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Bioclimatic Wisdom in Minangkabau Houses

Case Study of Gadang Jopang Manganti House

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Abstract

Bioclimatic architecture is an adaptive design to the equatorial tropical climate through passive cooling strategies. This paper aims to evaluate the bioclimatic wisdom of the Minangkabau houses to formulate passive design knowledge with visual observation techniques and measurement of the air temperature and relative humidity. The visual observation method is used to find the level of application of bioclimatic design. The measurement techniques are used to evaluate the thermal environmental comfort in the case study of the Gadang Jopang Manganti House, Munka, Limapuluh Kota, West Sumatra. The result of bioclimatic wisdom elements in the appropriate Gadang Jopang Manganti house is the orientation of the building mass and openings, placement and form of single dwelling space without partition and big roof space. The living room has a comfortable thermal environment performance indicated by the average comfort air temperature, decreasing air temperature, and a longer comfortable period. The development of a bioclimatic design for the Gadang Jopang Manganti House could be taken by improving naatural cooling or optimizing natural ventilation to remove building's humidity.

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1. Introduction

Bioclimatic Architecture and Traditions of Equatorial Tropical Buildings

The climate in the equatorial tropics is characterized by hot and humid conditions and high solar radiation intensity. This condition should not be seen as a hindrance to tropical life. Comfortable living in the tropics is possible if the principles of bioclimatic architecture principles are utilized appropriately. The tradition of equatorial tropical buildings is an architectural knowledge based on building science principles, especially in an environment of high air temperature and humidity, focusing on climate-responsive building elements. The tradition of responding to the equatorial tropics on past architecture is a continual process that involves testing techniques over time. Its sustainable process driven by changes in the natural and human environment. The tradition of transferring knowledge and culture living in a tropical setting eventually manifests in the form of a traditional house. Traditional architecture is a source of knowledge that should be preserved and improved in response to changing environmental conditions and inhabitants' lifestyles. Traditional architecture evolves not only in terms of building form but also in terms of the building's natural environmental system (Gou et al, 2015). Tropical bioclimatic wisdom is one of the knowledge of the building's natural environment system to achieve the natural thermal comfort of the occupants.

Nugroho (2018), Zang et al (2018), Nguyen et al (2019), and Zenu et al (2020) conducted studies on bioclimatic wisdom on traditional building objects, especially in equatorial tropical climates. They come out with several criteria and parameters of climate responsive design. The design criteria and parameters including: first, the orientation and shape of the building with the parameters facing south and avoiding west and east directions; orientation of the opening to the wind; the main living area being protected. Second, the shading element with its presence parameter shading the window; the width corresponds to the size of the window, the west side shading tree. Third, natural conditioning features such as roof space dimensions, roof ceiling use, uninsulated space, the use of bright colors in the building envelope, wall thickness, and the existence of transition spaces. Fourth, the moisture control element with the parameters of the moisture-absorbing material and the difference in the floor or stage. Fifth, natural ventilation is discussed in detail, including the parameters for ventilation openings on each side of the building, large ventilation openings, and latticed or porous types of opening.

Bioclimatic Wisdom of Minangkabau Building, Indonesia

The form of bioclimatic wisdom in tropical responsive design criteria and parameters helps visually identify building elements that affect the comfort of living in the equatorial tropics. The results of these visual observations, when connected with the study of measuring the thermal environment, can help advance our understanding, development, and discovery of new equatorial tropical bioclimatic designs in the future. This is the first step toward determining bioclimatic wisdom, which is important in the buildings that have passed a long period of time, for example, traditional houses. The variety of traditional houses in Indonesia, primarily located in the equatorial tropical climate, can be seen in their natural design principles (Nugroho, 2019). Natural shade is utilized to prevent exposure to solar radiation entering the building. If the conditions are not met, then the principle of natural conditioning is applied to reduce the air temperature in the building. In similar situations, attempts to keep the air temperature within the bounds of thermal comfort can result in a rise in air humidity. The principle of controlling humidity needs to be carried out to absorb the water content in the air. The last principle is natural cooling by the use of wind to provide a cooling sensation to the human body if the previous three have not yet achieved the ideal condition.

The study of bioclimatic wisdom in the context of traditional houses is critical for two reasons. The initial purpose is to visually assess the feasibility of the equatorial tropical bioclimatic design features. The second purpose is to evaluate the thermal environment’s performance using field measuring techniques for temperature and humidity components. The selected object of study is the Gadang Jopang Manganti House, Munka District, Limapuluh Kota Regency, West Sumatra. In the Minang cultural area, the Gadang Jopang Manganti house is a form of traditional dwelling.

