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PASSIVE COOLING PERFORMANCE IN VERNACULAR JAVANESE ARCHITECTURE

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Abstract

Through the development of passive design solutions, architecture has to deal with issues relating to the subject of the energy crisis and building comfort. Vernacular architecture contains design principles that optimize natural systems for the creation of habitable comfort. This needs to be proven through the study of natural design for thermal environments in vernacular architecture, especially in Joglo buildings. This paper aims to evaluate the performance of passive cooling in Javanese vernacular houses through observation techniques and field measurements. Passive cooling performance is limited to visually appropriate aspects of building elements as well as air temperature measurement results that fall within the comfortable temperature limit along with the magnitude of the decrease in air temperature in the building. Visual methods are used to determine the suitability of passive design parameters, while field measurements are carried out to assess comfort levels and air temperature reductions. The object of this research is Joglo House in Karangjati, Ngawi, East Java. The air temperature and humidity measurement tool used is the RC 4H Data Logger with a measurement duration of seventeen days. The results showed that the main elements of passive cooling based on visual observation techniques were orientation, roof volume and porous walls. Passive cooling performance results include two things, namely: first, the average air temperature (27.5°C) in the building is within the comfortable temperature limit; second, the rate of decrease in air temperature in buildings during the day reaches 3.3°C.

Keywords: Passive Cooling, Joglo House, Comfortable Temperature Performance

INTRODUCTION

The development of the building sector, especially residential buildings, is a logical consequence of population growth and the need for shelter (Saputra, 2016). The building sector has a close relationship with the problem of energy crisis and environmental degradation. More than forty percent of the world's energy consumption is used for the building sector. Environmental damage occurs when the housing industry abandons the use of local natural materials and passive design principles handed down through the tradition of building houses in the past (Pongtuluran, 2015). The tradition of applying passive design to vernacular houses that continues to be maintained for generations is known as traditional houses. Passive design knowledge aims to provide comfort to live according to the conditions and availability of natural resources.

The basic principles of passive design in humid tropics such as Indonesia are: shading, cooling, humidifying and natural ventilation Nugroho, (2019) shading is the regulation of solar heat radiation that hits buildings through orientation, roof shape and sheath material. Natural ventilation is the regulation of heat entry from outside the building as well as heat dissipation from inside the building through the thickness, type and material of the wall. Humidification is related to providing comfortable humidity conditions through adjusting the floor height to prevent moisture from accumulating at the bottom of the room. Cooling is related to providing wind flow and speed to achieve optimal conditions between air temperature and humidity through the size, position and type of window openings along with the precise direction of the side of the building facing the local wind direction.

In particular, natural ventilation is an effort to obtain comfortable optimization of air temperature and humidity through natural energy utilization techniques that can reduce the use of artificial systems (Nugroho & Iyati, 2021). Furthermore, Nugroho & Iyati, (2021) states that the main principle of natural ventilation is the prevention of heat entering the building and heat dissipation so that comfortable level of air temperature is obtained. The goal of natural ventilation techniques is to achieve time temperature conditions during the day in buildings that are lower than the air temperature outside the building. Another aspect is the maintenance of air temperature stability in the house according to comfortable temperature limits at all times, both day and night. The main strategy of natural ventilation design is to eliminate or reduce external heat sources coming from the external environment by applying appropriate design based on the natural ventilation parameters. Natural ventilation elements and parameters based on the results of previous studies can be formulated as follows: first, the orientation element of the building with the widest side of the wall is protected from the direction of incoming sunlight and facing the direction of the wind (Beccali et al., 2018). Second, the roof casing with large volume parameters and wide and bright in color (Nugroho, 2021). Third, wall envelopes that have a barrier, brightly colored and low conductivity (Nugroho, 2019). Fourth, window openings have a size, position, type that is in accordance with the floor area and wind direction and has teritisan (Nugroho, 2019). Fifth, the floor of a building that has a height or can be a stage (Victoria et al., 2017). Sixth, the external environment that contains the existence of solar shade plants, wind directors and material's surface (Nugroho, 2018).

