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Numerical analysis on the thermal performance of a building with solar chimney and double skin façade in tropical country

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Abstract. This research compared the use of Double Skin Façade (DSF) with its combination with 3 types of solar chimney; vertical solar chimney, slopped solar chimney, and horizontal-vertical solar chimneys on a eight-storey prototype office building in Jakarta, Indonesia. All simulations were performed by simulation using Ansys 15.0. The results are based on the air velocity and pressure flowing in the DSF gap and chimney, as well as the room. From three types of solar chimney simulations which used, it shows that the best result is DSF combination with vertical solar chimney utilization of DSF combined with solar chimney proved effective in increasing wind velocity in space.

1. Introduction
Efforts to achieve thermal comfort for buildings in Indonesia are somewhat heavier due to the humid tropical climate characteristics with high rainfall, high humidity (up to 90%), relatively high air temperature (up to 38 ° C), less airflow, as well as intense and disturbing solar radiation. Climatic conditions in the Tropics have characteristics; high air temperature, high relative humidity and low wind speeds that make the environment uncomfortable. Several studies related to the thermal system in the humid tropics see that the tendency of problems faced is the same ie the amount of heat load in the building that affects the formation of indoor air temperature. In humid tropical climates, different thermal comfort equations are specific and different from other climates. The thermal comfort environment in space is formed not only because of the microclimate (building) but also its human factors (activity, size, and clothing). The results of Hidayat's (2016) and Vidiyanti (2016) studies show that the wind velocity that touches the human body affects the sense of comfort in humid tropical climate chambers significantly[1, 2]. To maximize the comfort required a passive strategy that is efficient in energy and cost. Located in the tropical area, the utilization of solar energy becomes important.

The main purpose of solar passive design strategy is to maximize the potential of abundance of solar radiation to enhance the building heating/cooling. One of them by utilizing ventilation stack strategy. Stack ventilation is caused by stack pressure or buoyancy at an opening in terms of water density variation as a result of the difference in opposite openings. The same principle can be used with different height openings, where the pressure difference between the two openings is in relation to the vertical gradient. Double Skin Façade (DSF) and Solar Chimney are technologies that utilize these effects.

DSF and Solar Chimney have been widely researched by experts. Talarosha in Kurniansyah (2016) examines the effect of orientation and the use of DSF with shading device, and the use of vegetation as a DSF[3]. The advantages of DSF are also discussed by some experts. Poirazis (2004) has observed that the DSF is able to lower the air temperature received by the building walls[4]. While Ghaffarianhoseini et al. (2016) state that DSF aids in natural ventilation[5]. R Høseggen (2008) argues that DSF has a low g-value value (sun absorption and u-value) and is able to reduce wind pressure into the building[6]. For the utilization of solar chimneys in buildings, a number of experimental, numerical and theoretical investigations have contributed to the current understanding of solar chimneys, related to various aspects (shape, height, material, location, weather, and other aspects). Hassanein, et al. (2012) experimentally to investigate the effect of the number of solar chimneys, the height of the chimney, the width of the air gap, and the orientation of the chimney in the natural ventilation in space[7]. Ding, et al. (2004) investigated the performance of the natural ventilation of the double skin facade highlighted[8]. A prototype of the proposed building, which is considered an eight-storey office building with an atrium room on the north side. Sakonidou, et al. (2007) developed a mathematical model to determine the slope that maximizes natural airflow within the sun's chimney using daily solar radiation data on the horizontal plane of a site[9].

Utilization of DSF and Solar Chimney is believed to induce natural ventilation to flow better into buildings and inside the room. The main purpose of this research is to find the right composition of solar chimney when combined with DSF in office prototype building. This paper investigated the use of DSF and solar chimney on a prototype eight-storey office building located in Jakarta. However, investigations on both are frequent, the advantages of this research are the use of DSF and solar chimney combination for humid tropics. This investigation is believed to be a guideline for the same typical building designs with the same location, which adopts a passive ventilation system.

