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HOUSE'S SOLAR CHIMNEY A NUMERICAL ANALYSIS ON THE THERMAL PERFORMANCE IN JAKARTA

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Abstract -- *The abundance of solar light in tropical countries is the advantage of the utilization of solar energy. Increasingly expensive electricity forces buildings to use passive ventilation as building coolers. One of them is the use of the stack effect through the solar chimney. The absence of residential buildings that use the solar chimney as part of a passive ventilation system makes the need for prototypes for residential buildings. The application of solar chimney to homes in Jakarta is something new. Six types of the solar chimney have been tested on a prototype, one-story residential houses in Jakarta. The location was assumed to be in the densely populated area of South Jakarta. Wind velocity ambient data using Rubber locations. Using ANSYS 16.0, simulations have been carried out, and solar chimney with double-full roof collector was able to induce a wind velocity of 0.41 m/s on average*

Keywords: *Solar chimney; Passive ventilation; One-story house*

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INTRODUCTION

A humid tropical climate like in Jakarta, in general, buildings are designed with natural ventilation systems that maximize wind velocity to be able to cool the building or to achieve [1, 2]. The concept of design with a natural ventilation system that maximizes wind speed, in addition to paying attention to the movement of wind flow, also looks at the influence of the surrounding environment and buildings on the wind flow [3]. A ventilation strategy is needed to ensure maximum comfort. Ventilation is a process whereby the 'clean' air (outside air) enters (deliberately) into the room while simultaneously pushing the dirty air inside the room out [4]. Several studies related to the use of building energy indicated that the energy required for heating and cooling buildings is approximately 40% of the world's total energy consumption [5].

One type of passive ventilation strategy is the utilization of the stack effect. Satwiko explained that the movement of air created by the stack effect is usually not enough to achieve physiological cooling, because it is less than the recommended airspeed to cool from 0.15-1.5 m/s in humid tropical climates [6]. The Bernoulli principle used for designing the stack effect ventilation. One device that utilization stack effect is a solar chimney.

The solar chimney is a construction used to promote air movement throughout a building by using solar energy to improve ventilation. The use of solar chimney in buildings has been widely discussed by experts, especially in the humid tropics, where sunlight is abundant. The solar chimney from the previous research can be induced by wind velocity reach 35% [7][8]. Building density is one of the principal factors that influence microclimate conditions and determine ventilation conditions and air temperature conditions. The effects of urban warming are primarily caused by city density rather than city size itself; the denser the house, the worse the ventilation [9, 10]. On the other hand, high density also provides an advantage in reducing sunlight from buildings during the tropical period. The effect of city density on ventilation conditions also depends on wind conditions, spatial arrangement, and height of buildings [11].

Therefore, this study is conducted to explore how solar chimney ventilation can increase air velocity in the house to create thermal comfort for occupants in Jakarta? Abundant availability of solar energy is a significant advantage. Solar rays can be used as energy to produce buoyant flow to increase the air velocity in buildings. The effect of air movement that is currently applied to cross ventilation is not enough to create physiological cooling.

METHOD

ANSYS-CFX Version 16 used for simulation purposes in this study. ANSYS-CFX Version 16 uses the unsteady Navier-Stokes equation in their conservation form to solve a series of equations. The location itself is on South Jakarta. This location is fit with the two requirements surrounded by taller buildings/trees and house without a passive ventilation system. In this case, only assumed the location to get the condition of an existing site, then other conditions related to the building physics aspect will be ignored. This research focuses on how to induce win velocity to the house without electricity.

Previous solar chimney research by Nugroho and Tatarestaghi said two types of the solar chimney could be used by homes to induce wind velocity into the house [12, 13]. Tower chimney solar form and roof shape are the two types of solar chimney. Due to that reason, it is necessary to examine how the development of the two solar chimneys in Jakarta's houses with humid tropical climate conditions. The model dimension used 6x12m, according to the size on the site. Each floor consists of two inlets right inlet and left inlet. There is a total of 8 inlets, each dimension 0.5x1.3m on both sides (right and left). In the two-storey model, void separated between the first floor and the second floor. This void will produce air to flow from the first floor to the second floor that are modelled in several type. First, model 1A is without a chimney to validate the absence of solar chimney. Then, models 1B is with a single chimney. After that, models 1C and model 1D are with full chimney and a chimney with a single roof collector, respectively. Then, model 1E and model 1F are a chimney with a full roof collector, both. Finally, model 1G is a chimney with a full double-roof collector. Those models are shown in Figure 1.