2. METHODS

The design of the research is divided into two components: field observations and field measurements. The first section addresses the first research objective, which is the suitability of bioclimatic design elements, while the second section addresses the second research objective, which is the thermal environment's performance. The case study takes place in Gadang Jopang Manganti, Munka District, Limapuluh Kota Regency, West Sumatra, specifically at 0°01' south latitude and 100°05' east latitude. The study location's climatic conditions are equatorial tropical, with an average daily air temperature of 25.7°C and an average humidity of 82.3 percent.

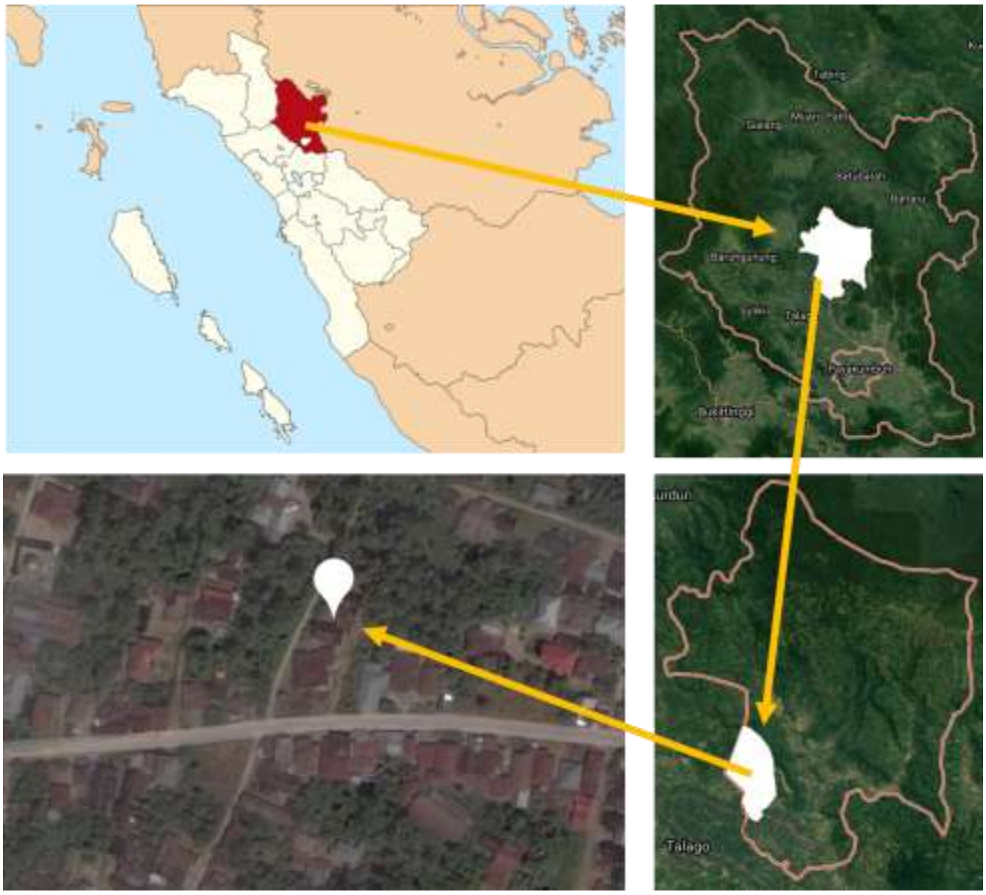

Figure 1. The case study object is located in the village of Gadang Jopang Manganti, Munka District, Limapuluh Kota Regency (https://id.wikipedia.org/wiki and google earth)

The Gadang Jopang Manganti House is a typical Gadang house with a box-shaped dwelling space and five Gonjong roof shapes. The data on the building elements are used as a visual observation unit for the study, and it is grouped according to their compliance with the bioclimatic design criteria. The Data Logger tool is used to locate measurement points at six locations within the house and one location outside the house. From July 14, 2018 to September 13, 2018, measurements are taken automatically every hour. The performance of the comfortable air temperature system is determined by the neutral temperature value of the object's location. The study area is in West Sumatra's Limapuluh Kota Regency. Based on average climatic data from the nearest BMKG station, Padang

Pariaman Class II Climatology Station, a neutral temperature of 25.6°C is calculated, with a comfortable temperature range of 23.1°C - 28.1°C.

