Visualisation of Naturally Ventilated House in Tropical Hilly Area of Indonesia, Case Study: Vatutela Village, Tondo Hills, Palu

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Abstract. The settlement of Vatutela village’s in Tondo hills Palu has only one road access with a linear residential pattern following the topography. This situation affects the pattern of wind flowing through the settlement areas, which is undoubtedly affecting the house’s temperature and humidity profile and influencing thermal comfort of the occupants. The research was conducted to visualise the pattern of the wind flow entering the house through openings in the perspective of building’s thermal performance. The method used to visualise the air movement was the smoke decay method. The method was performed in two scaled dwelling Models representing brick-constructed houses and wood-constructed raised floor houses in Vatutela village. The smoke decay result is elaborated with the results of microclimate measurements using Hobo data loggers to analyse the thermal condition in the houses. The results showed that a design strategy is needed to achieve a thermal comfort zone in both types of houses. The design strategy can be in the form of the arrangement of openings and additional building elements, such as adding ceilings, fins, sunscreens. Additionally, the opening placement, width, and type should be reconsidered for the houses in the area according to houses’ plan and section. This study is expected to give a visual evidence of wind pattern in a naturally ventilated house with a three-layers plan.

1. Introduction

The importance of air temperature and air movement for the thermal comfort of the building’s occupant has been studied by many scholars [1–3]. In the tropical area, where the swing temperature of day and night is small, the effect of thermal capacity from buildings element is not favourable for 24-hour occupied buildings such as a residential building. Therefore, the effort taken for the thermal comfort of the building is through natural ventilation for physiological cooling [4,5]. Additionally, effective natural ventilation in a building not only important for providing a healthy internal environment [6–8] but also gives benefit for energy efficiency [9,10].

The effectivity of natural ventilation in providing comfortable indoor thermal environment has been proven by many researchers. Some of natural ventilation strategies are using single sided ventilation [11], cross-ventilation [12], porous wall [5,13,14], and wind catcher [15,16]. The example of natural ventilation has been provided by the vernacular architecture since ages. Vernacular architecture adapted from the environmental variations of place relating to local conditions such as sunlight, temperature, humidity, rain, and wind [5]. Furthermore, vernacular architecture also included earthquakes, flood and other natural disasters as considerations.
Some contemporary natural ventilation strategies are adapted from vernacular solutions [12]. For the strategies provided are more affordable and energy-efficient than some high-tech ventilation solutions. Several methods are introduced to study the pattern of air movement in the building. Some studies used wind tunnel Models [17], CFD Simulation [18–20], or test chambers by smoke tracing [8,21–23] for controlling the boundary conditions. However, the method may lose the real information about the influence of the atmospheric conditions in the design of the building [24]. On the other hand, the visualisation research on air movement through indoor spaces of vernacular architecture is relatively limited.

Therefore, this study aims at visualising the air movement in the vernacular house of tropical hilly area for natural ventilation analysis. The visualisation is conducted in the open area to present the real air movement pass through the scaled building Models. This study is expected to give visual evidence of air movement within the buildings with a three-layers plan. Additionally, this research is supposed to give a design recommendation for natural ventilated building, especially in the tropical hilly area.

2. Materials and Methods
2.1. Case Study
The vernacular settlements in Vatutela Village located in the hilly area of Tondo-Palu City, Central Sulawesi Province, Indonesia, are taken as the study case (Figure 1). It is situated near the equator with 00°50'30" - 00°50'55" South, 119°55 - 119°55'35" East, and the altitude 224 – 342 meter above the sea level. The climatic condition is categorised as tropical warm and humid.

![Figure 1. Study location in Tondo Village](image)

The geographical features of Vatutela village have a special characteristic where the dwellings are placed linearly on one access road following the hill’s topography and run from the west to the east. This road is the one and only access road served as an entrance and exit to the settlement area.

2.2. The Dwellings’ Model
The Models of the study are taken from two types of dwellings in Vatutela village. Model 1 represents the wooden raised-floor construction house with three-layer house plan. Meanwhile, Model 2 represent brick construction house with three-layer house plan (Tabel 1). These two Models are scaled 1:5 from
the original size of the houses. Where the top of the Models’ materials is made from transparent materials to facilitate the recording of the air movement in the houses’ interior.

