สมรรถนะผนังแบบทรอมบ์ กรณีศึกษาของตึกแถวในกรุงพนมเปญ
Trombe Wall Performance in Case of Phnom Penh Row House

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บทคัดย่อ

การศึกษาในครั้งนี้เป็นการศึกษาถึงพฤติการณ์ของระบบผนังแบบทรอมบ์ เพื่อใช้ในการปรับปรุงการระบายอากาศภายในอาคารตึกแถวในกรุงพนมเปญ ด้วยการติดตั้งผนังแบบทรอมบ์บริเวณช่องบันไดที่ชั้นบนสุดของอาคาร โดยผนังแบบทรอมบ์หันหน้าไปทางทิศใต้หรือทิศตะวันตก ทั้งนี้การศึกษาได้ทำการศึกษาคุณลักษณะการไหลและสมรรถนะของผนังแบบทรอมบ์ ในปัจจัยของความเร็วลม อุณหภูมิ และปริมาณการไหลของมวลอากาศ ตั้งแต่เริ่มต้นการทดลองจนถึงภาวะเสถียรของปรากฏการณ์ โดยใช้เครื่องมือโปรแกรมพลศาสตร์ของไหลเชิงคณนา (CFD program) ผลการศึกษาพบว่า ที่ปริมาณความร้อนต่อหน่วยพื้นที่ (heat flux) 200 วัตต์ต่อตารางเมตร, 400 วัตต์ต่อตารางเมตร, 600 วัตต์ต่อตารางเมตร 800 วัตต์ต่อตารางเมตร และ 1000 วัตต์ต่อตารางเมตร ผนังแบบทรอมบ์ก่อให้เกิดการไหลเวียนของอากาศที่ความเร็วเฉลี่ย 0.14 เมตรต่อวินาที 0.19 เมตรต่อวินาที 0.22 เมตรต่อวินาที 0.26 เมตรต่อวินาที และ 0.28 เมตรต่อวินาที ตามลำดับ และผนังแบบทรอมบ์มีศักยภาพในการทำให้เกิดความเร็วลมที่จะทำให้เกิดภาวะน่าสบายตั้งแต่ปริมาณความร้อนต่อหน่วยพื้นที่ 600 วัตต์ต่อตารางเมตรขึ้นไป

นอกจากนี้ผลการศึกษา ยังพบว่าอุณหภูมิในช่องผนังแบบทรอมบ์เมื่อเปรียบเทียบกับอุณหภูมิที่กระจกและผนังเมื่อเริ่มแรกทำการทดลองในภาวะเสถียรมีค่าลดลง ตั้งแต่ 4 องศาเคลวิน ถึง 33 องศาเคล

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วิน อันเป็นผลมาจากการแทนที่ของอากาศเย็นจากช่องอากาศเข้า (inlet) ของระบบ อัตราการไหลเวียนมวลอากาศสูงสุดที่ช่องทางเข้าของผนังแบบทรอมบ์ มีค่าแปรผันโดยประมาณระหว่าง 0.06 กิโลกรัมต่อวินาที ถึง 0.115 กิโลกรัมต่อวินาที ที่ปริมาณความร้อนต่อหน่วยพื้นที่ ตั้งแต่ 200 วัตต์ต่อตารางเมตร ถึง 1000 วัตต์ต่อตารางเมตร ผลการทดลองดังกล่าวแสดงให้เห็นถึงสัญญาณที่ดีในการประยุกต์ใช้ผนังแบบทรอมบ์ในตึกแถวเพื่อช่วยการไหลเวียนของอากาศภายในอาคาร โดยยังคงมีประเด็นที่ควรศึกษาต่อเพื่อพัฒนาระบบในประเด็นของขนาดของระบบผนังแบบทรอมบ์ ปริมาตรของห้องเป้าหมาย และระยะทางระหว่างพื้นที่เป้าหมายกับระบบผนังแบบทรอมบ์

