Proposal of stack Effect technology for predicted future years

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Abstract. Recently, stack effect is a general problem solver in providing vertical ventilation for urban environmental issues. However, study on resilient technology of stack effect for future years as predicted by climate trend should be conducted. Therefore, this research proposes a design of new technology on operable and adaptable vertical ventilation to the environmental change. The research method is conducted by comprehensive simulation of Ecotect Analysis, ANSYS Fluent and Matlab. Urban environment of Surabaya, as the research location, is the representative of tropical region. The results showed that the stack effect height and area could be modified instantly adjusting the environmental condition time by time in the future years. With 1.8 m of stack width, the proposed technology could capture 40 m^3 of vertical air flow which is useful for physiological cooling and its dimension could be modified depending on the environmental condition. By providing resilient technology, predictable and sustainable ventilation method is offered to anticipate an unpredicted global warming and environmental change.

Keywords: air flow, building technology, stack effect, sustainable design, urban space

1. Introduction

In general, passive control for thermal environment could be distinguished into four basic strategies (Szokolay, 2008): (1) passive solar heating (with 0.5 and 0.7 efficiency), (2) mass effect (summer and winter + for summer with night ventilation), (3) air movement (physiological cooling) effect, for 1 and 1.5 m/s, and (4) evaporative cooling (direct and indirect). For Indonesia, the tropical country, the suitable method could be mass effect, air movement and evaporative cooling. Considering of high both air temperature and relative humidity in tropical climate and material cost, the ventilation development with accelerating of the air movement is the most possible way. The mass effect is very expensive and the evaporative cooling has risk in raising relative humidity. Nguyen and Reiter (2014) reported that natural ventilation and direct evaporative cooling have the similar effect. Natural ventilation is low-cost, easy to apply and provides good indoor air quality, but it relies strongly on natural wind and the building configuration as well as the building location. Prianto and Depecker (2003) explained that the indoor thermal comfort could not be reached by a higher air speed only. The integration between other environment factors and building design elements was required.

If solar irradiance is more than 700 W/m^2, the significance of the ambient air speed will drop (Tan and Wong, 2014). Furthermore, under the tropical weather conditions of high solar irradiance and low ambient air speed, cross ventilation performs better than a solar chimney which is recommended under a zero ambient air speed. In addition, Chungloo and Limmeechokchai (2007) reported that at high ambient temperatures and high solar intensity in the daytime, the solar chimney can reduce the indoor temperature by 1.0–3.5°C compared to the ambient air of 32.0–40.0°C. The velocity magnitude can be increased to 4–25% (Kasaeian *et al.,* 2014). Recently, stack effect is a general problem solver in providing vertical ventilation for urban environmental issues. Resilient technology of stack effect for future years as predicted by climate trend should be conducted. Therefore, this research proposes a design of new technology on sustainable vertical ventilation in future environmental change.

2. Methods

This research utilizes the existing tropical building model, Eco-house building in ITS, as the case study. The research method is conducted by comprehensive simulation of Ecotect Analysis, ANSYS Fluent and Matlab. Urban environment of Surabaya (7.2°S, 112°E, 3 m above mean sea level), as the research location, is the representative of tropical region. The field experiment using anemometer for obtaining wind speed was conducted for simulation input. As shown in Figure 1, the building stack is 1.8 x 1.8 m^2 from 3 storey building with solar penetration potency around the site (open area).

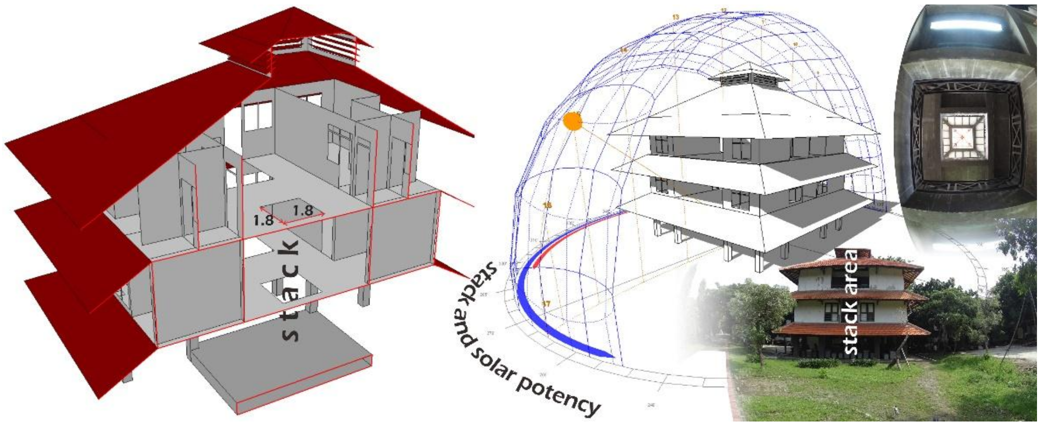


Figure 1. Building model.

