Passive Cooling Design Opportunities: Lessons Learned from Traditional Banjar Houses

by Elvina Shanggrama Wijaya

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Abstract. Indonesia is an archipelago country that encompasses many different ethnicities across five large islands, one of which is Kalimantan (Borneo) Island. The river has become the lifeline in Borneo, especially for Banjar people. Banjar people have eleven types of traditional houses, each designed for specific social classes, which differ from one another in terms of materials, layout, and roof proportions. In this paper, three different types of Banjar traditional houses are compared to study the passive cooling conditions related to the proportions of the floor plan and cross-section. These three types are: (1) Bubungan Tinggi House, (2) Palimbangan House, and (3) Lanting House. The three types of houses are modelled and simulated using RWIND CFD software, by inputting the maximum and minimum wind speed (3.5 and 17 m/s), to study the potential of imitating vernacular forms that assures effective passive cooling. The result is that the Palimbangan house has the most balanced passive cooling performance through wind movements and direction. The findings could serve as an alternative for application in modern housing architecture that is sustainable and energy-efficient.

1. Introduction

In the midst of climate change and the energy crisis, research regarding passive cooling has gained significance. In terms of tropics, previous studies found that vernacular design is more responsive to their surrounding climates [1], and development concepts in vernacular buildings emphasise adaptation to the environment, climate, culture, and social context. The physical characteristics of vernacular buildings in Indonesia are usually characterised with high roofs, using wood materials for building envelopes, large openings, and wide overhangs as a preventive effort against climatic conditions. These characters are means of adaptation to the climate in the building envelopes: roof, walls and floor, that assures the thermal comfort of a building [2]. Even though some vernacular buildings have undergone modifications, vernacular buildings continue to survive today [3].

1.1. Passive Cooling through Roof

The passive design strategies through roof in the tropics targeted to minimise the thermal load and to give shade to the building elements below, such as openings, so that the building can minimise the energy used for cooling [4]. Building roof's area are exposed to the sun for almost every hour at daytime in tropical areas, therefore, could contribute to a large thermal load. Previous research regarding the thermal performance of roofs has concluded certain variables that effectively affect the performance, such as the form of the roof [5] [6], the materials used [5], the volume of the attics [7] and also the presence of gaps for roof ventilation [6]. More recent research also concluded that roof coating, thermal insulation and ventilation on the attics will improve the thermal performance of a building, in tropical climate conditions [8]. The recent research regarding roof thermal performance optimization are focussed on modern roof design, such as in flat concrete roof with insulated material [9] , or in roof with vegetation, yet the relationship between vernacular design and the thermal performance of the roof is rarely explored.

1.2. Passive Cooling Through Openings

The passive design strategies through openings vary from one climate to another. One factor that will affect the exposure of a building to wind is the building orientation to the prevailing wind. To maximise the effectiveness of ventilation, the longer axis of the building is usually oriented perpendicular to the prevailing wind direction to obtain the highest wind speed [10]. When the building is placed with rotating angles to prevailing wind, the spread of the wind will be distributed more equally across the building.

Beside building orientation, variables like the size and placement of the opening affects the movement of wind inside the building. Outlet is suggested to be at least 25% bigger than the inlet to maximise the ventilation [11]. The position of the opening could also direct the wind presence in the building. The purpose of designing the opening position is to make a cross ventilation, and to design so that the wind passes through the human activity area. Regarding the height of the opening, previous research has found that an inlet (+ 1.022 from floor level) that is higher than the outlet height (+ 0.52 from floor level) could bring out the best ventilation design for the calculated room [12]. In vernacular building facades ventilation as an opening has a function to reduce heat and humidity, but it can increase the room temperature when unprotected and result in the entry of solar heat [13].

1.3. Passive Cooling Through Raised Floors

One of the characters in Vernacular house, especially when located in a swamp or riverbanks area, is an elevated floor made from wooden beams and joists. Here, the gap below the activity area can serve as a leak where the wind can enter the building [14]. As mentioned in the previous research, the use of cross ventilation outperforms single sided opening, as the cross ventilation make the indoor thermal conditions at comfort state for 70% of all the time [15], so when the leak in the floor can assure better ventilation.

