

Utilizing A Bioclimatic Architectural Approach on The Roof To Optimize Building Thermal Performance.

Case Study: Universitas Diponegoro Campus Mosque

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INFORMASI ARTIKEL

Abstract: *Local wisdom enhances building aesthetics and imparts philosophical values. Bioclimatic architecture has become popular among architects and designers because it reduces energy consumption without harming the environment. A study at the Universitas Diponegoro Campus Mosque applied bioclimatic design using a traditional joglo roof model simulated with Autodesk Ecotect. Measurements showed the maximum suhue on the second floor reached 28°C. Simulations indicated that bioclimatic design could reduce indoor suhues by 4.3°C - 5.2°C to 24.5°C. This result shows a lower suhue difference compared to the existing design by 7.5°C. This design can be a prospective solution for improving thermal comfort and providing an environmentally friendly design.*

Keywords: *Autodesk Ecotect, Bioclimatic Design, Field Measurement, Indoor Suhue, Modelling Simulation*

Abstrak: Kearifan lokal meningkatkan estetika bangunan dan memberikan nilai-nilai filosofis. Arsitektur bioklimatik menjadi semakin populer di kalangan arsitek dan desainer karena mampu mengurangi konsumsi energi tanpa merusak lingkungan. Sebuah studi di Masjid Kampus Universitas Diponegoro menerapkan desain bioklimatik dengan menggunakan model atap tradisional joglo yang disimulasikan menggunakan Autodesk Ecotect. Hasil pengukuran menunjukkan bahwa suhu maksimum di lantai dua mencapai 28°C. Simulasi menunjukkan bahwa desain bioklimatik dapat menurunkan suhu dalam ruangan sebesar 4,3°C hingga 5,2°C menjadi 24,5°C. Hasil ini menunjukkan perbedaan suhu yang lebih rendah dibandingkan dengan desain eksisting sebesar 7,5°C. Desain ini dapat menjadi solusi prospektif untuk meningkatkan kenyamanan termal sekaligus menyediakan desain yang ramah lingkungan.

Kata Kunci: Autodesk Ecotect, Desain Bioklimatik, Pengukuran Lapangan, Suhu Dalam Ruangan, Simulasi Pemodelan

Article history:

Received; 2024-08-13

Revised; 2024-08-27

Accepted; 2024-09-30

INTRODUCTION

Nowadays, the development of traditional architecture is still in demand by most Indonesian people. Although the modernization is regularly minimizing the magnificence of local wisdom and at the same time decreasing the meaning of culture (Ashadi, 2020). One of local wisdom that coming from traditional Javanese Architecture is the roof named joglo. This typical roof can be seen not only in the traditional houses but also in the modern buildings. The concept of joglo roof resembles the shape of a mountain named “tajug” (Hermawan & Prihatmaji, 2019). The characteristic of joglo roof that

differentiate from one another are the component that containing the value, convictions, standards, and social values of Javanese traditions from other roofs (Ghefra Rizkan Gaffara et al., 2021).

Mostly, the preference of using joglo roof in the modern buildings is due to its philosophical values and its positive contributions to the environment. Considering the magnificence values of joglo roof, the Diponegoro University applied this roof for the design of campus mosque. It is not only giving philosophical values but also improves the aesthetic of the mosque.

In other hand, bioclimatic architecture is recently famous among architect and building designers. The bioclimatic is a science that studies the relationship between climate and life, especially the influence of climate on health and daily life (Yeang, 1994). The purpose of bioclimatic architecture is to create an environment and buildings designed to reduce energy consumption without causing environmental damage (Amelia Megawati et al., 2018). The designs also consider the integration between technology and materials in the building cycle system to minimize environmental damage from the use of materials to the recycling process (Talarosha, 2005). This emphasizes the integration of local ecological conditions, climate, site conditions, building programs, and climate responsive design concepts. Similar theory also said the bioclimatic architecture concept has three main principles i.e. energy saving, refers to the local climatic condition, and environmental friendly (Handoko & Ikaputra, 2019). Teori lain menjelaskan tujuan utama desain bioklimatik adalah untuk mengurangi ketergantungan bangunan terhadap penggunaan sistem mekanis dan elektrik untuk sistem pendingin pasif (Kusuma Cahyaningrum & Nugroho, 2017). Karena desain bangunan yang mempengaruhi lingkungan dalam ruangan berkaitan dengan jumlah area paparan sinar matahari, perolehan panas dari radiasi matahari, konduktif, konvektif, dan potensi ventilasi alami untuk meningkatkan pendinginan pasif (Kurnia & Purwantiasning, 2022). Pada akhirnya arsitektur bioklimatik dapat menjadi solusi untuk meningkatkan kinerja termal bangunan.