3. Discussion

3.1. Environmental condition

The building model was also built in low density terrain roughness (rural) that has changed to sub-urban condition in the current time and potential of becoming urban or city in the future. The reduction of wind speed is about twice slower than before which it gives problem for present psychological cooling (Figure 2). Compared to other location, this research was conducted for critical area, lowland, which has higher wind speed decrease from past to present than highland because of faster change (The lowland condition is *city* terrain roughness while the highland is *urban* or the lowland condition is *urban* while the highland is *sub-urban)*.

Figure 3 shows the climate change, increasing problem for temperature from past to present. Developed from climate data, it describes trend-line equation that could be baseline for predicting future temperature as shown in Figure 4. Based on this climate trend, the temperature tends to increase while relative humidity will decrease continually. It impacts on wind speed and its minimum requirement for physiological cooling for future years. Therefore, Figure 5 provides equation that has the capability in predicting wind speed. Developed from Aynsley et al (1977) and Aynsley and Spruill (1990), 0.3 m/s will be the minimum wind speed that will be utilized for restoring thermal comfort for year 2200 with lower wind speed for its previous years. However, it should be noted that most of all time in tropical environment needs wind speed for thermal comfort indicated by a little number (time) area in ≤ 0 (no need wind speed).

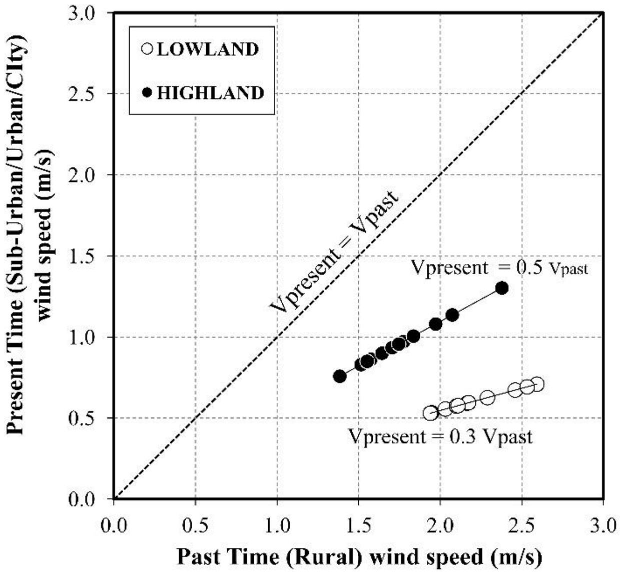


Figure 2. Terrain roughness change effect in wind speed.
(Calculation based on Climate Data from the Center of Meteorology, Climatology, and Geophysics at Juanda and Perak, Surabaya (1997-2012) for Lowland and the Center of Climatology at Karangploso, Malang (1993-2012) for Highland)

