Implementation of Solar Chimney in Orang Asli Settlement in Bukit Lagong, Selayang

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Abstract. In compliance with the Malaysia Housing Policy, providing adequate, affordable and quality housing for all is the major goal. The case study house for the study is in the existing settlement for Indigenous people located at Bukit Lagong, Selayang, Kuala Lumpur which was built under the 7th Malaysia Plan (1996-2000). However, the poor thermal performance of the existing house does not satisfy the occupants and cause most of the occupants rather carrying out the daily activities outside the house during the daytime. A field measurement was carried out from 12am of 4 March 2011 to 11pm of 5 March 2011 in order to obtain the real-time data and compared with the CFD simulated result. The experiments followed by introducing solar chimney at the simulation model and examine the result of the thermal performance. The findings show that the thermal performance of the mean air temperature and mean air velocity of the indigenous house has been improved after introducing solar chimney by 2.6% and 15% respectively at the hottest hour compared to the measurement results. This has shown that the solar chimney is useful and functions as the stack ventilation tool in the tropics.

Introduction

The housing for poor project (Projek Perumahan Rakyat Miskin Tegar – PPRT) was introduced under 7th Malaysia Plan since 1996. Under this policy, Orang Temuan settlement in Bukit Lagong, Selayang has been resettled and reorganized into single storey concrete house. However, the provisioned concrete house do not achieved the minimum accepted mean neutral temperature in the tropical climate, which ranged between 23.3°C to 29.2°C [1-4] while the comfort mean air velocity from 0.2m/s to 0.4m/s [5] In order to improve the thermal performance of the settlement, the solution has to be environmental friendly, cost efficient, applicable to existing building especially low-rise building, cost-free or low maintenance. Passive strategy is one of the most effective methods to induce the natural ventilation and increase the thermal performance of the building. This paper intended to provide an alternative to enhance the thermal performance of the settlement with solar chimney via field measurement and Computational Fluid Dynamic (CFD) simulation.

Application of Solar Chimney

Solar chimney has been widely recognized as the passive ventilation tool for centuries especially in Europe, Middle East and North East[6]. The early stage of solar chimney is used for space heating only and the concept was proposed by Trombe and Michel [7]. There is various form of solar chimney which is modified and integrated according to the solar position and building orientations, for instance: Trombe wall, vertical solar chimney, roof solar chimney, roof solar collector and so forth. [8-10]

The advantages of solar chimney have been scientifically proven by researchers all over the world. [11-13] Researchers have put the effort into the research on solar chimney configurations, the material, typologies, integrated solar chimney in order to discover the better alternative for natural ventilated building. Khedari et al. has reported that the average daily consumption of electricity in the air-conditioned building was reduced by 10-20% with the integration of 14cm air gap solar chimney with CPAC monier concrete in a 25m^3 single room installed with 1 tonne split unit HVAC. [14] Bansal et al. has researched on the absorber area optimization area of solar chimney for a 16m^3 single room.

The result shows that 2.25m^2 optimum absorber areas could produce 0.233m/s air velocity for the indoor room. [15] The first numerical modeling for the solar chimney in Trombe wall form was design by Bansal et al. in 1993. He has proven that the increase of solar irradiation would increase the air flow. [15] Other than that, J. Marti Herrero and M.R. Heras Celemin has proposed the numerical model to investigate the solar chimney energy performance for 24m height concrete wall as heat absorber and storage surface and the results show that 2m height and 14.5cm width of chimney could produce 0.011kg/s air mass flow rate. [16] Hirunlabh. et al. have studied the performance of the metallic solar wall for solar chimney with the combination of four different height and air gap. [17] Chantawong et al. experimented with the glazed solar chimney wall with size opening 0.05-0.5m^2 with 6mm thick clear glass. The results show that the glazing could induce airflow rate about 0.13 to 0.28m^3/s. [18] Other than numerical model and experimental model, some researchers have utilized the CFD software to investigate the performance of the solar chimney. Bassiouny et al. developed a FORTRAN software programme to solve the numerical modeling. The optimum air flow rate could be achieved via 500W/m^2 solar radiation in an inclined solar chimney with slop 45° to 70° for latitude 28.4° in the solar chimney with width 0.2m to 0.35m gap. [19] Afonso and Oliveira has validated the simulation of solar chimney with measurement and the results were agree with each other. [20] The bulk of precedent researches on the application of solar chimney has lead this research to examine them in term of air velocity and air temperature of Orang Temuan settlement (PPRT) under hot and humid climate in Malaysia. Knowing the alternative solution for the low cost houses and clarifying their thermal performance enabled architects and designers to opt for a better design decision under limited project conditions.