1.4. Banjar Vernacular Building

The culture within the tribes in Kalimantan is rich and encompasses from mountainous to waterways region. One of the ethnic groups that resides in southern Kalimantan is the Banjar tribe, who were a part of Dayak Tribe, that has been exposed and assimilated to Islamic Religion. Banjar tribe has various types of traditional houses, as it was a sultanate in the past. The various kinds of traditional houses include Bubungan Tinggi, Palimbangan, and Lanting houses. Bubungan Tinggi house was occupied by the top strata on a social level. It is also the oldest Banjar house and characterises the architecture that represents the culture and image of the Banjar people [16]. Palimbangan houses were inhabited by religious leaders [17] and merchants. Moreover, Lanting houses that float on the waterways are made of wood and become local wisdom for the riverbank community [18]. Up to now, this kind of houses are inhabited by nomadic traders, who live on boats along rivers that have economic potential, and also ordinary people. Because of this need to support their activities as sellers, Lanting houses are floating and can be a practical dock for the economic activities of its residents [19], who will carry out their economic activities by jukung boats. These three types of houses were chosen because they represent users that were socially ranked: The Bubungan Tinggi for kings, the Palimbangan for religious leaders, and the Lanting for merchants or the lower middle class.

Additionally, these three types of houses have the same type of roof, namely a gable roof, with different roof slope angles and direction. The presence of different proportions in attic areas of the house can be compared to the movement of the indoor air. Openings in the different sides of the building envelope theoretically can ensure the cross ventilation, but its effectiveness is rarely measured, especially in the vernacular building, as well as the effect of the partition inside the building, though proved to affect the movement of indoor air significantly [20].

As seen in Figure 1, Bubungan Tinggi house has a deep plan, with 1:3 to 1:4 width and depth proportion. In the middle of the house, there is a more private area, divided by partition, with additional room in the left and right side, making the room more spacious. This part of the house has a high pitched gable roof with 60^0 angles. From the section, the height of the attic could reach 6 metres [21]. We can also find a deep overhang in the front terrace. The roof's material used to be straw or wooden shingles. There are still a few original Bubungan Tinggi houses that remain until now, which have lasted for more than 200 years.

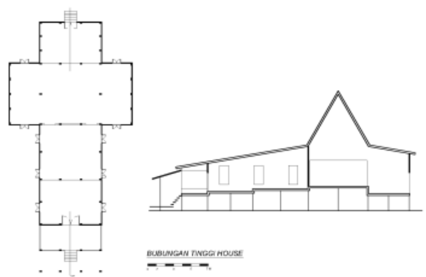


Figure 1. Bubungan Tinggi house

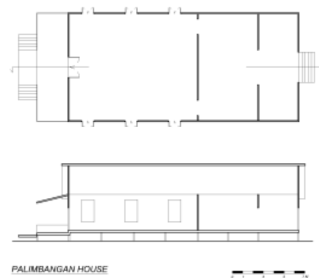


Figure 2. Palimbangan house

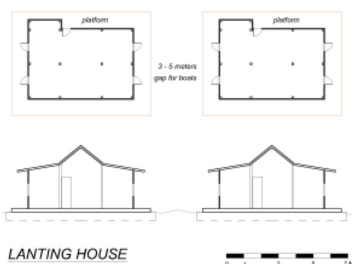


Figure 3. Lanting house

Palimbangan house, as in Figure 2, is wider in width and shorter in depth compared to Bubungan Tinggi house. It has a 1:2.5 to 1:3 width to depth ratio. The height of the roof is constant from the front to back area of the house with the peak of 6 metres. The roof attic area could reach 3 metres in height. There are additional roofs in the front and back terrace. The house is usually built perpendicular to the street. Moreover, this house has an indoor partition, yet the attic is still connected, making the wind move more freely throughout the building. The presence of a large opening makes the cross ventilation move effectively when opened, and helps the thermal performance of the building [22].