A traditional house is one of the studies of architecture from the past that have been tested for a very long time, and natural ventilation design components and standards continue to change along with them. The study of natural ventilation design in traditional houses through qualitative and quantitative approaches provides a comprehensive understanding of the advantages and limitations of living comfort performance. Traditional Javanese houses based on the type of roof are divided into Joglo houses, Kampung houses and Limasan houses. Various forms of Joglo houses in Java Island are found in each district that are influenced by adaptation to the natural and cultural environment. Some variations of Joglo houses, especially in East Java are Joglo Cebukan, Joglo Kepuhan Limasan and Jempongan. Joglo Cebukan has a higher roof center compared to other variations. One type of Joglo Cebukan House that still exists is in Puhti Village, Karangjati District, Ngawi Regency, East Java or called Puhti Joglo House. The neighborhood and residential buildings around Rumah Joglo Puhti are still original. The prominent character of the roof shape and the authenticity of the Joglo Puhti building are the main reasons for conducting a study of natural ventilation performance with qualitative and quantitative approaches. The novelty of the findings of this study is on objects and the use of a combination of visual techniques and thermal environment measurements. Studies related to vernakular house objects have not been widely carried out while the combination of visual and measurement techniques is different from research conducted by (Hildegardis et al., 2019), (Nugroho, 2021), and (Nugroho, 2022) which focused on field measurement techniques on traditional house objects Uma Kbubu, Bugis and Minangkabau.

RESEARCH METHOD

The two primary stages of the research phase are the visual analysis of passive design components and the investigation of passive cooling performance measurement. Qualitative visual assessment is conduct to answer the level of application of passive cooling elements in the case study of Rumah Joglo Puhti. While measuring the passive cooling performance of air temperature to evaluate comfort level and decrease in air temperature during the evaluation period (Sugiyono, 2013). The correlation and accuracy of the use of visual techniques and measurements according to the research stage is an observation of the relationship between the results of visual elements based on the level of conformity of natural ventilation design criteria with the performance of building elements to the level of air temperature reduction in the object of Joglo House. So that the findings at each stage of the study will precisely explain the relationship between visual analysis and field measurements.

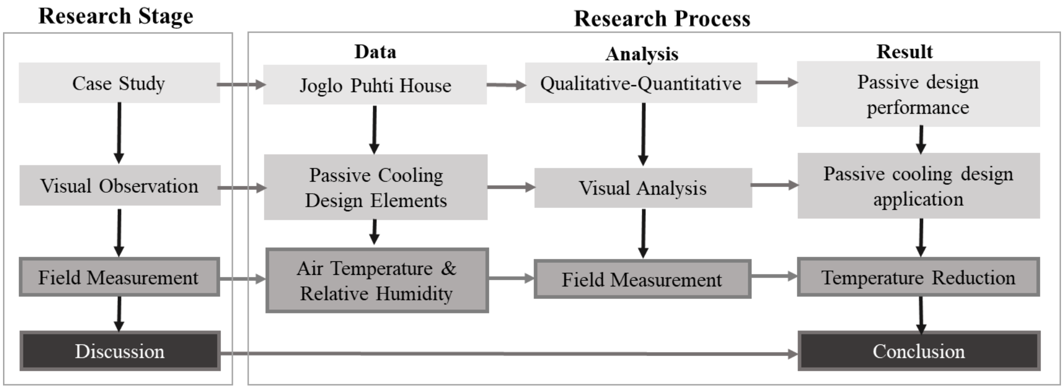


Figure 1. Stages of research

The research location is in Puhti Village, Karangjati District, Ngawi Regency, East Java. Joglo House according to locals is the largest Joglo in Karangjati District. The location of Joglo House is at a position of 7°29'01 South latitude and 111°35'51" East longitude. Climate conditions are influenced by a tropical climate with an average temperature of 20°–34°C and air humidity of 68–85%. The Ngawi Regency experiences a monsoon tropical climate with distinct dry and rainy seasons. The dry season lasts from May to October while the rainy season occurs from November to April.