A. Field Measurement

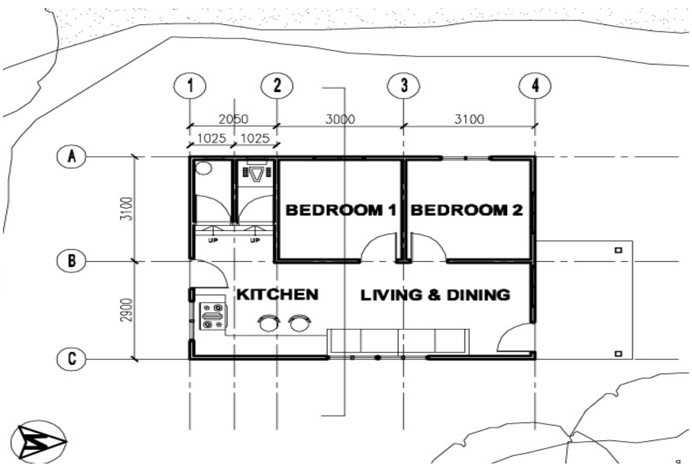

Figure 1: Location of HOBO U30 (X) weather station and HOBO U12 data logger (O)

The authors carried out a field measurement to determine the environmental parameters of the existing Orang Temuan PPRT housing in order to investigate the thermal performance of the house from 1200am of 4 March to 11pm of the mentioned day. The house comprises of 2 rooms and 2 bathrooms while kitchen, living and dining were open plan. The window of the 1st bedroom and living area main entrance is facing towards the north while the windows of the cooking area are facing south. Except for the open plan, both bedrooms are receiving single sided ventilation. All the windows are clear glazing louvres window (1.2m height, 1.2m width and 0.9m from floor level) except bathroom and toilet (0.45m height, 0.6m width and 1.8m from the floor). All the doors and windows remained open when the measurement taken including night time. The roof and walls of the case study house are not come with heat insulation. Furthermore, the building structure comprises of 150mm thick external wall and 100mm thick internal wall with both side plastered while the roofing applied with corrugated cement asphalt sheet. The total U-value for the wall is 0.510 W/m^2K and the roofing material is 0.238 W/m^2K. The measurement instruments included HOBO U30 outdoor weather station and HOBO U12 air temperature and relative humidity data logger. The U30 instruments set has the monitoring sensors for solar radiation, wind velocity, relative humidity and air temperature whule set U12 able to measure the air temperature and relative humidity. The location of the data loggers are stated in figure 1**.**

B. CFD Simulation

The CFD simulation was carried out with the input data from outdoor field measurement from 12am of 4 March 2011 to 11pm of 5 March 2011. Prior to the simulation, the validation of air temperature for CFD has been done by comparing with the field measurement data of case study house. The purpose of simulation is to investigate the air velocity of the case study house that contributes to the thermal comfort other than air temperature. The air temperature and air velocity of the modified case study house which were examined with CFD simulation after the validation and investigation of case study house. Designbuilder was used for the CFD simulation software in this study since it has been validated and the results have proven its reliability[21, 22]. DesignBuilder was developed by Energyplus for ventilation, cooling, heating, energy flows, daylighting, the simulation of CFD, and so forth. The Energyplus is developed by U.S. DOE Building energy simulation program. [23] In this study, the measurement is taken at coordinate X=-1.41, Y= -4.17, Z=1.45 at living space of the case study house with intervals of one hour. The boundary condition for the CFD simulation was taken from the outdoor field measurement from 1200am of 4 March 2011 until 11pm of the day in the case study house. The scope of the study only involves living space where the occupants spend more time to carry out daily activities. A layer of adiabatic components was modeled at the external wall of the model since the thermal condition of the indoor would not be affected by the external climatic condition. Designbuilder applied domain-decoupled technique that separate internal and external airflow. [24] For tropical climate region where ventilation is needed over heating, the “calculated” mode is preferred over “scheduled”, where the calculation of natural ventilation is based on the total air flow in and air flow out from openings. “Infiltration” was set to off mode since it is not involve the mechanical ventilation. The Cartesian type grid system applied in this study comprises of 25 numbers (x-direction) x 72 numbers (y-direction) and 55 numbers of cell (z-direction) with max aspect ratio of 5.236. The CFD calculation applied turbulence model k-Ɛ and 5000 iterations.

