Investigation of Ecohouse through CFD Simulation

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Abstract. Natural ventilation and raised floor can be found in many traditional houses throughout Indonesia. Moreover, this concept currently applied for modern Javanese house called Ecohouse. The Ecohouse is a prototype single-family house with a raised floor, open plan, located in Cibinong, Indonesia. The investigations were made with the CFD DesignBuilder software package. CFD simulation is conducted to simulate wind behavior and the temperature of the buildings. Ventilation in the house is studied during the summer months. This research has found that the natural ventilation and raised floor of Ecohouse is the potential to provide thermal comfort inside the house. Flow patterns show raised floor and horizontal fin on the roof can reduce the heat store in the room. The result of the study will become a reference to optimize the performance of Ecohouse before applied it as a government recommendation for a residential house in Indonesia.

1. Introduction
About 30% of the total electricity consumption in Indonesia is contributed to by the residential sector [1]. Electricity in households is influenced by the increasing number of households of about 70.6 million in 2025 and 80 million in 2050 [1]. The electricity demand increases from 60% in 2018 to 90% in 2050 [1]. Moreover, modern houses in Indonesia rely mostly on lighting fixtures and air conditioning. It means more energy is used to drive mechanical appliances, and increase greenhouse gas emissions. Climate adaptation strategies are necessary for housing. Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI), Indonesia has been introducing a prototype house called Ecohouse to implementation of energy conservation efforts in buildings. Ecohouse was designed by adapting to Indonesia’s vernacular house. Various studies have shown that vernacular architecture consumes less
energy and leaves a little environmental impact to achieve good indoor thermal comfort [2,3,4]. A key

![Bogor wind direction and wind speed](image)

**Figure 1.** (a) Location of Ecohouse in Research Center for Biomaterials, LIPI, Cibinong, Indonesia [7], (b) Bogor wind rose with wind direction majority came from south [7], and (c) Wind velocity profile from Power Law equation in Cibinong, Indonesia.

characteristic of vernacular architecture is its location-specific climate-responsive design strategies [2].

The strong characteristics of an Indonesia dwelling are naturally ventilated and elevated floor [8,9]. These two characteristics appear to have a strong impact on the effectiveness of indoor air movement. Ecohouse was designed to combine these two main important factors. However, previous research only focused on one factor, whether natural ventilation or elevated floor. This present work offers a unique insight into wind behavior in an actual house to analyze the best strategies weather raised floor or natural ventilation using DesignBuilder CFD. Computational fluid dynamics (CFD) simulations provide a comprehensive analysis of the internal flow pattern and can be used as a guideline in the preliminary design concept. Both, outside and inside the house will be simulated in DesignBuilder CFD. When applied to buildings can provide the designer with information on probable air velocities, wind flow, and temperatures.

2. **Ecohouse**

Ecohouse is located in the Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI), Cibinong, Bogor, west of Java Island (Figure 1a). Since Cibinong located nearby Bogor, this research used Bogor weather data. From the data, it found that wind direction majority came from the south (Figure 1b). The rectangular plot of Ecohouse runs south-north. The plot follows the orientation of the street. The northern, eastern, and western side of the plot is adjacent to a vegetated land strip. The southern (front) side faces the street, parking lot, and two-story office building. Ecohouse is a wooden raised floor house from fast-growing trees which refers to a traditional house in Indonesia (Figure 2a and 2b). The house has strong characteristics of an Indonesia dwelling: one-story building with a gabled roof, small windows, open plan floor, without ceiling, and elevated floor [8,9]. Because there are no tall buildings nearby, the roof is directly exposed to sunlight. This house was built with a traditional technique by using wood as the main material (Figure 2c).

This house had building area 48 m². The house has four main rooms, living room, bedroom, kitchen, and bathroom as shown in Figure 2d. The floor is elevated up to 1 m above the ground. For the windows,
there is only clear glass and combine with a horizontal fin. Interior partitions were made of lightweight composite wood. Its roof shape is a combination of a gable roof with open ventilation in the east side (Figure 1c) with the pitch’s angle 30 degrees. This angle slope was chosen from previous research [6]. This angle has the best wind potential density than another roof design. Moreover, it will increase the wind flow inside the house. Roof opening is beneficial to remove heat stored in the room [10].

![Figure 2](image)

**Figure 2.** (a) Ecohouse detail dimension; (b) plan of the Ecohouse showing the five main rooms; (c) Ecohouse view from south; (d) view from north; (e) Ecohouse structure shows the wood column and roof opening to reduce the heat storage.