2. Model Description

2.1. System mechanisms
In order to simulate, a model is assumed to be located in a residential building located in Jakarta, with coordinate around 6°12′S 106°49′E. An eight-storey office prototype has a front-facing orientation towards the north/south (in this case assumed to be the same) using DSF technology. DSF wall uses clear glass with a 1.2m wide gap. Buildings are assumed to use only passive cooling systems. Airflow into each room will be induced by DSF system and solar chimney. The face with inlet is located opposite with the DSF position. The inlet position is at the bottom of the room. According to Gan (2006) inlet location on the bottom will create air flow well distributed[10]. The wind then will flow into the DSF gap before entering the solar chimney. After that, wind will flow out through outlet.

2.2. Geometric model
This research is using the analysis using the CFD (Computational Fluid Dynamics) simulation method, with Ansys 15.0 as a tool[11, 12]. In this program, Ansys Workbench 15 has been prepared facilities to create a geometry that is Design Modeler integrated with ICEM and Fluent 15 so that the process of defining the material, domain set, boundary condition, meshing to output all can be done on one software.

In this paper, the building prototype has a total width of 13.2m with the height of each floor (floor to floor) 4m. The number of floors being simulated is eight-storey. DSF will be simulated by comparing the 3 alternative variations, as shown below in Figure 1. First (type A) is to validate the effectiveness of DSF itself. DSF is simulated without the use of solar chimneys. Second, (type B) double skin combined with a 90˚ vertical solar chimney based on previous research[13-15]. The height of the chimney is assumed to have the same height as the three-story high[8]. Third (type C), is to combine DSF with slopped solar chimney. Slopped solar chimney expect to capture maximum sunlight radiation in the tropics. The slope is taken based on some previous research[9, 16, 17]. Fourth (type D), combine DSF with horizontal-vertical solar chimney with the shape adopt from solar chimney power plan.

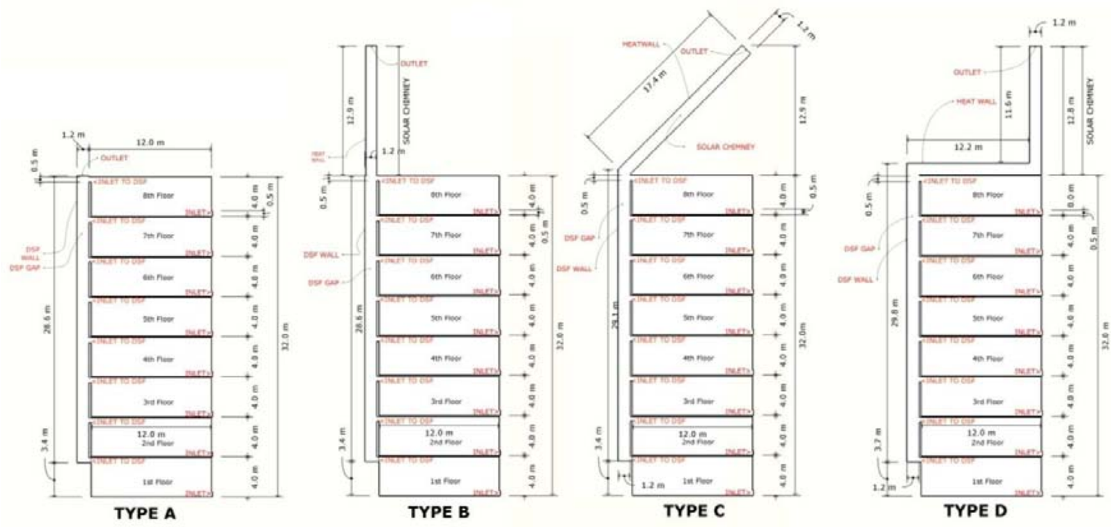

Figure 1. Geometry of the simulation's model

The analyze aspect is the velocity of the wind-induced by DSF system and solar chimney in the building. Measurement point of velocity is divided into two parts, measuring line in DSF gap + solar chimney, and measuring point in the room (as shown in Figure 2). Measuring in DSF gap always start in point 3.5, this means start at 3.5 m above the ground. The highest point is 42.63, this means the measurement line end in 42.63 m for type D. Specific point space is divided into three parts, point A is in front of the inlet, the measuring point B is in the middle of the room, and the measuring point C is before the DSF gap.