Graph wind velocity and streamline, compared to wind velocity's standard by SNI 03-6572-2001 and ASHRAE. In both graphics, there will be only two points measurement points, line measurement in front of the inlet and line in working space. Line in front of the inlet will be 2.5m above the floor surface. Line in working space will be in 0.75m above the floor surface, as described in Figure 2. Both of these measurement points will describe room comfort according to the wind velocity inducing by the passive system.

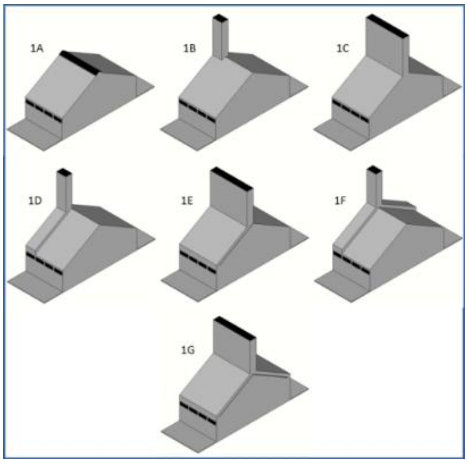

Figure 1. All models used in this research 1A-1G

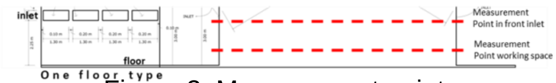

Figure 2. Measurement points

Boundary Condition

As described in Table 1, in the simulation, the properties of air were considered at 20˚C, and Boussinesq's estimate was considered. Gravitational acceleration was set at -9.81m/s2 at the y-axis. The energy model is k- ε with the 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's in 1.205 kg/m3, the thermal expansion coefficient is set at 3.41E-03 1/K. Ambient temperature simulations were set at 293 K [14], while the heat-wall surface was thought to be exposed to a heat flux of 850 w/m^2 [15]. Glass wall set with 305K temperature. All other surfaces are designated as adiabatic. The items are without partition as openings above the door are supposed to be used, as in homes in Jakarta in general.

Table 1. The boundary condition of the 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

RESULT AND DISCUSSION

Result

Different contour and wind streamlines are displayed as a result of the simulation. It described the direction and amount of wind velocity. The two points observed are the point in front of the inlet (in front of the upper window, 2.5m above floor) and the working space point (0.75 m above the floor). These two points are a reference to thermal comfort based on wind velocity in space [16, 17].

One Floor Model with Single Chimney

Figure 3 described the wind velocity contour from model 1A. The above model is a model without a solar chimney. Wind velocity occurred due to heat from the roof that produces the effect of inducing heat through the inlet. The wind velocity inside the room does not exceed an average of 0.15 m/s at both observation points in the room. Still far below the SNI 03-6572-2001 standard and ASHRAE recommendations of 0.25 m/s.

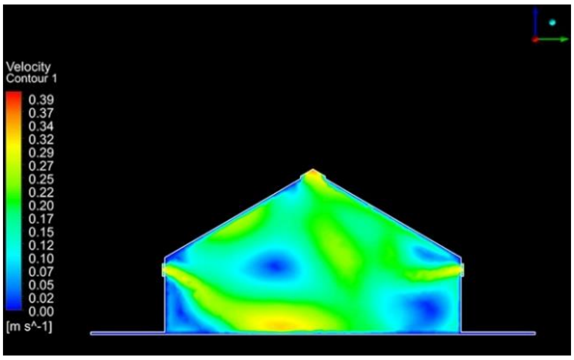

Figure 3. The contour of wind velocity in model 1A

With streamlined Figure 4, the 1A model still induces wind velocity from the inlet to the room, released in the outlet. However, the velocity is still below the standard. The direction of the wind was pointing well towards the bottom of the room before going up to the outlet.

