 185.6mm to 4116.7mm throughout the year. In general, Kuching experiences constant high air temperature and high relative humidity throughout the year accompanied by heavy rainfall as well as low wind velocity.

1.2. Thermal comfort studies in Malaysia

Thermal sensation of the occupants is influenced by the environmental aspects, which are air temperature, relative humidity, mean radiant temperature, air velocity, clothing as well as activity done by occupants (P.O.Fanger, 1970). Amounts of literatures about thermal comfort has been published and proposed by researchers. Producing a standard and universal assessing thermal comfort index to fit some or all of the regulating factors into single index was major concerns of researchers. (Sadafi et al., 2011). In this paper, the thermal comfort determined by air velocity and air temperature, which is indicated at Table 1. Since Malaysia experienced high air temperature that determined the discomfort level, the minimum target thermal comfortair temperature of 29°C and ideal indoor air velocity is 1m/s.

Table 1. Thermal comfort studies in Malaysia

Study	Ambient Air Temperature Range (°C)	Thermal Comfort Range (°C)	Type of Study	Humidity Range (%)	Air Velocity (m/s)
FANGER (P.O.Fanger, 1970)	-	24.5 – 26.5	Climate Chamber	80	0.1
Zain Ahmed (Ahmed, 1998)	24.5 – 28.0	24.5 – 28.0	Field Study	72 - 74	0.3
Abdul Malik (A.Abdul Malik and Young, 1993)	25.5 – 29.5	25.5 – 29.5	Climate Chamber	45 - 90	-
Davis (Mohd Peter Davis et al., 2006)	-	24 - 28	Field Study	-	-
Ministry of Energy, Telecom and Posts Malaysia(Ministry of Energy, 1989)	22.0 – 26.0	22.0 – 26.0	Field Study	-	-
Brooks (Brooks, 1950)	23.0 – 29.0	23.0 – 29.0	Field Study	-	-
ASHRAE (ASHRAE, 2004)	23.0 – 25.0	23.0 – 25.0	Climate Chamber	-	-
Abdul Rahman(Abdul Rahman and Kannan, 1997)	23.4 – 31.5	27.4	Climate Chamber	54 - 76	0.1

Source: Ali, 2004

1.3. Impact of solar chimney length and width gap configuration

The parameters of solar chimney play important roles in enhancing the ventilation of the room, other than external factors such as solar irradiation, air temperature, outdoor wind direction, wind velocity and so forth. The ability of solar chimney to generate induced ventilation is depends on the air flow rate and air speed inside the solar chimney. (Nugroho, 2007) There are numerous of research study on solar chimney length and width gap in order to increase the performance of solar chimney to induce indoor ventilation.

(Bouchair, 1988) mentioned that an optimum chimney length/gap width ratio for the optimum air velocity is necessary. Reverse circulation and turbulence would happen if the solar chimney gap was too big since there was a downward flow of air through the center of the duct. (J. Hirunlabh et al., 1999) has studied Metallic solar wall in Thailand for indoor natural ventilation with 14.5cm air gap and $2m^2$ of surface area which giving the highest air mass flow rate of 0.01 – 0.02 kgs^{-1} . (Zhai et al., 2005) has studied solar air collectors in green house. He found that the natural ventilation air flow rate increases continuously when the channel gap increase from 100mm to 500mm. Exceeding 600mm the air flow will decelerate. The authors also found out that the optimum inclination angle for natural ventilation is 45°. In other paper by (Chen et al., 2003) , he carried out the experiments by using experimental solar chimney model with uniform heat flux on a side of solar chimney wall with different chimney gap-to-height ratio from 1:15 to 2:5 with different heat flux and inclination angle. The results show that the maximum airflow rate could be achieved at inclination of 45° with 200mm gap and 1.5m chimney height. In the solar chimney study for single storey residential building in Malaysia, (Nugroho, 2007) stated that optimum width gap of 1m is recommended for 3.5m solar chimney height. The study reported that the airflow rate increases from $0.001m^3/s$ to $0.03m^3/s$ when the lengths of solar chimney increase from 0.05m to 3m. (Arce et al., 2009) investigated the natural ventilation of solar chimney performance with experiment study in Mediterranean climate. The absorber wall height is 4.5m high, 1.0m wide, 0.15m thick, and 0.3m deep while the glass cover is 0.004m thick. The results show that under solar irradiation of 604 W/m^2, a maximum air temperature of 7°C and the air flow rate ranging from 50 to 374 m^3/h was obtained via the solar chimney. (Bouchair, 1994) has done a complete full scale solar chimney experiment. The solar chimney dimensions were 2m high, 3m wide, 0.1m and 0.4m high inlet, varies depth (0.1m to 1.0m). The solar chimney was part of room of $12m^3$. He reported that the optimal air flow rate can be obtained if the aspect ratio of 1:10 (height/depth) achieved, and inverse flow would happen if the cavity gap is bigger than 0.5m.

Most of the literature reviews have studied the length and width of solar chimney; however there is only few research have studied in tropical climate in Malaysia. This means that study on solar chimney to induce natural ventilation has high potential as research topic especially for the housing in East Malaysia.

