The Effect of Opening and Interior Layout in Controlling Airflow of A Building in Salatiga

Bryan Putra Parsada Sinaga[1], A. Robbi Maghzaya[2]
[1,2] Architecture Program, Universitas Islam Indonesia
[1]Surel: 17512167@student.uii.ac.id

ABSTRACT: Salatiga is a city in the slope of Mt. Merbabu and has relatively low-average temperature throughout the year. This means that buildings in the city can have a low-energy consumption design by reducing the use of AC. This is good due to the rising of 0,50 C yearly temperature rise in Indonesia (via BMKG). Airflow is when a certain amount of wind speed which went in through an opening and flow past interior or objects inbetween another opening then make it to outside again. It is the premise of airflow in general with the variables being wind velocity, opening, interior, and the room shape itself. Wind velocity and openings both impact directly in how much the wind can cool the room, while interior and room shape impact the effective area coverage of the wind. Research is done by changing the variation of the variables in digital experimental model, which is made in Grasshoper using Rhino 6. The application simulates the effects of corresponding variables to room temperature from height 1,5 to 2 meter. The experiment shows how the variables affects each other. This research is useful to design a low-energy usage building specificly in Salatiga.

Keyword: Airflow Control, Cross Ventilation System, Opening, Wind Velocity, Room Size.

BACKGROUND

Salatiga is located at an altitude between 450-825 meters above sea level. Geographically, Salatiga is in slope of Mt. Merbabu and other small mountains, namely Mt. Telomoyo, Mt. Ungaran, Mt. Payung, and Mt. Rong. The combination of the slope and the foot of the mountain also causes Salatiga to lie on a sloping plain to the west with a slope of between 50-100, so it can be said that Salatiga is a plains as well as mountain slope.

The average all-day temperature in Salatiga is between 22,40-24,10 C (by Climate-Data), while in Indonesia the average all-day temperature is 250-320 C throughout the year (by BMKG in 2019). According to SNI 03-6572-2001, the range of cool-comfortable is between 20.50-22.80 C, while the range of optimum comfort is between 22.80-25.80 C. However, there is also a data by BMKG in which the rising temperature of Indonesia yearly is roughly 0,50 C due to global warming. Thus, it is possible for buildings in Salatiga to not rely on Air-Conditioning system which worsen global warming effects.

But, if cold nights temperature data are taken away from the equation to get the day-only temperature data, it's not close to being comfortable. On hot days, the average temperature is 290-330 C, while the average overall day-only temperature is 260-310 C (by Meteoblue). This means that temperature at daytime is still not comfortable and the ones that should be taken into the calculation. This means that buildings in the city can have a low-energy consumption design by maximizing natural airflow in day time and reducing the use of fan and air conditioner.

The key to achieve comfort without air conditioner is cross-ventilation system. Cross-ventilation is a system which drives air from openings at one side of a building through to the other. It's success depends on the tightness of the building envelope – the physical separator between the interior and the exterior elements of a structure.

Cross-ventilation can be applied in buildings, but it has some shortfall such as lack of diversity in designing building envelope, the opening, and the deficiency of the system if there were to put interior inbetween the openings. Deriving from this system however is to maximize the airflow itself. Airflow is the movement of air, with the knowledge of airflow movement pattern in set conditions, it is possible to achieve good airflow without having 2 parallel openings. Givoni (1994) mentioned that oblique winds at angles between 30 and 120 degrees to the wall can provide effective cross ventilation if openings are provided in the windward and leeward walls (Assuming the building lies in the wide location without influence by other buildings).

This paper will emphasise on understanding airflow and how to get the best of it with the set of variables that are examined. This paper is important in making a possibility of low running cost design in Salatiga, because with utilizing natural airflow the user can reduce the cost of electricity which comes from fan, air conditioner, etc.

LITERATURE REVIEW

Opening and Airflow

In tropical region, openings play a major role in determining the thermal comfort of the users as the location and size of the window determine how much the wind enters the building. In this aspect, large openings in all walls can provide the design solution for effective cross ventilation. However, solar radiation can penetrate directly through un-shaded openings into the interior of the building and elevate the indoor temperature above the outdoor level. Therefore, utmost care should be taken in ensuring that all openings in the envelope of the building are effectively shaded (Givoni, 1994). In this case, window size, location and shading are the main factor to the efficiency of openings affecting the airflow.