Abstract

This work studies about the performance by Trombe wall system to improve indoor ventilation of Phnom Penh row house by installing it next to a stair block wall on top floor which faced south or west. The current work investigated on flow characteristic and phenomena of Trombe wall in term of velocity, temperature, and air mass flow reception from the beginning of experiment until steady state. CFD program was used as processing tool. The result indicated that from the heat flux 200W/m², 400W/m², 600W/m², 800W/m², and 1000W/m², Trombe wall induced average ventilation of 0.14m/s, 0.19m/s, 0.22m/s, 0.26m/s, 0.28m/s respectively. Trombe wall had capability to reach velocity of comfort zone induced from heat flux 600W/m² up. Temperature in channel at steady state decreased from 4K to 33K compared with temperature on glass and on wall at first set up due to the replacement of cool air from inlet of the system. Highest mass flow rate got at inlet were approximately varies from 0.060 kg/s to 0.115kg/s from heat flux 200W/m² to 1000W/m². The outcome showed a good sign for the application of Trombe wall on row house while size of the system, volume of target room, and distance from target room to the system should be further investigated.

Keywords – CFD program, indoor ventilation, Phnom Penh row house, Trombe wall.

INTRODUCTION

To respond to climate change problems, Passive design technique roles an essential factor to minimize the energy usage in buildings (McGee, 2013). To take best advantage of the local climate, passive design with renewable sources of energy such as sun and wind to provide cooling and ventilation is prior which should be implemented. As a part of a movement towards sustainable architecture, there are several types of passive ventilation strategy which had been researched to improve indoor living comfort. Since the typical opening such as single-sided ventilation and wind-driven cross ventilation (Mozaffarian, 2009) could not apply to satisfy for all conditions of building design, the advance techniques of stack effect and wind-catcher were subjected in experiments. In case of Phnom Penh row houses, Lay (Lay, 2013) did a study about wind-catcher to induce ventilation in row house by designing the system on the top chamber of stair block. He found out that wind-catcher did not provide any significant to ground floor living room or kitchen neither all apertures are closed nor opened. It worked for only for family room which was on a floor below the system and next to the stair block itself. Moreover, Mazran (Mazran Ismail, Abdul Malek Abdul Rahman, Ruhizal Roosli, Md Azree Othuman Mydin, 2012) stated that this strategy depends on wind speed and direction relative to quadrants (of catcher tower), and temperature differential. Therefore, it is not effective in low-wind velocity condition and low indoor-outdoor temperature differential. Anyway, instead of depending on the irregular wind blowing or natural stack effect, previous studies have revealed that advanced stack ventilation strategies could be more reliable strategies to induce upward air movement and extract it out from the building especially in low indoor-outdoor temperature differential condition like hot-humid tropical climate region.

Trombe wall technique (J. Khedari, et al., 1999) is one of the passive solar applications adding on stack effect. This wall can be constructed on the sun side of a building with a glass external layer and a high heat capacity painted black wall separated by an air layer. The air in channel sucked from inlet and move up to outlet by buoyancy force. Omidreza S. et al. (Omidreza Saadatian, et al., 2012) investigated about the opportunities and challenges in research and development of Trombe wall. There are categorized into 9 types of solar induced ventilation system such as classic trombe wall, Solar transwall, Trombe wall with phase-change material, Photovoltaic (PV) Trombe wall (Kashif Irshada, Khairul Habiba, Nagarajan Thirumalaiswamya, 2014)- (Ji Jie, Yi Hua, et al., 2007), and so on. In addition to these basic systems, some researchers had been focused about others kind of materials which were expected to produce high capacity of mass flow rate or air velocity. J. Hirunlabh (J. Hirunlabh, W. et al., 1999) took a test on metallic solar wall separated with a gap from glazing panel. Air mass flow rate received from the scheme was about 1.01-0.02 kg/s with surface area 2m². Besides, the other proposed glass solar chimney wall compare to single layer glass wall to apply in tropic region (Jaran Ratanachotinun; Pithan Pairojn, 2014). Upon three seasons of the year, glass solar chimney wall could afford 1.28°C to 2.46°C reduction of room temperature compared to the single layer one. Another experiment case of Mozart house in Lyon, France, two Trombe walls installed at south side of the house help to save energy for heating around 20% for a year (Milorad Boji ́c, Kévyn Johannesb, Frédéric Kuznikb, 2014). Anyway, for tropic region, Akkeepas L. (2009) studied the performance of glazing Trombe wall discovered that in comparison with common wall, glazing trombe wall could save up to 38% of the electricity on air-conditioner for a sample room volume of 27m³. Due to these studied, it was proofed that the system contributed the economic benefit in energy saving and assisted to maintain occupants' comfort. In case of this topic pilot case study, the typical Trombe wall which consists of normal glass panels and wall should be first considered while the system would not be paid a high range cost, thus give more feasibility in renovation on the existing houses. Top chamber of stair block was a good location in mean of stack ventilation channel to link the air flow from every floor of the house arisen up to the exit.