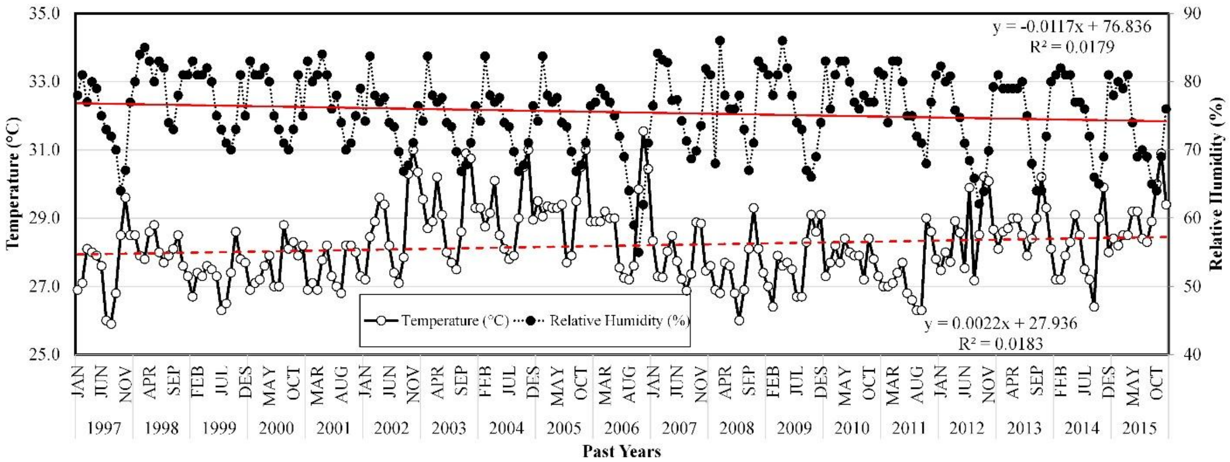


Figure 3. Climate change trend.

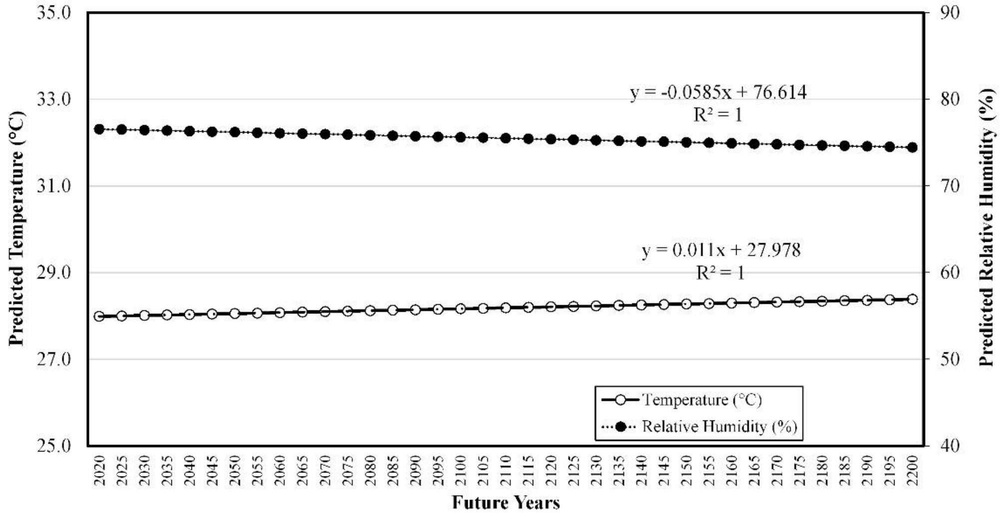


Figure 4. Predicted future temperature.

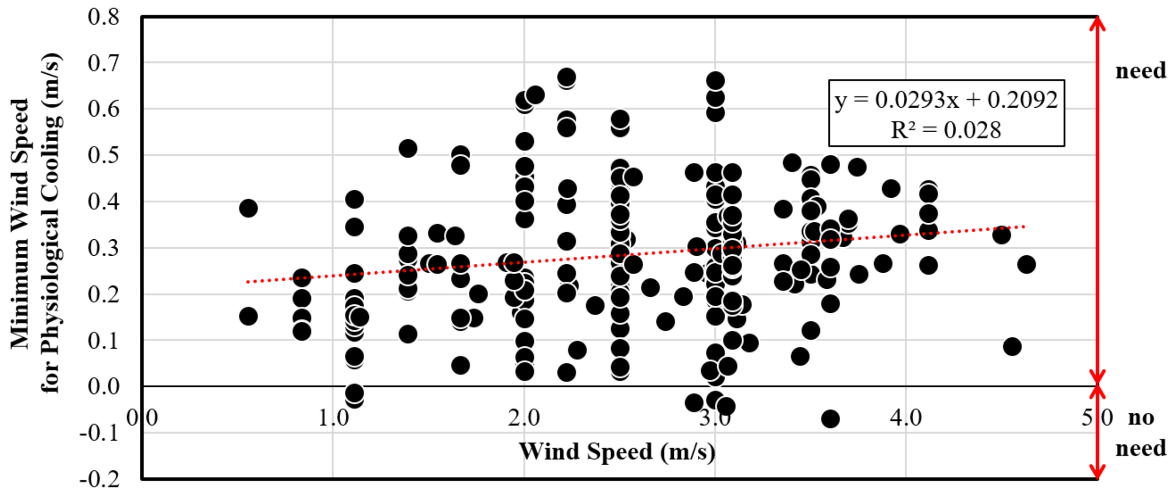


Figure 5. Wind speed and minimum wind speed for physiological cooling.