As mentioned before, Lanting house is floating by the river. There is a 3 to 5 metre space between the houses to park the Jukung boat [23]. The space has become a leeward side when the prevailing wind is parallel to the Lanting house configuration, so the presence of the neighbouring Lanting is affecting . The Lanting house has around 1:1.25 width : depth plan proportion. The indoor space is rarely partitioned, and the attic does not have a ceiling. The plan of a Lanting may be varied, due to the placement of the furniture. The total height of the Lanting house is 4 metres. The roof is usually a low gable roof, with angle variation between the centre and the perimeter area of the roof.

Therefore, this research aims to contribute to the development of passive cooling strategies based on the local cultural heritage of the Banjar tribe, to be an alternative solution for sustainable housing architecture design and raise awareness of the importance of the benefits of cultural heritage in technological innovation for environmental sustainability. This research combines aspects of local culture with modern technology in the context of passive cooling strategies. Through the use of CFD simulations of vernacular buildings, this research bridges local wisdom with practical applications in modern architectural design and hopes to offer solutions that have not been widely explored in previous literature.

2. Methods

The research was done, firstly by doing literature research regarding the targeted Banjar house type, namely: (1) Bubungan Tinggi House, (2) Palimbangan House, and (3) Lanting House. For each type of the house, plans and sections were documented, to find the unique proportion of each house type. The second step is to do the analysis on the houses by using CFD software RWIND Dlubal. The CFD simulation will picture the wind movement and speed within the house, to show the effectiveness of the passive cooling strategies. The data input for the simulation in RWIND are location, prevailing wind direction and speed. The setting of simulation parameters, as in figure 4, are then set, where the speed of the wind is relative, proportional to the characteristics of chosen surrounding landscape condition. The input wind speed is measured at the height of 10 meters, and RWIND will generate the speed for the other heights.

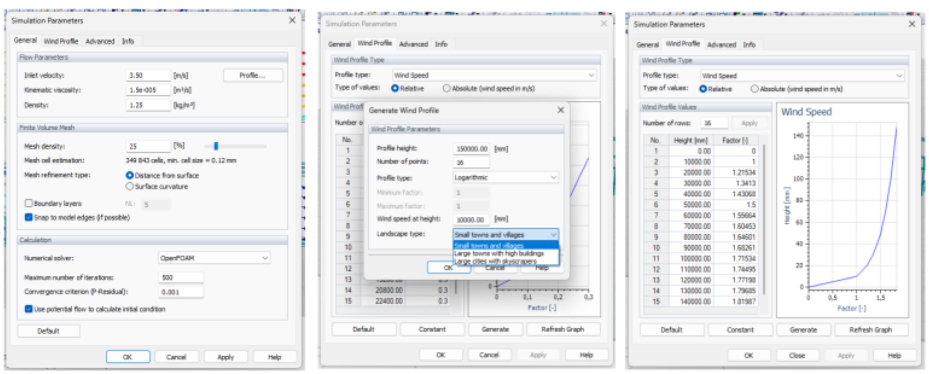


Figure 4. Input data for RWIND Simulation in the research

As found in the Banjarmasin's database for 10 years, most of the time, the wind blows in a South East - West direction, with the speed ranging from nearly zero in minimum, 3.5 m/s in average to 17 m/s at maximum [24]. In this research, we did not do the simulation for the minimum wind speed, as it will be stagnant. Instead, we did the simulation in 10 m/s wind speed, as the average from 3.5 to 17 m/s. Therefore, the simulation for the houses were done in nine conditions within the mentioned speed: 3.5 m/s (average wind speed that becomes the minimum), 10 m/s (labelled average in this paper), and 17 m/s (maximum), with prevailing winds from perpendicular, parallel and diagonal to the houses, as the prevailing wind direction is objected to building's orientation. The opening condition for the simulation is all open. The scale for the simulation and simulation output can be seen in figure 5. The findings in each house are then being compared, to understand more regarding the effectiveness of passive cooling strategies in the implemented local wisdom from Banjar.