Results and Discussion

The outdoor field measurement result plays important roles in setting up the benchmark for indoor field measurement and simulation. According to the outdoor field measurement, the variation of air temperature is maintained within range of 25 to 35°C whiles the humidity decrease when the air temperature increases. The highest air temperature recorded as 30.7°C at 1:00pm while the lowest air temperature recorded as 24.7°C at 8:00pm. The relative humidity is inversely proportional to the air temperature, where the lowest point of humidity73% recorded at the hottest point, which is 1pm. The highest solar intensity recorded at 136Wh/m² at 1:00pm and 3:00pm respectively while the range of wind velocity recorded as 0m/s to 1.83m/s. During daytime, the outdoor wind velocity is less than 2m/s which is hardly has a significant impact in providing the thermal comfort for the house. Thus, buoyancy induced natural ventilation from the temperature differences of indoor and outdoor is one of the strategies to increase thermal performance of the case study house.

According to Figure 4&5, the simulated air temperature and the measured air temperature were closely agreed with each other. The obvious deviation happened on 4am, 1pm and 12am of 4 March 2011. From Figure 5, the overall percentage of deviation not more than 2% to -2%, shows that the software is valid for research. The difference is less than 10% for all the calculated point of air temperature at the case study living space.[12] Although there are slightly deviation between the field measured and CFD simulated results but the fluctuation patterns are within the range of flow. It can be surmise that the CFD simulation is appropriate to regenerate the measurements condition . The use of CFD simulation to investigate the thermal performance in temperature is thus validated.

From the measurement results, the air temperature of case study house ranged between 25.81°C at 7am and 30.02°C at 2pm while the indoor air velocity ranged from 0.003m/s at 10am to 0.057m/s at 9am. When the solar chimney introduce to the case study house, the range of the air temperature ranged from 25.61°C at 8am to 28.31°C at 12pm while the air velocity from 0.003m/s at 5am to 0.076m/s at

6pm. The percentage deviation of the mean air temperature and air velocity between case study house with and without solar chimney are 2.6% and 15% respectively.

The air flow velocities and the air temperature were taken from the monitoring point 1.5m above the floor level. The airflow patterns around the space is observed. According to the results, air ventilation is induced by the solar chimney and the significant increase of 15% of mean air velocities is observed. The changing of air speed is varies according to the solar radiation and wind effect at respective times. The mean air temperature of the indoor with solar chimney marked as 26.62°C, which is 0.72°C lower than the case study house without solar chimney. The mean air velocity of solar chimney space is 0.025 m/s which is 0.004m/s higher than the mean air velocity of non-solar chimney house. Both parameters show the positive results compared to the non-solar chimney house.

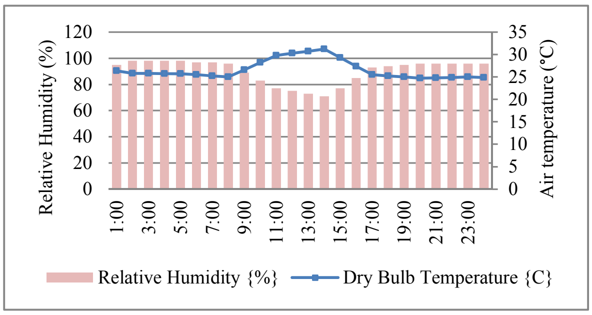

Figure.6: Field measurement: air temperature and relative humidity of Bukit Lagong, Selayang at 4 March 2011