3.2. Existing building performance

For supporting stack ventilation technology, the building performance should be evaluated. Figure 6 shows the results of Ecotect Analysis simulation for annual solar radiation and its effect on Mean Radiant Temperature (MRT) which is 2/3 of environment temperature in the tropical area (Szokolay, 2008). It could be explained that the building has capability in reducing solar radiation penetration into building through designing sufficient overhang for each floor. Meanwhile, indirect solar radiation effects on the high distribution for MRT while the stack effect could be developed effectively. The building stack has highest MRT for ground floor as the consequence of opened floor. The upper floors, 2^{nd} and 3^{rd} have lower MRT which is good for restoring thermal comfort by vertical ventilation.

The stack environment temperature is relative low because of the roof insulation effect while its roof gets the highest temperature in the hottest time (Figure 7). There is a problem in accelerating wind. The ventilation design does not provide significant indoor thermal comfort because ventilation generates heat gains (Figure 8). The existence of horizontal ventilation results a dilemma in providing ventilation cooling. As illustrated by Figure 9, air movement through space between one room to another room reduces the role of stack effect. As the result, the existing stack ventilation only maintains the inlet air temperature (Figure 10).

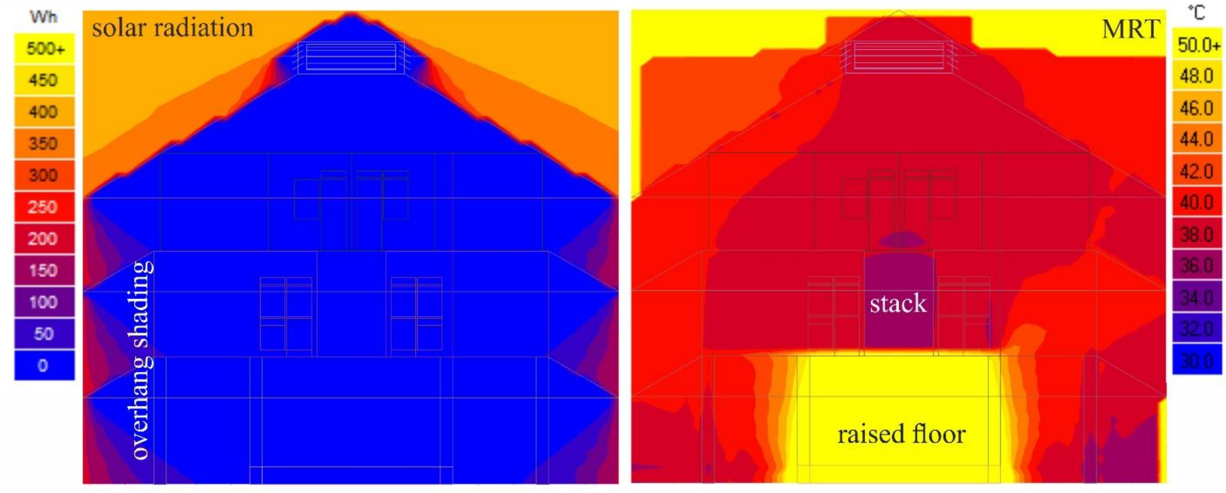


Figure 6. Solar radiation and MRT.

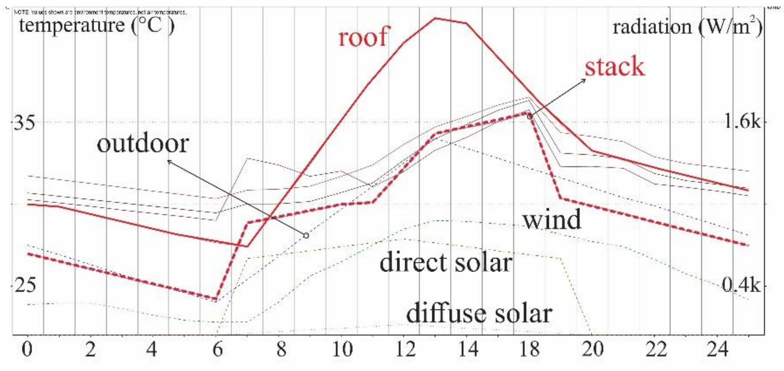


Figure 7. Stack environment temperature in hottest time.