The object of the Joglo House stands out among the surrounding houses with a large roof shape, the building plan tends to be square, there is a teritisan on the front, and there are two large windows on the front wall. This house is still used as a residence for a mother and her two children with the division of space in the building consisting of two bedrooms and one common room. Visual data includes images of floor plans, building elevations and sections also the photos of the buildings. Visual analysis is carried out by describing the application of passive cooling design parameters to objects such as orientation, Roof sheath, walls, floors and outdoor layouts. Measurement data are air temperature and humidity at two points inside and outside the house using the Hobo Data Logger tool. The position of the tool is at a height of 1.5 meters and is in the middle of the main room and in the terrace area of the house as shown in figure 2. Data recording is recorded every 15 minutes from May 6 to May 23, 2018. Analysis of passive cooling performance by calculating the average hourly air temperature during the measurement time, maximum and minimum values and outside and inside air temperature drop values. The analysis was conducted descriptively and evaluatively against comfort standards. In the discussion section, a discussion was held between the results of visual analysis and passive cooling performance analysis as well as comparisons with the results of previous studies.

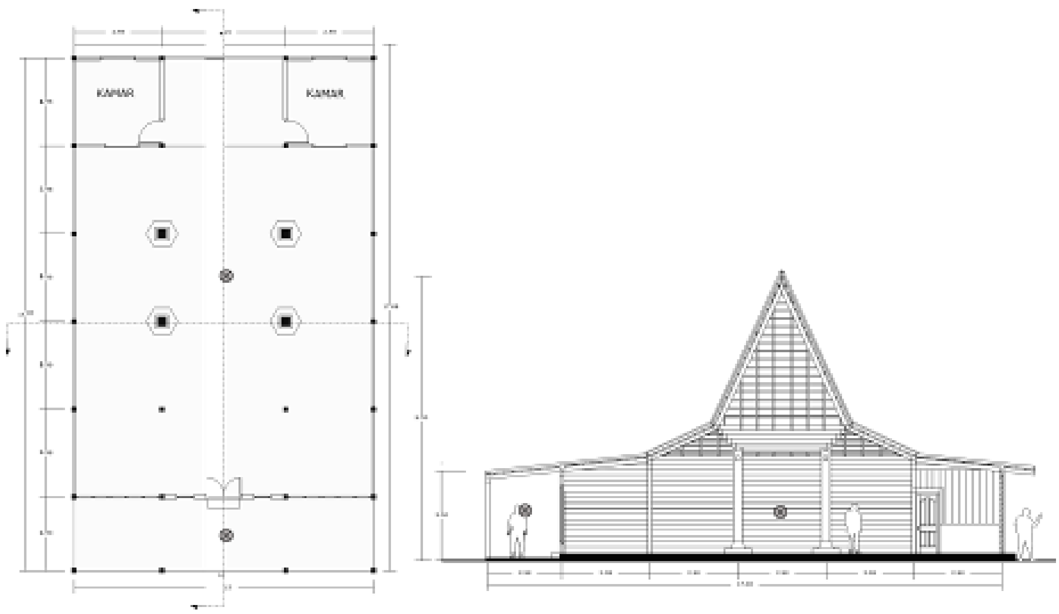


Figure 2. Data logger placement position in Joglo House

RESULT AND DISCUSSION

Passive design elements in Rumah Joglo Puhti

Joglo Puhti House is a Javanese Traditional House with an age of more than 100 years with a floor area of 180 m2 with a size of 18 x 10 meters. Joglo-shaped roof with slopes of 15°, 30° and 45° and uses clay tile material. The walls of the house as high as 3 meters with wooden board material with a thickness of 3 cm are arranged vertically. The building's floor is still made of earth, and there are two window apertures on the front wall. The surrounding buildings are located in a row with a distance of 1-2 meters, each of which has a large yard at the front of the house. The back of the house is generally a cage and bathroom separate from the house. The results of visual analysis based on the parameters of orientation, roof, walls, window openings, floor and surrounding environment according to table 1.