Another theory explains the main purpose of bioclimatic designs is to reduce building dependence on the use of mechanical and electrical systems for the passive cooling systems (Kusuma Cahyaningrum & Nugroho, 2017). Since the building design that affect to the indoor environment relates to the number of exposure area to sunlight, heat gain from solar radiation, conductive, convective, and potential for natural ventilation to improve passive cooling (Kurnia & Purwantiasning, 2022). In the end, the bioclimatic architecture can be a solution to improve building thermal performance.

Through previous studies, researchers proved the cooling effect of bioclimatic design on the buildings. A study conducted in public library in Malang city using several bioclimatic approaches i.e. shading from wall design in response to building orientation, wall opening to optimize natural

ventilation, vertical landscape to improve natural element, and the use of artificial lighting such as open plants and transitions (Amalia et al., 2014). Furthermore, the study also found using bioclimatic elements will reduce the solar radiation effects on the walls.

Although there have been studies of bioclimatic architectural design, yet the discussion only relied on middle parts of the building. There are very limited study discussing the use of bioclimatic design on the roof. In response to this issue, a study using bioclimatic design was conducted in Universitas Diponegoro Campus Mosque. The joglo roof as the mosque icon was the main object. The purpose of this study was to conduct a model of the traditional joglo roof that can be applied to the Universitas Diponegoro Campus Mosque. Several thermal parameters were measured to observe the thermal performance of the mosque. The bioclimatic architectural design was used as the theoretical approached. Simulation using Autodeks Ecotec software was conducted to strengthen the research method.

METHODS

2.1 Study object

The object of this study is Universitas Diponegoro Campus Mosque. It located in Semarang City, Indonesia at 6°58'S 110°25'E (Figure 2.1). Based on its geography condition, the area of the city is divided by three main areas i.e. coastal areas, low lands, and high lands.

The Universitas Diponegoro Campus Mosque is known with its joglo roof. The roof has opening located on the lower and upper parts. The functions are for natural lighting and air circulation. The roof material is metal roof and tend to absorb heat that radiated from solar radiation.



Figure 2.1. Detail of study object **(a)** Location of Universitas Diponegoro Campus Mosque **(b)** Universitas Diponegoro Campus Mosque

2.2 Research method

This study used a parametric and qualitative quantitative method. Field measurements were conducted to obtain the data of the thermal parameters i.e. room temperature and humidity. The measurement campaigns were carried out on 12th November 2022. The data were measured in the morning (7:50 a.m. and 09:00 a.m.), afternoon (1:00 p.m. and 3:00 p.m.), and evening (7:30 p.m.).

Table 1. Parameters, type, accuracy, and range of measurement devices.

Devices	Manufacture r	Model	City, Country	Parameter s	Accuracy	Range
Digital Thermometer TPM-10	Airmend	LR44	Guangzhou ,China	• T_{ia}	$\pm 1^{\circ}\text{C}$ ($\pm 2^{\circ}\text{F}$)	$-50^{\circ}\text{C} \sim 110^{\circ}\text{C}$ ($-58^{\circ}\text{F} \sim 158^{\circ}\text{F}$)
HTC-1 Clock Hygrometer Thermometer	Heybits	AAA xl	Guangzhou ,China	• T_{ea} • T_{ia} • RH	• $\pm 1^{\circ}\text{C}$ ($1-8^{\circ}\text{F}$) • $\pm 5\%$ RH (40% -80%)	• $-50 \sim +70^{\circ}\text{C}$ ($-58 \sim +154^{\circ}\text{F}$) • 10%-99% RH