Ventilation Gains - Qv - All Visible Thermal Zones — Surabaya, Indonesia

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	213.319	211.054	219.85	217.888	224.998	214.196	199.783	74.6426	228.734	397.365	380.547	241.449
	332.569	332.386	355.526	331.704	353.433	340.739	335.43	197.859	356.579	562.354	527.74	357.469
22	480.065	462.478	480.567	479.034	509.099	488.306	484.524	329.579	504.796	734.142	683.926	517.593
	633.061	623.01	638.472	636.428	672.914	657.562	656.064	470.133	678.166	917.801	840.568	670.417
20	789.609	776.393	799.232	794.222	852.31	831.981	828.8	655.202	870.64	1101.56	1009.28	828.579
	971.167	953.416	998.939	948.101	1026.15	1006.12	999.349	836.151	1053.9	1279.74	1189.79	996.461
18	1133.36	1101.22	1167.02	1121.86	1169.28	1160.26	1163.9	1007.91	1220.32	1449.42	1365.18	1183.61
	1316.17	1297.92	1345.56	1303.11	1352.62	1348.58	1356.95	1198.61	1403.48	1636.63	1558.7	1371.26
16	1485.33	1496.39	1538.97	1496.73	1552.49	1511.14	1518.56	1370.03	1588.19	1815.86	1750.51	1560.28
	1674.63	1662.42	1724.43	1640.52	1711.13	1677.5	1707.93	1515.41	1749.82	1994.72	1930.54	1766.47
14	1838.83	1855.64	1882.14	1821.74	1877.43	1903.3	1851.11	1668.87	1893.61	2168.25	2096.46	1900.37
	1431.39	1439.3	1442.55	1426.89	1460.42	1441.91	1437.48	1249.82	1469.15	1736.13	1677.41	1460.16
12	1005.78	1007.5	1026.81	998.699	1027.83	1002.48	990.751	824.891	1039.13	1284.45	1245.3	1035.96
	602.729	609.684	617.578	592.018	624.325	595.925	577.021	416.175	622.5	863.855	831.323	643.368
10	262.847	273.747	273.89	260.917	267.775	250.835	233.447	109.031	269.59	467.175	443.515	288.97
	0	0	0	0	0	0	0	0	14.4705	150.31	135.706	10.709
08	0	0	0	0	0	0	-0.325466	-15.3436	0	0	0	0
	-49.1704	-51.4326	-50.919	-44.027	-47.0503	-46.3745	-52.5224	-85.2626	-41.5722	-5.33999	-7.12549	-45.0086
06	-19.6607	-20.3363	-20.1688	-18.7628	-19.4704	-19.8098	-26.6497	-56.6339	-17.3334	0	0	-15.0861
	0	0	0	0	0	0	-2.87911	-27.9002	-1.81088	0	0	0
04	0	0	0	0	0	0	0	-2.54566	0	0	0	0
	0	0	0	0	0	0	0	0	0	53.9872	46.0111	0
02	0	0	0	0	0	0	0	0	22.5131	157.733	147.486	17.3273
	98.1139	97.1923	97.7291	95.1262	102.648	97.2999	75.0089	0.616798	110.356	272.004	259.047	124.642

Figure 8. Ventilation gains and losses (in Watt).

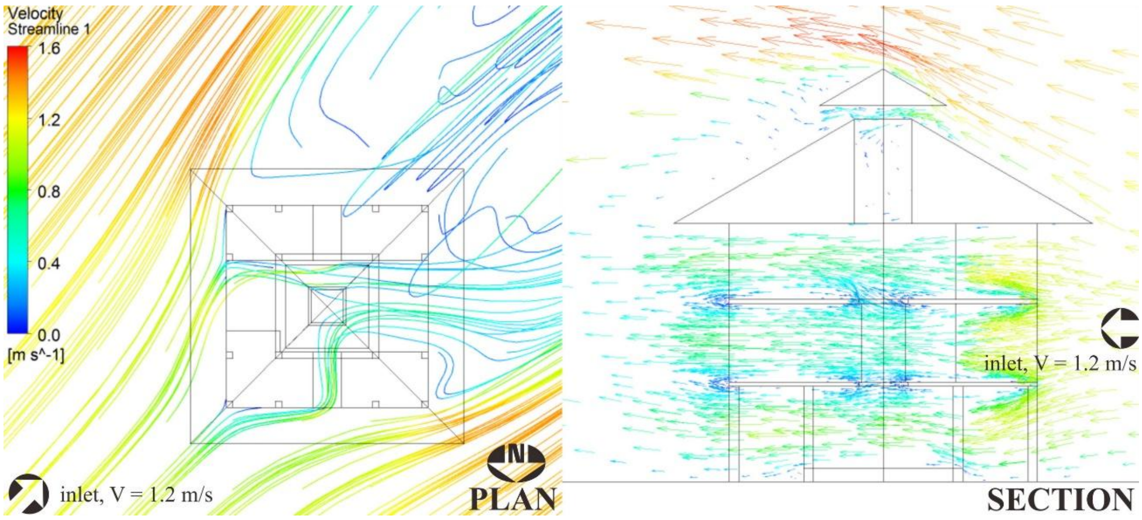


Figure 9. Simulation for existing air movement.

