LOCAL WISDOM, 15 (2): 81-94 , 2023
Local Wisdom Scientific Online Journal
ISSN: 2086-3764

The Impact of Tropical Vernacular Courtyard on Air Temperature Reduction

The Case Study of Djaduk Ferianto's House

Agung Murti Nugroho
[1]*Universitas Brawijaya, Indonesia*
Corresponding Author: agungmurti@ub.ac.id

Keywords:
tropical design; vernacular courtyard; air temperature reduction

Abstract

The study of contemporary architectural work incorporating vernacular tropical design strategies is not widely done. Architect Eko Prawoto did a lot of design exploration to provide comfort by including natural elements and the relationship between outer and inner space in his contemporary residential work. Vernacular courtyards in buildings are one of the passive design strategies for lowering the air temperature in Djaduk Ferianto's house. This paper aims to evaluate and analyze the impact of the vernacular courtyards as passive tropical design elements on air temperature reduction through visual observation and thermal environmental measurements. Visual observation is conducted by observing building elements, including building massing, building's longitudinal position, width-to-length ratio, roof, wall, material, floor, opening, and courtyard. Visual analysis is done by analyzing building elements using tropical design criteria and indicators, followed by a conformity analysis. Thermal environment measurements are limited to air temperature and humidity inside and outside the building on several measurement points. Then, measurement analysis is done through descriptive, evaluative, and comparative analysis of neutral temperature and the value of air temperature reduction. The study findings are as follows: First, the main criteria of tropical design elements in Eko Prawoto's work according to the value of highly appropriate are courtyard elements, building form, roofs, and natural shades. Second, the lowest average comfortable air temperature and the longest duration of comfortable conditions are found in the courtyard room, which is 28.7°C for 17 hours per day. Third, the most significant reduction in air temperature occurred in the courtyard, with an average of 1.4°C compared to the dining room (1°C) and bedrooms (0.6°C). Recommendations for improving courtyard performance are adjusting proportions, adding a roof, placing shade plants, and raising the courtyard enclosure.

Article History	Received	:	Oct 24, 2022
	Accepted	:	Jul 11, 2022
	Published	:	Jul 15, 2023

1. Introduction

Tropical architecture is the art, science, and technology of creating and adapting to tropical environmental conditions. The adjustment or adaptation can be in the form of position or longitudinal axis; shade area; spatial layout, and the dynamics of the place over time and activities. The prominent tropical environmental characteristics are extensive solar radiation, high air temperature and humidity, and low airflow in dense urban areas.

Tropical building adaptations are typically found in vernacular architecture that has evolved over time. Some of the existing tropical design strategies include the position of the building that stretches west-east, a large roof shading area, the presence of a veranda as a transitional space, and the flexibility of the function of the space to adjust the variety of activities and time.

Vernacular tropical design strategy can be formulated into tropical design criteria in contemporary architecture. In order to achieve a comfortable natural thermal environment, some of the primary characteristics of tropical architecture include shading from solar radiation, conditioning air temperature, controlling humidity, airflow conditioning, and user conditioning.

Several researchers have studied passive design strategies, which are summarized in design criteria, such as building orientation that stretches east-west (Beccali et al., 2018; Prasetyo, 2016; Sardjono, 2011), wind direction (Manzano-Agugliaro et al., 2015; Nguyen et al., 2011), slim building massing and the presence of a veranda (Nguyen et al., 2011; Nugroho, 2012), roof with a large slope, lightweight materials, roof openings, wide eaves (Beccali et al., 2018; Hildegardis et al., 2019; Nguyen et al., 2011; Victoria et al., 2017), thin walls made of lightweight materials (Hildegardis et al., 2019; Manzano-Agugliaro et al., 2015), porous walls (Nugroho, 2012; Prasetyo et al., 2017), proper placement and size of openings (Beccali et al., 2018; Victoria et al., 2017), platform floor with a certain height and floor gap (Prasetyo et al., 2017; Sardjono, 2011; Victoria et al., 2017), landscaping with shade plants and placement on the west side (Nugroho, 2018; Prasetyo, 2016). These criteria are increasingly complete with the latest research on passive design in contemporary buildings in the tropics.

Thermal comfort constraints are most common in increasingly congested urban residential settings with limited land. This state was caused by changes in land use into settlements that often utilize materials with a high albedo, absorbing heat from solar radiation during the day and releasing it at night. The rising temperatures and humidity levels aggravate the condition. The solution to existing problems is the innovation of developing passive designs using vernacular architectural criteria, particularly in terms of air temperature reduction.

One of these innovations is the courtyard model as an open space in the building. Courtyards are a common design element used in most vernacular buildings in the Mediterranean, Middle East, and Tropical regions. Building geometry, cover, orientation, building density, and air movement play a role in influencing the courtyard's microclimate.

In hot and humid areas, courtyards show different responses to climate. Tropical courtyard functions as an air passage as well as sun and rain protection. Vernacular courtyards in the hot and humid tropics have often been adapted for cross-ventilation through their cross-sections to create different pressures along the wind flow axis (Rajapaksha et al., 2003).