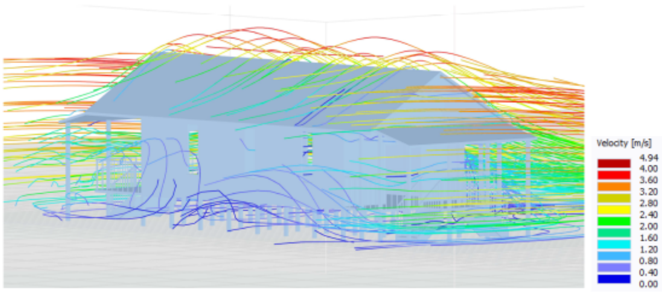


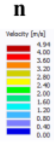
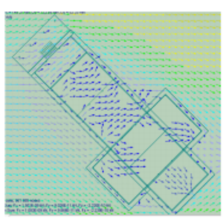
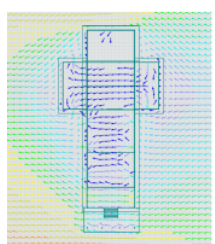
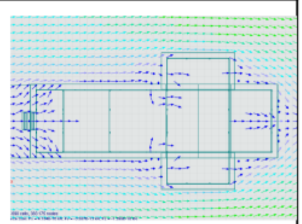
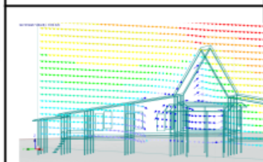
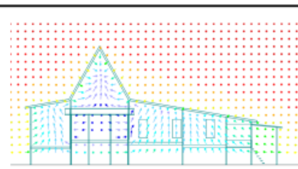
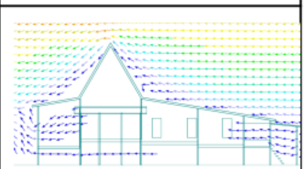
Figure 5. The streamline in Palimbangan House, simulated in average wind speed

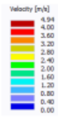
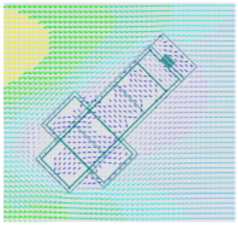
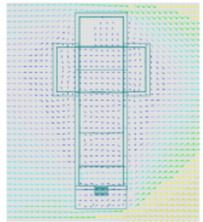
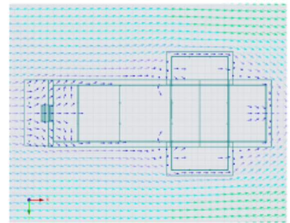
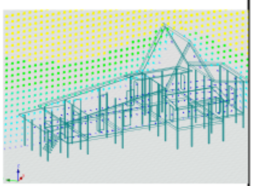
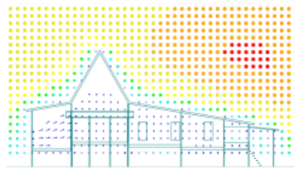
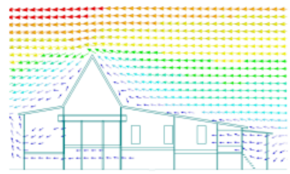
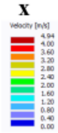
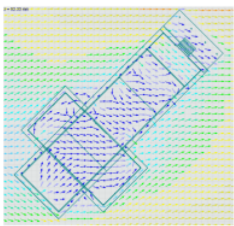
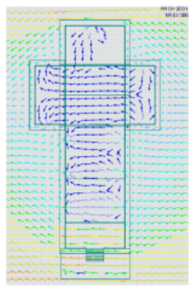
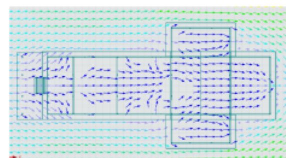
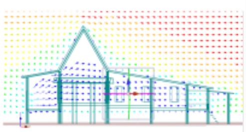
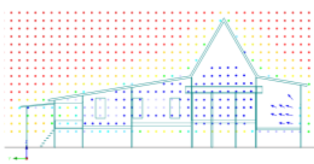
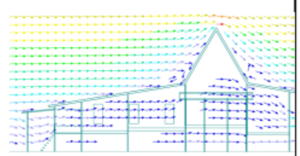
3. Result and Discussion