Researchers also paid deep attention on factors offered high flow performance in Trombe wall channel. S.A.M. Burek et al (S.A.M. Burek, A. Habeb, 2007) reported on an experimental study about air flow and thermal efficiency characteristics in solar chimneys and Trombe walls. The results gave out the correlation parameters of mass flow and thermal efficiency in dimensionless form. It is distinguished that mass flow rate through the channel was a function of heat input and channel depth. Gan (Gan, 1998) also noticed on the effect of the gap between wall and glazing, wall height, glazing type, and wall insulation. The prediction of ventilation rate increased while the temperature and heat rate increased. The inlet and outlet height should be equally increased by the increasing of channel gap width. Aniroot T. (2005) studied about the relationship between heat flux and mass flow rate in gypsum board trombe wall. The outcome showed that the maximum air flow rate referred to depth of the channel on length of the wall (D/L) ratio 0.25 with heat flux 1000W/m². However, the highest thermal efficiency gave its best at ratio 0.05, the mass flow rate resulted lesser. However, different researcher (2006) explored the most effective design of the Trombe wall, considering the heat flux applied, mass flow rate of air in a channel and wall aspect ratio (channel gap and wall height). The consequences showed that in the steady state, the air flow rate in the channel was constant in all cases of heat inputs from 200W/m² to 1000W/m². It also found that the air mass flow rate increased with the rise of the heat flux input and the decrease of air gap depth. Air flow rate reached a maximum at the aspect ratio of 0.05 with heat flux of 1000 W/m2. According to the constraints declared by previous studied, heat flux contributed to the effect of flow in channel of Trombe wall. The objectives of this paper was to apply the best ratio of Trombe wall gap with different heat flux varies from 200W/m² to 1000W/m² due to the assumption of heat flux from the sun from low light till the highest light during a day. Trombe wall was designed on top stair block chamber of Phnom Penh row house. The results brought out the comparison of output data of each testing case identified as velocity, temperature, and mass flow quantities. Next, it was detailed about flow pattern process in notable position in channel along step of times until steady state. The simulations were done by computational fluid dynamic (CFD), since this program was validated compared to real experiments as well as its revealing results in feasible visualization, low cost of labor and equipment (Ni-tawichit, 2008).

MODELING SETUP

Trombe wall was designed to install on the stair block top chamber of typical low stories row house in Phnom Penh. This type of row house consists of three floor layouts include a mezzanine floor. As shown in figure 1, section of an existing row house explained the connection between each facilities of the house to the vertical tunnel of the stair block. Trombe wall would be installed on south or west wall of an external stair block wall depends on the direction of the houses. While applying the design, the existing opening with cement grill on the chamber was ignored as solid wall, so that air flow pattern from inlet into Trombe wall could be emphatically defined and analyzed. Figure 2 elaborated about Trombe wall size according to the research of P. Thongnut (2006). Since the best ratio 0.05 between gap and wall high was followed, the gap depth was set 12cm. and equaled with inlet and outlet height. 3D modeling which was input into simulation program was highlighted in break-line rectangle as shown in figure