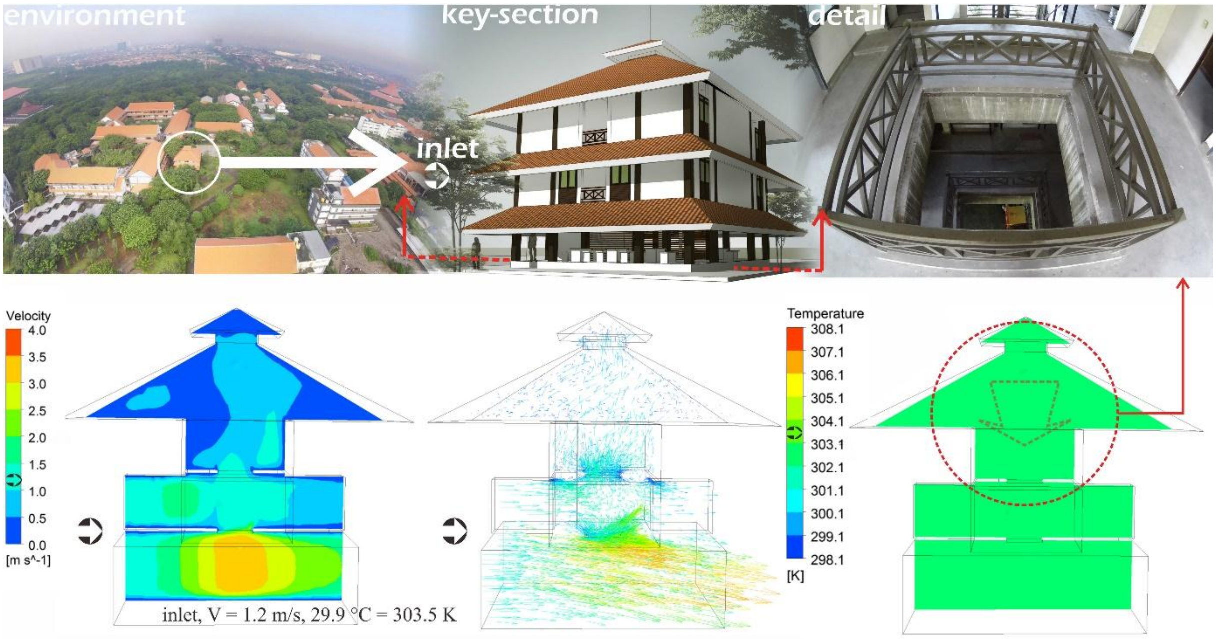


Figure 10. Existing stack ventilation.

3.3. Proposal Stack Ventilation

In general, proposal for improvement of the existing stack ventilation is explained as follows:

a) Considering the future condition which has predicted the condition in higher density by providing upper part of building stack as outlet.
b) Generating 0.3 m/s as minimum wind speed for physiological cooling as illustrated by the previous parts.
c) Reducing indoor temperature lower than inlet temperature.
d) Proposing 2 alternatives of stack technology; alternative 1: full vertical ventilation (closing direct horizontal outlet) without any treatment on ground and top of building stack; alternative 2: full vertical ventilation with ground treatment through providing cool pond and solar chimney in the top of building stack.

Figure 11 shows the implementation of proposed stack technology. Alternative 1 is more efficient than the 2nd one because it needs no treatment. It has capability for increasing wind speed. 0.5 m/s is minimum of wind speed resulted by this method. However, it has a weakness in reducing indoor temperature. The temperature is constant. Therefore, it needs an improvement and the alternative 2 is the logical method on providing lower temperature. By passive cooling for inlet with cooling pond (evaporative cooling) at the ground floor, the 20°C of air temperature could be reduced more than 5°C. The increasing flow rate by installing high material temperature as solar chimney generates wind speed. Analysis for solar chimney technology could be described in Figure 12.