3.1. Bubungan Tinggi house

As we run the simulation, as seen in Table.1, we can find that when the wind is parallel to the depth of the house, then the wind movement inside the house is relatively stagnant. Other than that, the wind can move throughout the house at the speed that is comfortable for indoor activities, which is 0.2 to 0.5 m/s. The wind also moves below the elevated floor of the house. From the simulation, we can also see that when the speed is high, the wind does not reach the highest part of the attic area. It just moves from inlet through outlet at the activity level height. The condition is different than in lower wind speed, where the wind moves through the attic area of Bubungan Tinggi house, in diagonal and perpendicular

Table 1. Bubungan Tinggi CFD Simulation in different wind speed and prevailing wind directions

	Diagonal	**Perpendicular**	**Parallel**
M i n 			
			

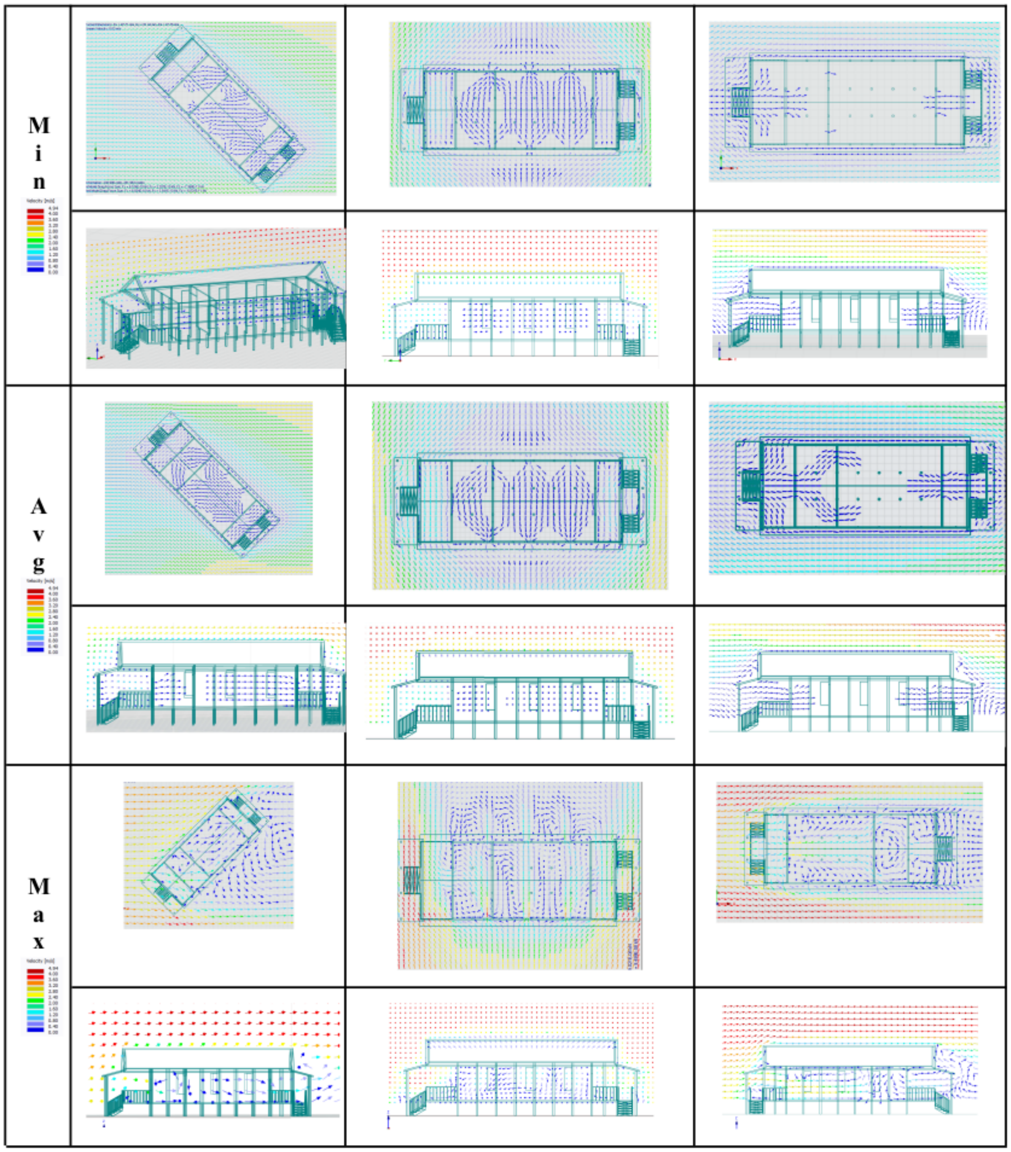
Avg 			
			
Max 			
			

3.2. Palimbangan house

In Table.2, we can see the same condition with the one in the Bubungan Tinggi house, that when the wind blows at lower speed and is parallel to the depth of the house, the wind movement inside the house is relatively stagnant. Nevertheless, the wind can penetrate further into the Palimbangan house, for at least at one third the depth of the Palimbangan house. Cross ventilation through the openings can be found in all simulation conditions. When the wind blows faster, parallel to the depth of the house, the wind will move through the main entrance at the speed 2 - 2.4 m/s, as the inlet is smaller than the outlet in the back of the house.

Table 2. Palimbangan CFD Simulation in different wind speed and prevailing wind directions

	Diagonal	Perpendicular	Parallel