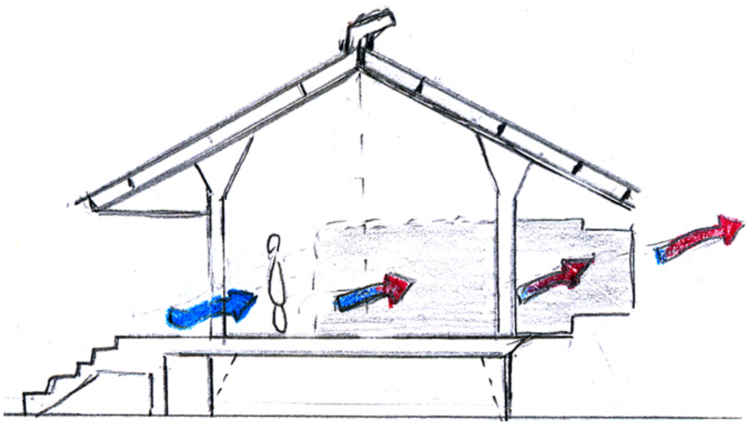


Figure 1: Parallel Openings effect on Cross-Ventilation System
Source: Marika Alderton House

However, if the best building orientation for sunlight control is in conflict with the best orientation for natural ventilation, which is the primary factor. In hot and dry climates, shading is of great or importance than ventilation; in hot and humid climates, on the other hand, emphasis is given to cross ventilation as the high humidity of the air creates discomfort for human beings (Santamouris & Asimakopoulos, 1996).

Interior and Airflow

The indoor space or layout determines the ventilation conditions. An open plan combined with a proper distribution of openings is preferable for undisturbed ventilation in the interior. As practical needs require separation of spaces, restriction of airflow should be avoided and the positioning of partitions should help channelling the air through the occupied space (Santamouris & Asimakopoulos, 1996).

Figure 2: Airflow adjusting the existing cupboard.
Source: phius.org

Wind Velocity and Airflow

Wind forces act on all buildings side, typically creating positive pressure with the wind direction, and negative pressure on the walls. Low-slope or flat roof tends to have mostly negative pressure, especially on the edges. While sloped roof with slope above 25 degree experience positive pressure on the wind direction, and negatives pressure on the other side. This means that wind velocity will differs in multi storey building as lower stories has no roof and the upper has roof, which means the ones will have better airflow potential than the rest.

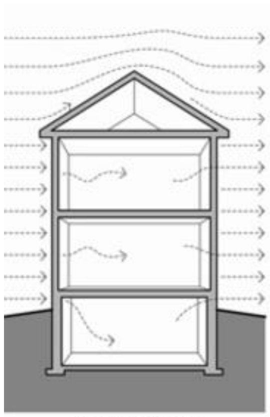


Figure 3: Wind Velocity affecting in various wind behavior
Source: buildingscience.com

Orientation for ventilation does not imply that the building should be perpendicular to the prevailing wind direction. Givoni (1994) mentioned that oblique winds at angles between 30 and 120 degrees to the wall can provide effective cross ventilation if openings are provided in the windward and leeward walls (Assuming the building lies in the wide location without influence by other buildings).

Room Shape and Airflow

Space or room has many variety of size and shape adjusting to its function. Both of the shape and size directly affect the effectiveness of airflow as wind velocity has limit of efficiency after entering opening. So, the longer the route to other opening is achievable or too far depends on the size and the shape, whether it will support the airflow or not.