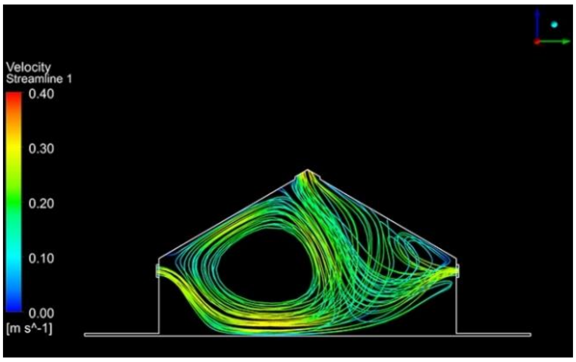

Figure 4. Streamline of wind velocity in model 1A

One Floor Model with Single Chimney

Figure 5 described the wind velocity contour from model 1B as a model with a single solar chimney. The solar chimney is only on one side of the house. Single solar chimney able to induce wind velocity into the room, on average 0.13 m/s. This amount divided into two parts, 0.12 m/s in front of inlet and 0.15 m/s in the working space. Wind velocity in the working area was more significant because the wind flow is more directed to the working space from the inlet.

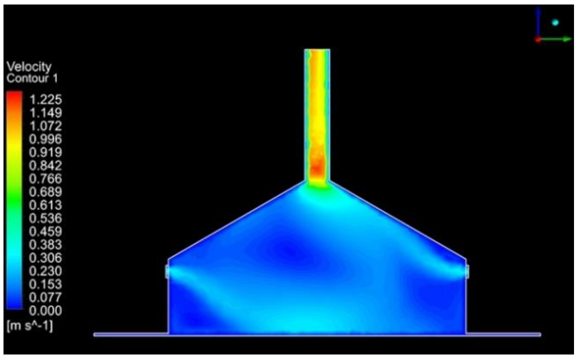

Figure 5. The contour of wind velocity in model 1B

Meanwhile, the highest wind velocity occurs in chimneys due to high pressure. This phenomenon called the Jetstream effect. Where a speedy flow will force and persuade the flow around it. As a result of this phenomenon, the air outside the inlet can be induced into the house.

Figure 6 explains the flow tends to rotate in the working space after being induced through the inlet. Also seen Jetstream on the chimney persuade flow around it. From the Figure above can be seen that one side solar chimney was not optimal in inducing wind velocity from the inlet.

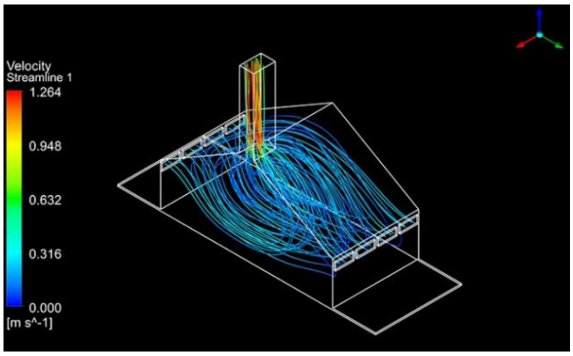

Figure 6. Streamline of wind velocity in model 1B

One Floor Model with Full Chimney

Figure 7 shows the full chimney in the whole house's width. The solar chimney works better than a single type of solar chimney. Chimney can improve 35% better than the previous type, 0.2 m/s is the average value achieved by the solar chimney (0.17 m/s in front of inlet and 0.23 m/s in the working space). The uniqueness made not due to the Jetstream phenomenon. Jetstream flow that occurs is only 0.3 m/s. Induced wind velocity due to differences in pressure is at 3.7 Pa between the end of the chimney and the inlet. This difference causes the wind to flow according to the pressure-gradient force principle, as shown in Figure 8.