Note: RH : Humidity; T_{ea} : External air temperature; T_{ia} : Indoor air temperature

Several instruments were installed to collect data measurement for the building thermal performance. **Table 2.1** presents the type of instruments for each parameter and its details. Room thermometer (Digital Thermometer TPM-10) was used to measure indoor temperature. The room humidity was obtained using Hygrometer (HTC-1 Clock Hygrometer Thermometer). **Figure 2.1** shows the instruments for measurement campaign. As for the data collection was conducted in the prayer room on the first floor and second floor. Samples were taken at several points. Due to limited of measurement instruments, there was time difference about 1 – 5 minutes for each data measurement. However, the data was valid since the measurement campaign conducted in the sunny day. The sample points and the position of the measurement instruments can be seen in **Figure 2.2**.



(a)



(b)

Figure 2.1. Measurement instruments **(a)** Thermometer **(b)** Hygrometer Tools

Apart of field measurement, this study also used computer simulation using Autodesk Ecotect software. The 3D model of bioclimatic roof was created using the SketchUp. Several parameters such as building temperature and humidity were inputted before starting the simulation. Result from field measurement and bioclimatic model simulation was compared to evaluate the thermal effect of bioclimatic design on the building. **Figure 2.3** shows the simulation procedure.

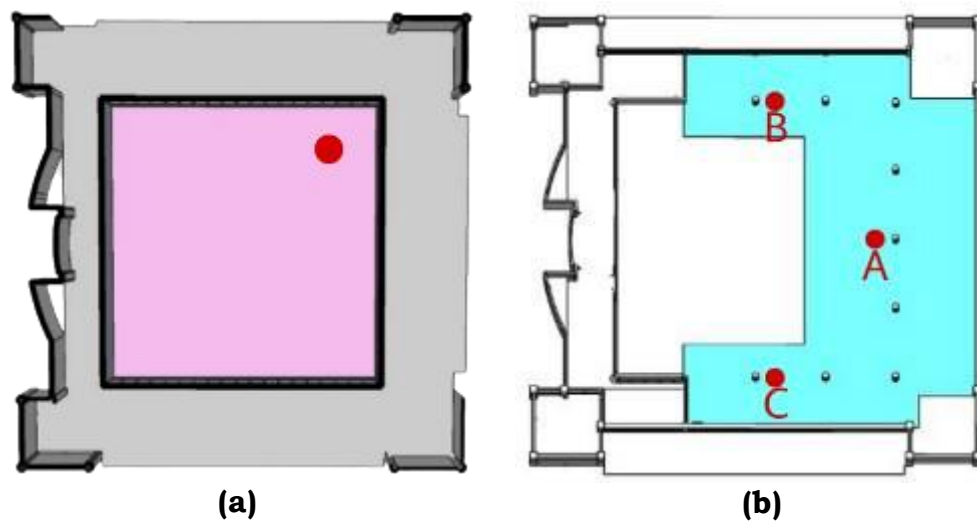


Figure 2.2. Position of measurement instruments **(a)** 1st floor measuring point **(b)** 2nd floor measuring point