3.3. *Lanting house*

In the Table. 3, we can find the wind movement around and also inside of the Lanting house. As it is rarely partitioned, the wind can move freely throughout the house, but the prevailing wind direction affects the distribution of the wind. When the prevailing wind is parallel to the series of Lanting, the first house that faces the prevailing wind can block the wind from the second parallel house, as the size of the side opening is rather small, to maximise the Lanting house's privacy. Therefore, the gap for jukung boat is relatively stagnant and needs to be simulated to understand the wind movement in the jukung's space. Turns out that at higher wind speed, the form of the roof can direct the wind to move through the gap between the houses, therefore providing wind intake for the neighbouring Lanting, at the gap distance simulated in 3 meters.

Table 3. Lanting CFD Simulation in different wind speed and prevailing wind directions

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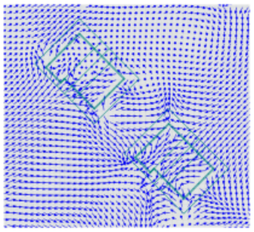
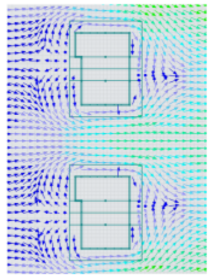
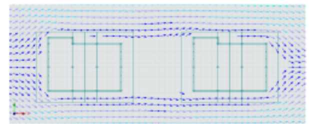
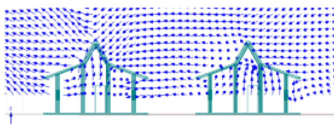
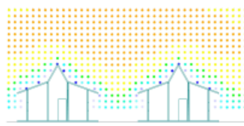
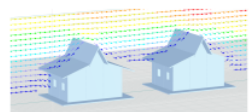
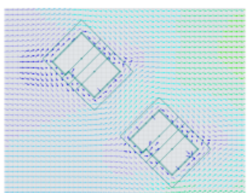
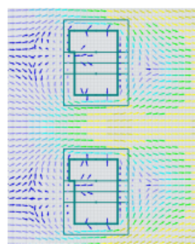
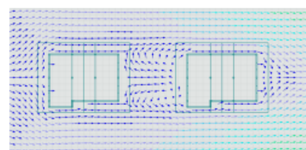
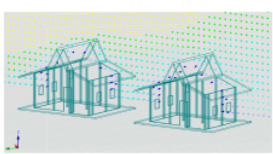
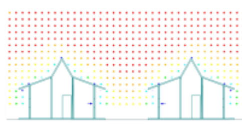
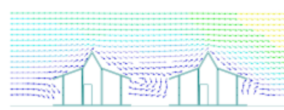
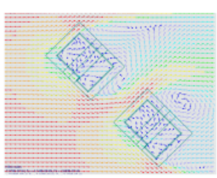
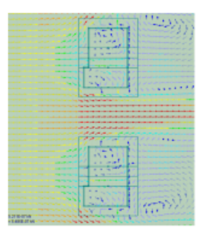
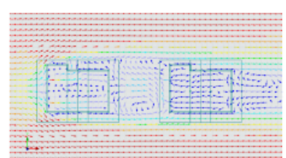
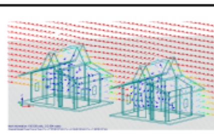
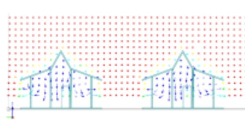
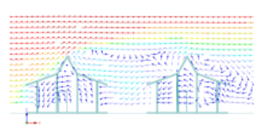
Min 			
			