2. Research methods

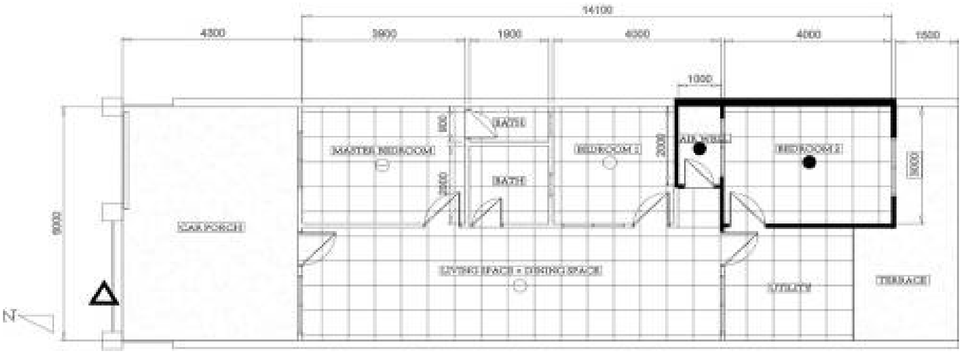

Fig.1. The location of the air well and test room in case study house with position of field measurement point - (Δ) outdoor weather station and (●) indoor air velocity as well as indoor air temperature

2.1. Field measurement

Field measurement has been conducted to investigate the thermal conditions in an existing terraced house in natural ventilated condition. Other than that, the purpose of field measurement is to obtain the real time outdoor weather data as input of boundary condition for the baseline model for CFD work. In this study, DesignBuilder simulation and CFD was applied to construct and run the thermal evaluation of a model for case study house. The room with existing air well with dimension 2m (length) x 1m (width) x 4.5m (floor to outlet height) which attached with the test room (bedroom 2) was modelled. Air temperature and air flow of test room 2 were measured with HOBO U12 data logger which placed 1.5m from floor level, while the HOBO U30 weather station placed 2.0m from floor level at case study house compound were used to log the air temperature, air humidity, air flow and solar irradiation since 1.5m to 2.0m is the human sensory height. For validation purpose, the field measurement was carried out from 0:00hr 28 September 2013 to 0:00hr of 29 September 2013. September was chosen as the measurement month since it was the month with most numbers of hourly mean maximum air temperatures and solar irradiation

A low cost single storey terraced house with built up area of 82m² was selected as the case study. Figure 1 shows that the house consists of three units of bedroom, a living cum dining space as well as utility. Bedroom 2 was selected as test room since it is attached to the air well. The front façade of building openings are oriented towards North direction. The case study house partitioned with two 230mm plastered thick party wall while the internal with thickness 150mm was plastered both side and 200mm thick external wall. The U-value of the wall is about 0.5 W/m²K. All the window are single clear glazed sliding windows (1.5m x 1.2m, and 0.9m above the floor) except bedroom 2 which attached to the solar chimney, which is fitted with glass panes louvers window (1.5m x 1.2m, 0.9 above the floor). The single layer clear glass pane window with U value 1.22 W/m²K which installed in case study room (3m x 4m with ceiling height 3m) is facing south and the solar chimney (0.5m x 2m x 8m height) is attached on the north wall of the room. Clay tiles are utilized as the roofing material with U value 6.16 W/m²K. There is no insulation material occupied for both walls and roofs for heat transmission. Figure 2 indicated the location of monitoring points for CFD (A to D). For field measurement, only point A will be investigated for software validation purpose. The existing air well served for ventilation opening, however without the aids of glazing to heat up the upper zone there is no induced ventilation happened. The dotted line in Figure 2 indicated the proposed chimney, which will be the objective of study. The maximum extended air well part can go to 2.1m above roof level limited by the local authority regulation, and the south oriented extended part is modeled with glazing in order to function as solar chimney.

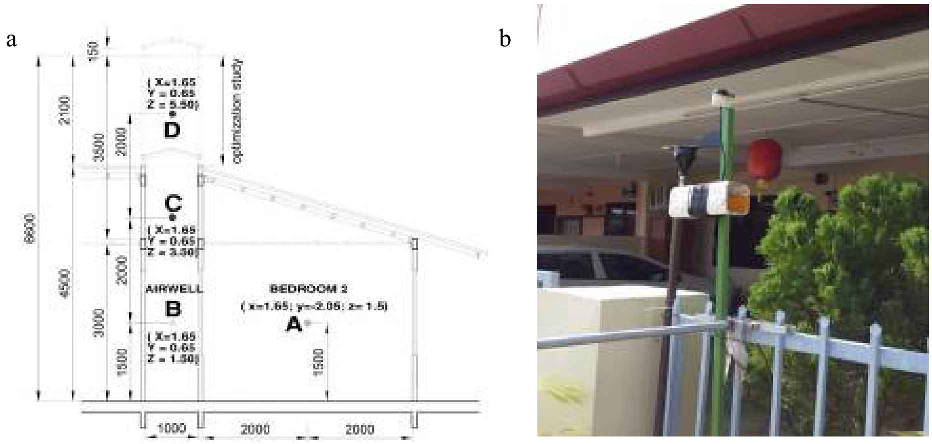

Fig. 2. (a) Position of monitoring points for test room and solar chimney (B&C points indicating the existing air well while point D indicates the proposed solar chimney to enhance the air well for stack ventilation purpose; (b) Field measurement for outdoor weather condition (solar radiation, air temperature, relative humidity and wind velocity)