The orientation of the building as an element of natural ventilation design in Rumah Joglo Puhti is shown by the elongated sides of the building facing west and east so that the building mass extends north-south. Based on natural ventilation design parameters, the best elongated side of the building is to face north and south to avoid direct solar radiation. In this case study, the side facing west and east is protected by the house next to it because the distance between the buildings is quite tight. So that the orientation parameters are not yet appropriate, but in principle, the countermeasures of solar radiation have been achieved. The building's orientation is also evaluated from the side that faces the prevailing wind. At Rumah Joglo Puhti, the longest side faces the main wind direction, namely west and east. However, the placement of window openings is on the side of the south wall and on the west and east sides blocked by neighboring buildings. Although the orientation is correct, the airflow cannot freely enter the building due to the location of the building and the existing window openings.

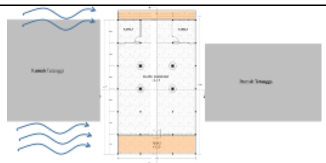
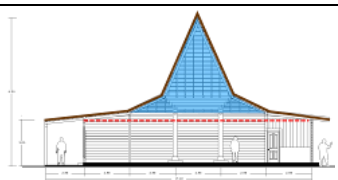
The next parameter is a roof envelope with a large volume, wide teritisan and bright color. Compared to other nearby homes, Joglo Puhti House has the biggest roof. The volume of the roof is more than half the volume of the residential space. The height of the roof reaches 6 meters or twice the height of the wall (3 meters). The slope of the roof consists of three types, namely 15 °, 30 ° and 45 °. On the north and south walls of the building there is also a 2.5-meter-wide terrace that adds to the roof shade area. The color of the roof of this building tends to be dark and without a ceiling so that it absorbs more heat than brightly colored tiles. A ceiling less roof also allows heat accumulated under the roof to descend into the space below.

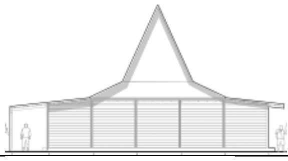
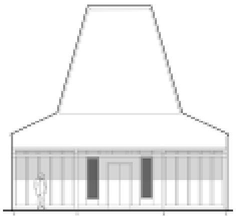
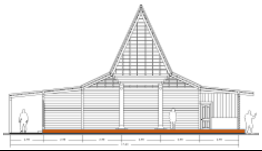
The building envelope contains three passive cooling parameters, namely: the presence of shading elements in the form of teritisan, brightly colored and low material conductivity. The walls of Joglo Puhti House on the west and east sides are shadowed by the houses beside them while the north and south sides have shade elements. The color of the walls of this building is painted white with wood board material that has low conductivity. The wall type has gaps at the bottom and top and there are cavities between the board arrangements vertically. The presence of gaps between boards helps the airflow to dissipate heat which is quickly absorbed and released by the material properties of wood.

Window openings are important element in natural ventilation through airflow that dissipates heat inside the building. One of the parameters of the design of natural ventilation in window openings is their size. With a floor area of 180 m2, window openings of 10-20% of the floor area or a minimum of about 18 m2 are needed. There are two window openings in Joglo Puhti House with a total area of 6 m2. So it still doesn't match the parameters. The natural ventilation design parameter for window opening elements is the presence of shading elements above the windows to protect against solar thermal radiation. In this building, window openings located in the terrace area are sufficiently shaded by the existing terrace roof.

The floor of Joglo Puhti House has a height of 15 cm from the yard with material in the form of soil. Based on the aspect of floor elevation, it has met the parameters of natural ventilation, especially to overcome the high humidity of the air. However, based on the type of material that still uses soil, the problem of air humidity still occurs. The last parameter of natural ventilation design is the layout of the external environment which includes the presence and placement of shade plants and yard surface characteristics. In the object of Joglo Puhti's house, there are no shade plants around the building and the character of the barren yard surface causes thermal environmental conditions during the day tend to be hot. Based on the analysis above, the building elements of Rumah Joglo Puhti that are in accordance with the natural ventilation design parameters include large roof volume elements, wide teritisan, brightly colored walls with low material conductivity and floor elevation. Elements that do not match the natural ventilation design are dark roof colors, minimal window openings, floor material and the absence of shade plants. There are elements in Rumah Joglo Puhti that are related to natural ventilation design and support temperature reduction performance, namely: a lean period with a building width of less than 10 meters with a proportion of building mass of 1: 1.7 and the lack of space barriers.