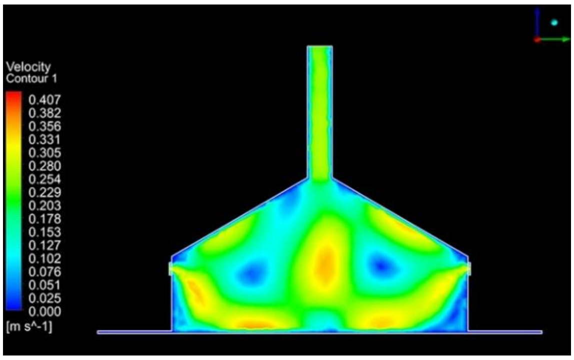

Figure 7. The contour of wind velocity in model 1C

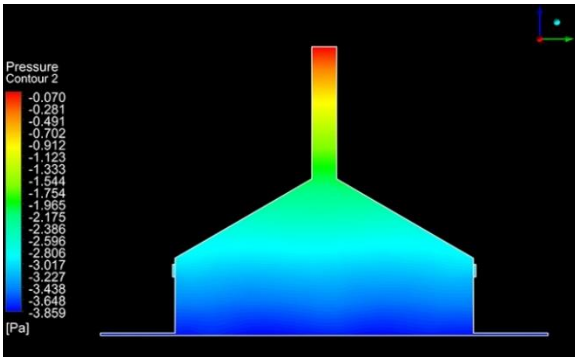

Figure 8. The contour of pressure in model 1C

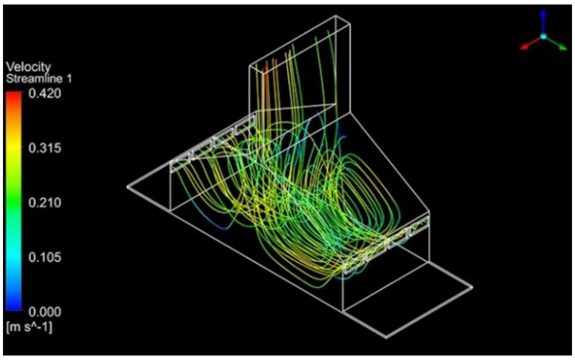

Figure 9 Streamline of wind velocity in model 1C

Figure 9 explains that chimney in whole house width does not create Jetstream. But this creates fair distribution in inducing wind velocity from the inlet.

One Floor Model's Chimney with Single Roof Collector

Figure 10 illustrates the contour wind velocity produced by the use of solar chimney with the heat collector in the roof shape on one side of the house. The solar chimney can induce an average wind velocity of 0.13 m/s, which divided into 0.11 m/s in front of the inlet and 0.16 m/s in the working space. Jetstream occurs in chimneys in the roof area of a maximum of 3 m/s, but in fact, this Jetstream is not able to induce wind velocity into the house.

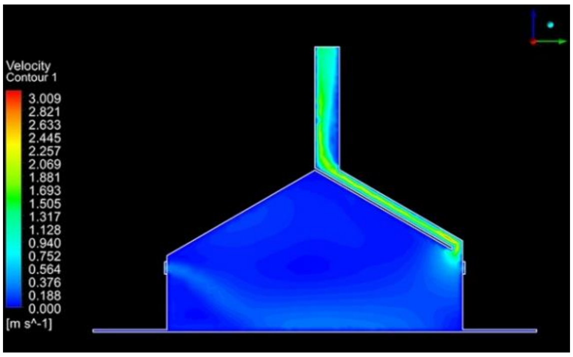

Figure 10. The contour of wind velocity in model 1D

Based on Figure 11, high pressure occurred only in the room, reached 6.5 Pa. Due to this reason, causes the chimney cannot induce wind velocity.

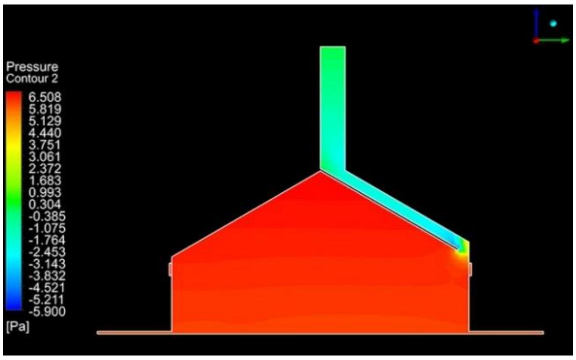

Figure 11. The contour of pressure in model 1D

One Floor Model's Chimney with Full Roof Collector

Based on Figure 12, the full chimney with roof shape in the whole house's width can induced wind velocity, on average, 0.16 m/s. This value much better 21% than type 1D, but 17% worse than type 1C. Those average divided into two parts, 0.12 m/s in front of inlet and 0.21 m/s in the working space. The better performance than type 1D was because solar chimney type 1E wider than type 1D: the wider, the better performance in inducing wind velocity.