3. **Methodology and input data for CFD simulation**

Cibinong (6.4° S, 106.8° E) is approximately 130 m above sea level. The average temperature is 26 °C every month [11]. Daily, the highest daytime temperature can reach above 34 °C, while the lowest can
drop below 20 °C. The average wind speed (in 10m height) is higher in October (close to 6 m/s) and lower in other months (less than 4 m/s) [11]. The specific wind direction and wind speed in Cibinong can be seen in Figure 2b. To investigate the wind behavior of Ecohouse, this research using DesignBuilder CFD [12] as the simulation program. The simulation is Bogor weather data to simulate the current condition and analysis of the whole house. The building was classified in a suburban area. This condition will be used as a reference in CFD simulation analysis.

This simulation begins with creating simplified building geometry in DesignBuilder CFD (Figure 3a). DesignBuilder is a simulation software that specializes in its development in environmental performance. This software allowing the user to have an advanced simulation tool and analysis about building performance that integrated with environment control [13]. In this study, DesignBuilder is chosen to be the analytical software to simulate wind performance inside the vernacular house using CFD simulation.

DesignBuilder CFD simulation tools used to construct the flow geometry, along with the mesh for solving the equations of motion. DesignBuilder CFD can be used for both external and internal analyses [13]. External analyses provide the distribution of air velocity and pressure around building structures due to wind effect and this information can be used to calculate more accurate pressure coefficients for EnergyPlus calculated natural ventilation simulations. Internal analyses provide the distribution of air velocity, pressure, and temperature throughout the inside of building spaces and this information can be used to evaluate interior comfort conditions [12].

Activity input data based on actual Indonesia time use data from previous research [14]. Time-use data has recorded the information on an individual’s activities for 24 hours. This data is completed with one family (4 members) daily behavior. User behaviors with detailed information will improve the building design. Detail time use data for this family can be seen in Table 1. Input data for house construction refers to original materials. The current wall in Ecohouse is using a plywood board. This wall was applied for interior and exterior wall configuration. The outer layer of Ecohouse’s roof is using clay tile. The glasses are clear glass and it’s a fixed window, meanwhile, the frame is wooden and combined with a horizontal fin. The general template for the window is uninsulated glass. The HVAC settings will specify the configuration for energy simulation mostly. This setting is important also to allow wind CFD simulation works. The template for HVAC is natural ventilation with no heating and cooling systems.

| Table 1. Detail time uses data for Ecohouse [14]. |
|-----------------------------------------------|
| Detail Information | Column A (t) |
| Family name | Family A |
| Occupant detail information | Father (36), Mother (35), Son (6), Woman (22). |
| Occupant origin | Jakarta |
| Assembly schedule | |

![Graph](image_url)
The reference wind velocity is considered to be 1 m/s. This reference is based on average wind speed in Bogor, Indonesia. Wind direction comes from the South (Figure 1b). The wind speed profile within the atmospheric boundary layers belongs to the turbulent boundary layer type, which can be approximated either by a power law (Figure 1c). Wind speed profile can be seen in Figure 1c, where $Z$ is height and $V$ is the average wind speed in $Z$. This condition will be used as a reference in CFD simulation analysis.

![Wind Direction](image)

**Figure 4.** The plan view slice that illustrate the wind velocity and pressure control.
Two different CFD analysis was done, first is external CFD analysis and second internal CFD analysis. This External CFD analysis results compared with Indonesia weather data then used as validation. Next, wind behavior will be simulated using Internal CFD analysis. The standard k--ε model was considered to simulate the turbulence effects. k-ε model is one of the most widely used and tested of all turbulence models, belonging to the so-called RANS (Reynolds Averaged Navier-Stokes) family of models [12,13].

3.1. External analysis

Simulation tools allow us to study outside air flows as accurate as anemometer measurement and meteorological data. In this study, CFD simulations have been conducted to evaluate the wind flow around Ecohouse. In this study, a non-uniform grid system with 24 x cells, 24 y cells, and 11 z cells.
Figure 6. Predicted Percentage Dissatisfied (PPD) result show only 22-40% dissatisfied with most of the spaces, but for kitchen about 65% respectively dissatisfied.

With maximal aspect ratio 4.359 (Figure 3b). The results compared with anemometer measurement data from Indonesia metrological data.