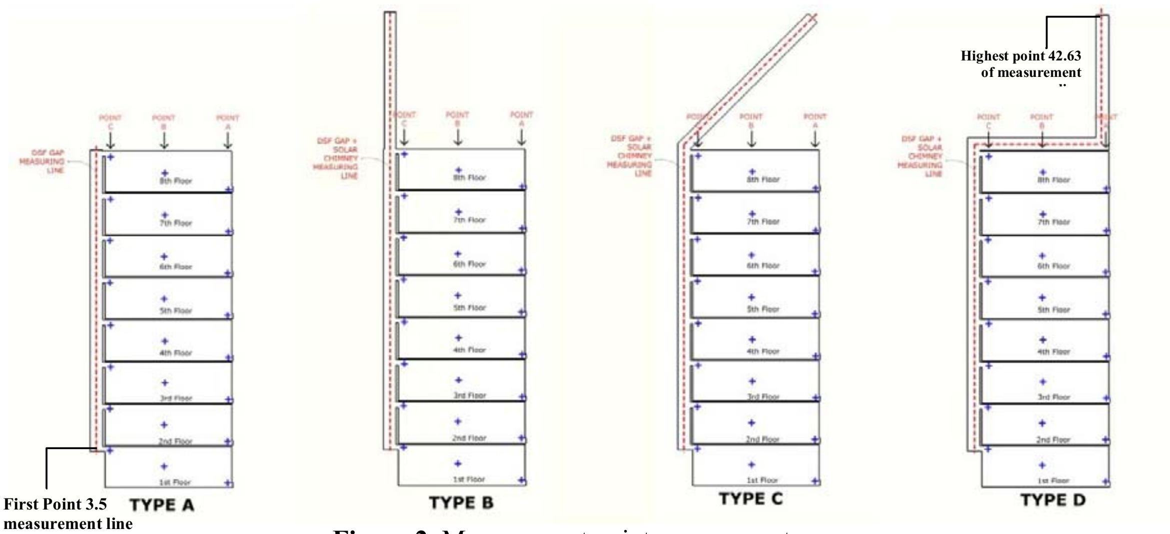

Figure 2. Measurement point arrangement

2.3. Mathematics equation

Mathematical equations include the Mass Flow equation, the Navier-Stokes equations, the energy equation and k- ε Turbulence Model equations which are presented as followings:

Assuming one-dimensional, steady state flow, the following mass flow rate could be valid equation:

$$m = \rho_f A U_f \tag{1}$$

Navier-Stokes equation:

$$\rho \frac{du}{dt} = -\frac{\partial P}{\partial r} + \frac{\partial}{\partial r}\left[2\mu \frac{\partial u}{\partial r} + \mu' \, \vec{\nabla}.\vec{v}\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial v}{\partial r}\right)\right] + \frac{2\mu}{r}\left(\frac{\partial u}{\partial r} - \frac{v}{r}\right) \tag{2}$$

$$\rho \frac{dv}{dt} = -\frac{\partial P}{\partial r} + \rho g + \frac{\partial}{\partial r}\left[2\mu \frac{\partial v}{\partial z} + \mu' \, \vec{\nabla}.\vec{v}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial v}{\partial r}\right)\right] \tag{3}$$

Energy equation:

$$\rho C_p \left[\frac{\partial T}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(rTu) + \frac{\partial}{\partial z}(Tv)\right] = \frac{1}{r}\frac{\partial}{\partial r}\left(rw\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(w\frac{\partial T}{\partial z}\right) + \frac{\partial P}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(rPu) + \frac{\partial}{\partial z}(Pv) + \phi \tag{4}$$

k- ε Turbulence Model equations:

$$\rho\left[\frac{1}{r}\frac{\partial}{\partial r}(rku) + \frac{\partial}{\partial z}(kv)\right] = \frac{\partial}{\partial z}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial z}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial r}\right] + G_k + \beta g \frac{\mu_t}{Pr_t}\frac{\partial T}{\partial z} - \rho\varepsilon \tag{5}$$

$$\rho\left[\frac{1}{r}\frac{\partial}{\partial r}(r\epsilon u) + \frac{\partial}{\partial z}(\epsilon v)\right] = \frac{\partial}{\partial z}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial z}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial r}\right] + C1_\epsilon G_k \frac{\epsilon}{k} - C2_{\epsilon\rho}\frac{\epsilon^2}{k} \tag{6}$$