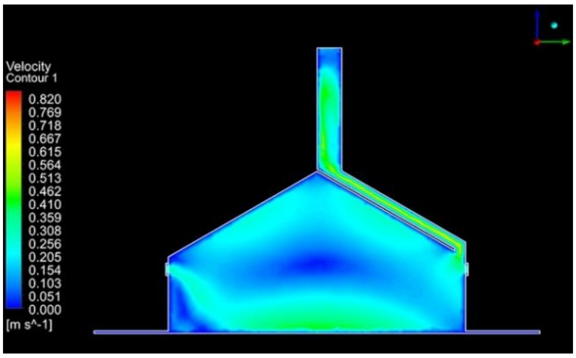

Figure 12. The contour of wind velocity in model 1E

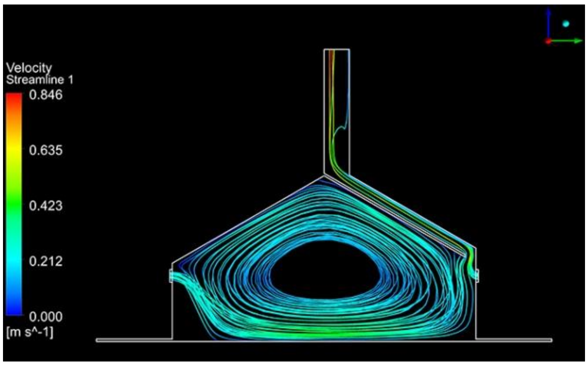

Figure 13. Streamline of wind velocity in model 1E

Figure 13 explains the airflow to the chimney is higher than the inlet that is opposite the solar chimney position. Wind flows from the inlet in the opposite position into the working space area. From the working space, the wind stream turns back to the top area before heading to the chimney while the flow from the inlet under the chimney goes directly to the chimney, without going to the working space area first.

One Floor Model's Chimney with Double-Single Roof Collector

Based on Figure 14, the chimney was only able to induce wind velocity in a room of 0.09 m / s. These values are for both areas, both in front of the inlet, and the working space area. This value is a very small amount compared to other types. That's because Jetstream on the chimney is only able to persuade wind velocity in the heat wall chimney area only. The situation occurs due to the pressure in the room, according to the Figure below.

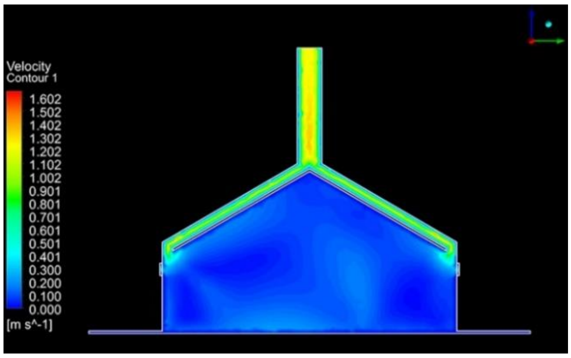

Figure 14. The contour of wind velocity in model 1F

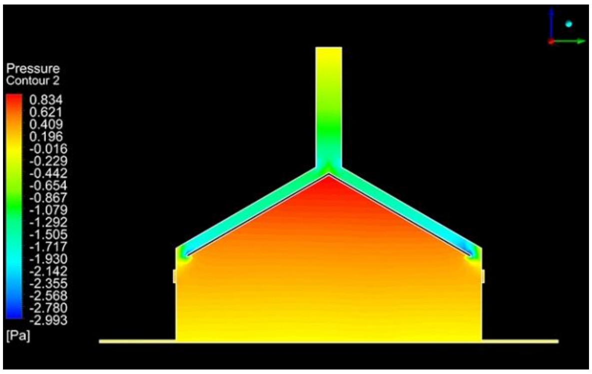

Figure 15. The contour of pressure in model 1F

From Figure 15, the pressure in the room was too high as the same as the pressure in chimney 0.1 Pa. Meanwhile, a very large pressure occurs at the top of the room (0.8 Pa). Due to the pressure-gradient force principle, wind velocity flow from the high-pressure area to the low-pressure area, there is very little difference in the water pressure between the room and the end of the chimney.

One Floor Model's Chimney with Double-Full Roof Collector

Based on Figure 16, the one-floor model's chimney with a double-full roof collector was able to induce wind velocity into the room by an average of 0.4 m/s. This value divided into two parts, 0.27 m/s in front of the inlet area and 0.56 m/s in the working space area. Due to the evenly distributed by chimney width and on both sides of the roof, the solar chimney was able to induce wind velocity properly.