Studies on the effect of vernacular courtyard elements related to air temperature conditions and solar radiation reception have been carried out by several researchers in the tropics regarding its position within the building (Tablada et al., 2005); the presence of a roof (Kubota et al., 2014; Sadafi et al., 2008; Tablada et al., 2005; Zakaria & Kubota, 2014); the shape that is not too big (Muhaisen, 2006); surrounded by space with window openings (Dili et al., 2010; Kubota et al., 2014); porous wall as the enclosing element (Almhafdy et al., 2013; Sadafi et al., 2008); the presence of plants (Jamaludin et al., 2014) and height maximization (Ghaffarianhoseini et al., 2015; Muhaisen, 2006).

The application of tropical vernacular architectural criteria coupled with courtyard elements in contemporary architecture is found in several Indonesian architectural works, including the work of architect Eko Prawoto. The house of the artist Djaduk Ferianto is one of the works of architect Eko Prawoto that uses tropical architecture and courtard features, but the performance of the thermal environment has never been evaluated. The research question is: what is the effect of vernacular courtyard elements as tropical passive designs on the performance of the thermal environment, particularly the air temperature reduction, in the case study of artist Djaduk Ferianto's house?

The purpose of this research was to analyze tropical passive design elements as well as the performance of the thermal environment and air temperature reduction in a case study of architect Eko Prawoto's work using visual observations and field measurements. The benefits of this study prove the effect of passive tropical design on the performance of the thermal environment on the object of study through the use of vernacular tropical courtyard elements. The novelty of the research is a study related to the relationship of passive design visual elements based on the latest tropical architectural criteria with the results of measurements of the thermal environment that can add new knowledge, especially the application of vernacular courtyard elements in the tropics. Table 1 depicts the research novelty, which simultaneously examines the effect of courtyards' position, presence of roof, shape, window openings, porous walls, presence of plants, and height on temperature reduction inside the house.

Table 1. Research position among previous publications on courtyard

No	**Author**	**Courtyard elements studied**						
		Position	**Presence of roof**	**Shape**	**Window openings**	**Porous wall**	**Presence of plants**	**Height**
1	Tablada, Blocken, Carmeliet, Troyer, & Verschure, 2005	√						
2	Kubota, Toe, & Ossen, 2014;		√		√			
3	Sadafi, Salleh, Haw, & Jaafar, 2008;		√			√		
4	Tablada et al., 2005;		√					
5	Zakaria & Kubota, 2014		√					
6	Muhaisen, 2006			√				√
7	Dili, Naseer, & Varghese, 2010				√			

No	Author	Courtyard elements studied						
		Position	Presence of roof	Shape	Window openings	Porous wall	Presence of plants	Height
8	Almhafdy, Ibrahim, Ahmad, & Yahya, 2013;					√		
9	Jamaludin, Hussein, Mohd Ariffin, & Keumala, 2014						√	
10	Ghaffarianhoseini, Berardi, & Ghaffarianhoseini, 2015							√
11	Present Study	√	√	√	√	√	√	√

2. Method

The research object is the house of the artist Djaduk Ferianto in Kembaran Village, RT.06/ RW.21 No.97, Tamantirto, Kasihan, Bantul Regency, Yogyakarta Special Region with coordinates 7.83 South Latitude, 110.33 East Longitude. The location is shown in Figure 1.

The research uses qualitative and quantitative methods with a descriptive, evaluative, and comparative analysis to obtain the effect of passive design elements, especially courtyards, on air temperature reduction, through visual observation techniques and field measurements. The comparative analysis technique is used to explain the relationship between the findings of visual observations and the measurements of the thermal environment. Comparative analysis is also performed by contrasting the study's findings with those of other researchers.

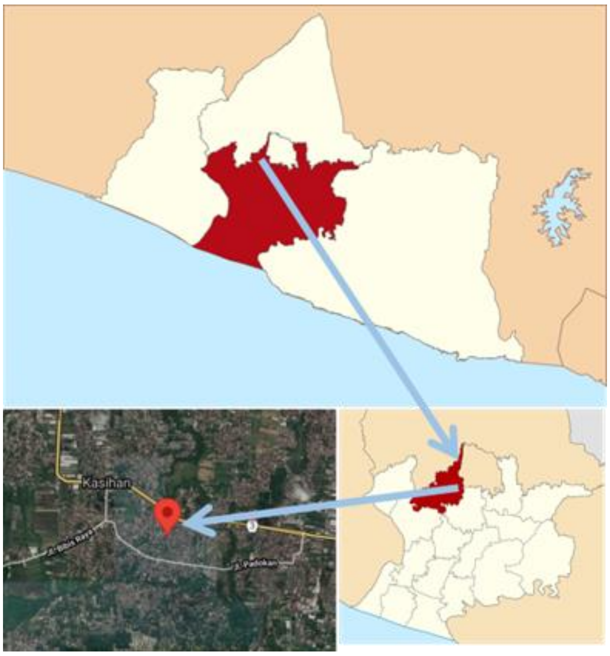


Figure 1. Location of the artist Djaduk Ferianto's house in Yogyakarta. Source: Google Map

Visual observation method

Visual observation of passive design is a simple technique based on the level of conformity between the criteria and parameters of tropical architecture to the building elements under study. The data collection technique describes the building observation units, which are classified into three main parts: roof, walls, and space. The visual analysis technique includes a descriptive explanation of each prominent building element followed by an evaluation analysis related to the criteria and parameters of tropical architecture so that simple weighting and assessment can be carried out. The assessment uses five scales: very appropriate, appropriate, neutral, inappropriate, and very inappropriate.