Figure 2. Gadang Jopang Manganti House, Munka, Limapuluh Kota, West Sumatra as the object of study (Source: author documentation)

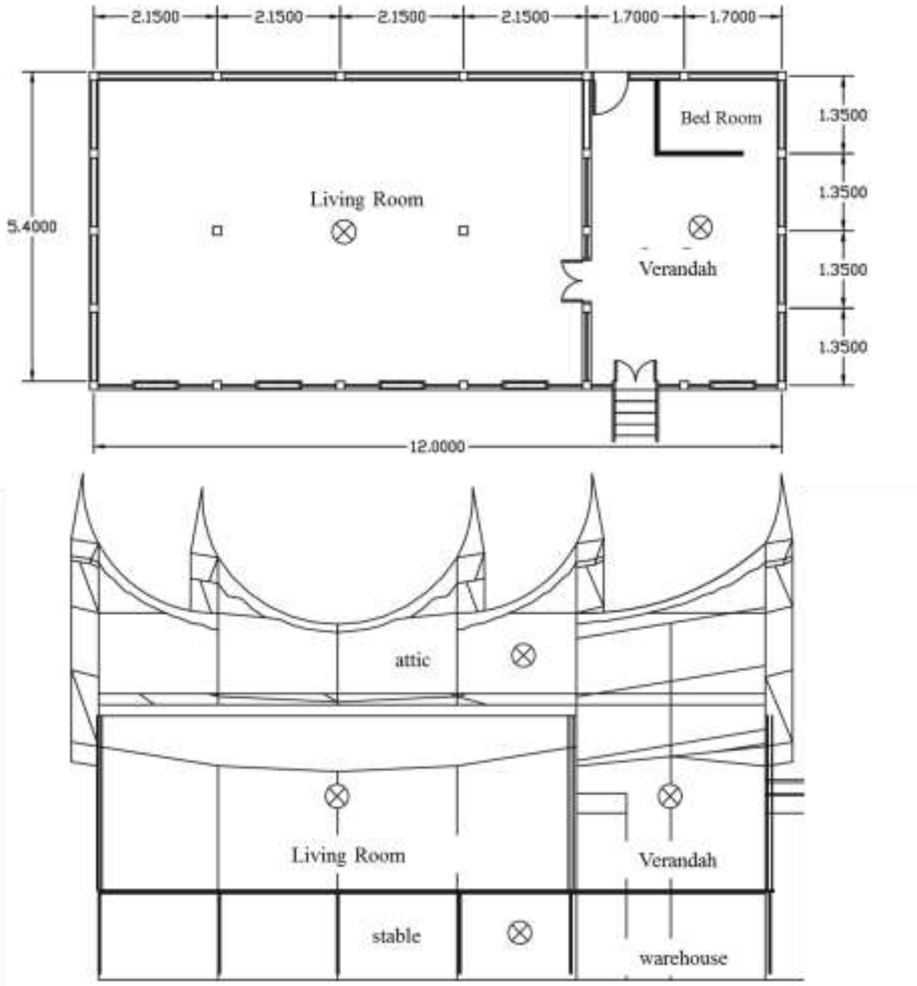

Figure 3. Data Logger positions measurement in the plan and section of Gadang Jopang Manganti house [⊗](author documentation)

3. RESULT AND DISCUSSION

Bioclimatic Design Elements in Gadang Jopang Manganti House

The bioclimatic design elements are based on previously developed tropical bioclimatic design parameters (Nugroho, 2018; Zang et al, 2018; Nguyen et al, 2019; Zenu et al, 2020). There are nineteen tropical bioclimatic design parameters that pertain to natural shading and conditioning. Seven parameters were determined to be appropriate based on a visual observation study at the Gadang Jopang Manganti House, including the orientation of the building mass, the orientation of the openings, the arrangement of the main dwelling space, a large roof space, the use of roof ceilings, the absence of space insulating walls, and porous wall materials. The Jopang Manganti Gadang House is oriented south, and it is consistent with local wisdom, as Minang houses are generally oriented toward Mount Marapi. The case study is located to the north of the mountain. The box-like composition of the main space and the orientation of the window openings take advantage of the prevailing wind direction, which comes from the south. The size of the Gadang House is also proportionate to the size of the land to achieve a harmonious composition with the surrounding environment. Placement of sheltered dwelling space with a roof and eaves.. The roof element of the Gadang Jopang Manganti House features a large roof space, which serves as one of the strategies for dealing with heat generated by solar radiation or acts as thermal insulation. The wood ceiling prevents solar radiation that accumulates in the roof space from entering the dwelling space. Uninsulated or single-room dwelling space is also a critical component of bioclimatic design.