Table 1. Visual Assessment of Passive Cooling Design Parameters of Joglo House

No	Design Elements	Natural ventilation parameters	Visual result
1	Building Orientation	The widest side of the wall is protected from the direction of coming sunlight. On the south side there is a terrace.	
		The wall's broadest side faces the wind's direction.	
2	Roof sheath	Roof with large volume and teritisan	
		The color of the roof is bright and there is a heat-retaining ceiling	
3	Wall envelopes	The wall has a shading element, a bright color for the reflection of solar radiation	

No	Design Elements	Natural ventilation parameters	Visual result
		Porous walls help dissipate heat absorbed and released by building materials	
4	Window openings	Window openings have a size, position that matches the floor area and wind direction	
		Window Openings have shade	
5	Building floor	The difference in floor height is like a stage to reduce moisture with moisture-absorbing materials	
6	Outdoor layout	Plant placement for shading	
		Air flow steering plants' configuration	

Temperature and humidity conditions in Joglo house

The neutral temperature as a reference for the local comfortable temperature level is calculated based on the average monthly air temperature over the past few years. The use of climate data uses data sourced from Climate-Data.org. which is on the official website of Ngawi Regency, East Java. Based on the equation of Humphreys and Auliciem Nugroho, (2019), a neutral temperature of 24.7°C is obtained based on the formula 17.6 + (0.31 x monthly average temperature). The comfortable temperature range is 5°C, which is 2.5°C up and down, so the comfortable temperature limit is 22.2°C-27.2°C as shown in figure 3.

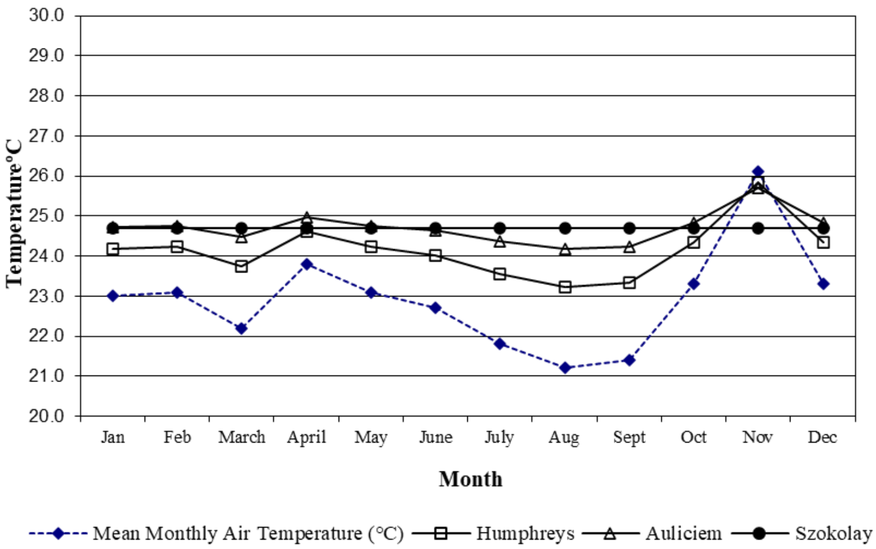


Figure.3. Neutral Temperature of Ngawi Regency as a reference for the comfortable temperature level of the object of study

The average outdoor air temperature at Joglo House is 28.3 ° C with the maximum air temperature at 14.00 which shows 34.9 ° C and the minimum air temperature of 23.8 ° C at 06.00. The maximum and minimum outside air temperature difference is 11.1°C. The average humidity of the outdoor room air is 74.1% with a maximum value of 88.4% at 07.00 and a minimum value of 52.9% at 14.00. This humidity figure is outside the limit of healthy air humidity, which is between 40% to 60%. The limit of air humidity in a healthy outdoor space occurs in the time range of 11.00 to 16.00 with an average value of 55.8%.