Table 2. Field measurement data for validation and boundary condition of simulation

Time	**Weather Station HOBO U30**					**Test Room 2 HOBO U12**	
	Air temperatu re (°C)	**Humidity (%)**	**Wind speed (m/s)**	**Solar irradiation (W/m²)**	**Wind Direction (°)**	**Air temperature (°C)**	**Wind speed (m/s)**
6:00	23.65	100	0.02	5.93	74.4	23.48	0
7:00	23.87	100	0.01	153.13	74.4	23.51	0
8:00	24.12	94	0.51	380.95	74.75	23.90	0.02
9:00	25.67	80	0.08	551.85	74.05	24.91	0
10:00	28.12	84	0	797.83	68.8	25.48	0
11:00	30.12	75	0	854.08	47.375	25.80	0
12:00	30.36	72	1.1	866.25	50.9	26.11	0.42
13:00	31.82	75	0.7	545.63	181.475	26.36	0.03
14:00	34.35	59	1.0	859.71	297.275	26.66	0.66
15:00	33.71	77	0.4	363.75	100.375	26.94	0
16:00	34.92	59	1.3	149.38	168.45	27.16	0.22
17:00	32.44	71	0.5	20.12	290.275	27.83	0
18:00	30.98	94	0.5	2.22	57.575	28.95	0
19:00	29.42	94	0	0.67	113.025	28.44	0

2.2. CFD simulation

CFD simulation plays an important role in this study, since the final results of simulation on the virtual environment represent the actual environment results. Hence, the validation of software based on the field measurement is necessary in order to justify the software results accuracy in simulating the actual environment. DesignBuilder was used in this study, and some literature (Mohammad Baharvand et al., 2013, Bangalee et al., 2013, Leng et al., 2014, Dragicevic et al., 2013) has applied and validated that this CFD simulation software is reliable. DesignBuilder was developed by EnergyPlus which is the U.S.DOE building energy simulation program to model and examine the performance of building such as ventilation, cooling, heating, energy flow and so forth (DesignBuilder, 2014). In this study, the scope of experiment concentrates on the air well and the test room. Thus, in order to reduce the model complexity, simulation running time, and increase the accuracy of results, the study spaces were modelled and enclosed with a layer of adiabatic component at the external part of the room.

DesignBuilder applied domain-decoupled technique where the indoor air and outdoor airflow fields happened separately. (Jiru and Bitsuamlak, 2010) In the setting mode, in order to carry out natural ventilation, it's preferred to use "calculated" over "scheduled" since the "infiltration" level is high. CFD in Designbuilder applied Cartesian type-grid system. In this study, the total amount of cells generated from this grid system is 32 numbers (x-direction) x 49 numbers (y-direction) x 51numbers (z-direction) with max ratio 14.83. The calculation in CFD applied the standard k-ε turbulent model with 5000 iterations.

2.3. Boundary condition for optimization

Investigation of the model configurations based on a fixed boundary condition is necessary in order to examine the effectiveness of solar chimney configurations. In this study, hourly weather data in Kuching (year 2013) was analyzed. Figure 4 and figure 5 indicated 34°C was the maximum air temperature that happened most frequent especially in 22nd of September, which is the Equinox time. Meanwhile, for solar irradiation, 988W/m² was the maximum value of the year and it happened most frequent at September too. The wind speed measured at 10m height for 22nd September 2014 is 2.6m/s with relative humidity 59%. Both can be ignored since the meteorological data was measured on 10m from ground level. The conversion of the wind speed value with power law to human level would cause little or no effect since the converted wind velocity is within 0m/s to 0.5m/s, which is considered as static or no air movement.

3. Results and discussion

3.1. Field Measurement

The field measurement results were analyzed in order to obtain the macroclimatic and microclimatic condition of the existing site. The site of field measurement located at Kuching, Sarawak, and East Malaysia. Malaysia experienced hot and humid climate throughout the year. Furthermore, the country experienced Monsoon season twice a year which caused heavy rainfalls. According to table 3, the maximum air temperature happened at 16:00hr, which is 34.92°C while minimum air temperature happened at 06:00hr, which is 23.65°C. In the same hour, the highest air humidity with value 100% happened at the time with lowest air temperature while the lowest air humidity, 59% at the hottest hour. In general, according to Malaysia meteorological department, the maximum mean air temperature in Kuching could reach 32°C to 35°C while the air humidity ranged from 62% to 100%. (Malaysia, 2013) The highest value of solar irradiation of the day recorded as 866.25W/m² at 12:00hr while the maximum record from the national data recorded as 1038W/m².The overview of the air temperature, relative humidity and solar irradiation considered as viable data since the deviation of the field measurement and the metrological department recorded less than 16.5%. For air velocity, which measured 1.5m and 2m from the ground at test room and outdoor respectively, was ranged from 0m/s to 1.30m/s while the test room ranged from 0m/s to 0.66m/s. The statement thus proven that air movement in the terrace house is considered low and static, which caused thermal comfort problem to occupants. (Hui, 1998)