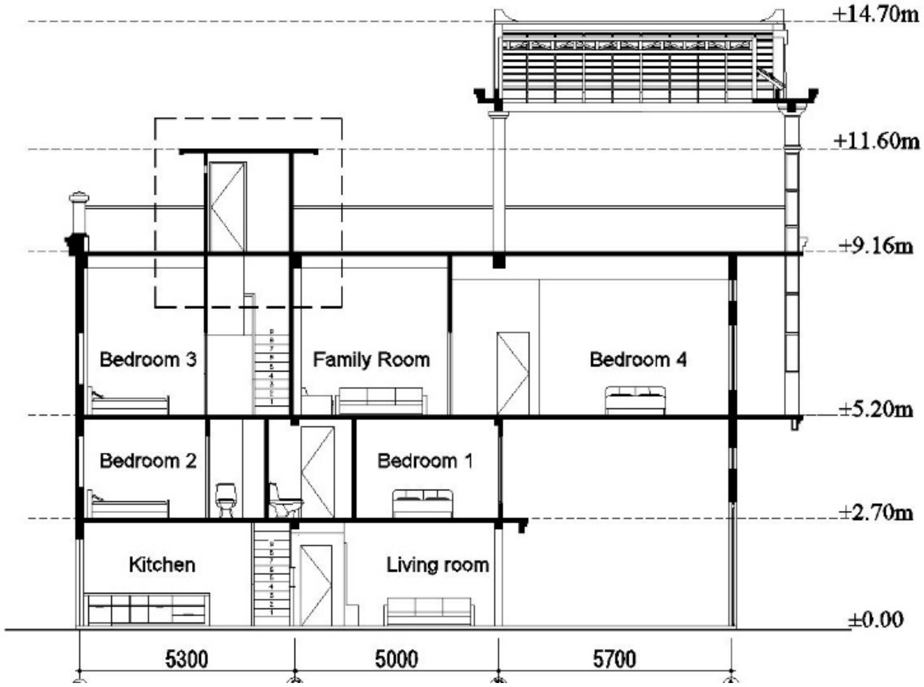

Fig. 1. Section of typical row house

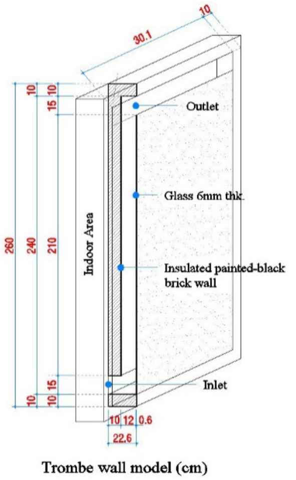

Fig. 2. Dimension of Trombe wall installation

There contains 5 groups of simulation cases according to heat flux input from 200W/m², 400W/m², 600W/m², 800W/m², 1000W/m². Hence, to measure the effectiveness of the system, XFlow CFD program (Next Limit, 2014) were function as simulation tool. By heat fluxes input, referred to table 1, the conversion into a range of temperature on internal wall and glass surface were surveyed to be used in pre-simulation setting up due to Phanuphong T. (2006). All surfaces of the domain are considered as isothermal walls and no slippery condition was set to the walls. Other primary boundaries condition input were considered as earth gravity, indoor and outdoor temperature, ambient pressure. Inlet condition was set by not using initial wind speed assisted, but based on a small pressure different which 2Pa was input. According to ASHRAE standard of comfort zone, the indoor temperature was set 27°C (ASHRAE-55, 2004), as this range started to dissatisfy occupant comfort. Furthermore, based on a whole day surveyed on temperature in row house (Lay, 2013), there were no lower temperature than 27°C noticed. The outdoor temperature was referenced from Phnom Penh airport weather data station as the average of hot temperature during summer from 2003-2012 (Cedar Lake Ventures, n.d.). Table 2 showed important input parameters for simulation. The simulation were put to run until steady state.

The result of simulation would be analyzed in term of temperature, velocity, and mass flow rate reception in channel. At steady state, the comparison of each heat flux consequences would bring out for discussion. Post progressing of simulation will be resulted in 3D field view, and vector of flow by time steps.