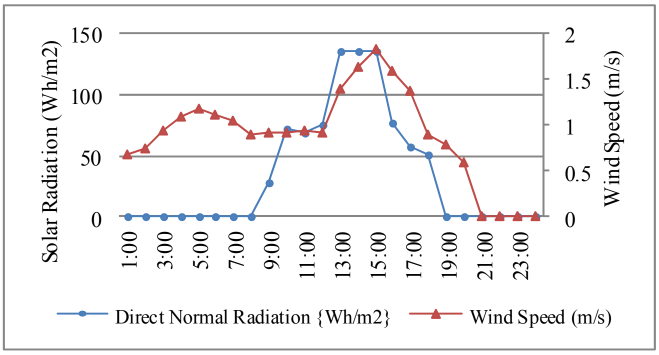

Figure 5: Field Measurement: solar radiation and wind speed of Bukit Lagong, Selayang at 4 March 2011

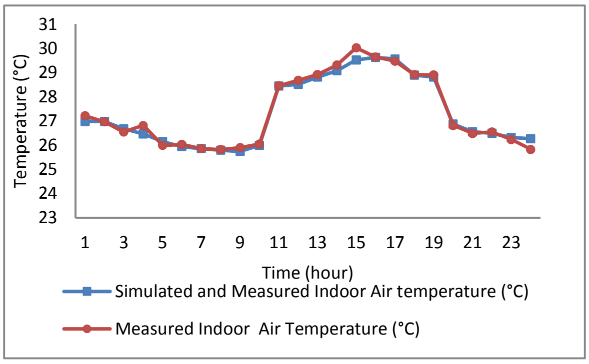

Figure 4: Comparison between field measurement and simulated air temperature of case study house 4 March 2011

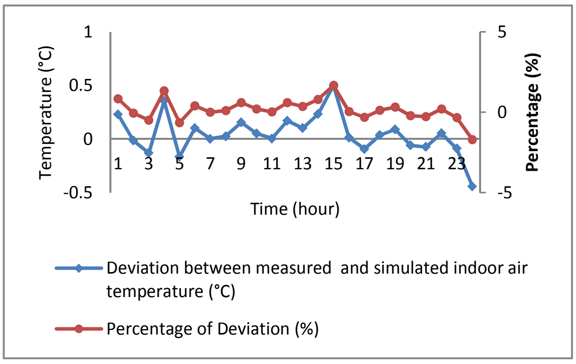

Figure 3: Deviation of temperature between indoor simulated and measured as well as percentage deviation

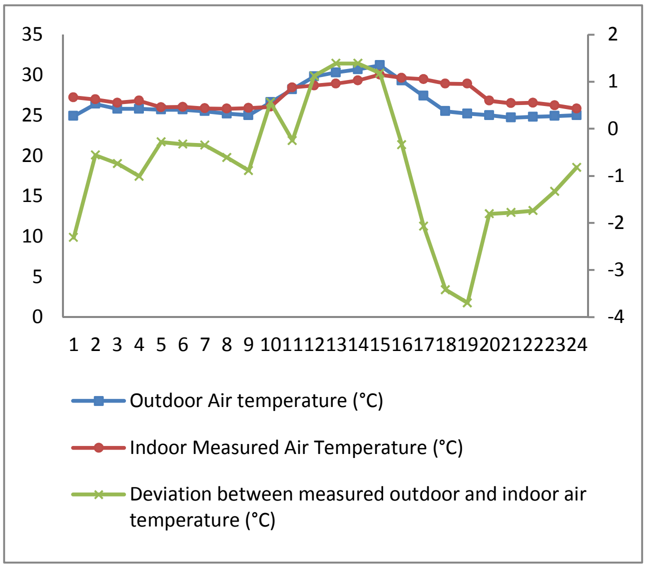

Figure 2: Comparison between measured outdoor and indoor air temperature and deviation