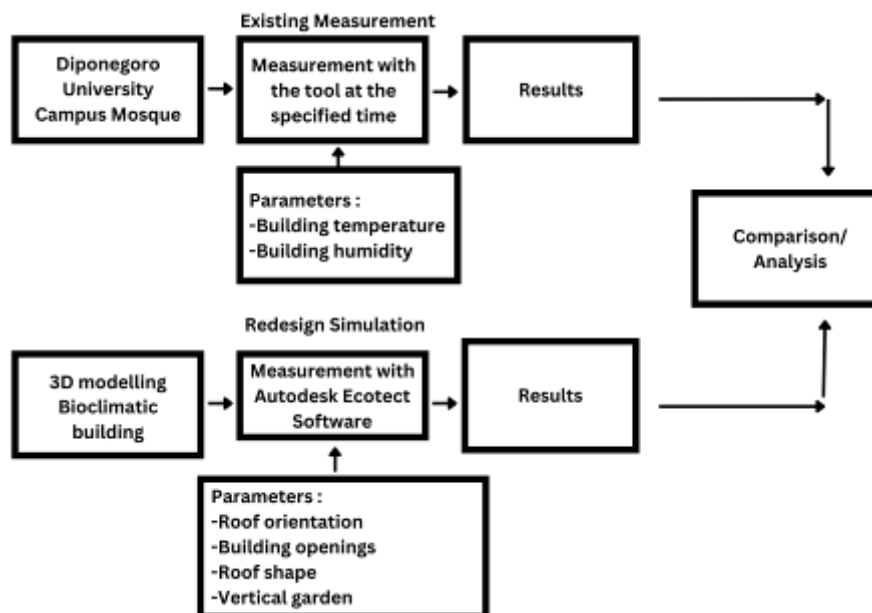


Figure 2.3. The simulation procedure between existing and bioclimatic design

RESULT AND DISCUSSION

3.1 Local climate condition

As mentioned in the **method section, sub section study object**, the location of the Diponegoro University Campus Mosque is in Semarang City. According to Köppen climate classification, the climate of the city is tropical rain forest and tropical monsoon climate (Köppen et al., 2011)

Furthermore, data from Maritime Meteorology Station of Semarang City mentioned the average daily temperature from 2021 to 2022 was around 32°C. While the normal and the highest temperature were 26°C and 37°C, respectively. The range of relative humidity was from 73% to 100% (Youlanda & Cherish, 2022). Most of the time, the daily climatic condition was hot and humid with minor temperature variation.

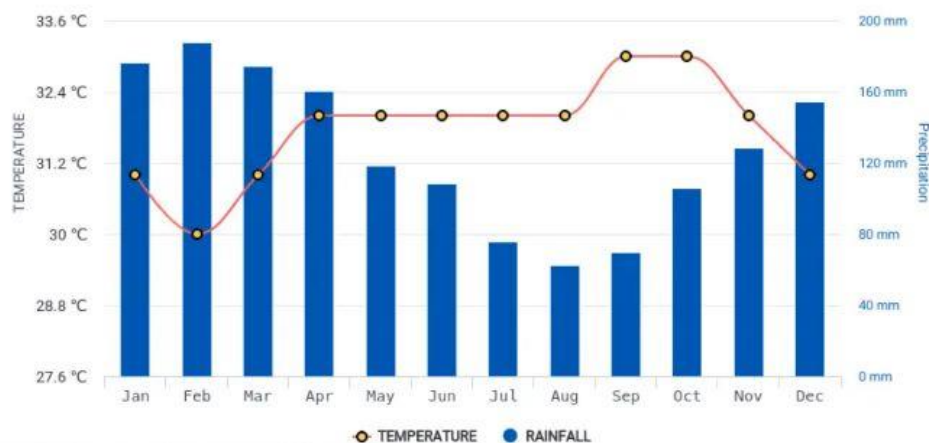


Figure 3.1. Monthly temperature variation of Semarang City

3.2 Building thermal profile

A summary on the statistical calculation of room temperature variations was presented in **Table 3.1**. The results showed the average temperature and relative humidity on the first floor were 28.8°C and 77.2%, respectively. On second floor, the average temperature and humidity in each measurement point were 28.9 °C and 76.4% (point A), 28.9 °C and 77% (point B), and 28.9 °C and 76.8% (point C). Compared to the first-floor area, the second floor had higher thermal performance, respectively from point A, C, and B. Therefore, the implementation of bioclimatic design was the roof design that focused on the area of second floor at point A and point C.