Figure 4: Wind Velocity weakened while crossing large space.
Source: phius.org

RESEARCH METHOD

Digital Experimental Model using Grasshoper (Butterfly)

1. **Create Openfoam Case**

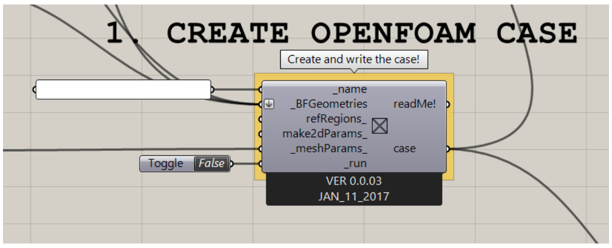


Figure 5: Creating Openfoam Case

2. **Create Meshing Logic**

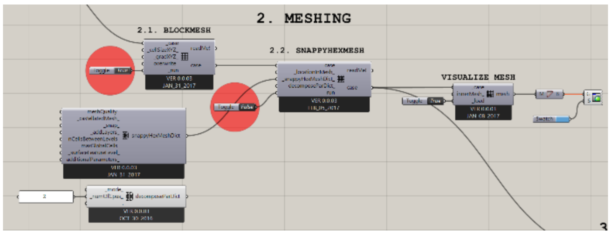


Figure 6: Recognizing the model as mesh

3. **Create Solution**

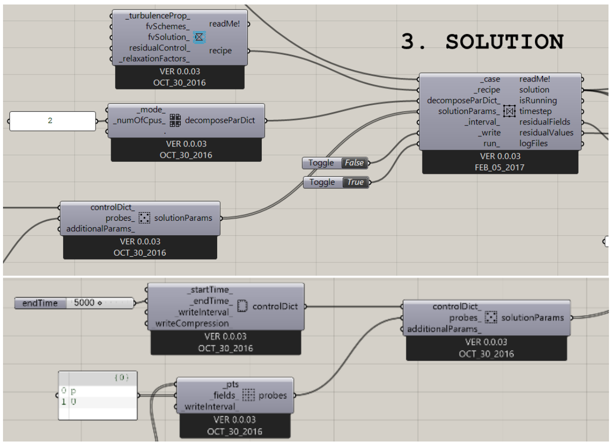


Figure 7 & 8: Creating solution code based on geographic location and adding wind velocity.

4. **Result Visualization**

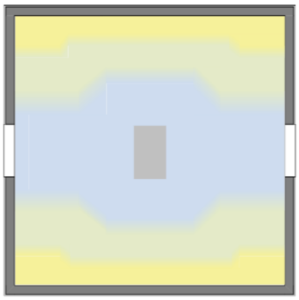


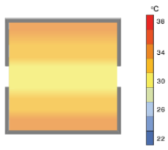
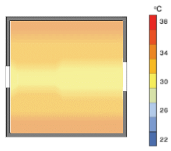
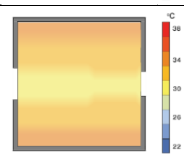
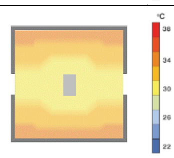
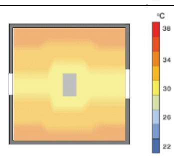
Figure 9: Results are shown horizontally with it being the average temperature of height 1,5 to 2m.

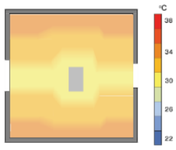
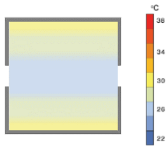
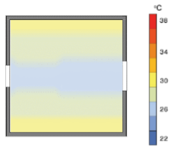
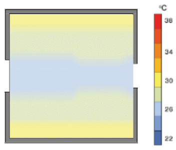
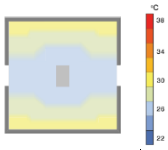
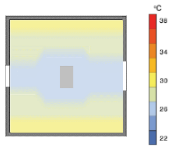
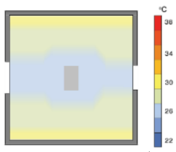
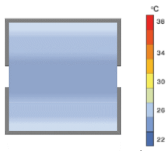
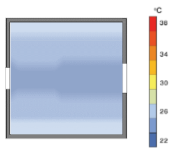
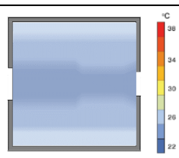
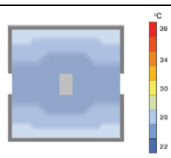
5. **Model Experiment**
   - Models are made in a software with a fix dimension and shape.
   - Models then tested with several size of openings without and with interior.
   - Then repeat with different wind velocity as there are 3 value of wind taken from average wind velocity in Salatiga.
   - Then repeat again with different room shape.