At Joglo House, the average air temperature for one month was 27.5°C with the highest and lowest air temperatures of 31.8°C and 24.3°C, respectively. The peak air temperature takes place at 14.00 while the lowest air temperature occurs at 07.00. The maximum and minimum air temperature range is 7.5°C. So, it can be said that there is no significant difference in air temperature between day and night. The humidity in the house has an average of the same as the outdoor space, which is 74.1%. The highest humidity was recorded at 84% and the lowest at 59.6%, at 08:00 and 15:00 respectively. Conditions of maximum and minimum air humidity in the house show a time difference of one hour slower than similar conditions for air humidity outside the building. Similarly, the time difference between air density and maximum-minimum air temperature is one hour. This is influenced by the condition of the building floor which is slower in receiving heat which causes the increase in evaporation to be delayed.

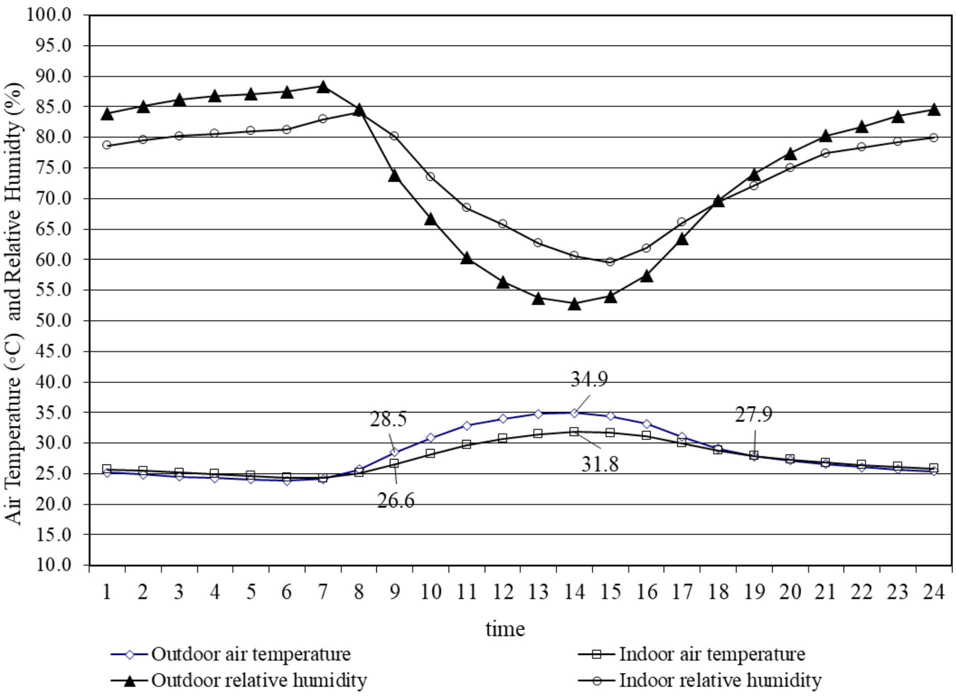


Figure.4. Comparison of air temperature and humidity inside and outside Rumah Joglo Puhti

The comfortable air temperature range based on the neutral temperature of 5°C is or between 22.2°C-27.2°C, while according to Nguyen et al., (2019), the comfortable temperature standard for vernacular houses has a larger comfortable air temperature range of 6°C or 21.7°C-27.7°. The average air temperature outside Rumah Joglo Puhti is at an uncomfortable limit both according to neutral temperature and comfortable temperature in vernacular houses in Southeast Asia. However, this does not happen all the time because there is a considerable difference in maximum and minimum temperatures (11.1°C). The large temperature difference between day and night indicates that the climatic conditions of the outside environment are quite extreme and there are certain times beyond the comfortable temperature limit. The outside air temperature that passes through the comfortable air temperature range lasts from 08.00 to

18.00 or tends to take place during the day with an average uncomfortable air temperature of 31.9° C. While the average comfortable air temperature that occurs from 18.00 to 10.00 or at night is 25.2 °C. The average condition of the outside air temperature is the basis for the natural ventilation performance of Joglo House in order to achieve better conditions in the building.