Djaduk Ferianto's house consists of two floors with a building area of 290 m^2. The house faces the northeast. The surroundings are residential because the research object is located in a suburban residential area, as shown in Figure 2.

Figure 2. Research object condition

Field measurements method

Field measurements use temperature and humidity data loggers positioned in outdoor areas, dining rooms, courtyards, and bedrooms. The measurement instruments are positioned as illustrated in Figure 3, with a height of 110 cm above the floor, and installed for 12 days. The measuring instrument for temperature and humidity is Elitech RC4-HA with an accuracy of + 0.01°C and + 1% RH.

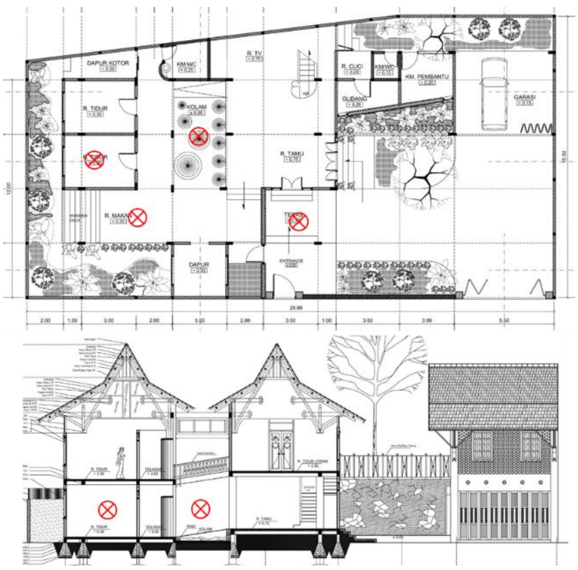


Figure 3. The measurement points of temperature and humidity at the artist Djaduk Ferinto's house [⊗]

Measurement analysis includes a descriptive explanation of the average, minimum, and maximum air temperature on the outdoor area, bedroom, dining room, and courtyard, followed by evaluative analysis such as comparation with the comfortable neutral temperature limit and evaluation of air temperature reduction values. The field measurement results inside and outside the house is compared with Yogyakarta's comfortable neutral temperature limit. The difference in peak temperature between indoors and outdoors is used to calculate the time lag associated with the thermal conductivity of the material. The temperature reduction performance is evaluated by comparing the air temperature differences between the outdoors and each room inside the house, as well as the thermal environmental comfort factor and the material's thermal conductivity.

3. Result and Discussion

The result of passive design elements based on tropical architecture visual criteria

Vernacular and contemporary tropical architecture criteria become the basis for assessing the visual appropriateness of passive designs on the research object. Table 2 shows that five criteria are considered **very appropriate**: two criteria for courtyard design, building massing, roof, and natural shade. The vernacular courtyard design criteria with a very appropriate value are its position in the center of the building and its condition surrounded by space with cross ventilation so that the courtyard elements can adequately serve the air change for the surrounding spaces. In terms of building massing, a slim building floor plan that is no more than four times the height of the building allows for easy air movement inside. Then, because the roof slope varies between 30° and 60°, only a tiny portion of the roof is exposed to direct solar radiation. Natural shade is provided by plants surrounding the building, while a large canopy tree on the west side protects the house from afternoon sun radiation.

Eight **appropriate** criteria include three criteria for building mass, three criteria for the building envelope, two criteria for the roof, and one criterion for the courtyard. The appropriate value of building mass consists of three aspects: extended west-east, its longitudinal position, and the proportion of the building mass. The mass of the building stretches in a northwest-southeast direction so that the west side is not overly exposed to solar radiation. The long side of the building faces the prominent wind direction by making a 45° angle to allow the breeze from the south to enter evenly throughout the building. The predominant wind direction is from the south, allowing even airflow distribution in the room. The building's width:length ratio is 1:2, less than the optimal tropical proportion of 1:3.

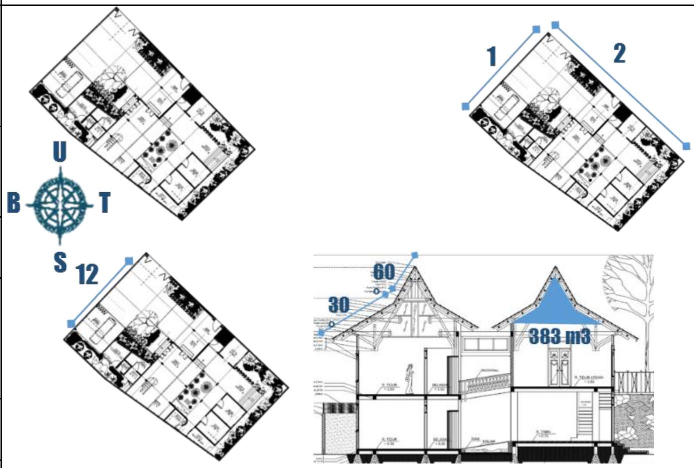
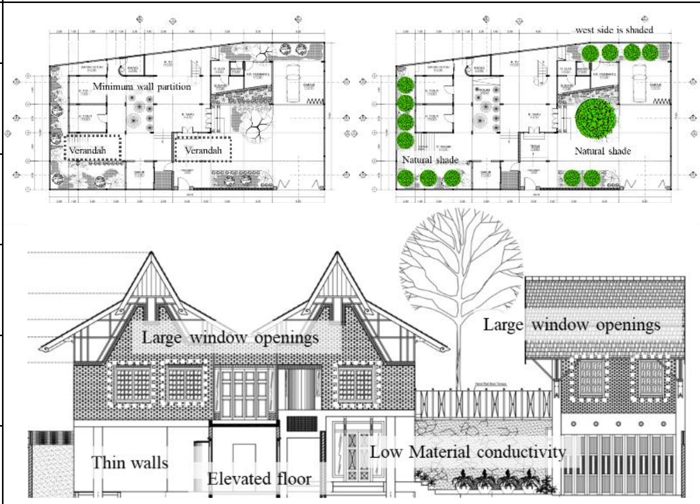
In the building envelope, there are three criteria with appropriate values, namely the presence of openings around the building, the shaded west side, and minimum wall partition. Every room has window openings that are far too large. The wide opening increases the wind speed even though the incoming air temperature is generally the same as the outside air temperature. Another criterion for the building envelope is that the plants shade the west side with a narrow canopy. The next criterion is the absence of a partition wall inside the building. The lack of partitions allows for even distribution of airflow in the house.