2.4. Boundary condition

Gravitational acceleration was set at -9.81m/s^2 at y-axis. The energy model is k- ε with full buoyancy effect used to model the turbulent flow. Input and output are conditioned as pressure input/output, so the wind velocity's input set at 0 m/s (without outside wind). While air density was set as boussinesq in 1.205 kg/m3, thermal expansion coefficient set at 3.41E-03 1/K. Ambient temperature simulations was set at 293 K[18], while the heat-wall surface was thought to be exposed to a heat flux of 800 w/m^2[19]. Glass wall set with 305K temperature. All other surfaces are designated as adiabatic. Outside building temperatures were ignored in this research.

Table 1. Boundart condition of simulation

Place	Type	Value
Room inlet	Pressure inlet	$P_{r,i}$=0 Pa, T_0=293K
Chimney outlet	Pressure outlet	$P_{r,0}$=0 Pa
Glass wall	Temperature	305K
Heat wall	Heat flux wall	800 w/m^2
Others wall	Adiabatic wall	q=0 W/m^2

3. Result and Analysis

3.1. Type A (DSF only)

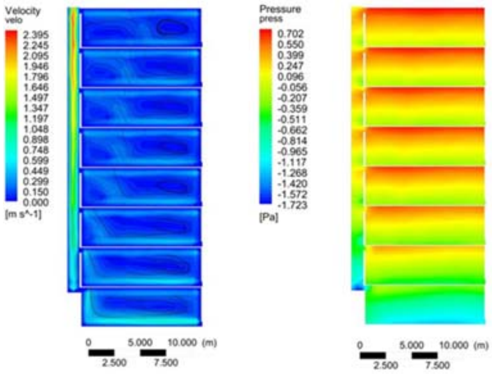

Figure 3. Result contour of velocity (left) and pressure (right) of simulation type A

From the Figure 3 above shows that DSF is able to induce indoor wind velocity to 0.7 m/s on the first floor. But that only happens around the inlet. At the top of the room (ceiling area), the wind velocity is about 0.2 m/s. However, the wind velocity seen in the DSF gap is capable of reaching 2.3 m/s but has not been able to increase the wind velocity that goes into the room. That is because pressure in the DSF gap is still not strong enough to induce wind flow well distributed into the room.

3.2. Type B (DSF + Vertical Solar Chimney)

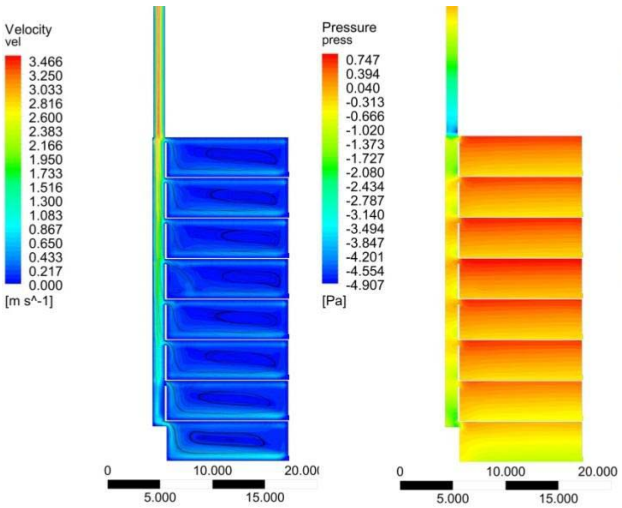

Figure 4. Result contour of velocity (left) and pressure (right) of **simulation** type B

Figure 4 above can be seen that the air flow is better distributed in each room. There was a slight increase in wind velocity, especially around the inlet of each floor. For air pressure, it tends to be well distributed in each room. The use of 90˚ vertical solar chimney can increase wind velocity in DSF gap reaching max 3,466 m/s. This result is because the pressure in the solar chimney is able to induce wind flow from the room better than others.