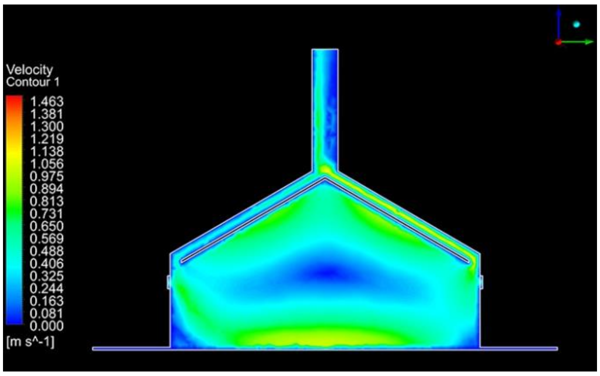

Figure 16. The contour of wind velocity in model 1G

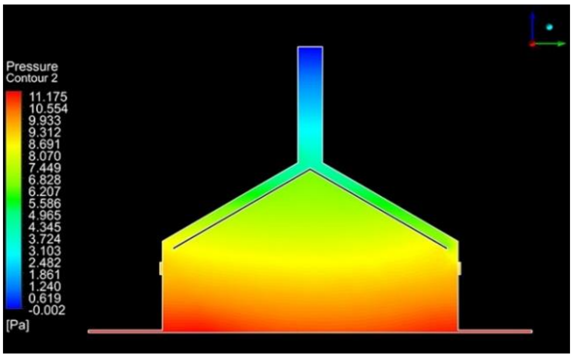

Figure 17. The contour of pressure in model 1G

Figure 17 illustrates that, based on the pressure-gradient force principle, the pressure that occurs causes airflow from outside to enter the room with a pressure of 11 Pa. With a pressure of 11 Pa, wind velocity was able to flow towards the lowest pressure in the house at the end of the chimney (0.3 Pa). This significant pressure difference (10.6 Pa) causes wind velocity to flow appropriately.

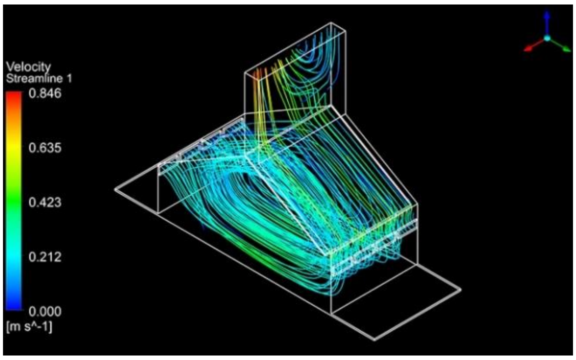

Figure 18. Streamline of wind velocity in model 1F

Figure 18 described the wind streamline of type 1G. The chimney was able to induce the flow of wind from the inlet to the chimney. Wind flow rotates in the area of the room before heading to chimney. Jetstream phenomenon that occurs at the end of the chimney was able to persuade the airflow in the area of the room.

Discussion

Based on Figure 19, the maximum wind velocity that a solar chimney can induce is 3.09 m/s. This value occurs due to induced by type 1D, in the solar chimney gap. But most important is inducing wind velocity in the lower room, working space, and front of the inlet.

Base on the Figure above, only models without a chimney (1A), 1C models, and 1G models that contour map show the best results. All three were able to induce wind velocity in the room to reach a maximum of 0.9 m/s.

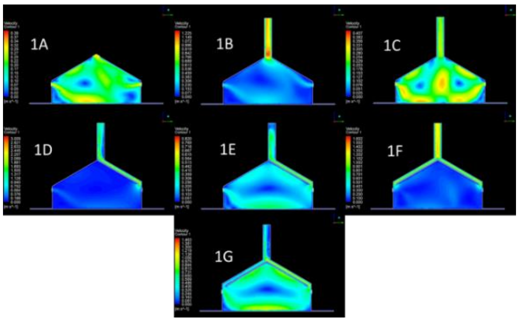

Figure 19. Compilation of wind velocity contour from type 1A-1G

However, the assessment of which type was able to persuade the best natural ventilation must be seen from the factor of average wind velocity that occurs in the room.