Avg 			
			
Max 			
			

3.4. *Findings and Discussion*

From the simulation in lowest wind speed (3.5 m/s) we can find that the cross ventilation works best when the position of the house is perpendicular or diagonal to the prevailing wind direction. When the maximum wind speed is used for the simulation, it shows a better performance on the passive ventilation. This could be a challenge in application of the passive cooling through wind movement, as the density of the city has evolved, making the wind speed is far slower then in the past.

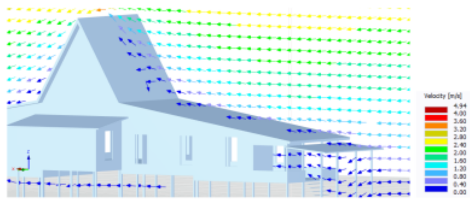
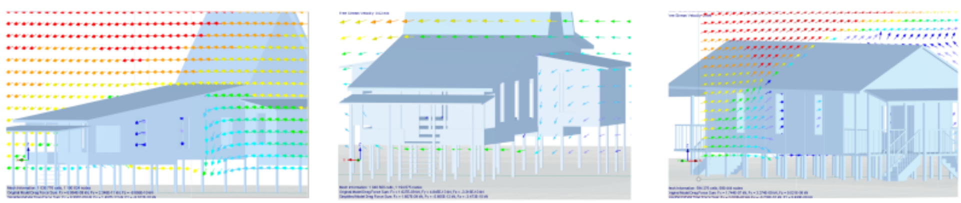


Figure 6. Simulation with maximum wind speed at Bubungan Tinggi House

The presence of kallang beneath the elevated floor plan in Bubungan Tinggi and Palimbangan house has created a wind streamline below the activity area. As the material of the house is wooden, therefore, the gaps between the wooden floor panel and wooden beam configuration can serve a 'leak' outlet for the houses, that removes the humidity in the house through the kallang wind movement, as the previous research stated. In this case, Bubungan Tinggi house has a higher space of kallang than the Palimbangan house, therefore the speed found in the Bubungan Tinggi's kalang (0.95 - 1.14 m/s) is faster than the one in Palimbangan house (0.19 - 0.57 m/s), as seen in figure 7.



(a) (b) (c)

Figure 7. Wind movement in Kallang at (a) Bubungan Tinggi - high wind speed, (b) Bubungan Tinggi - low wind speed, (c) Palimbangan - low wind speed

One of the cross ventilation principles is that the wind will move in the shortest stream between the openings, and will have a better performance when the outlet is about 25% bigger than the inlet [11], as it will maximise the wind spread and speed. Therefore, the presence of wall partitions in the Bubungan Tinggi as well as Palimbangan house blocks the indoor wind movement, especially when the prevailing wind is parallel to the house depth. The partition usually has two symmetrical openings that lets the wind move to the back side of the house. In Bubungan Tinggi house, additional openings with different orientation is provided, maximising the comfort of the private areas that are usually used as a bedroom, but the air movement is really stagnant just behind the partition. The outlet at the back of the house is a back door, that makes the wind concentrated to pass the only back outlet.