3.3. Type C (DSF + 45˚ Solar Chimney)

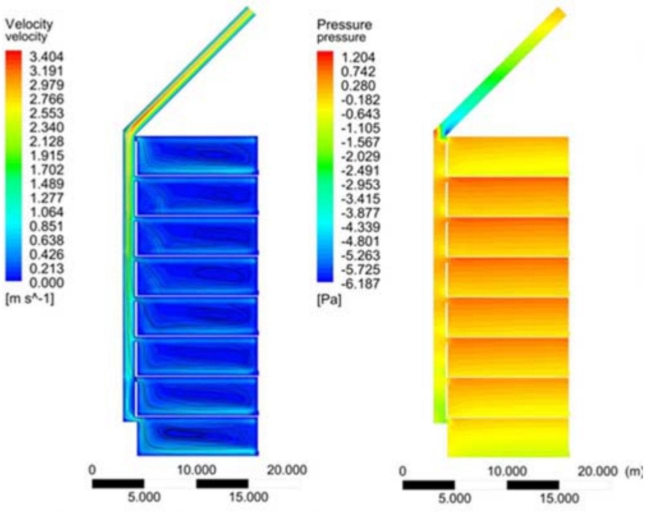

Figure 5. Result contour of velocity (left) and pressure (right) of **simulation** type C

In the above Figure 5 can be seen a slight increase in wind velocity, especially on the 8th-floor area, around the inlet. Overall, solar chimneys capable of this variation are able to induce better than previous variations, although airflow in the double-skin gap and chimney tends to decrease. While the air pressure of each room pressure to decline to a maximum of only 0.2 Pa. This is due to the air flow to the DSF gap more smoothly.

3.4. Type D (DSF + Horizontal-Vertical Solar Chimney)

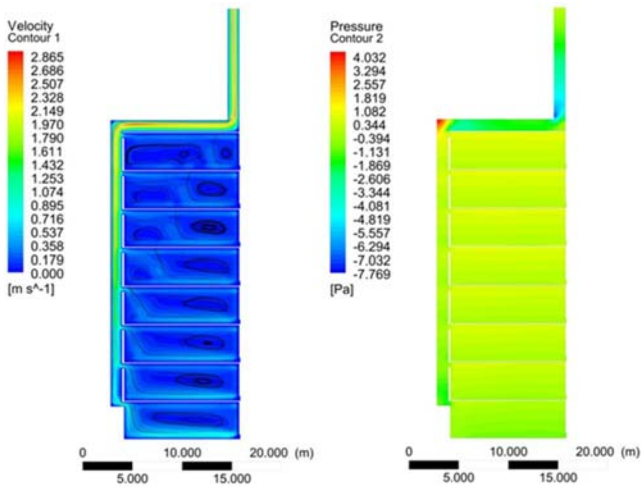

Figure 6. Result contour of velocity (left) and pressure (right) of **simulation** type D

In the above Figure 6 can be seen that wind velocity in DSF gap and solar chimney cannot be increased significantly. Although the wind velocity of the lower floor area tends to increase, the other floors do not increase. It can even be said to be small. Air pressure tends to decrease in every room. This is because the wind flow is slightly hampered due to the bending, which causes the air pressure slightly unchanged in the DSF gap.