Five parameters are entirely appropriate: roof and eaves slope, shade trees, transition space, stage floor, and stage height. The slope of the building's roof is quite suitable for draining rainwater, but an overhang to deal with rainwater splashing still needs to be added. The existing eaves are less than 50 cm wide, compared to the recommended 100 cm. Bangsal's yard lacked shade plants, particularly along the west wall. There is no transitional space in the building's corridors, despite some of the walls being porous. The difference in floor height affects the amount of moisture removed from the air, but it is not supported by moisture-absorbing materials such as dry bricks. The floor height of the Gadang Jopang Manganti House is about 250 cm when linked to the function of reducing air humidity, which is very effective compared to a minimum height of 75 cm, according to Nguyen et al (2019).

At the Gadang Jopang Manganti House, five parameters were recorded that were not in accordance with the bioclimatic design. It is inluding the presence of window shading, the lack of window opening width, sufficient number of window openings, wide opening size, and porous type of opening. The Ward house's window openings are not equipped with enough wide shading elements to protect against solar radiation and rain. The ideal width of a window shade is equal to the width of the window. In the study object, the window shade becomes one part with roof eaves with a width of less than the window height. The Gadang Jopang Manganti House has five openings on the south side and not on the west, east, or north sides. Due to the limited number of windows on the south side, the window opening elements do not conform to the opening area's parameters. On this side, the ventilation opening area is 5 m2, while the building area is 65 m2 or less than the standard opening area of 10-20% of the room area. A type of opening with jalusi shutters allows gradual airflow in and out.

Building color and wall thickness are two bioclimatic design parameters that are inappropriate for the study object. Dark colors are used on all exterior surfaces of walls and roofs to ensure that certain areas of the building absorb more solar radiation. The Gadang house already has double wooden walls that are more than 10 cm thick.

Table 1. Evaluation of the suitability of climate-responsive design (author documentation)

No	Climate responsive design parameters and results	Visual Indicators
1	Building facing south avoids solar radiation from west and east. Appropriate on the object.	
2	The arrangement of the main dwelling space is protected and the main facade faces south. Appropriate on the object.	
3	Window openings should be oriented in the direction of the predominant wind. The windows in the case study object face west and east, the two predominant wind directions.	
4	Above the window opening, there is shade. There is no window shade in the object, which blends in with the roof's eaves.	
5	Shade width should be at least equal to the height of the window opening. The roof shade is 1-meter-wide on the object.	
6	The roof slopes more than 25 degrees and has a greater than one-meter overhang. The roof slope is 45 degrees, but the eaves width is limited to one meter.	
7	To the west of the building, in the yard, there is a shade tree. There is a shade tree on the object that is a type of banana tree.	
8	Utilization of extensive roof space, double walls, and roof ventilation. There is a roof space on the object.	
9	The utilization of roof ceilings. The object features a wooden plank ceiling.	

No	Climate responsive design parameters and results	Visual Indicators
10	There are no insulating walls in this room, which is a single room. The study is focused on a single dwelling space devoid of partitions.	
11	The roof, walls, and floors are all painted in bright colors. The study's subject was made up of dark colored clay tiles.	
12	Solar radiation-resistant thick walls. The subject of investigation is a thin-walled wooden structure.	
13	Moisture-absorbing wall and floor materials. This material is used to cover the object's wall.	
14	There is a corridor or transition room. The object features a terrace as a transitional space, but lacks a perimeter corridor.	
15	The difference in floor height that contributes to humidity reduction. On the object, the elevation of the floor in conjunction with the stage construction.	
16	Elevation of the floor. The object is a stage floor with a height of more than one meter that doubles as a cage and warehouse.	

No	Climate responsive design parameters and results	Visual Indicators
17	Numerous window openings. The object contains the specified number of openings on each side of the building's wall.	
18	Size The opening of the window is quite large. The object's opening-to-floor area ratio remains below the standard.	
19	Type of latticed/porous window opening. The window covering object is made entirely of glass on the inside and entirely of wooden planks on the outside	

Thermal environmental conditions at the Gadang Jopang Manganti house

The external environment has an effect on the thermal environment at the Gadang Jopang Manganti House. The average outside air temperature was 25.1°C, reaching a maximum of 33.3°C at 12.00, and a minimum of 20.4°C at 06.00, with a difference of 12.9°C between the highest and lowest values. The outside air has an average humidity of 82.3 percent, with the highest value of 99.1 percent at 07.00 and the lowest value of 55.9 percent at 14.00.