Heat Flux	Tem. glass		Tem. Wall	
W/m²	K	°C	K	°C
1000	356.35	83.20	334.15	61.00
800	349.62	76.47	331.82	58.67
600	338.95	65.80	326.58	53.43
400	332.82	59.67	321.32	48.17
200	325.62	52.47	317.35	44.20

Table 1. Input data of temperature on internal surface of glass and wall

Input	Unit	Data
Gravity	m/s^2	9.81
Initial temperature	K	300.15
Operating temperature	K	306.15
Inlet pressure	Pa	2
Inlet temperature	K	306.15
Outlet		Gauge pressure outlet
Simulation time	s	200
Resolve scale	m	0.1

Table 2. Other input data for experiments

RESULT

This section brought out the comparison of each case of test in term of output data identified as velocity, temperature, and mass flow quantities. Thus, flow pattern process in notable position in channel at steady state would be detailed and analyzed.

Simulation result of velocity

Figure 3 showed the average velocity of each heat flux from initial operation until steady state. The average result at each point of time received from a line which was drown from wall to the inner surface of glass inside the channel near the outlet as shown by line 1 in figure 6 . All graphs expressed a very similar pattern of velocity from one to another heat flux input. Lower heat input gave lower wind velocity than higher heat input. It is noticed that after the system was stably heated, the air started to flow out at outlet of channel at 20 seconds of time. From 0 to 20 seconds, it seemed that the air was arranging itself to adapt with heated area between wall and glass. At first 5 seconds the air rose in a very high level as the result of a great sucking speed from inlet due to low pressure in channel. Then air speed decreased a little bit back caused from the movement up and down of self-arrangement. From 40 seconds, there appears the initial of steady state since then air flow rate won't dramatically change its range. The result of average velocity at steady were 0.14m/s, 0.19m/s, 0.22m/s, 0.26m/s, 0.28m/s for the heat flux 200W/m², 400W/m², 600W/m², 800W/m², and 1000W/m² respectively. According to standard of comfort zone which from 0.2m/s of air velocity is acceptable (ASHRAE-55, 2004), the system reached the comfort zone from heat flux 600W/m² up.

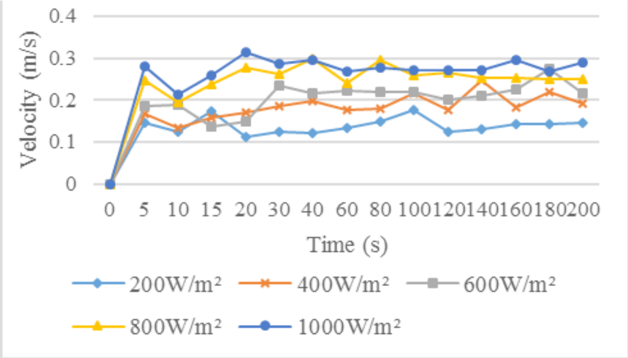

Fig. 3. Average of velocity in channel by all heat flux at step of times

Pending further on steady state as visible in figure 4, a repeated equivalent pattern of each flow line had discovered in very similar shape by any situation of heat flux. The highest wind speed was produced by heat flux 1000W/m² in range of 0.89m/s at steady state of 200 seconds. The lowest heat flux created its maximum wind speed of 0.39m/s.

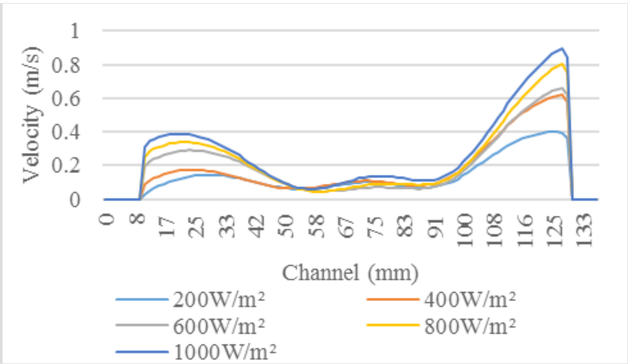

Fig. 4. Comparison of velocity flow pattern in channel at steady state by all heat flux