3.2. Comparison between simulation and field measurement results

The field measurement results were extracted and compared with the simulated results. For comparison purpose, only the daytime results (0600 to 1800hr) were compared since in this study, the effect of solar irradiation plays important role in regulating the indoor air temperature. Furthermore, the purpose of the comparison is to find out the deviation between the two results.

Figure 4, 5 and 6shows a good agreement between field measurement and CFD simulation results. The percentage differences of the results ranged from 0.44% to 1.49% for indoor room temperature while the average air temperature deviated between 0.4 to 1.5°C. In the case of air velocity, the percentage differences of measured data and CFD simulation data ranged from 7.2% to 18%. In Figure 4 and 5, the regression squared between the simulation and field measurement for test room air temperature and air velocity results shows value of 0.9534 and 0.9274 respectively. Both values are close to 1, in the other words mean that the similarities for both parameters result are very high. According to (Nugroho et al., 2007) although there are slightly differences between the CFD simulation data and measured data set, it can be deduced that CFD simulation can reproduce the similar conditions occurred in the field measurement. This can be seen from Figure8that the graph pattern fluctuated in the same trend. The use of CFD model to investigate the building thermal and ventilation performance is thus validated.

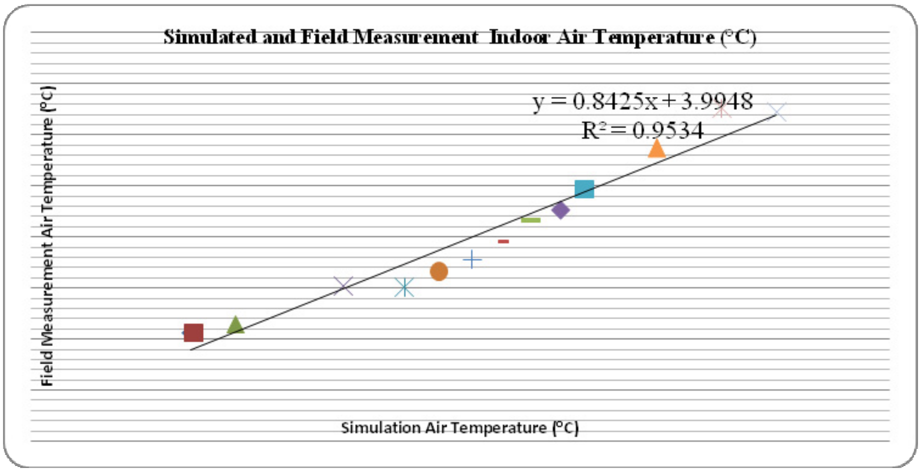

Fig.3. The simulated indoor air temperature shows close relationship with the field measurement results, with regression squared value of 0.9534, which is near to 1.

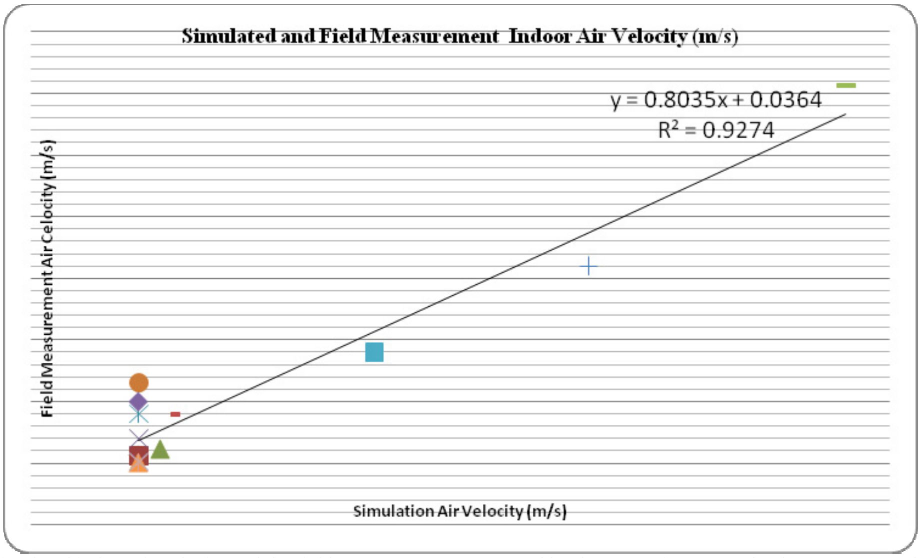

Fig. 4. The simulated indoor air velocity and the field measurement represented by the regression squared value of 0.9274, which is near to 100% similar result. This means that DesignBuilder is reliable and viable software to simulate indoor ventilation performance in Malaysia.