On the other hand, in the Palimbangan house, as the side opening sizes are larger, and there is no additional width of the room, the wind can move more thoroughly throughout the space. The presence of a large terrace in the back of the house also creates different pressure that lets the air flow through the outlet of the house. In Lanting house, the house can serve as a block to another house when the prevailing wind speed is slow, but when the wind blows at higher speed, the roof of the house can direct the wind movement.

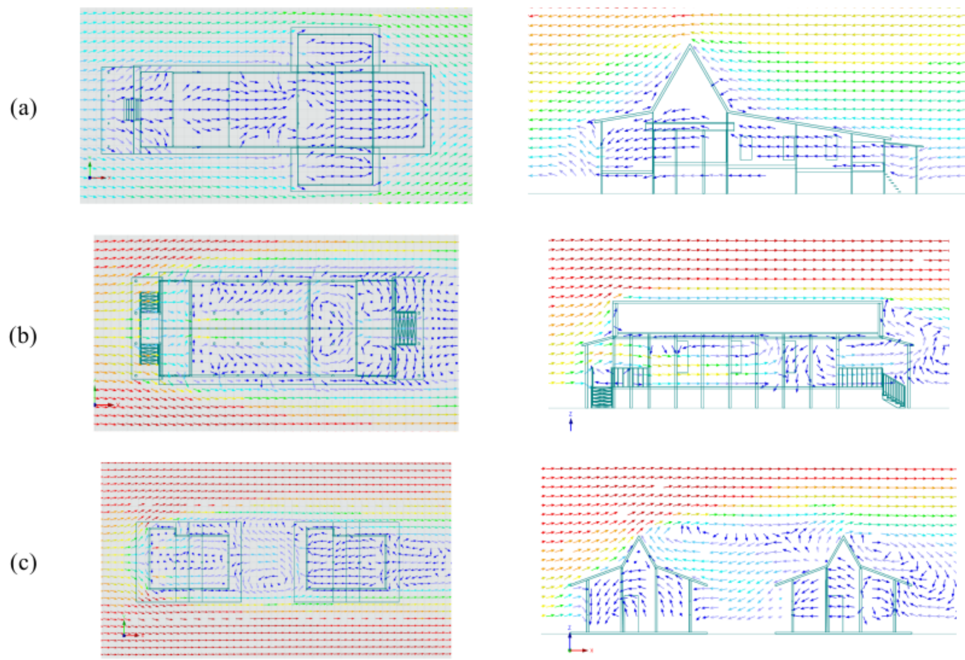


Figure 8. The effect of the partition in (a) Bubungan Tinggi, (b) Palimbangan, and (c) Lanting House

4. Conclusion

From these simulation results, we can see that the openings design in all the house types has different effects on the wind movement throughout the building. As actual houses may differ in orientation, this paper simplifies the simulation by categorising the prevailing wind direction from the diagonal direction of the house, perpendicular to the house, and parallel to the house, at the minimum (3.5 m/s) and maximum (17 m/s) existing wind speed.

Bubungan Tinggi house was the house of the kings and the design of the house is proved to maximise the passive cooling strategies, especially ventilation. The additional windows with different orientation ensure that the additional space that adds width to the whole building, can obtain direct fresh air from the surrounding. The partition in this house blocks the wind movement, so that the wind does not pass a certain area of the house, mostly at the back side of the house.

Palimbangan house has the most balanced passive cooling performance through wind movement, as the wind could reach in almost 90% area of the houses when exposed to different prevailing wind directions, even in a minimum wind speed. Further research that integrates temperature in the wind movement is necessary to study the possibility of the stack effect in this certain vernacular building.

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