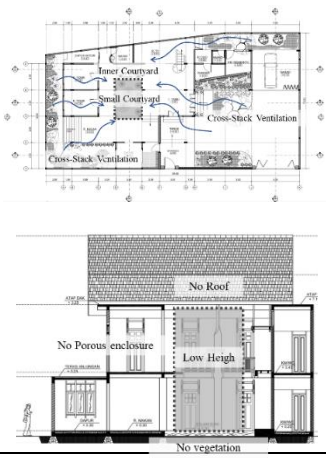
There are two appropriate roof criteria: large roof volume and the presence of eaves. A large roof volume in proportion to the room volume underneath it can prevent solar radiation from affecting the room. Wide eaves give shade and help to cool the air. However, because the eaves do not surround the building, the air temperature in the unshaded room may vary.

The only appropriate criterion in the courtyard is the porous enclosure. The porous walls are only found on one side of the courtyard enclosure and are underused to filter and direct wind

Seven criteria were considered **inappropriate**, including four courtyard design criteria and one criterion on wall, material, and floor. As one of the key features, the vernacular courtyard design in Djaduk Ferianto's house contains not only very appropriate criteria but also several inappropriate criteria, namely: large courtyard area, the absence of a roof, the absence of shade plants, and less than the maximum height. The courtyard size is 3 m x 6 m, which is too large to reduce the air temperature. Large size allows for turbulence or the downward flow of air that should be moving upwards. The absence of shade plants and a roof above the courtyard limit its potential to cool the inside air. Other criteria considered inappropriate are the wall and its materials. Suitable materials in the tropics have low conductivity, while the research object uses brick walls with a conductivity larger than wood. The building also does not use a platform structure and has no variation in floor height, limiting its ability to provide cooling from beneath the floor.

Table 2. Visual analysis of the appropriateness of passive designs in Djaduk Ferianto's house

No	Tropical Criteria of Passive Design	Visual Indicators	VI	I	N	A	VA
1	The building massing is extended west-east.					√	
2	The building's long side faces the wind.					√	
3	Width to length ratio = 1:3					√	
4	Slim floor plan of not more than 12 meters width for a height of 3 meters						√
5	Roof with slope >30°						√
6	The larger the volume of the roof, the better.					√	
7	The presence of a terrace or veranda					√	
8	Minimum wall partition inside the building					√	
9	Thin walls with adequate ventilation			√			
10	Material conductivity is low.			√			
11	There is a variation in floor height.			√			
12	The presence of window openings around the building					√	
13	Presence of natural shade						√
14	The building's west side is shaded					√	

No	Tropical Criteria of Passive Design	Visual Indicators	VI	I	N	A	VA
15	The presence of the courtyard in the middle of the building						√
16	Small courtyard size			√			
17	Courtyard surrounded by cross-ventilated space						√
18	The presence of roof over the courtyard			√			
19	Porous courtyard enclosure					√	
20	Shade plants in the courtyard			√			
21	Maximum courtyard height			√			

VI: very inappropriate; I: inappropriate; N: neutral; A: appropriate; VA: very appropriate

Based on the number of appropriate and inappropriate criteria, only a few courtyard elements are appropriate, namely position, surrounding space, and the porosity of the enclosure. In contrast, inappropriate ones include size, height, and the absence of a roof and plants. The influence of the seven criteria can be studied more deeply by comparing them with the results of the thermal environment performance.

The result of thermal environment performance of Djaduk Ferianto's house

Figure 4 shows the average temperature and humidity in the outdoor area, bedroom, dining room, and courtyard. The average outdoor air temperature is 29°C with a maximum value of 33.6°C at 13.00 and a minimum value of 25.6°C at 06.00. There is a maximum-minimum value difference of 8°C. The average outdoor humidity is 87.4%, with a maximum value of 99% at 06.00 and a minimum of 71% at 13.00. The pattern of maximum and minimum temperature and humidity level reveals an inverse relationship, where the highest air temperature is accompanied by the lowest humidity and vice versa.