2.3. Smoke Decay Setup

There are four methods used to visualise air movement for natural ventilation analysis namely: wind tunnel, smoke chamber, water bath and water table [22]. This study used the smoke decay visualisation method to see the performance of ventilation through airflow patterns in two building Models, namely raised floor construction house and non-raised floor construction houses. Instead of using the smoke chamber, this study conducted in the open area to visualise the real wind speed flowing through the house Models’ opening.

The visualisation scheme is started from the smoke released by the smoke generator through two hollow pipes placed vertically and adjusted in the windward side of Models (Figure 3). After that, the results obtained from smoke decay visualisation were then elaborated with the results of on-site microclimate measurements using HOBO micro station data logger. These results are then analysed for design recommendations and strategies to optimise natural ventilation in tropical houses especially the
houses located in the hilly area (Figure 2). The visualisation by the smoke tracer decay was performed at the day time because the result of the air temperature at night is relatively within the comfort zone of the people living in the tropical hilly area. The nozzles were set to produce the smoke for 1 minute during several visualisations.

![Figure 2. Smoke decay visualisation scheme](image)

Figure 3. Smoke decay instrument setup

3. Result and Discussion

3.1. The Result of Field Measurement

The field measurement result for 15 days in May 2019 by using HOBO data loggers showed that outdoor air temperature in the daytime is always above the comfort zone for warm and humid tropical areas. The outdoor temperature varied from 22.5°C to 42°C and relative humidity ranged between 30% and 83%. The outdoor wind speed frequency distribution was 61.8% categorised as calm, 37.9% of the wind speed measurement were between 0.5 and 2.1 m/s, and only 0.3% were between 2.2 and 3.1 m/s. The prevailing wind direction is from North (N) and South (S), while the secondary wind direction is North-North-East (NNE) (Figure 4) [25].
The simultaneous result of indoor thermal measurement was indicated that both types of houses were experiencing overheating during the daytime following outdoor air temperature profile. The indoor air temperature in Sample 1 swung between 23°C and 40°C, with relative humidity varied from 30% to 85% and indoor wind speed occurred between 0.5 m/s to 1.7 m/s. Similarly, the indoor air temperature in Sample 2 is varied from 26°C and 32.5°C, with relative humidity range from 60% to 83%, and indoor air movement is mostly calm (Figure 4) [25].

3.2. The Result of Tracer Smoke Decay Visualization

The physical form of the two Sample houses Model and environmental setup of the visualisation is given in Figure 5. The visualisation result of tracer smoke decay is generally revealed that the air movement in two Model houses is not really good but still has a potential strategy of natural ventilation. It was proven that when the prevailing wind speed is between 1.5 – 2.7 m/s, the smoke dissipated within 4 to 6 seconds after the nozzles were stopped providing the smoke to the Models’ interior. This small-time difference in smoke dissipation is due to a small volume of the Model. In the real house, however, where the volume is 125 times bigger than the Model, there will be a significant delay of the air mass escape from the houses.

It is revealed from the smoke decay visualisation that the room farther from the prevailing wind did not catch the wind by the windows (room E and F) but by the rooms’ doors (Figure 6 and 7). It is related to the negative pressure which is formed on the west side of the Models where room E and F is placed. Therefore, the opening in these rooms is served as the outlet instead of the inlet. In consequence, when the rooms’ doors are closed, the air movement in the rooms is stacked, resulting in most of the time the air velocities of the field measurements are relatively calm (Sample 2).
Both Models displayed that the air movement mainly came from the openings of the north side. This result is to be expected because the prevailing wind direction at the daytime both in the recorded field measurement and the performed tracer smoke decay is from the North-North-East (NNE) and North (N). Moreover, the angle of the wind direction is between 90° and 22.5° of north windows (Figure 6 and 7). Thus, the wind can easily enter through the north openings.

Similarly, the input of air flows entered the building are also gained from the front door of the two Models, where most of the time at the daytime are opened. These two Models’ door is placed on the east side of the buildings. These conditions explained the reason why the air movement also came from the doors. Because the wind directions angles were approximately coming from 22.5° of these doors. An interesting phenomenon is presented in the visualisation work where the wind was circling the terrace (room A) instead of easily dissipated to the east side of the Model where the height of both terrace walls is only 1 meter. This situation is lead by the obstruction of the winding path by the north wall of room F, thus created the disturbed area and formed a turbulent wind before it flowed both to the east side of the Model and enter the room B.