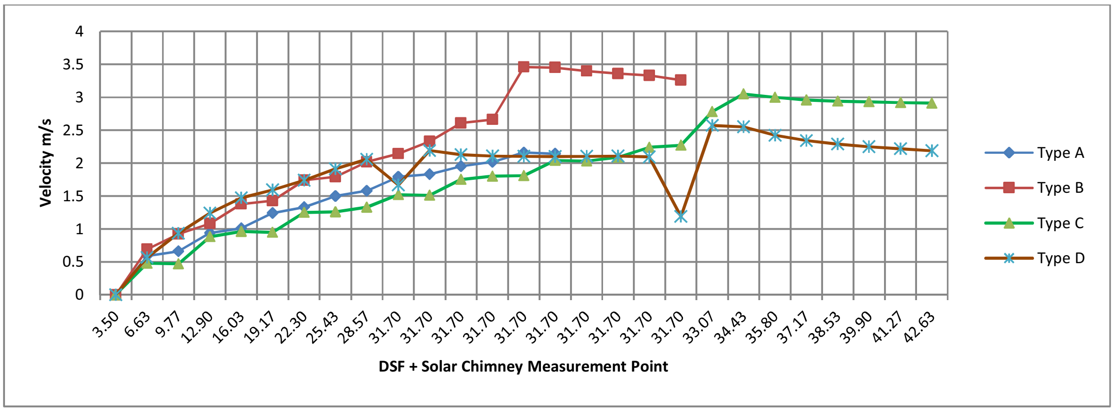

Figure 7. Graph of velocity inside DSF gap and solar chimney (point 3.50-31.70 is DSG gap measurement point, 31.70-42.63 is solar chimney measurement point)

Figure 7 shows the use of DSF only in simulation type A does only produce low wind velocity, but the wind velocity inside DSF gap is still better than DSF gap when combined with slopped solar chimney (before point 31.7) in simulation type C, although then wind velocity increased after passing through the gap (while inside the chimney). In simulation type D, the horizontal-vertical performance of solar chimney has not been able to increase wind velocity in the DSF gap. This is because there is slowing of airflow in both bending areas. The best performance can be seen in simulation type B. Performance of vertical solar chimney can increase wind velocity stably from DSF gap to chimney outlet. It remains to be seen how the performance of all types of simulation s on the inside of room.

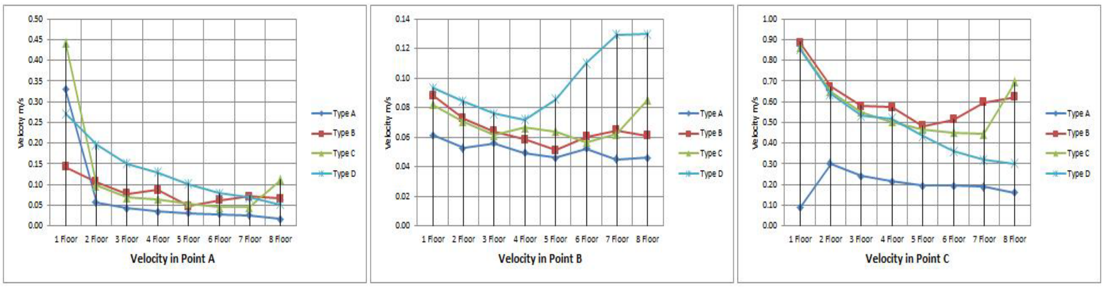

Figure 8. Graph of velocity in room measurement point A, B, and C

In general, all the above Figure 8 explain that solar chimneys are proved in able to induce better airflow into the room. Its velocity can be said to be comfortable (exceeds 0.25 m / s). Observations on all three points (A, B, and C) on each floor can be deduced that the vertical solar chimney (simulation type B) is able to maintain wind velocity to be well distributed on each floor. Compared to other simulation types that only increase wind velocity on the ground floor only and tend to decrease its ability on other floors. Observation at point C (near the DSF gap) further confirms the ability of vertical solar chimney (simulation type B).

4. Conclusion

The performance of DSF and solar chimneys has been evaluated. Thus, this study proved that the DSF combined with solar chimney could increase the wind velocity in the DSF gap itself as well as air flow in space. Well distributed of wind velocity is better than high wind velocity but not well distributed. It is recommended that further work, in this case, is addressed to the chimney parameter (the height or width), chimney material elements to enhance the stack effect, as well as the performance of thermal storage to run chimneys at night.

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