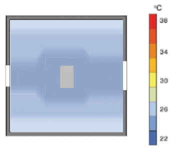
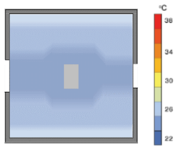
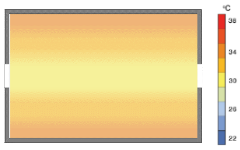
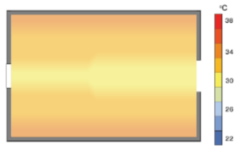
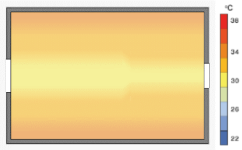
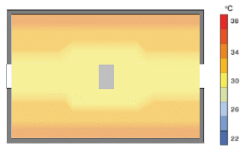
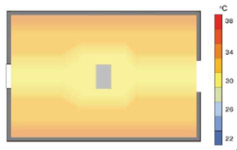
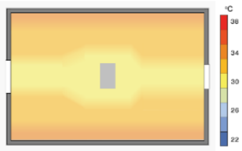
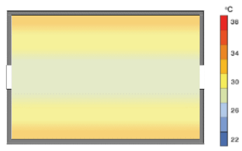
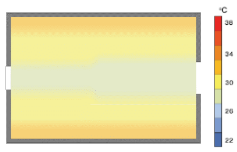
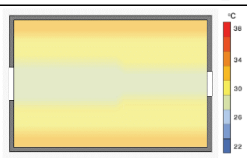
FINDINGS AND DISCUSSION

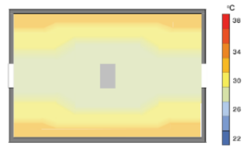
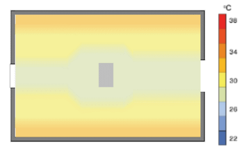
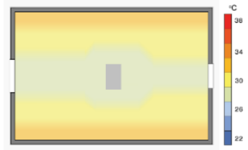
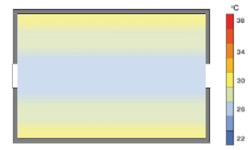
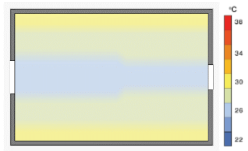
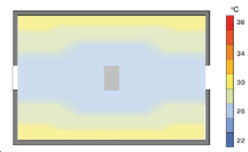
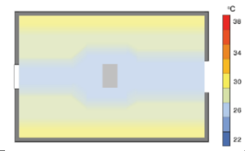
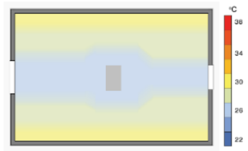
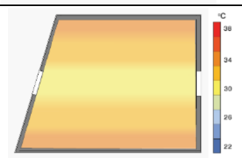
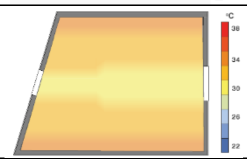
A. FINDINGS

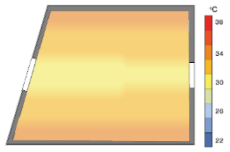
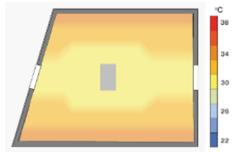
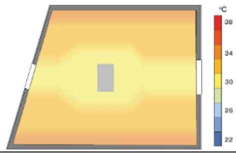
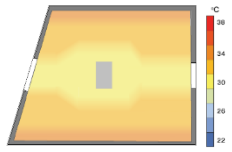
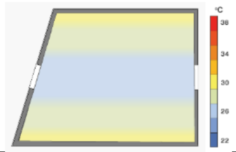
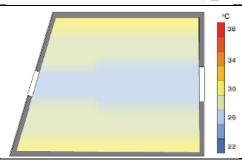
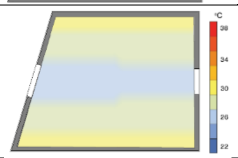
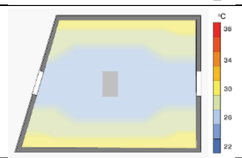
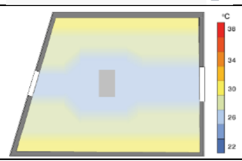
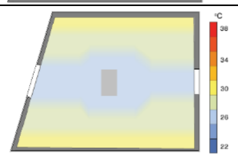
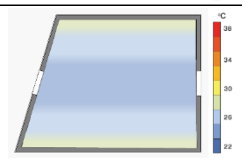
Experiment Data Variables:

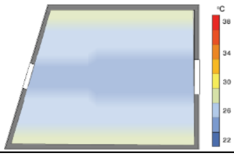
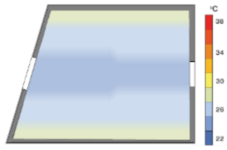
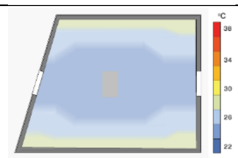
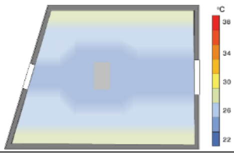
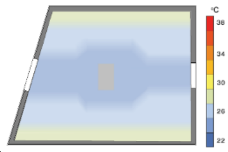
No.	Shape	Velocity	Interior	Opening	Visualization	Comfort Area
1	Square	0,3 ms	Without	Same size		0%
2	Square	0,3 ms	Without	Bigger Inlet		0%
3	Square	0,3 ms	Without	Bigger Outlet		0%
4	Square	0,3 ms	With	Same size		0%
5	Square	0,3 ms	With	Bigger Inlet		0%

6	Square	0,3 ms	With	Bigger Outlet		0%
7	Square	1,3 ms	Without	Same size		50%
8	Square	1,3 ms	Without	Bigger Inlet		40%
9	Square	1,3 ms	Without	Bigger Outlet		40%
10	Square	1,3 ms	With	Same size		50%
11	Square	1,3 ms	With	Bigger Inlet		45%
12	Square	1,3 ms	With	Bigger Outlet		45%
13	Square	3,3 ms	Without	Same size		100
14	Square	3,3 ms	Without	Bigger Inlet		100
15	Square	3,3 ms	Without	Bigger Outlet		100
16	Square	3,3 ms	With	Same size		100

17	Square	3,3 ms	With	Bigger Inlet		100
18	Square	3,3 ms	With	Bigger Outlet		100
19	Rectangle	0,3 ms	Without	Same size		0%
20	Rectangle	0,3 ms	Without	Bigger Inlet		0%
21	Rectangle	0,3 ms	Without	Bigger Outlet		0%
22	Rectangle	0,3 ms	With	Same size		0%
23	Rectangle	0,3 ms	With	Bigger Inlet		0%
24	Rectangle	0,3 ms	With	Bigger Outlet		0%
25	Rectangle	1,3 ms	Without	Same size		0%
26	Rectangle	1,3 ms	Without	Bigger Inlet		0%
27	Rectangle	1,3 ms	Without	Bigger Outlet		0%

28	Rectangle	1,3 ms	With	Same size		0%
29	Rectangle	1,3 ms	With	Bigger Inlet		0%
30	Rectangle	1,3 ms	With	Bigger Outlet		0%
31	Rectangle	3,3 ms	Without	Same size		50%
32	Rectangle	3,3 ms	Without	Bigger Inlet		40%
33	Rectangle	3,3 ms	Without	Bigger Outlet		40%
34	Rectangle	3,3 ms	With	Same size		45%
35	Rectangle	3,3 ms	With	Bigger Inlet		40%
36	Rectangle	3,3 ms	With	Bigger Outlet		40%
37	Trapezoid	0,3 ms	Without	Same size		0%
38	Trapezoid	0,3 ms	Without	Bigger Inlet		0%