Different circumstances were found in Model 1 and Model 2 related to the air movement pattern of room B and C. In Model 1, the air did not stay in room B and C for too long. The air is moved freely
from the openings of room B (served as inlet) through the south side opening of room C. Even though the distance of both openings is relatively far, there is no obstruction wall between room B and C. Hence, the wind passing through both rooms was relatively fast. On the contrary, due to the existence of the wall between room B and C of Model 2, the air accumulated on both rooms longer than Model 1 before escaped through openings.

![Figure 7. Tracer Smoke Decay Result for Model 2](image)

3.3. Discussion
From both field measurement and tracer smoke decay visualisation, it can be concluded that the result is agreeable for both Models. The air masses of Sample 2 stay longer than Sample 1 in the real situation because of the plan form and the interior arrangement. Sample 2 formed a deep plan with three to four layers room. Additionally, even though the north openings of Model 2 was not included the vertical bars that exist in Sample 2, the general phenomenon of Sample 2 is still represented by Model 2. The smoke decay visualisation of Model 2 conveys that the most influencing factor in natural ventilation of Model 2 is spatial arrangement instead of the size of its opening.

On the contrary, although Sample 1 formed double to three layers of rooms, better cross ventilation is still created by its openings compared to Sample 2. Room C of Sample 1 creates positive air pressure and flows to each room before finally left through all openings, especially the south opening. This situation is vividly displayed in Figure 6 where the smoke is rarely concentrated in one room. From this result, it is recommended that the house plan should accommodate two-sided cross ventilation from the windward to the leeward although the plan is considered deep. Additionally, the windows in the negative pressure area should be served as an outlet when the rooms’ door is usually opened.

In the case of Sample 2 where the door of the rooms is mostly closed, the single-sided cross ventilation can be produced by using 2 openings in one side of the walls aided by the vertical fins to catch the wind current. If the opening is placed in the windward, the reasonable solution is by directing the wind flow using vegetation or by forced convection. Another solution is to modify the building shape according to the wind currents around the building and to prioritise the sides that can change the wind flow into the building.
The result of the temperature measurement of Sample 1 is higher than Sample 2, though the cross ventilation is revealed to be acceptable from the smoke decay visualisation. It is believed that this condition is closely related to the non-existence of ceiling in Sample 1. Consequently, the hot air from the attic is mixed with the cool air in the rooms hence creates a higher air temperature. This phenomenon implies that the existence of the ceiling and the ventilated attic is one of the important factors in the tropical house design, especially in the hilly area. These design elements of buildings can prevent the solar radiation heat gain entering the houses by the roof element. Moreover, the ventilated attic can avoid the convection heat flow from the air beneath the roof to the interior spaces.

The material of the roof is also an important aspect needed to be included in a building design analysis for a better internal thermal condition. Sample houses use corrugated zinc as the roof materials. This material performed poor in the daytime because it transmitted the solar radiation faster to the building interior. However, it cooled relatively fast at night hence it suitable for a night-occupied building. High resistive roof material is preferable in this type of climate [26]. Therefore, a higher temperature of Sample 1 is closely related to roof design rather than its natural ventilation strategies.

4. Conclusion
This study is aimed at visualising the air movement in the house interior of a vernacular house in the tropical hilly area for ventilation analysis under the real wind environment. The results showed that the plan, interior design arrangement and position of the openings of Model 1 is feasible to be adapted as the natural ventilation strategies in a tropical hilly area. The three layers plan houses can be arranged by creating a corridor pass through the windward side to the leeward side of houses without any obstacle between the inlet and the outlet. This can assure the air masses in the building can escape through the outlet easily. Hence, there are no accumulated warm air masses accumulated in the rooms created a thermally uncomfortable living environment.

Some improvement in openings position with the help of vertical fins and vegetation are needed in a certain condition where the openings of the room can only provide single-sided cross ventilation and placed in the leeward. The use of ceilings and ventilated attic are imperative in a tropical hilly area. It can help in averting the hot air under the roof mixing with the air mass in the interior spaces. Additionally, the suitable materials for the roof is a porous or fibrous material thus the natural ventilation strategies performed in the house is more effective.

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