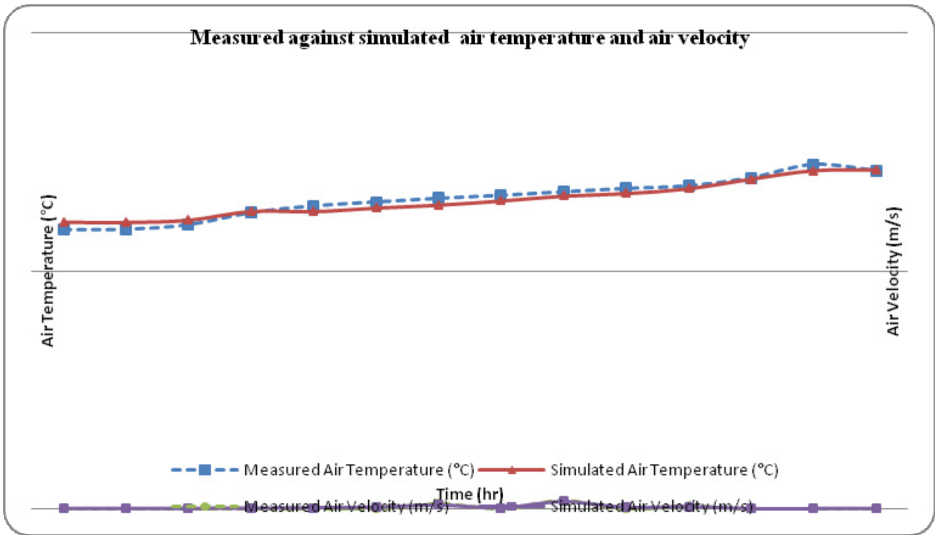

Fig.5.The comparison between results from simulation (DesignBuilder) with the field measurement.

3.3. Optimization of solar chimney

The solar chimney cross section optimization was divided into two phases, which are width gap optimization (width gap hereby means the dimension of innershaft/ air well) and length (length of the inner shaft/ air well) optimization. In the preliminary test, the existing length of the case study house air well was fixed (2m) and varies of width gap (0.2m, 0.3m,0.6m 1.0m and 1.5m) were tested with the validated CFD software. Air flow in (from room's external window), air flow out (air well roof opening), indoor air velocity, indoor air temperature as well as outdoor and indoor air temperature differences were recorded as shown in Table 3 and Table 4. Same procedures were repeated to investigate solar chimney length, the results were shown in Table5and Table6.

For the optimization of width gap, varies solar chimney gap size were tested. According to the observation results, solar chimney air density increased with the width gap. However, the smaller gaps (0.2m to 0.6m) give more significant results compared to the big gap from 1.0m onwards. It can be seen that the air density flow in and out increase 40.8% from 0.2m to 0.3m and 42.8% from 0.3m to 0.6m while only 2.8% of air density increment from 1.0m to 1.5m. However, from Table3, 1.0m gap gives the greatest differences between air flow in and air flow out, which means the suction of air, happened significantly in the existing gap, where the differences of 0.4m³/s occurred. For the indoor air velocity and air temperature as in Table 4, the air velocity increase averagely 63.61% from gap 0.2m to 1.0m, and the increase of the value start to become constant after 1.0m, from 63.61% to 18.46%. This means that larger width gap is preferable to induce air suction and increase air velocity. However, the width gap larger than 1.0m is not giving much effect of air suction. It should be noted that the air flow rate was independent to the air velocity. Hypothesis above is supported by (Nugroho, 2007), where the optimum air gap for 3.5m height solar chimney is 1m, under tropical climate in Malaysia.

Table 3. The air flow in (external window) and air flow out (solar chimney outlet) resulted from 0.2m, 0.3m, 0.6m, 1.0m and 1.5m solar chimney width gap

Solar Chimney Width Gap (m) (fixed parameter: 2.0m length)	**Air Flow In (m²/s)**	**Air Flow Out (m²/s)**
0.20	0.3563	0.3562
0.30	0.6021	0.6019
0.60	1.0524	1.0523
1.00 (existing air well gap)	1.0498	1.4632
1.50	1.0763	1.0759

Table 4. The indoor air velocity, air temperature and temperature differences from outdoor temperature caused by 0.2m, 0.3m, 0.6m, 1.0m and 1.5m width gaps of solar chimney.