The average air temperature in the bedroom is 28.3°C, with the maximum air temperature occurring at 13.00 at 29.2°C while the minimum air temperature at 08.00 is 27.7°C. The maximum-minimum air temperature range is 1.5°C, indicating that the air temperature in the room is stable.

The dining room's average air temperature is 27.9°C with a maximum value of 30.8°C at 14.00 and a minimum of 25.6°C at 07.00. Maximum and minimum temperature range of 5.2°C. The courtyard has the lowest average air temperature, with an average of 27.6°C. The maximum air temperature value was 29.6°C at 14.00, and the minimum was 24.8°C at 06.00. The maximum-minimum temperature range value is 4.8°C. Based on the average value and the air temperature range, it can be seen that the outside air temperature is more dynamic than the air temperature inside the building. This is indicated by the larger average and range of air temperatures compared to the indoor space.

The average humidity in the indoor room (91.1%) tends to be higher than the outdoor area (87.4%), with the highest order of air humidity being the courtyard room (93.2%), dining room (93%), and bedroom (87.1%). A fish pond at the bottom of the courtyard room influences the humidity level. The maximum-minimum humidity range in the outdoor area, which reaches 28% compared to the indoor humidity range of 13.4%, indicates a significant change in climatic conditions outside the building.

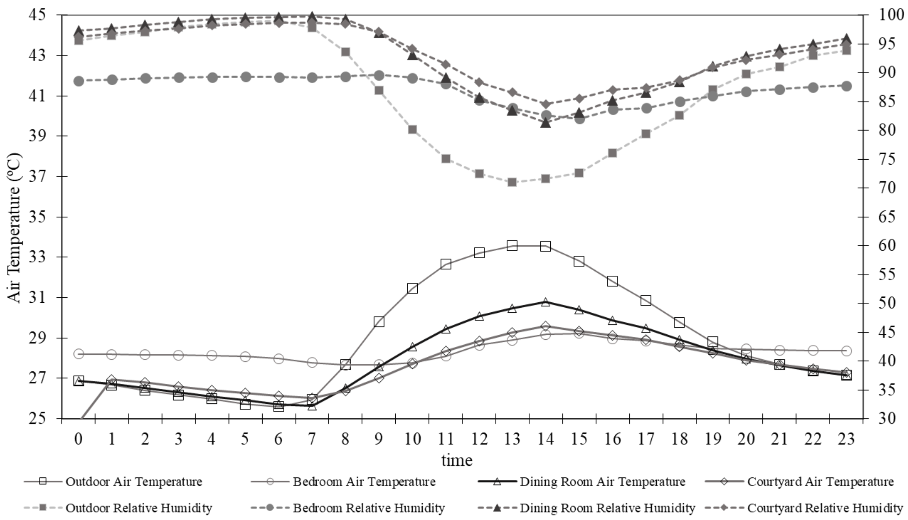


Figure 4. Graph of the average temperature and humidity in the outdoor area, bedroom, dining room, and courtyard

Comfortable temperature and duration in each room can be determined based on Yogyakarta's neutral temperature limit of 23.3°C - 28.3°C. The outside air temperature shows comfortable conditions at 20.00 to 08.00 in the morning with an average comfortable and uncomfortable temperature of 26.7°C and 31.7°C, respectively, as shown in Figure 5. Comfortable for 13 hours and uncomfortable for 11 hours. In the bedroom, comfortable conditions occur for 12 hours, starting from 00.00 to 12.00, with an average air temperature of 28°C. The uncomfortable air temperature in the bedroom is, on average, 28.7°C or better than the outdoor area. The average comfortable temperature in the dining room is 26.7°C for 14 hours, starting from 19.00 to 10.00, which means it is better than the comfortable condition of the bedroom temperature. The courtyard has the longest comfortable air temperature recording of 17 hours, with an average comfortable temperature of 26.7°C. Uncomfortable conditions in the courtyard occurred from 12.00 to 19.00.

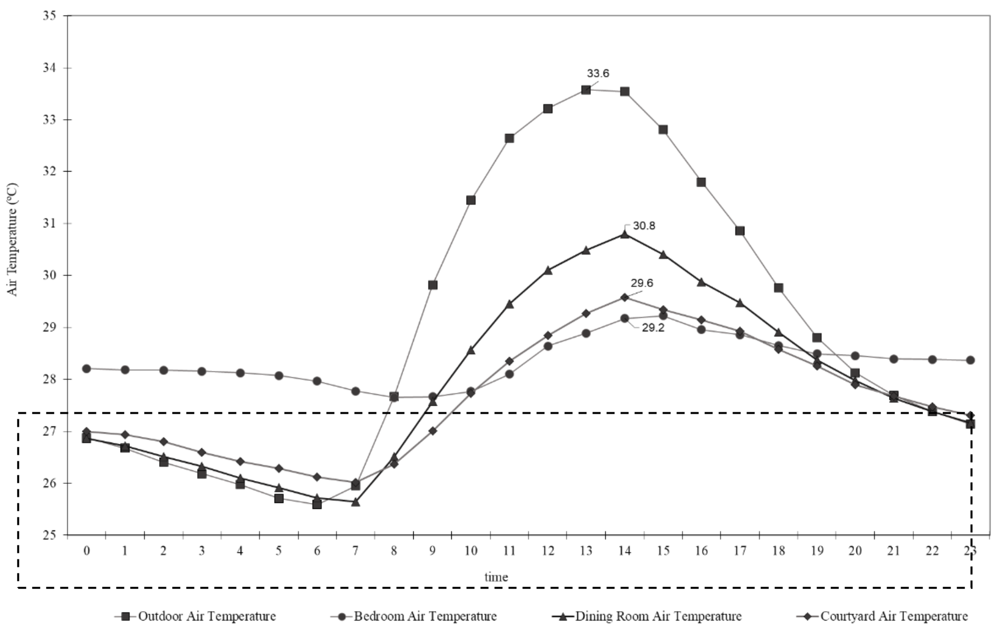


Figure 5. Graph of comfortable temperature and time of outdoor area, bedroom, dining room and courtyard