Comfortable air temperature conditions in Joglo House are shown through the average value of air temperature in the building, the difference in maximum and minimum air temperature and comfortable time span. The average air temperature in the house is 27.5°C or 0.8°C lower than the average outdoor air temperature. The difference between maximum and minimum air temperature (7.5°C) is also lower than the difference in maximum-minimum air temperature of the outdoor space (11.1°C), which is 3.6°C. Both of these are indicators that the average air temperature in the building is more stable than the outside air temperature. The time span of comfortable air temperature inside the building is for 14 hours or 58.3%, especially in the afternoon, night and morning. Uncomfortable times occur at 09:00 to 18:00 or one hour less than the uncomfortable time of the outdoor room. The difference in average air temperature during the comfortable range between the inner space (25.6°C) and the outdoor space (25.2°C) is 0.4°C and for the uncomfortable temperature of 1.8°C (the difference between 31.9°C and 30.1°C). Based on these results, the air temperature conditions in Joglo House have an average uncomfortable air temperature, a maximum-minimum air temperature range and a comfortable time span that is better than the outside environment with differences of 0.8 °C, 3.6 ° C and 1 hour, respectively.

Performance of air temperature reduction at Joglo House

The air temperature reduction in Joglo House was obtained by displaying data on the difference in air temperature of the outdoor room and indoor room at each measurement hour during the measurement period. The average reduction in air temperature in the indoor space is 0.8 °C with a maximum decrease around 13.00 which is 3.3 °C. An increase in air temperature or maximum air warming happened in the room between 03.00 and 04.00, with an average temperature of 0.7 °C. The average decrease in air temperature occurred during the day for 11 hours with an average decrease in air temperature of 2.2°C from 09.00 to 18.00. The effect of decreasing air temperature time proves that the natural ventilation design of Joglo House provides a better average comfortable air temperature (25.1 °C) at 08.00.

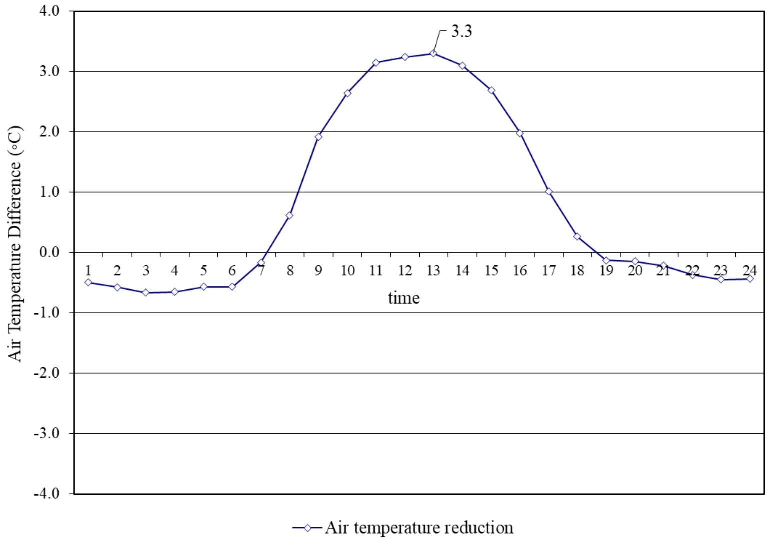


Figure.7. Decrease in air temperature at Joglo House

The decrease in air temperature is also related to the value of the time lag of the building envelope as stated by (Dili et al., 2011) that the time lag can be observed by finding the difference in peak air temperature time between inside and outside the building. There is no time difference between the peak temperature outside and inside the building at 14.00. Thus, it can be concluded that the time lag of the Joglo House veil is 0; or have low material conductivity.

The effect of natural ventilation elements on the effectiveness of air temperature reduction

The impact of passive cooling elements on air temperature reduction performance can be explained based on the relationship between the suitability of passive cooling elements and whether or not air temperature and humidity performance is achieved. The achievement of air temperature and humidity performance includes: a comfortable daily average air temperature; decrease in daily air temperature, there is no difference in peak air temperature and the average air humidity is the same number outside and inside the house. Meanwhile, the non-achievement of air temperature and humidity performance includes: the average air temperature in the building in the afternoon to evening (10.00-18.00) outside the comfortable temperature limit; average air humidity above health standards (40-60%); The time difference in air humidity conditions between outside and inside the building.