39	Trapezoid	0,3 ms	Without	Bigger Outlet		0%
40	Trapezoid	0,3 ms	With	Same size		0%
41	Trapezoid	0,3 ms	With	Bigger Inlet		0%
42	Trapezoid	0,3 ms	With	Bigger Outlet		0%
43	Trapezoid	1,3 ms	Without	Same size		50%
44	Trapezoid	1,3 ms	Without	Bigger Inlet		48%
45	Trapezoid	1,3 ms	Without	Bigger Outlet		45%
46	Trapezoid	1,3 ms	With	Same size		60%
47	Trapezoid	1,3 ms	With	Bigger Inlet		50%
48	Trapezoid	1,3 ms	With	Bigger Outlet		45%
49	Trapezoid	3,3 ms	Without	Same size		95%

50	Trapezoid	3,3 ms	Without	Bigger Inlet		95%
51	Trapezoid	3,3 ms	Without	Bigger Outlet		95%
52	Trapezoid	3,3 ms	With	Same size		95%
53	Trapezoid	3,3 ms	With	Bigger Inlet		95%
54	Trapezoid	3,3 ms	With	Bigger Outlet		95%

B. DISCUSSION

Experiment 1-6

Done in square room and 0,3 ms wind velocity and various types of opening and interior. In these combination, it can be seen that averagely the room is uncomfortable, even with the addition of interior or changes of inlet or outlet size, the area coverage won't matter much if the average room temperature isn't comfortable.

Experiment 7-12

Done in square room and 1,3 ms wind velocity, it can be seen that the middle part of the room is quite comfortable, but the side of the room isn't. The addition of interior widen area coverage but only effective on Experiment 10, while on Experiment 11 and 12 it's not much.

Experiment 13-18

Done in square room and 3,3 ms wind velocity, it can be seen that all the combination are comfortable with Experiment 13 and 16 has the best area coverage of all. This is due to the compactness of the room and high velocity speed, making it quite easy to cool the room.

Experiment 19-24

Done in rectangle room and 0,3 ms wind velocity, it can be seen that the area coverage is lower than square room. Due to the wind loses it's velocity as the room is wider, it directly impact room temperature.

Experiment 25-30

Done in rectangle room and 1,3 ms wind speed, it can be seen that there are yellowish area on rectangle room, where there isn't at square room. Due to the same aspect as before impacting the lower average room temperature.

Experiment 31-36

Done in rectangle room and 3,3 ms wind speed, it can be seen that averagely the room is comfortable, with the edges being quite uncomfortable.

Experiment 37-42
Done in trapezoid and 0,3 ms wind speed, it can be seen that the data shown is more or less similar with square room. The different part is near the outlet the wind is kinda deflected again on Experiment 40-42, making the wind being deflected twice.
Experiment 43-48
Done in trapezoid and 1,3 ms wind speed, it can be seen that the room is averagely comfortable. Starting to look different from square room as the area coverage is better due to lesser inside area.
Experiment 49-54
Done in trapezoid and 3,3 ms wind speed, it can be seen that the room can be either half comfortly cover or almost all the experiments.

CONCLUSION AND RECOMMENDATION

A. Conclusion

1. At square room with direct cross ventilation, area affected by wind is relatively big to the proportion of the room. However, with the same case but in rectangular room, area affected by win is smaller as the wind travel through the room. This is due to the loss of wind velocity over time and a direct reflection of room shape effectiveness. Cross ventilation works best with proportional opening size and room shape, as well as decent wind velocity.
2. Bigger inlet is somewhat an enhancement for wind velocity, to make sure it won't easily lose it's velocity overtime to some distance. The effect of bigger inlet can be seen clearly in rectangular room as both coverage area and average temperture is higher near the inlet. It also can be seen in trapezoid room as the deflected wind is still somewhat strong to make it to the outlet.
3. Bigger outlet affects on pulling wind from inside the room faster. The effects are the complete opposite of bigger inlet. In rectangular room both the coverage area and average temperture is higher near the outlet. While in trapezoid room even thogh the deflected wind is weaker, the wind velocity gets faster as it gets closer to the outlet.
4. The absence of interior however, making the cross-ventilation works as what it is. While the effect of interior is a bit different as it's not as simple as the others. With cross ventilation and interior in both square and rectangular room, area affected by deflected wind is the same as the area of interior itself. There is also no wind velocity loss overtime as the wind deflected twice by interior and wall, making it pass through to the exit with roughly the same speed before it deflected. However, in trapezoid room, due to the wall is being further from the interior compared to in square and rectangular room, the second deflection of wind is rather delayed thus making it loss some of the wind velocity on it's way to the outlet. It comes down to the radius of wind deflected by interiors to effectively use it in pursue of airflow control. The amount and height of interiors can also varied in order to achieve it.
5. Wind velocity heavily effects by the size of opening and room shape. For example with 0,3 ms wind velocity, it loss wind speed overtime in an instant. Making the room average temperature is always higher than 1,3 and 3,3 ms. However, in the mix of opening size and room shape, either the area affected by the wind differs or the average temperature of the room differs. As can be seen that square and rectangular shape has different area coverage and average temparature even though both has 1,3 ms wind speed. This due to the wind loss overtime affects rectangular shape more than square ones. However, with the mix of bigger inlet or outlet, it can be seen that the area coverage is much better due to more wind comes in or the wind faster to get out. Though the average temperature isn't change much.