The time lag of the peak air temperature between the indoor and outdoor areas reveals the material conductivity of each room. In general, the peak air temperature in the bedroom, dining room, and courtyard have a one-hour gap with the outside air temperature, indicating that the material's conductivity is the same and does not easily absorb and release heat.

Figure 6 shows the air temperature reduction in the bedroom, dining room, and courtyard. The air temperature reduction is based on the difference between the indoor and outdoor air temperature. Based on the measurement results, the air temperature reduction in the dining room occurred from 07.00 to 21.00, while in the courtyard from 08.00 to 20.00. The fastest decline in air temperature is found in the bedroom for 11 hours (09.00-19.00). It demonstrates that the duration of the indoor air temperature reduction depends on the room's proximity to the outside. The most significant air temperature reduction occurred in the bedroom at 4.7°C at 13.00, followed by the courtyard at 4.4°C at 12.00 and the dining room at 3.2 at 11.00. This performance shows that the delay in the maximum air temperature reduction in the bedroom, courtyard, and dining room with a one-hour difference is due to the room's proximity to the outside. The results of air temperature reduction in the room near the outdoors have an accumulated effect on the room in the deeper part.

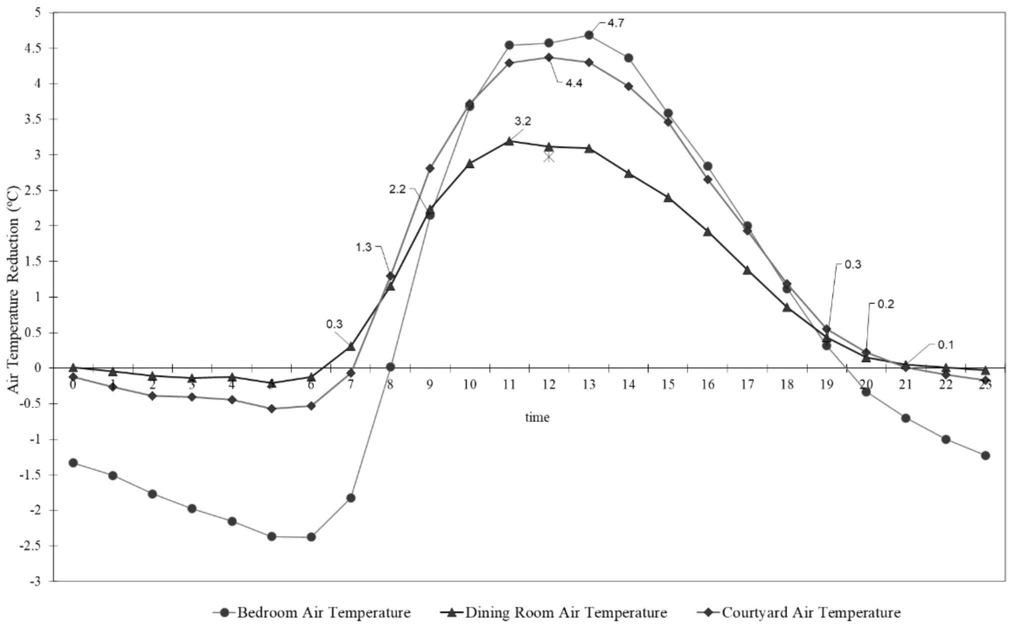


Figure 6. Graph of the air temperature reduction in the bedroom, dining room, and courtyard

Discussions on the impact of passive design and vernacular courtyard elements on air temperature reduction

Based on the thermal environment performance results, the vernacular courtyard has the best comfortable temperature and air temperature reduction compared to the dining room and bedroom. The effect of the vernacular courtyard on comfortable air temperature conditions and air temperature reduction can be explained by comparing with the results of visual studies and previous research.

Based on the visual analysis, it was found that the **very appropriate** criteria of tropical architecture are the courtyard position and the enclosure, as well as the building mass, roof, and natural shade. Courtyard at Djaduk Ferianto's house serves as a connector between rooms. It has a rectangular shape and is positioned at the center of the building. This is consistent with Meir (2000), who mentioned that appropriate courtyard orientation and position help to achieve thermal environment comfort inside the room. He discovered that a square courtyard with cross ventilation yields the best thermal environmental performance.