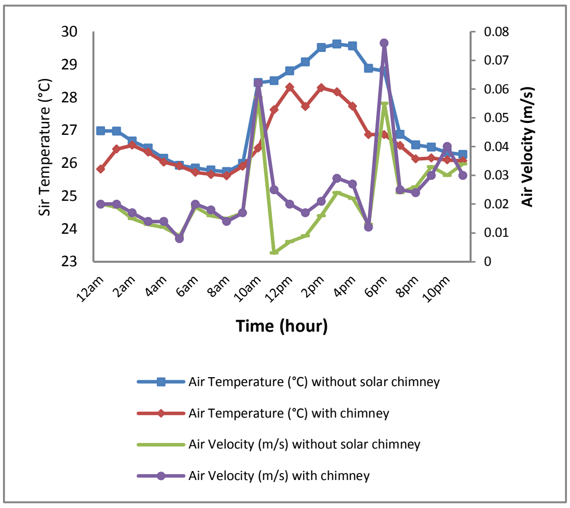

Figure 6: Comparison of air temperature and air velocity between before and after installation of solar chimney via CFD

In the daytime (8am to 6pm), the non-solar chimney house gives the highest value of 29.626°C and air velocity 0.026m/s at 3pm while at the same hour; the solar chimney house gives value at 28.166°C with air velocity 0.029m/s. The percentage of decreasing air temperature of the indoor environment with solar chimney is about 1.46°C and 0.003m/s. Although the cooling effect of solar chimney is relative small, but the enhancement of the thermal performance is proven.

Conclusion

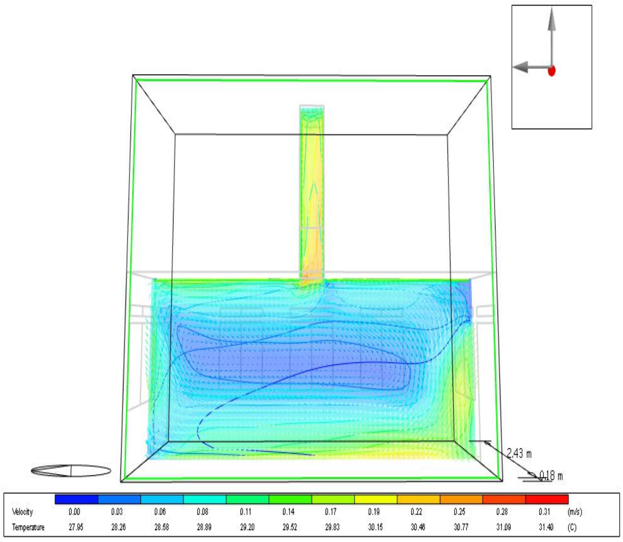

Figure 7: The CFD simulation shows the improved condition with solar chimney

The aim of the study is to shows that the case study house thermal performance can be enhanced via the application of solar chimney. In order to understand the thermal performance, a specific date is chosen to see the thermal performance of the case study house and the effect of solar chimney after installed via CFD simulation. Prior to the investigation, field measurement has been carried out on site from 12am to 11pm at 4 March 2011with HOBOware U12 air temperature and relative humidity data logger at living hall and U30 weather station as benchmarking data set. The simulated air temperature has been validated with the field measurement and both has agreed with each other.

The thermal performance of the original house is inadequate to provide the thermal comfort. The findings shows that the installation of solar chimney can decrease average daily air temperature by 2.6% and mean air velocity of 15% . From the observation, higher air velocity needed in order to increase the thermal comfort level. However, with the use of solar chimney, the air temperature at the hottest point could be reduce and shows that the natural ventilation can be improved. Thus, further experiments are required to determine the optimum configurations of solar chimneygeometry to enhance the natural ventilation of houses in hot and humid climate.

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References

[1] Kwong, Q.J., N.M. Adam, and B.B. Sahari, Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. Energy and Buildings, 2014. 68, Part A(0): p. 547-557.

[2] Mallick, F.H., Thermal comfort and building design in the tropical climates. Energy and Buildings, 1996. 23(3): p. 161-167.

[3] Gail, G.S. and a.R.D. Dear, Thermal adaptation in the built environment: A literature review. Energy and Buildings, 1998(27): p. 83-96.