3.2. Internal analysis
In this study, a non-uniform grid system with 30 X cells × 33 Y cells × 24 Z cells with 19,303 cells as the extreme aspect ratio (Figure 3c). For the analysis results divided becomes 4 slices: Slice 1 is top view slice. For Slice 2 and slice 3 sides view slice in a different location (from the south and the west). The slices illustrate the airflow (temperature, velocity, and percentage of people satisfied ratio).

4. CFD simulation results and analysis

4.1. External CFD analysis results
Figure 4 shows the CFD results for a height of 0.45 m from the ground. The plan view’s slices illustrate the velocity and pressure contour. The wind speed range on the simulation is 0.75 m/s to 0.82 m/s, wind direction from the South. These results (Figure 4 and Figure 1b) show that the wind speed average is not that different and it can be concluded that the outdoor experimental from the simulation is validated.

4.2. Internal CFD analysis results
Similar data like external CFD analysis, Figure 5 shows the simulation results for internal CFD analysis. Three different slide contour shows in Figure 5a, the first slice shows wind condition in the living room and front bedroom (1.5 m from the front), the second slice shows wind condition in the living room and second bedroom (3.5 m from the front), and the last slice shows wind condition in kitchen and bathroom (6.5 m from the front). The temperature beneath the floor has cooler than the roof. In Figure 5c, a particular air movement can be observed passing the living area (south) and flowing out by the opening near in kitchen area (north). Wind velocity mostly comes from a horizontal fin nearby glass window. Simulation results from the front slice (Figure 5c) showed that the strongest wind velocity is occurred in the front area beneath the floor and then decreased when reaching inside the house. Heat flow from inside the house also move to the ceiling and then move outside through the open ventilation on the roof (Figure 5c). A combination of the horizontal fin in the window and open ventilation on the roof reduce the temperature inside the house significantly (Figure 5b).
4.3. Predicted Percentage Dissatisfied (PPD)
DesignBuilder CFD allows the comfort calculations analysis of the comfort conditions in the Ecohouse. The comfort calculations are carried out for each cell in the grid and include consideration of the local air temperature and velocity [13]. Predicted Percentage Dissatisfied calculated using Fanger equations according to ISO 7730 [13]. The result of the PPD percentage can be seen in Figure 6. Most of the zoning area in this house (living room, bedroom, and bathroom) shows only 22-40% dissatisfied. But, for the kitchen, about 65% dissatisfied with this zone. Moreover, this kitchen is an open area. The results show that using two strategies from the vernacular house such as raised floor and cross ventilation will increase the airflow. Also, it leads to a reduction of the heated air inside to outside the house through open ventilation on the roof. The negative impact of this design, the kitchen cannot get the direct effect from the roof opening, because it located on the backside of the house.

5. Comparison of the indoor temperature with simulation
In January 2020, we did the actual comparison in Ecohouse using HOBO temperature/RH data loggers (Models: MX1101, MX2300) to analyze thermal comfort inside the house. Figure 7a shows five HOBO data loggers were installed in five locations: living room (1), bedroom south (2), bedroom north (3), living room (4), and kitchen (5). The measurement time was from 1 pm until 4:25 pm. The temperature between simulation and actual measurement closed to the typical day was selected (Figure 6b). The validation of simulation results is down by temperature records, the differences about 12% for bedroom, 7% for kitchen, and 2% for dining and living area.

![Figure 7](image)

**Figure 7.** (a) Measurement location for HOBO data loggers; (b) Temperature comparison results between CFD simulation and actual measurement.

6. Conclusion
This paper presents a detailed wind flow evaluation of the impact of the raised floor and horizontal fin (window and roof) on basic flow characteristics of cross-ventilation in Ecohouse. Computational Fluid Dynamic (CFD) Simulation can provide early information for building designers in an attempt to decide the best opening configuration. DesignBuilder CFD simulations of wind flow external and internal analysis are performed. The simulations are performed for the wind direction perpendicular to the front side of the Ecohouse. The evaluation is based on CFD simulation results such as wind velocity, wind pressure, temperature, and PPD. The following conclusion can be drawn:

- Raised floor contributes to creating better thermal comfort through heat transfer from ground to roof. Simulations results showed that lower temperatures beneath floor area if compared with other spaces.
• The open ventilation on the roof can significantly influence wind flow inside the Ecohouse.
• Horizontal fin near the window is increased internal wind velocity.

Both the raised floor and roof ventilation played a crucial for the wind movement. It should have received much attention from the building designer and the research community. Further investigations need to be performed for other kinds of ventilation design and different stilts height since it contributes to reducing the temperature.

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