Figure 20 and Table 2 show the graph of average wind velocity in all one-floor types. The average point of wind velocity in front of the inlet, working space, and average of all measurement points were revealed. Model without chimney was able to induce wind velocity an average of 0.15 m/s. One floor chimney model with a double-single roof collector (1F) was the worst solar chimney with an average wind velocity of 0.09 m/s. The value does not reach the thermal comfort standard based on wind velocity by SNI 03-6390-2000 and ASHARE of 2.5 m/s. The condition is due to the narrow single chimney space.

One floor model of the chimney with a double-full roof collector becomes the best solar chimney performance. The best inducing value reaches 0.41 m/s. This value is above the threshold for thermal comfort standards based on wind speed by SNI 03-6390-2000 and ASHRAE 2.5 m/s. The condition is because chimney space with full width was able to maximize Jetstream flow. Besides, the use of double chimney on both sides of the roof also adds suction power to wind velocity.

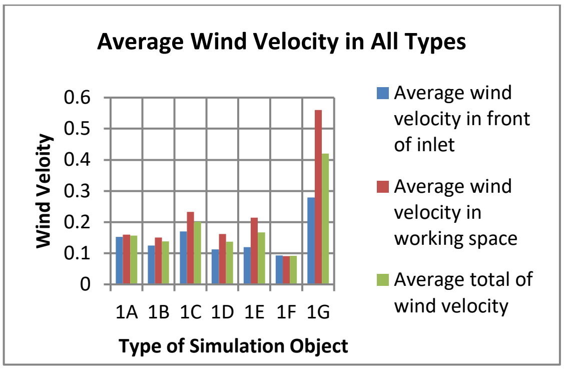

Figure 20. Graph of average wind velocity in all one-floor types

Table 2. Average wind velocity in all one-floor types

	Av. in front of inlet (m/s)	Av. Working space (m/s)	Average Total (m/s)
1A, One Floor Model without Chimney	0.15266	0.16004	0.15635
1B, One Floor Model with Single Chimney	0.12518	0.15044	0.13781
1C, One Floor Model with Full Chimney	0.17013	0.23251	0.20132
1D, One Floor Model's Chimney with Single Roof Collector	0.11217	0.16239	0.13728
1E, One Floor Model's Chimney with Full Roof Collector	0.11952	0.21408	0.1668
1F, One Floor Model's Chimney with Double-Single Roof Collector	0.09325	0.09096	0.0921
1G, One Floor Model's Chimney with Double-Full Roof Collector	0.27926	0.56048	0.41987

Based on the above simulation, the use of a single chimney on one side is the worst performance. Only reach a maximum wind velocity of 0.13 m/s. This value is achieved on a one-floor model with a single chimney and one-floor model's chimney with a full roof collector. A full chimney was able to produce a maximum amount with the 1G model, as mentioned earlier. The minimum value created by using full types chimney is 0.166 m/s on a one-floor model's chimney with a full roof collector.

Through a one-floor simulation, it can conclude that by using a one-floor model's chimney with a double-full roof collector. A house building can induce wind velocity into the room to reach the most comfort value according to SNI 03-6390-2000 and ASHRAE with a value of 0.25 - 0.5 m/s.

CONCLUSION

Simulations of using the solar chimney as a passive ventilation induction system have been carried out. The use of solar chimney in homes has proven to be able to induce wind velocity into the room through the inlet. In this study, comfort standards in the thermal space based on wind velocity were used by SNI 03-6390-2000 and ASHRAE.

Through the simulation of one-floor type and two-floor type, it can be concluded that the use of solar chimney in a one-story house is more effective. The solar chimney was able to induce wind velocity into the room to reach an average of 0.41 m/s by using a one-floor model's chimney with a double-full roof collector. The use of solar chimney on two-story houses is less effective. The use of a two-floor chimney model with a double-single roof collector is only able to induce an average wind velocity of 0.149 m/s.

Based on the simulation performed, several suggestions can propose related to the design of a passive ventilation system:

1. To make natural ventilation in the house effective, it requires minimum free clearance on one of the front or backsides.
2. The use of roof ventilation by opening the top of the roof is one solution if the use of solar chimney is not possible
3. The solar chimney that used with a minimum height equal to the height of the building (more than one-floor height solar chimney)

For future research related to this research, there are several suggestions. First is solar chimney performance at night/overcast day. Then, the solar chimney with chimney height of more than one floor for the house. Last is solar chimney without a chimney (only with solar collector) for the home

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