Joglo House's slim building mass and minimal space barrier are two factors that affect the average daily air temperature, which is 25.8°C. This is similar to the results of research by Zune et al., (2020) on the effect of building period and single space of Malaysian vernacular houses on the average daily air temperature. Large roof volume elements affect the performance of decreasing air temperature during the day in the research object. Victoria et al., (2017) strengthens this statement based on the results of her study on Dayak vernacular houses, where large volumes of roofs can reduce air temperature in buildings.

The reduction in air temperature is closely related to the ability to absorb and release heat which can be evaluated through the magnitude of the difference in peak air temperature between the outdoor and inside spaces of the building. Based on the measurement results, it can be observed that the highest air temperature time in the Joglo Puhti house is the same as the outside air temperature time, which is at 14.00. According to Dili et al., (2011), if there is no time difference between the peak air temperature inside and outside the building, the conductivity of the building envelope material is low. The influence of low conductivity on the Joglo Puhti house is also in accordance with the opinion of Nugroho, (2021) who explained that low conductivity in vernacular house wall material increases the cooling effect in buildings.

The floor elevation element influences the performance of the building's air humidity, with its value indication always reflecting the humidity outside the building. The humidity in the Joglo Puhti house has the same daily average as the outside environment. This is due to the elevation of the floor even though it is not too large. This performance can be improved by adding floor differences or by stage construction as stated by (Nugroho, 2022).

The impact of passive cooling features can also be seen in the outcomes of air temperature and humidity performance that were not reached. The average condition of the air temperature at Joglo Puhti's house is above the comfortable temperature limit during the day. One of the contributing factors is the dark color of the roof which is tends to absorb solar radiant heat and the absence of shade plants around the building. This is according to Nugroho, (2019) statement which states that the bright color of the roof helps reflect solar radiation and the placement of shade plants on the west side of the building can reduce the temperature in the building.

The opening elements in the Joglo House have a limited number and size. Therefore it has an impact on the flow of air entering the building to dissipate heat and humidity. This influence can be seen from the average air humidity in the building of 74.1% which is above the limit of residential health standards. This result was reinforced by Nugroho, (2019) opinion which reveals that in hot and humid climates, the presence of openings helps reduce air humidity in buildings.

The problem of air humidity in the object of study is a factor that must be resolved after the natural shading and cooling strategy has been carried out. Nugroho, (2023) stated that a decrease in air temperature should also be followed by a decrease in air humidity and if these two things have not produced optimal conditions, natural ventilation techniques are carried out with the help of air flow. The results of measuring air humidity at Rumah Joglo Puhti showed a difference in maximum air humidity in the room which was one hour slower than outside the building. One of the causative factors is the use of soil material as a building floor with material properties that release heat longer. Victoria et al., (2017) states that the use of hollow material helps reduce air humidity on the floor. According to Nugroho, (2020), local plant species can also assist lower air humidity and enhance air quality.

CONCLUSION

This study solves problems associated with the energy crisis and building comfort that can be solved through passive design in vernacular architecture in the past. The purpose of the study was to evaluate the performance of passive cooling in the case study of Javanese Vernacular House using visual technique methods based on passive cooling design criteria and air temperature and humidity measurements. In the end, the results of the study of passive cooling performance at Joglo House as a form of Javanese Vernacular Architecture resulted in three main conclusions, namely: passive cooling design elements; passive cooling performance and development of passive cooling strategies. The design elements of Rumah Joglo Puhti that fit the criteria of passive cooling are: large roof volume, wide teritisan, brightly colored walls and low conductivity, floor elevation, slim building mass and minimal space of barrier walls. While the design elements that are not yet suitable are: less bright roof color, limited window openings, damp floor material and the absence of shade plants in the yard. Passive cooling performance that meets is a comfortable average daily air temperature; decrease in air temperature during the day; There is no difference in peak temperature or low time lag and air humidity inside the building always following the conditions outside the building. However, there is a passive cooling performance that has not met, namely: air temperature conditions that are above the comfortable limit during the day and average air humidity above the humidity standard for health. It is suggested that the development of the passive cooling design of Joglo House in the future is to maintain elements that have met the criteria and improve those that are not optimal such as roof color, wall openings, floor material as well as placement and type of shade plants.

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