Table 3.1. Results of temperature data collection on the first and second floors

First floor				Second floor			
Time	Temperature [°C]	Time	Temperature [°C]	Time	Temperature [°C]	Time	Temperature [°C]
07:53 a.m.	27.6	07:57 a.m.	27.8	07:59 a.m.	27.8	08:00 a.m.	27.7
09:03 a.m.	28.1	09:00 a.m.	28.1	08:56 a.m.	28.3	08:58 a.m.	28.2
01:01 p.m.	29.7	01:03 p.m.	29.8	01:04 p.m.	29.9	01:06 p.m.	29.9
03:09 p.m.	29.6	03:02 p.m.	29.9	03:06 p.m.	29.8	03:07 p.m.	29.8
07:31 p.m.	29.2	07:34 p.m.	29.2	07:36 p.m.	29.1	07:38 p.m.	28.9

3.3 Implementation of bioclimatic design on the joglo roof

As mentioned in research method section, this study also used simulation using Autodesk Ecotect. Result from field measurements was used as the input for simulation. Several elements of bioclimatic design, such as orientation, form, opening, and selected materials were applied on the roof model during the simulation process (Melanira, 2022). **Figure 3.2** showed the elements of bioclimatic design that applied on the roof model.

The orientation of the building was facing east and according to the field measurement, the east area showed the highest temperature profile since most of the time, sunlight came from this side (**Figure 3.2.a**). To minimize the negative effect of solar radiation, a vertical greenery system was applied on the roof model (**Figure 3.2.b**). The greenery system is very useful to reduce the heat transfer from solar radiation to the indoor environment, especially in the morning (Kasus et al., 2014).

In response to wind circulation and to optimize the indoor air circulation, slanted roof was applied on the design of the joglo roof (**Figure 3.2.c**). In each part of the slanted roof, an opening design was applied on the roof ridge to provide cross ventilation (**Figure 3.2.d**). Bioclimatic design, the presence of opening system can be applied as cross ventilation, chimney ventilation, and wind tower (Sørensen, 2008). The opening system is very beneficial to provide more air circulation inside the roof ceiling. It produces cooler air temperature and creates cooler indoor environment (**Hildayanti & Wasilah, 2022**). The opening system also applied on the wall as windows.

Figure 2.3 shows the results of bioclimatic design using Autodesk Ecotect. Clearly the indoor temperatures on the first and second floor were lower compared to the result from field measurement. According to simulation, after the bioclimatic roof applied on the building design, the indoor temperature on the first and second floor was 21.0°C and 24.5°C, respectively.