Due to the very similar flow pattern of velocity induced from one to other heat flux, a case of heat flux 1000W/m² was chosen to elaborate ventilation flow appearance in channel. In the beginning, air in channel organized itself up and down by heat dispersion in channel until it could up-process in a regular pattern. From inlet, the air were sucked from down stair part of chamber. A great amount of air was pulled into the channel and a moderate amount was blowing up and spinning circulated in the top chamber. The air moved downward and collected to the inlet of the structure while crushing the bounding surface at the back side of Trombe wall's wall. Later in steady state, it was noticed that flow pattern had its regular form as shown in figure 5.

Moreover, the analysis of air flow in channel was taken measuring on the same three order positions: near the inlet, in the middle of channel, and near the outlet which were demonstrated in figure 6. It was noticed that around the area of inlet, the air were in fairly different range either in any position from wall to glass. For line 2 and 3, the appearance of air movement could be presented in three level of speed perceived on node of near-wall surface, middle of channel, and node of near-glass surface. The air arose up to blow down the heat on wall and glass, resulted the higher air velocity near those surfaces.

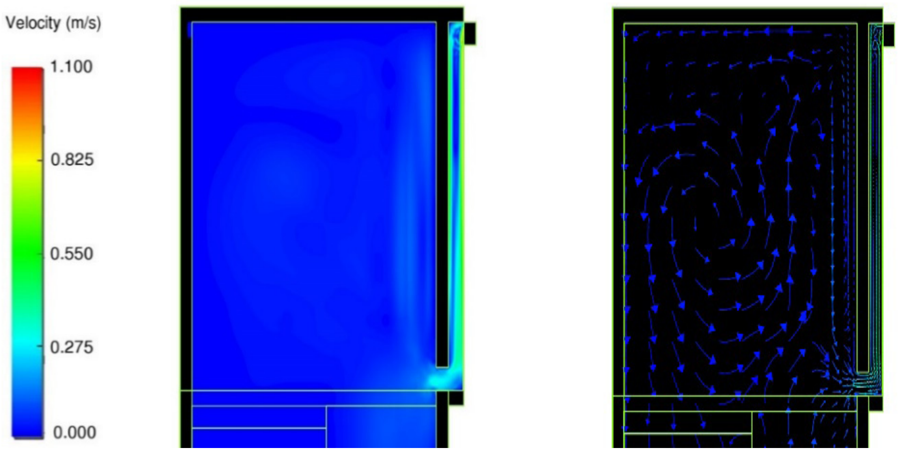

Fig 5. Color view and flow vector of velocity by heat flux 1000W/m², at steady state

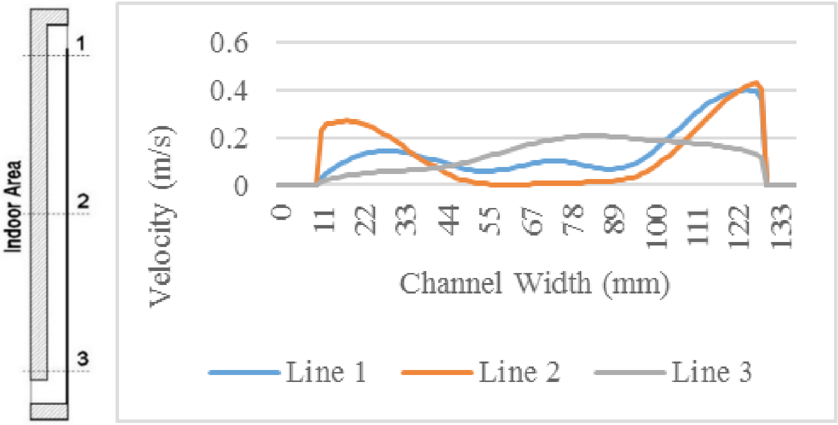

Fig 6. Velocity flow pattern in channel by heat flux 1000W/m², at steady state

Simulation result of temperature

The temperature at the beginning was dramatically intensified because the movement of air flow from inside the chamber was still slow. Soon, from 20 seconds the temperature was dropped and continued in a-mostly-equal range which could be confirmed that the system was on the path of steady state. Attributable to figure 7, the high average of temperature inside the channel after the continual of ventilation replacement was from 310.8K for heat flux 200W/m² to 316.53K for heat flux 1000W/m².