Solar Chimney Width Gap (m) (fixed parameter: 2.0m length)	Indoor Air Velocity (m/s)	Indoor Air Temperature (°C)	Air Temperature Differences (Outdoor and Testroom)(°C)
0.20	0.008	32.55	1.45
0.30	0.141	33.56	0.44
0.60	0.347	33.87	0.13
1.00 (existing air well gap)	0.552	33.95	0.05
1.50	0.677	33.96	0.04

In the second phase of optimization, 1m of solar chimney width gap was chosen. There are six types of solar chimney length, which are 0.2, 0.3, 1.0, 1.5, 2.0 and 3.0m were chosen in this case (Table 4). The lengths were varies according to the room length (3.0m). According to Table5,in generally air flow out increase when the length of solar chimney increase, which means the suction happened in the solar chimney and increase the air flow speed, other than infiltration. In Table 6, the lengths below 1.0m give the insignificant speed, which is 0.031m/s and 0.029m/s for 0.2m and 0.3m respectively, whereby 1.0m to 1.5m give almost double speed, from 0.291m/s to 0.444m/s. The indoor air velocity increases continuously from 2.0m to 3.0m, with value 0.552m/s and 0.691m/s. The increment percentage of 20.12% from 2.0m to 3.0m has proven that the larger size of solar chimney, the higher air flow speed. In term of air temperature, the larger size of solar chimney gives little or no different temperature deviation from outdoor temperature since it maximizes the solar irradiation when the size increased. As in Table6, 0.2m gives the temperature differences of 1.88°C, which is the greatest value among all. The significant of temperature deviation reduce significantly from models 1.5m to 3.0m.

Table 5. The air flow in (external window) and air flow out (solar chimney outlet) resulted from 0.2m, 0.3m, 1.0m, 1.5m, 2.0m, 3.0m solar chimney length.

Solar Chimney Length (m) (fixed parameter: 1.0m width)	Air Flow In (m^2/s)	Air Flow Out (m^2/s)
0.2	0.2151	0.1791
0.3	0.3205	0.3205
1.0	0.8787	0.8786
1.5	1.2124	1.2123
2.0 (existing air well length)	1.0498	1.4633
3.0	1.2691	1.7754

Table 6. The indoor air velocity, air temperature and temperature differences from outdoor temperature caused by 0.2m, 0.3m, 1.0m, 1.5m, 2.0m and 3.0m length of solar chimney.

Solar Chimney Length (m) (fixed parameter: 1.0m width)	Indoor Air Velocity (m/s)	Indoor Air Temperature (°C)	Air Temperature Differences (Outdoor and Testroom) (°C)
0.2	0.031	32.12	1.88
0.3	0.029	33.06	0.94
1.0	0.291	33.84	0.16
1.5	0.444	33.93	0.07
2.0 (existing air well length)	0.552	33.95	0.05
3.0	0.691	33.98	0.02

Table 7. The airflow and air density of varies solar chimney section at monitoring point A,B, C and D as shown in figure 2

Size of Solar Chimney (Length(m) x width (m)) & air velocity produced (m/s))	A	B	C	D	Air Volumetric Flow Rate of Test room(m^3/s)	Air Temperature Differences (Outdoor and Testroom (point A)) (°C)
1.5L x 0.6W	0.046	0.104	0.54	0.499	0.3985	0.98
1.5L x 1.0W	0.223	0.204	0.432	0.282	0.6084	0.88
1.5L x 1.5W	0.229	0.327	0.066	0.07	0.7980	0.84
2.0L x 0.6W	0.1	0.172	0.155	0.45	0.5188	0.87
2.0L x 1.0W	0.244	0.282	0.362	0.299	0.7472	0.81
2.0L x 1.5W	0.301	0.456	0.121	0.192	0.9231	0.79
3.0L x 0.6W	0.208	0.187	0.526	0.387	0.7083	0.77
3.0L x 1.0W	0.338	0.413	0.203	0.247	0.9269	0.73
3.0L x 1.5W	0.396	0.526	0.297	0.275	1.0520	0.72

3.4. Proposed solar chimney cross-section geometry

The discussion of the results in this simulation section referred to the basic cross section of the solar chimney without modifying on the existing house and solar chimney's orientation and height of solar chimney (3.5m). All models used the thickness of brick wall (0.15m) with both side plastered. Four monitoring points (A, B, C, and D as shown in Figure 2) were selected and the air volumetric flow rate of test room, air velocity and outdoor and indoor air temperature differences were observed as shown in Table7. Throughout the solar chimney configuration simulation tests, the highest value for air flow rate is 1.052m^3/s while the highest value of air velocity at living zone (monitoring point A) is 0.396m/s. Both highest value contributed by 3.0L X 1.5W. Although the largest cross section of solar chimney gives the highest value but the temperature differences is the least, which is 0.72°C. In additional, according to Figure9, the trend of air velocity for 3.0L x 1.5W is moving downwards, which means that the air velocity reduced along the way from monitoring point A to D. The reduction of air velocity from A to D shows that the suction pressure reduced, which do not fulfil the function as buoyancy induced ventilation tool. According to Figure 10, the 1.5L x 0.6W experienced the suction effect, since the air velocity increased from 0.046m/s (A) to 0.499m/s (D) while 1.5L x 1.5W experienced the reverse results, with high velocity at point A with value 0.229m/s to 0.07m/s at point D. Although 3.0L x 1.5W initiated with the high air velocity of 0.396m/s at point A, however, the air velocity reduced 43.5% after point B, from 0.526m/s to 0.297m/s. This shows that the large cross section of solar chimney reduce the suction effect of solar chimney. Furthermore, 1.5L x 1.5W giving the lowest suction effect since the air velocity at point C and D shows the lowest value out of overall, which are 0.066m/s for point C and 0.07m/s for point D. This means that smaller width gap with longer length give better suction effect. The suction effects decrease from shorter length to longer length, whereby air velocity decreased as the width gap increase.