The proposed stack (d = 1.8 m) receives of minimum a solar intensity more than 200 W/m^2 (see Figure 6), for each height, 1.5 m, 4.5 m, 7.5 m, and 9.0 m (top of chimney). For example, locating the glass on the top of the building for receiving solar radiation is the most effective method. It is indicated by the high volume of flow rate (40 m^3). If it is compared to d = 0.5 m and 1.0 m, for resulting higher and sufficient flow rate, wider chimney shows the higher requirement of solar intensity. The calculation is coded by Matlab programming (developed by Meshram, 2013).

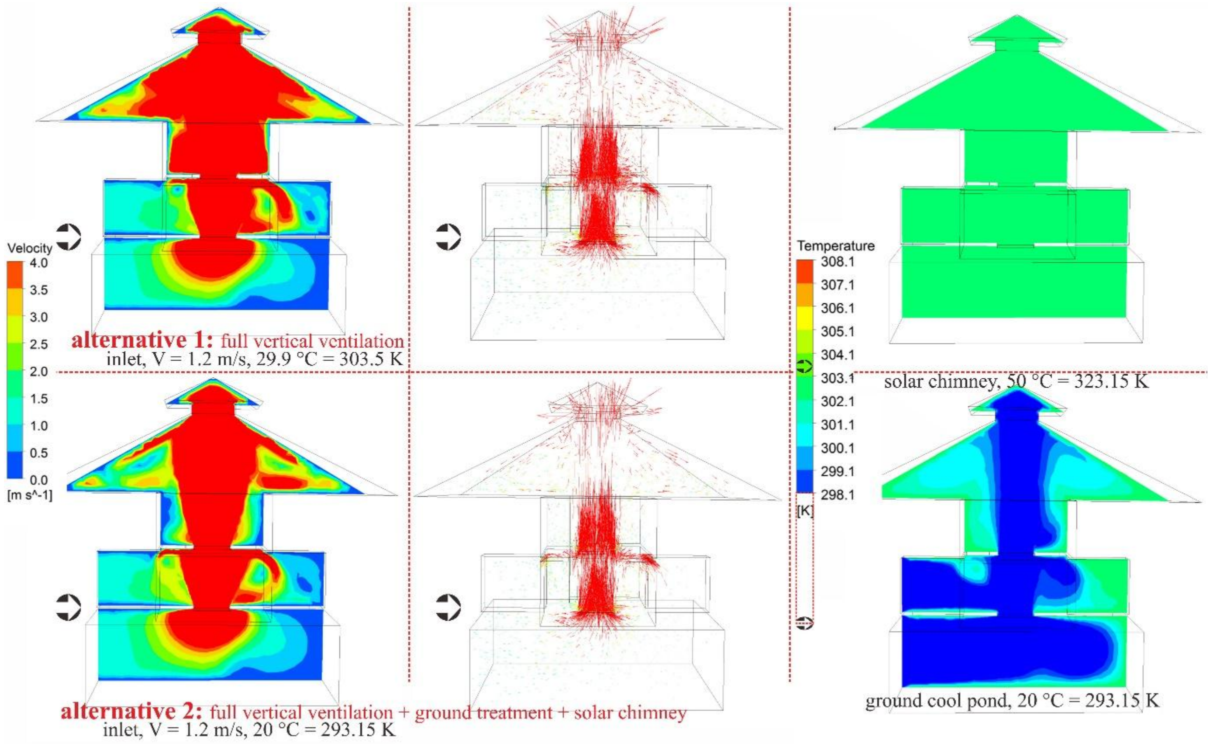
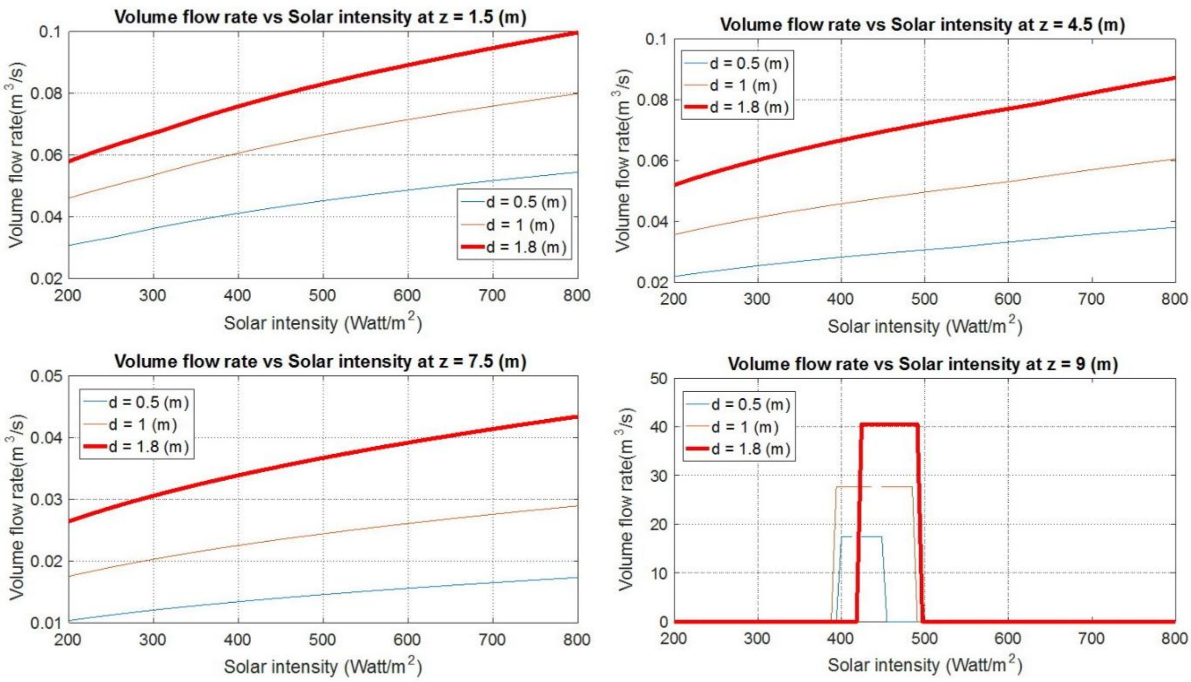