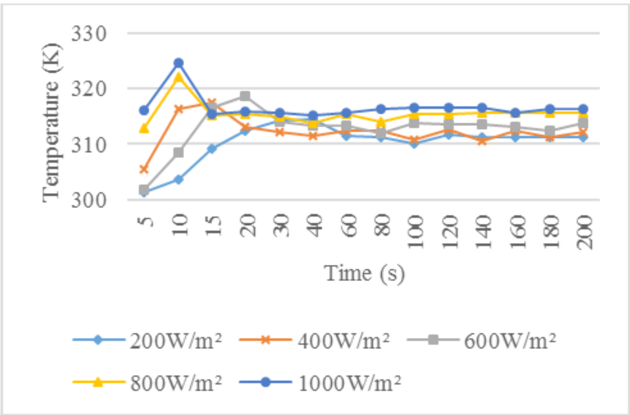

Fig 7. Average temperature in channel by all heat flux

In figure 8, the graphics showed the comparison of temperature in between wall to glass of each case of heat insertion. For heat flux 1000W/m² case, the temperature near the glass was around 323.94K which accelerated the reduction value around 33K from first set up in Table 1, thus 22K lower than the temperature on wall surface compared to 334.15K beforehand. For heat flux 200W/m² case, the temperature near wall and glass leveled off from 4K near wall surface to 12K near glass surface. This could apparently imply that high heat level in channel produced higher ventilation rate, so that the dropping temperature value appeared to be bigger than the lesser heat input as be evident on 200W/m² case. At steady state, the temperature in channel signified an identical pattern every occasion of heat flux input. Heat flux 1000W/m² provided a remaining high temperature than the lower and lowest heat flux input invariably.

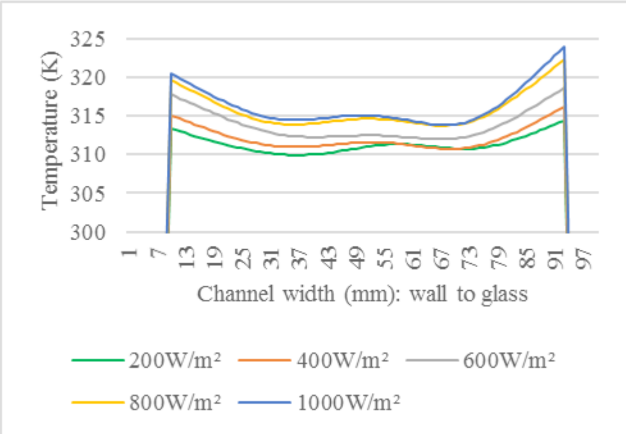

Fig 8. Comparison of temperature pattern in channel from wall to glass, at steady state

It was illustrated that by the color series, high temperature endured on the top part of channel and along the surface of wall and glass. The temperature near inlet was no longer high due to the cool air blowing in from stair chamber. At the same time the air rose up and store at the upper part of the channel resulting in a higher temperature near the outlet.