The air velocity obtained from the simulation for 1.5L x 0.6W, 1.5L x 1.0W, and 2.0L x 0.6W experienced significant stack effect compared to the original air well as shown in Figure 9. The internal of solar chimney also experienced suction effect since the air velocity increase from bottom gradually. Three models give the results of air movement in living zone (A) with values 0.046m/s, 0.223m/s and 0.1m/s respectively. The improvement of the test room (A) air velocity three stated models ranged from 93% - 98.6%. Although the induced indoor air speed is not considered as high as the reversed flow model, however, the mechanism of the solar chimney has been inferred. Reversed air movement from solar chimney opening towards indoor room brings down hot air with high air temperature which caused discomfort to the occupants. Even though the air velocity is high, the width gap and length which has caused the effect should be avoided, namely 3.0L x 0.6W, 3.0L x 1.5W and 2.0L x 1.0W with high air velocity at point D and low outdoor-indoor air temperature differences compared to 1.5L x 0.6W, 1.5L X 1.0W and 2.0L x 0.6W.(Table 7)

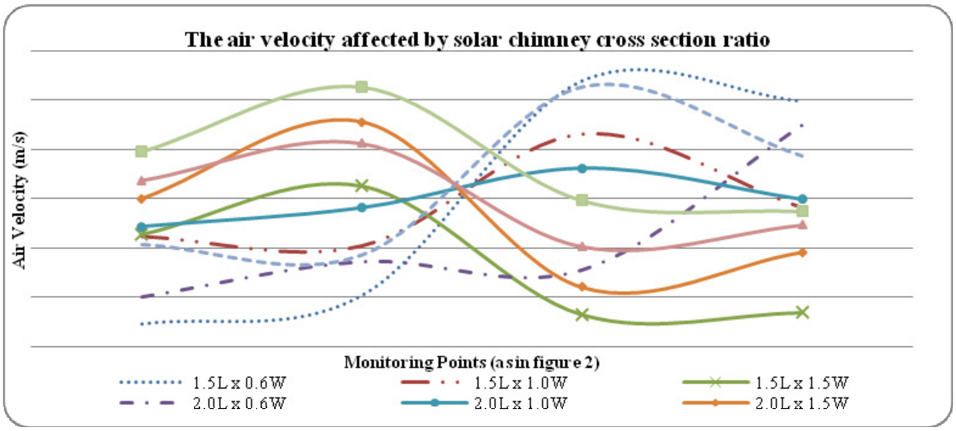

Fig.6. The air velocity induced by the varies of solar chimney section at monitoring points (as in figure 2)

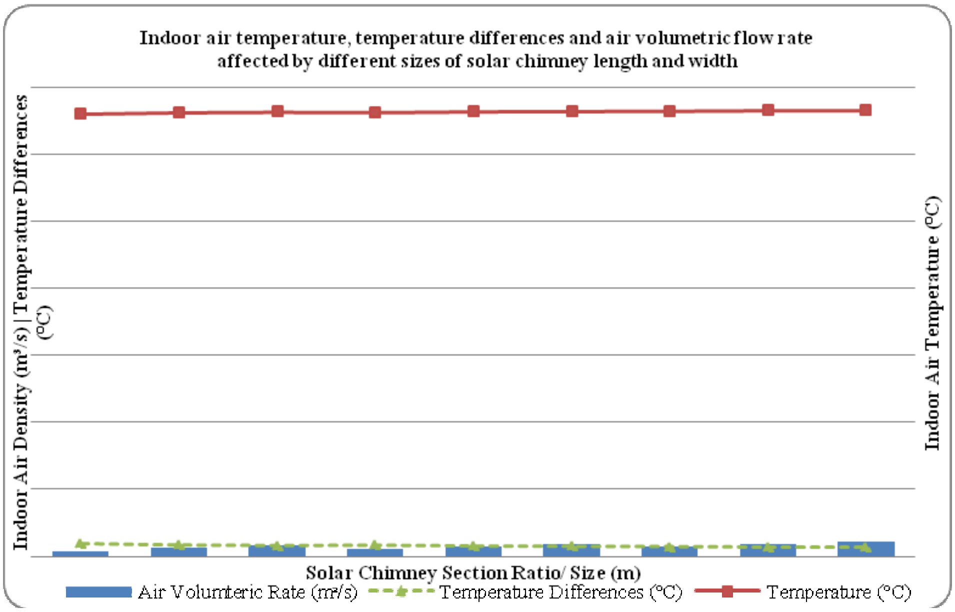

Fig.7. The indoor air temperature, temperature differences and air volumetric flow rate caused by different sizes of solar chimney length and width