This tells that it's not solely about getting the highest wind velocity to achieve good airflow control, but rather how the mixture of building components to support the existing wind velocity to be efficient.

6. Room shape directly affects both wind velocity travel time and deflected wind by interior. Simply put, longer space means lower travel time as the wind loss it's velocity overtime, and closer space won't be affected as much. While with deflected wind by interior, the distance and placement of walls affects directly to it. This means the further interior that deflect wind from the wall, the more likely the wind will lose some of it velocity along the way. To achieve good airflow control it is adviseable to make sure the interior isn't too far from wall or can be also stick to the wall.

B. Recommendation

This study revealed the behavior of airflow in set combination of variables and how good airflow control can be achieved both by tweaking one of the variables or balancing them. However, the case is very specific to Salatiga, The idea and premise of the study is to learn airflow behavior on set variables, therefore even if the behavior tend to be different on another area, the approach should be the same.

This study was limited to simulation of height of 1,5m-2m making it not fully representing vertical airflow movement. It also consider the room isn't surrounded by other buildings. These can be improved by better usage and understanding of Grasshoper Butterfly CFD. Future work experiments can branch the specific variable regarding airflow control, simulating on different region, or enhancing this exact study by adding vertical airflow visualization and using different height of openings and interiors. The results from this study can pave a path towards the development of sustainable low-running cost design.

REFERENCE

AlAnzi, A., Seo, D., & Krarti, M. (2009). Impact of building shape on thermal performance of office buildings in Kuwait. Energy Conversion and Management. doi: 10.1016/j.enconman.2008.09.033

Almeida, M., Maldonado, E., Santamouris, M., & Guarracino, G. (2005). The design of optimal openings. Natural Ventilation in the Urban Environment: Assessment and Design, 168-194.

Chen, x., & Zhong, D. (2011). The principles of passive cooling alley and its inspiration. New Architecture (in Chinese), 3, 4.

Fabi, V., Andersen, R. V., Corgnati, S., & Olesen, B. W. (2012). Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models. Building and Environment, 58, 188-198. doi: 10.1016/j.buildenv.2012.07.009

Fahmy, M., & Sharples, S. (2009). On the development of an urban passive thermal comfort system in Cairo, Egypt. Building and Environment, 44(9), 1907-1916. doi: 10.1016/j.buildenv.2009.01.010

Kleerekoper, L., van Esch, M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. Resources, Conservation and Recycling, 64(0), 30-38. doi: 10.1016/j. resconrec.2011.06.004

Sarkar, Ahana, & Bardhan, Ronita, (2018) Optimizing Interior Layout for Effective Experiential Indoor Environmental Quality in Lowincome Tenement Unit: A Case of Mumbai, India. International Building Simulation Association, England

Santamouris, M., & Asimakopoulos, D. (1996). Passive cooling of buildings. London: James and James

Straube, John, (2007). Understanding and Controlling Airflow in Building Enclosures. University of Waterloo, Canada

Visagavel, K., & Srinivasan, P. S. S. (2009). Analysis of single side ventilated and cross ventilated rooms by varying the width of the window opening using CFD. Solar Energy, 83(1), 2-5. doi: 10.1016/j. solener.2008.06.004