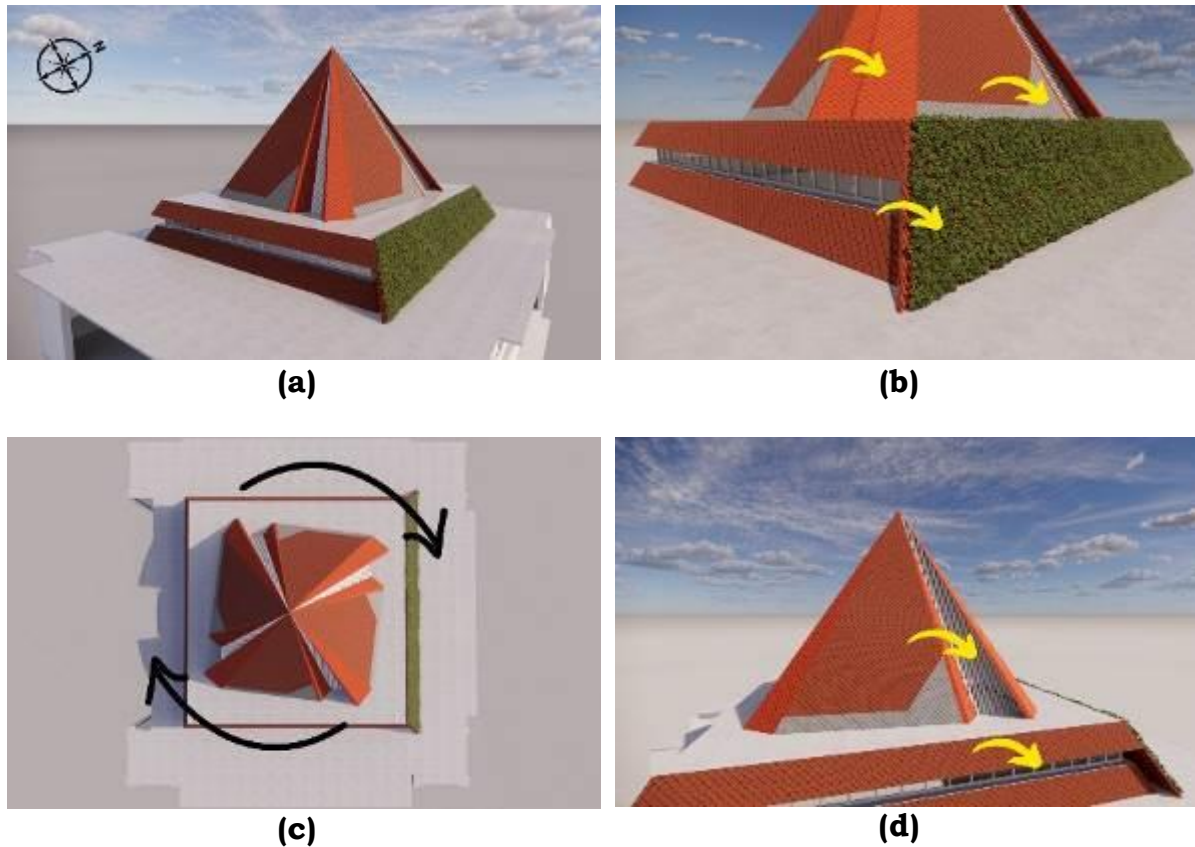


Figure 3.2. Elements of bioclimatic design that applied on the roof model **(a)** Implementation of bioclimatic design in response to the sunlight orientation; **(b)** Implementation of bioclimatic design in response to the materials; **(c)** Implementation of bioclimatic design in response to the forms; and **(d)** Implementation of bioclimatic design in response to the openings.

Table 3.2 presents the comparison between the result from field measurement and simulation. Refers to the data from field measurements, the indoor temperature range was from 28.8°C to 28.9°C. The highest temperature profiles were found on the second floor. Since the area was close to the roof area and tended to get direct solar radiation. The average indoor temperature was 28.9°C. In other hand, simulation results showed lower indoor temperature profiles. The temperature range obtained from simulation was from 21.0°C to 24.5°C with the average temperature of 23.6°C. The average temperature difference between the two methods was 5.3°C. According to the simulation, the application of bioclimatic design on the mosque can decrease the indoor temperature around 4.3°C - 5.2°C or at the level of 24.5°C.