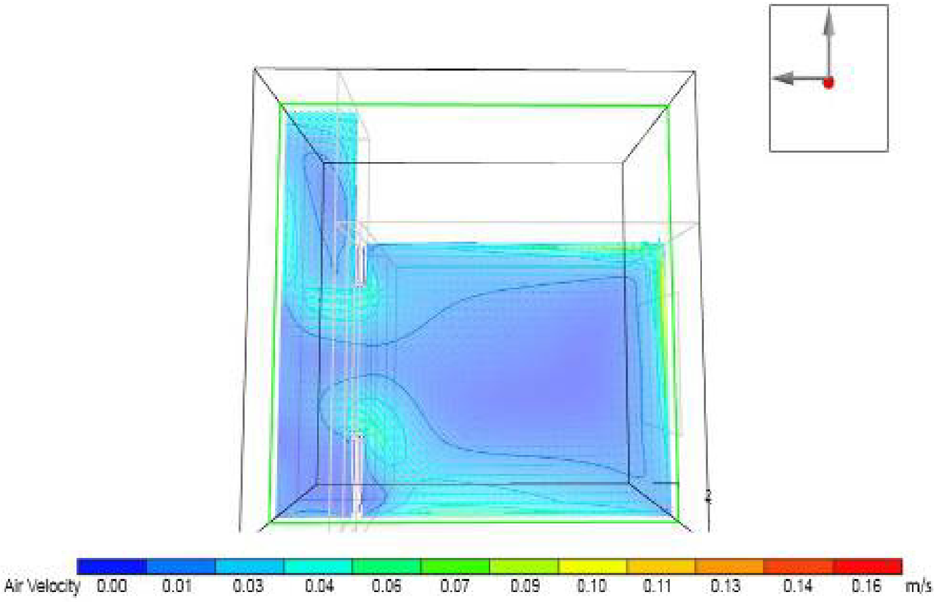

Fig.8. Air velocity of CFD slices for the existing air well in the case study house.

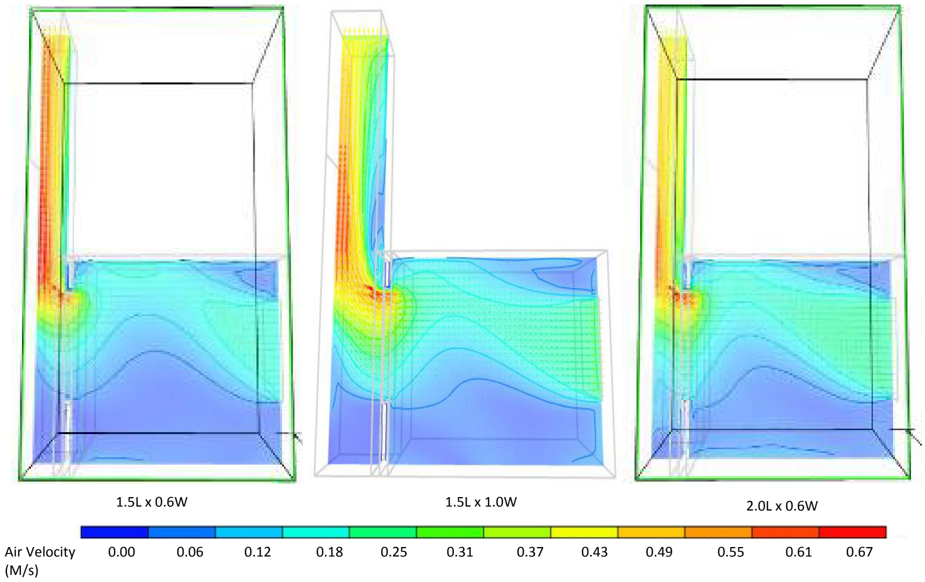

Fig.9. Air velocity of CFD slices for the selected models. The smaller the width gap the better the air suction effect .The shorter length gives better stack ventilation. The optimum width and length of solar chimney affects the wind velocity for the indoor environment.

4. CONCLUSION

The solar chimney width gap and length plays an important role in stack ventilation performance. The chimney height, width gap and length have a direct relationship with the output of air speed of indoor room. In this study, the air well height was extended to the maximum fixed level of roofing (2.1m) while the width gap and length of air well were studied in 9 varies combinations based on the original air well size: 1.5L x 0.6W, 1.5L x 1.0W, 1.5L x 1.5W, 2.0L x 0.6W, 2.0L x 1.0W (original air well), 2.0L x 1.5W, 3.0L x 0.6W, 3.0L x 1.0W, 3.0L x 1.5W. Under the weather condition of maximum outdoor air temperature 34°C and solar irradiation of 988W/m², the air velocity obtained from the simulation for 1.5L x 0.6W, 1.5L x 1.0W, and 2.0L x 0.6W experienced significant stack effect compared to original air well (2.0W x 1.0L). The maximum outdoor-test room air temperature differences of original air well 2.0W X 1.0L and enhanced solar chimney (1.5W X 0.6L)shown 17.35% improvement while for the air velocity, the maximum growth of solar chimney with stack flow could reached as high as 93% to 98.6% compared to the original air well. No reverse flow observed up to 2m length and 0.6m width gap cross section of solar chimney.

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