Figure 11. Alternative and proposal stack ventilation.



d=width of solar chimney, z=measured height in solar chimney

Figure 12. Flow rate of the solar chimney.

4. Conclusion

Different from Szokolay (2008), this paper offers evaporative cooling at ground floor combined with solar chimney for improving the exiting stack effect. As the result, the 20°C of air temperature of inlet air temperature with the same wind speed could be reduced more than 5°C. The increasing volume flow rate by installing high material temperature as solar chimney generates wind speed. The results showed that the stack effect height and area could be modified instantly adjusting the environmental condition in the future years. With 1.8 m of stack width, the proposed technology could capture 40 m^3 of vertical air flow which is useful for physiological cooling and its dimension could be modified depended on environmental condition. Proposing stack effect is one of providing resilient technology and the predictable of sustainable ventilation method is offered to anticipate an unpredicted global warming and environmental change.

5. Acknowledgments

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6. References

[1] Ashish Meshram 2013 *Experimental Investigation on Solar Chimney for room ventilation.* http://kr.mathworks.com/

[2] Aynsley, RM, Melbourne W, Vickery, BJ 1977 *Architectural aerodynamics* Applied Science, London

[3] Aynsley, RM, and Spruill, M 1990 Thermal comfort models for outdoor thermal comfort in warm humid climates and probabilities of low wind speeds *Journal of Wind Engineering and Industrial Aerodynamics* **36** 481-488

[4] Center of Climatology at Karangploso, Malang, Indonesia 1993-2012 *Climate data (Highland)*

[5] Center of Meteorology, Climatology, and Geophysics at Juanda and Perak, Surabaya, Indonesia. 1997-2015 *Climate data (Lowland)*

[6] Chungloo, S, and Limmeechokchai, B 2007 Application of passive cooling systems in the hot and humid climate: The case study of solar chimney and wetted roof in Thailand *Building and Environment* **42** 3341-3351

[7] Kasaeian, A, Ghalamchi, M, Ghalamchi, M 2014 Simulation and optimization of geometric parameters of a solar chimney in Tehran. Energy *Conversion and Management* **83** 28-34

[8] Nguyen, AT, and Reiter, S 2014 A climate analysis tool for passive heating and cooling strategies in hot humid climate based on typical meteorological year data sets *Energy and Buildings* **68** 756-763

[9] Prianto, E., and Depecker, P. 2003 Optimization of architectural design elements in tropical humid region with thermal comfort approach *Energy and Buildings* **35** 273-280

[10] Szokolay, SV. (2008). *Introduction to architectural science.* Elsevier, Oxford, UK

[11] Tan AYK, and Wong NH 2014 Influences of ambient air speed and internal heat load on the performance of solar chimney in the tropics *Solar Energy* **102** 116-125