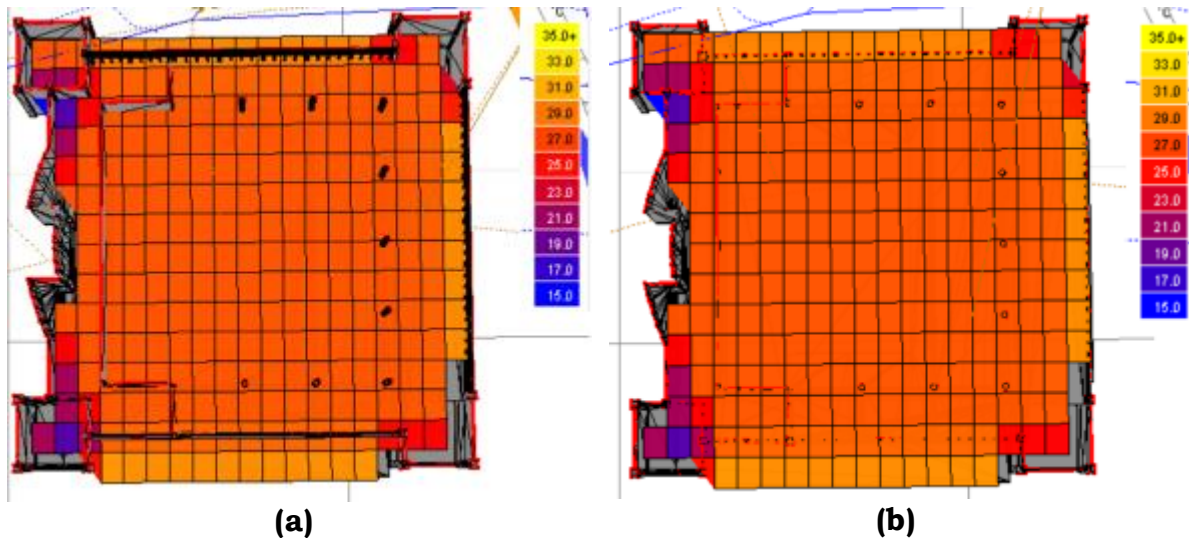


Figure 3.3. Simulation results of bioclimatic design using Autodesk Ecotect
(a) Bioclimatic design simulation of first floor; (b) Bioclimatic design simulation of second floor.

Furthermore, compared to the average outdoor temperature, the existing design had smaller difference by 3.1°C. While the simulation results performed higher temperature difference by 7.5°C. It means, if mechanical air conditioning system installed inside the mosque with bioclimatic design, possibility, lower energy consumption can be achieved. However, further study should be carried out to observe this issue. Thus, the application of bioclimatic design on the roof of Diponegoro University Campus Mosque can be a prospective solution to improve indoor thermal comfort and provide environmentally friendly design.

Table 3.2. Comparison between field measurement and simulation

Locations	Temperature (°C)	
	Field Measurement	Simulation
Lantai satu	28.8	21.0
Lantai 2 (titik A)	28.9	24.5
Lantai 2 (titik B)	28.9	24.5
Lantai 2 (titik B)	28.9	24.5
Rata-rata	28.9	23.6

CONCLUSION

Nowadays, the development of traditional architecture is still in demand by most Indonesian people. Although the modernization is regularly minimizing the magnificence of local wisdom and at the same time decreasing the meaning of culture. Considering the magnificence values of joglo roof, the Diponegoro University applied this roof for the design of campus mosque. It

is not only giving philosophical values but also improves the aesthetic of the mosque.

In other hand, bioclimatic architecture is recently famous among architect and building designers. The purpose of bioclimatic architecture is to create an environment and buildings designed to reduce energy consumption without causing environmental damage. This emphasizes the integration of local ecological conditions, climate, site conditions, building programs, and climate responsive design concepts.

In response to this issue, a study using bioclimatic design was conducted in Diponegoro University Campus Mosque. A model of traditional joglo roof was created and simulated using Autodesk Ecotect. Several thermal parameters were measured to observe the thermal performance of the mosque before and after the bioclimatic design applied.

Result from field measurement showed the maximum room temperature of the mosque was obtained on the second-floor area by 28°C. Possibility the highest heat transfer from the outdoor to the indoor occurred on the second-floor area. While significant temperature reduction was performed after bioclimatic roof applied. According to the simulation, the application of bioclimatic design on the mosque can decrease the indoor temperature around 4.3°C - 5.2°C or at the level of 24.5°C. Furthermore, compared to the existing design, the bioclimatic design had higher temperature difference with outdoor temperature by 7.5°C. It means, if mechanical air conditioning system installed inside the mosque with bioclimatic design, possibility, lower energy consumption can be achieved. Thus, the application of bioclimatic design on the roof of Diponegoro University Campus Mosque can be a prospective solution to improve indoor thermal comfort and provide environmentally friendly design.