The vernacular courtyard at Djaduk Ferianto's house, surrounded by cross-ventilated rooms, produces the best results for lowering the air temperature. This aligns with the findings of Dili (2010) and Kubota (2014). According to Dili (2010), low air pressure in the space surrounding the courtyard will move air circulation upwards. Meanwhile, Kubota (2014) reported on the effect of window openings and roofs on air temperature reduction in a Malaysian vernacular courtyard. The courtyard enclosure on the research object is open on all sides with no walls, which is consistent with Almhafdy et al. (2013)'s finding that the courtyard wall is a key part of establishing microclimate conditions.

A courtyard element that is **appropriate** but whose quality can be improved to reduce air temperature is the porosity of the courtyard enclosure. The courtyard at Djaduk Ferianto's house is open on all sides with no walls and is open at the top without any ventilated blocks. The enclosure is in accordance with research conducted by Aldawoud (2008), which states that the effectiveness of light materials and the large ratio of openings of the courtyard enclosure walls affect the decrease in air temperature. Edwards et al. (2005) stated that the small opening on the upper wall of the courtyard gives a stronger airflow effect.

The **inappropriate** courtyard elements, but when optimized, can improve the performance of reducing air temperature are dimensions, the presence of a roof and shade plants, and the height of the courtyard. The shade effect cannot be maximized because Djaduk Ferianto's courtyard is quite large. The efficacy of the courtyard design can be enhanced by reducing the proportion to provide shade in the space below. According to Muhaisen (2006), the proportion of the courtyard affects the shading conditions where a narrow and deep shape is better than a large and wide one, with an optimal height of three floors. Meanwhile, Zakaria and Kubota (2014) found that the shape and orientation had little effect on the performance of the thermal environment of the courtyard, while a significant effect was on the shade.

Because Djaduk Ferianto's courtyard lacks a roof, direct solar radiation enters the interior. According to Sadafi et al. (2008) and Zakaria and Kubota (2014), adding a roof to the courtyard will improve the performance of temperature reduction. Sadafi et al. (2008) mentioned the effect of roof and courtyard walls on increasing natural cooling and reducing solar radiation. Furthermore, Sthapak and Bandyopadhyay (2014) suggested covering the courtyard with a porous roof to provide a strong difference in ventilation pressure.

The vernacular courtyard in the research object contains a fish pond which increases the humidity. The design recommendation is to replace it with shade plants. Jamaludin et al. (2014) state that a courtyard with plants has a lower air temperature than a courtyard without plants. The addition of shade plants in the courtyard is also in accordance with Almhafdy et al. (2013), who stated that the natural elements of the courtyard could improve comfort conditions, especially during the day.

The height of the courtyard wall is the last aspect that is inappropriate for tropical courtyard standards. Courtyards in the study object lack additional height at the top, limiting the effects of stack ventilation and solar radiation protection. According to Ghaffarianhoseini et al. (2015), the higher the courtyard, the lower the air temperature and solar radiation in the room.

Recommendations for improving the courtyard performance at artist Djaduk Ferianto's house are by increasing the height of the courtyard walls, providing a roof, adding porous openings under the courtyard roof, adding shade plants in the courtyard area, reducing the size of the courtyard by providing enclosure walls composed of ventilated blocks. This recommendation complements the appropriate elements, namely the courtyard position at the center of the building and the courtyard surrounded by cross-ventilated space.

4. Conclusion

The research's conclusion addresses the formulation of the problem and objectives, namely, the effect of vernacular courtyards as passive tropical designs on thermal environment performance. The courtyard position at the center of the building, surrounded by cross-ventilated space, is the very appropriate criteria for passive tropical design. It is because the average air temperature in the courtyard is the lowest compared to other rooms, even though the humidity is the highest due to the presence of a fish pond in the courtyard. The vernacular courtyard keeps the temperature within Yogyakarta's comfortable neutral temperature range for 17 hours, except from 12.00 to 19.00. This is inseparably linked to the maximum average air temperature reduction of 4.4°C and 3.4°C during the day. Passive courtyard design elements that affect the decrease in air temperature from night to noon are the position at the center of the building, surrounded by cross-ventilated space, and a porous courtyard enclosure. Meanwhile, the decrease in air temperature from midday to evening is not optimal due to the absence of shade plants and roofs, the wide size, and the height of the courtyard. The courtyard's performance for air temperature reduction in the study object can be improved by adjusting the proportions, adding a roof, integrating shade plants, and raising the enclosure walls.

Acknowledgement
The author would like to thank Universitas Brawijaya for funding this research and Hannaswati Grahitasari Putri as as research assistance.

References

Aldawoud, A. (2008). Thermal performance of courtyard buildings. *Energy and Buildings*, *40*(5), 906–910. https://doi.org/10.1016/J.ENBUILD.2007.07.007

Almhafdy, A., Ibrahim, N., Ahmad, S. S., & Yahya, J. (2013). Courtyard Design Variants and Microclimate Performance. *Procedia - Social and Behavioral Sciences*, *101*. https://doi.org/10.1016/j.sbspro.2013.07.190

Beccali, M., Strazzeri, V., Germanà, M. L., Melluso, V., & Galatioto, A. (2018). Vernacular and bioclimatic architecture and indoor thermal comfort implications in hot-humid climates: An overview. In *Renewable and Sustainable Energy Reviews* (Vol. 82). https://doi.org/10.1016/j.rser.2017.06.062

Dili, A. S., Naseer, M. A., & Varghese, T. Z. (2010). Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses. *Energy and Buildings*, *42*(6). https://doi.org/10.1016/j.enbuild.2010.01.002

Edwards, B., Sibley, M., Hakmi, M., & Land, P. (Eds.). (2005). *Courtyard Housing: Past, Present and Future* (1st ed.). Taylor & Francis.