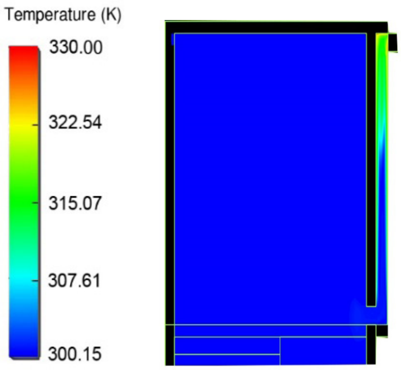

Fig 9. Color view of temperature pattern by heat flux 1000W/m², at steady state

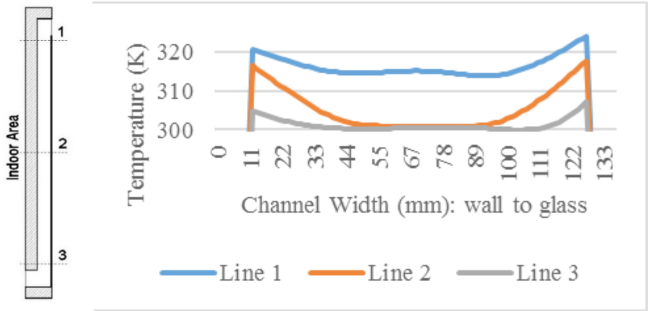

Fig 10. Temperature pattern in channel by heat flux 1000W/m², at steady state

Simulation result of mass flow rate

Figure 11 proclaimed the result from simulation about air mass flow rate from the beginning of operation till steady state. The pattern of graphs appropriately responded to the result of temperature and velocity pattern which were agreed on the phenomenon of beginning state until the steady state. Table 3 displayed the average of mass flow rate at steady state of experiments for each case of heat flux. Furthermore, air mass flow rate gotten at inlet of the system was approximately 0.109kg/s as the highest average value which heat flux 1000W/m² could create. The amount of mass flow rate slightly varied sometime along the operation period. It was predicted that the replacement of fresh air at a time cooler the channel and it took another short time to heat up again, thus the circle continually remained like that.

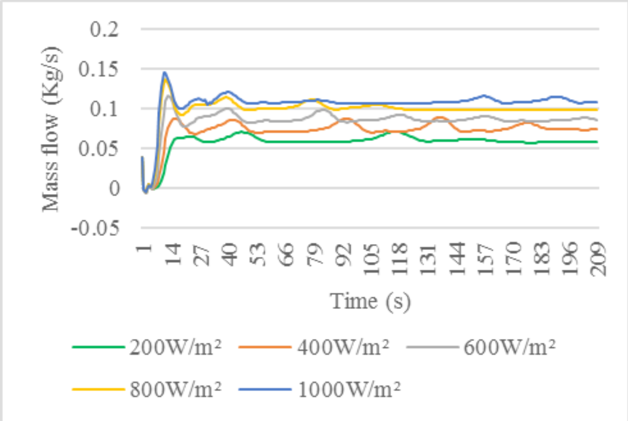

Fig 11. Mass flow at inlet of channel along steps to time

Heat Flux	Average of mass flow
200W/m²	0.060 kg/s
400W/m²	0.075 kg/s
600W/m²	0.087 kg/s
800W/m²	0.100 kg/s
1000W/m²	0.109 kg/s

Table 3 Average of mass flow rate at steady state of each heat flux

CONCLUSION

This work took noticed about modeling of top stair block chamber. It contained 5 cases varies by heat flux from 200W/m² to 1000W/m². The result of average velocity at steady were 0.14m/s, 0.19m/s, 0.22m/s, 0.26m/s, 0.28m/s for the heat flux 200W/m², 400W/m², 600W/m², 800W/m², and 1000W/m² respectively. The highest velocity in channel happened near the glass surface in value of 0.89m/s at steady state of 200 seconds. The lowest heat flux created its maximum wind speed of 0.39m/s. In comparison to comfort zone standard, the velocity could reach comfort induced by heat flux 600W/m² up. Likewise, temperature in channel was dropped by the presence of cool air from inlet passed through the channel. From heat flux 200W/m² to 1000W/m² temperature decreased from 12K to 33K compared with temperature on glass at first set up, and 4K to 22K compared with the temperature on wall beforehand. On the other hand, highest mass flow rate gotten at inlet of the system was approximately varies from 0.06kg/s to 0.115kg/s from heat flux 200W/m² to 1000W/m². This is such appreciable amount like other experiments from prior researchers.

In conclusion, it could be assumed that Trombe wall system could produce a good result of velocity which could reach the comfort velocity needed as stated by other researchers. The relationship between temperature, velocity, and air mass flow rate acceptance from the channel was logically response to the theory. For later researches, the distance from target room to Trombe wall and the volume of target room which expected to get benefit from Trombe wall system should be examined.

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