[4] Tareq G. Farea, D.R.O. Effect of Lightwell Combined with Horizontal Void on Natural Ventilation in an Apartment Building. in Proceedings of 4th International Graduate Conference on Engineering, Science and humanities (IGCESH) 2013. 2013. Universiti Teknologi Malaysia Johor Bahru: Universiti Teknologi Malaysia Johor Bahru.

[5] R.J. de Dear, K.G. Leow, and S.C.Foo, Thermal comfort in the humid tropics: Field experiments in air conditioned and naturally ventilated buildings in Singapore International Journal of Biometeorol, 1991. 1991(34): p. 259-265.

[6] Shiv Lal, S.C. Kaushik, and P.K. Bhargav, Solar chimney: A sustainable approach for ventilation and building space conditioning International Journal of Development and Sustainability, 2013. 2(1).
[7] Wikipedia. Trombe Wall. 2012 14 September 2012 [cited 2014 15 March 2014]; Available from: http://www.wikipedia.or.ke/index.php/Trombe_wall.
[8] Khedari, J., Ventilation impact of a solar chimney on indoor temperature fluctuation and air change in a school building. Jounal of Energy and Buildings, 2000. 32(1): p. 89-93.
[9] Zhai, X., Y. Dai, and R. Wang, Comparison of heating and natural ventilation in a solar house induced by two roof solar collectors. Applied Thermal Engineering, 2005. 25(5-6): p. 741-757.
[10] Hirunlabh, J., Study of natura ventilation of house by a metallic solar wall under tropical climate. Journal of Renewable Energy, 1999. 18(1): p. 109-119.
[11] Wang, L., Design of double skin (envelope) as a solar chimney: Adapting natural ventilation in double envelope for mild or warm climates. 2010, University of Southern California: Ann Arbor. p. 133.
[12] Nugroho, A.M., Solar Chimney Geometry for Stack Ventilation in Malaysia Terrace House, in Department of Architecture. 2007, Universiti Teknologi Malaysia: Malaysia.
[13] Bansal, N.K., et al., Modeling of window-sized solar chimneys for ventilation. Building and Environment, 2005. 40(10): p. 1302-1308.
[14] Khedari, J., N. Rachapradit, and J. Hirunlabh, Field study of performance of solar chimney with air-conditioned building. Jounal of Energy 2003. 28(11): p. 1099-1114.
[15] Bansal, N.K., J. Mathur, and M.S. Bhandari, Solar chimney for enhanced stack ventilation Jounal of Building and Environment, 1993. 28(3): p. 373-377.
[16] D.J. Marti-Herrero and M.R. Heras-Celemin, Dynamic physical model for has solar chimney. Journal of Solar Energy Engineering, 2007. 81: p. 614-622.
[17] Hirunlabh, J., et al., Study of Natural Ventilation of Houses by a Metallic Solar Wall under Tropical Climate. Jounal of Renewable Energy, 2001. 18: p. 109-119.
[18] Chantawong, P., et al., Investigation on thermal performance of glazed solar chimney walls. Solar Energy, 2006. 80(3): p. 288-297.
[19] Bassiouny, R. and N.S.A. Koura, An analytical and numerical study of solar chimney use for room natural ventilation. Journal of Energy and Buildings, 2008. 40(5): p. 865-873.
[20] Afonso, C. and A. Oliveira, Solar chimneys: simulation and experiment. Energy and Buildings, 2000. 32(1): p. 71-79.
[21] DesignBuilder, An Inter-program Analysis of Computational Fluid Dynamics Based on PHOENICS and DesignBuilder Software. 2012, Northumbria University: Newcastle. p. 26.
[22] Mohammad Baharvand, et al., DesignBuilder Verification and Validation for Indoor Natural Ventilation. J.Basic Appl. Sci Res, 2013. 3(4): p. 182-189.
[23] DesignBuilder. Energyplus. 2013 [cited 2013 28 November 2013]; Available from: http://www.designbuilder.co.uk/content/view/29/44/.
[24] Teshome E.Jiru and G. T.Bitsuanlak. Advances in applications of CFD to natural ventilation. in The Fifth International Symposium on Computational Wind Engineering (CWE2010). 2010. Chapel Hill, North Carolina, USA.