Ghaffarianhoseini, A., Berardi, U., & Ghaffarianhoseini, A. (2015). Thermal performance characteristics of unshaded courtyards in hot and humid climates. *Building and Environment*, *87*. https://doi.org/10.1016/j.buildenv.2015.02.001

Hildegardis, C., Agung Ayu Oka Saraswati, A., & Ketut Agusinta Dewi, N. (2019). Review of Thermal Comfort in Warm Humid Climate for Traditional Architecture in Indonesia. *KnE Social Sciences*. https://doi.org/10.18502/kss.v3i21.4965

Jamaludin, A. A., Hussein, H., Mohd Ariffin, A. R., & Keumala, N. (2014). A study on different natural ventilation approaches at a residential college building with the internal courtyard arrangement. *Energy and Buildings*, *72*. https://doi.org/10.1016/j.enbuild.2013.12.050

Kubota, T., Toe, D. H. C., & Ossen, D. R. (2014). Field investigation of indoor thermal environments in traditional Chinese shophouses with courtyards in Malacca. *Journal of Asian Architecture and Building Engineering*, *13*(1). https://doi.org/10.3130/jaabe.13.247

Manzano-Agugliaro, F., Montoya, F. G., Sabio-Ortega, A., & García-Cruz, A. (2015). Review of bioclimatic architecture strategies for achieving thermal comfort. In *Renewable and Sustainable Energy Reviews* (Vol. 49). https://doi.org/10.1016/j.rser.2015.04.095

Meir, I. A. (2000). Courtyard microclimate: a hot arid region case study. In K. Steemers & S. Yannas (Eds.), *Proceedings of the 17th PLEA International Conference* (pp. 218–223). James & James (Science Publishers) Ltd.

Muhaisen, A. S. (2006). Shading simulation of the courtyard form in different climatic regions. *Building and Environment*, *41*(12). https://doi.org/10.1016/j.buildenv.2005.07.016

Nguyen, A. T., Tran, Q. B., Tran, D. Q., & Reiter, S. (2011). An investigation on climate responsive design strategies of vernacular housing in Vietnam. *Building and Environment*, *46*(10). https://doi.org/10.1016/j.buildenv.2011.04.019

Nugroho, A. M. (2012). A Thermal Assessment of the Traditional House In Flores, Indonesia. *J. Basic. Appl. Sci. Res*, *2*(12), 12795--12801.

Nugroho, A. M. (2018). Arsitektur Tropis Nusantara: Rumah Tropis Nusantara Kontemporer. In *Malang: UBPress*.

Prasetyo, Y. H. (2016). Analisis Kinerja Termal dan Aerodinamis pada Rumah Tradisional Batak Toba Menggunakan Simulasi Digital dan Pengukuran Lapangan. *Widyariset*, *2*(2).

Prasetyo, Y. H., Astuti, S., Perumahan, P. L., Badan, P., Kementerian, L., Umum, P., Rakyat, P., Panyawungan, J., Wetan, C., & Bandung, K. (2017). Ekspresi Bentuk Klimatik Tropis Arsitektur Tradisional Nusantara dalam Regionalisme. *Jurnal Permukiman*, *12*(2).

Rajapaksha, I., Nagai, H., & Okumiya, M. (2003). A ventilated courtyard as a passive cooling strategy in the warm humid tropics. *Renewable Energy*, *28*(11). https://doi.org/10.1016/S0960-1481(03)00012-0

Sadafi, N., Salleh, E., Haw, L. C., & Jaafar, Z. (2008). Potential thermal impacts of internal courtyard in terrace houses: A case study in tropical climate. *Journal of Applied Sciences*, *8*(15). https://doi.org/10.3923/jas.2008.2770.2775

Sardjono, A. B. (2011). Respon Rumah Tradisional Kudus Terhadap Iklim Tropis. *Modul*, *11*(1).

Sthapak, S., & Bandyopadhyay, A. (2014). Courtyard houses: An overview. *Recent Research in Science and Technology*, *6*(1), 70–73. https://updatepublishing.com/journal/index.php/rrst/article/view/1168

Tablada, A., Blocken, B., Carmeliet, J., Troyer, F. DE, & Verschure, H. (2005). GEOMETRY OF BUILDING'S COURTYARDS TO FAVOUR NATURAL VENTILATION: COMPARISON BETWEEN WIND TUNNEL EXPERIMENT AND NUMERICAL SIMULATION. *SB05 Tokyo: The 2005 World Sustainable Building Conference*, 2184–2191.

Victoria, J., Mahayuddin, S. A., Zaharuddin, W. A. Z. W., Harun, S. N., & Ismail, B. (2017). Bioclimatic Design Approach in Dayak Traditional Longhouse. *Procedia Engineering*, *180*. https://doi.org/10.1016/j.proeng.2017.04.215

Zakaria, M. A., & Kubota, T. (2014). Environmental Design Consideration for Courtyards in Residential Buildings in Hot-humid Climates: A Review. *International Journal of Built Environment and Sustainability*, *1*(1). https://doi.org/10.11113/ijbes.v1.n1.7