REFERENCES

- Amalia, N., Nugroho, A. M., & Asikin, D. (2014). Fasad Bioklimatik Pada Rancangan Perpustakaan Umum Di Kedung Kandang Kota Malang.
- Amelia Megawati, L., Akromusyuhada Program Studi Arsitektur, A., & Tinggi Teknologi Pelita Bangsa, S. (2018). Pendekatan Arsitektur Bioklimatik Pada Konsep Bangunan Sekolah Yang Hemat Energi Bioclimatic Architectural Approach To Energy Efficient School Building Concepts. Prosiding Seminar Nasional Unimus, 1.
- Ashadi, A. (2020). Pendhapa Natabratan & Symbolic Meaning Of The Javanese House In Demak, Indonesia. International Journal Of Architecture, Arts And Applications, 6(3), 39. <https://doi.org/10.11648/J.Ijaa.20200603.12>
- Ghefra Rizkan Gaffara, Dayu Ariesta Kirana Sari, & Nanda Saputra. (2021). Javanese Cultural Heritage Building (Case Study: Joglo House). Lakhomi Journal Scientific Journal Of Culture, 2(4), 148–153. <https://doi.org/10.33258/Lakhomi.V2i4.533>

- Handoko, J. P. S., & Ikaputra, I. (2019). Prinsip Desain Arsitektur Bioklimatik Pada Iklim Tropis. *Langkau Betang: Jurnal Arsitektur*, 6(2), 87. <https://doi.org/10.26418/Lantang.V6i2.34791>
- Hermawan, B., & Prihatmaji, Y. P. (2019). Perkembangan Bentuk Atap Rumah Tradisional Jawa. In *Prosiding Seminar Nasional Desain Dan Arsitektur (Senada)* (Vol. 2).
- Hildayanti, A., & Wasilah. (2022). Pendekatan Arsitektur Bioklimatik Sebagai Bentuk Adaptasi Bangunan Terhadap Iklim. *Nature: National Academic Journal Of Architecture*, 9(1), 29–41. <https://doi.org/10.24252/Nature.V9i1a3>
- Kasus, S., Pertamina Jalan Pemuda Semarang Ratih Widiastuti, G., Prianto, E., Setia Budi, W., Besar Jurusan Fisika, G., Matematika Dan Sains, F., & Diponegoro, U. (2014). Kenyamanan Termal Bangunan Dengan Vertical Garden Berdasarkan Standar Kenyamanan Mom & Wieseborn (Vol. 8, Issue 1).
- Köppen, W., Volken, E., & Brönnimann, S. (2011). The Thermal Zones Of The Earth According To The Duration Of Hot, Moderate And Cold Periods And To The Impact Of Heat On The Organic World. *Meteorologische Zeitschrift*, 20(3), 351–360. <https://doi.org/10.1127/0941-2948/2011/105>
- Kurnia, Y., & Purwantiasning, A. W. (2022). Kajian Konsep Arsitektur Bioklimatik Pada Bangunan Hunian Vertikal (Studi Kasus Kampung Admiralty Singapura).
- Kusuma Cahyaningrum, H., & Nugroho, R. (2017). Implementasi Prinsip Desain Arsitektur Bioklimatik Pada Bangunan Perpustakaan Di Klaten. <https://jurnal.uns.ac.id/arsitektura/article/view/12580>
- Melanira, A. (2022). Penerapan Bangunan Rumah Lingkungan Dalam Kajian Arsitektur Bioklimatik (Sekolah Alam Bekasi (Sasi)). In *Jurnal Ilmiah Arjouna* (Vol. 4).
- Sørensen P., 2008, Wind And Ventilation. In: Torben Dahl, Climate And Architecture, Routledge, Taylor & Francis Group, English Edition, Oxon, 90-113
- Talarosha, B. (2005). Menciptakan Kenyamanan Thermal Dalam Bangunan. In *Jurnal Sistem Teknik Industri* (Vol. 6, Issue 3).
- Youlanda, S., & Cherish, R. (2022). Analisa Orientasi Massa Bangunan Terhadap Kenyamanan Thermal Pada Perencanaan Ma'had Aly Ummu Sulaim Dengan Pendekatan Arsitektur Ekologi. 9(2), 33–43. <https://journal.unilak.ac.id/index.php/arsitektur>