The average air temperature in the Gadang Jopang Manganti House was 25.6°C in the dwelling, verandah, underground space, and roof spaces; 25.6°C in the verandah; 24.9°C in the underground space, and 25.8°C in the roof spaces. The highest average air temperature in each room is 29.4°C in the dwelling area, 29.4°C in the verandah, 27.8°C in the underground space, and 34.4°C in the roof area. The time of peak air temperature in the roof space at the same time as the outside environment is at 13.00, while in the dwelling room, the verandah and underground space are one hour later. The difference between the highest and lowest values in the roof space (13.9°C) is greater than in the dwelling space (7.3°C), verandah (7°C), and underground space (5.3°C). This demonstrates that the underground space has a stable air temperature compared to other rooms.

Indoor air humidity is on average lower than in an outdoor room, at 80.9 percent compared to 82.3 percent. At 86.1 percent, the underground space has the highest average humidity, followed by the verandah room at 85.1 percent, the roof space at 78.5 percent, and the dwelling space at 73.9 percent. The time of the average peak air humidity in each room varies. As with the roof space, the verandah room opens at 07.00, followed by the underground space at 08.00 and the dwelling room at 09.00. This indicates the direction of moisture flow from the exterior to the interior of the building. In general, when considering the thermal performance of the Jopang Manganti Gadang House, there is a comfortable time span and a greater decrease in air temperature in the underground space.

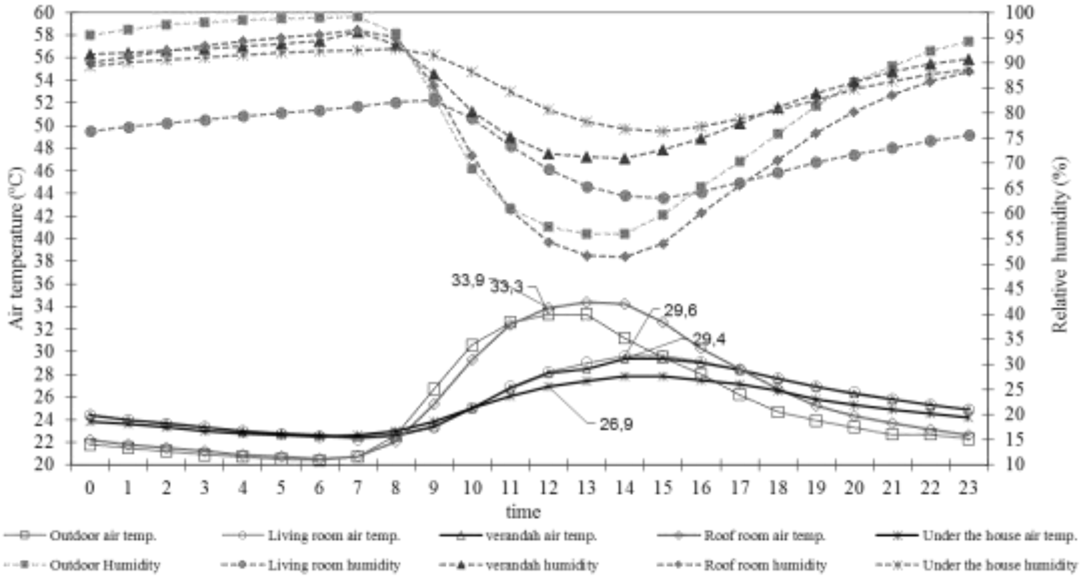

Figure 4. Profile of air temperature and humidity at the Gadang Jopang Manganti House (author documentation)

As mentioned in the neutral temperature calculation, the range of comfortable temperatures is 23.1°C-28.1°C. The average outdoor air temperature is within these limits. This is also consistent with Nguyen et al (2019) about tropical comfort limit, which is between 22.9°C and 28.9°C. The average air temperature inside the Gadang Jopang Manganti House is 25.5°C, which is within comfortable limits. The basement (24.9°C), dwelling space and verandah (25.6°C), and roof space (25.8°C) all perform exceptionally well. At all times, the basement maintains a comfortable temperature range. Meanwhile, the unsettling period in the dwelling space begins at 12.00 to 17.00.

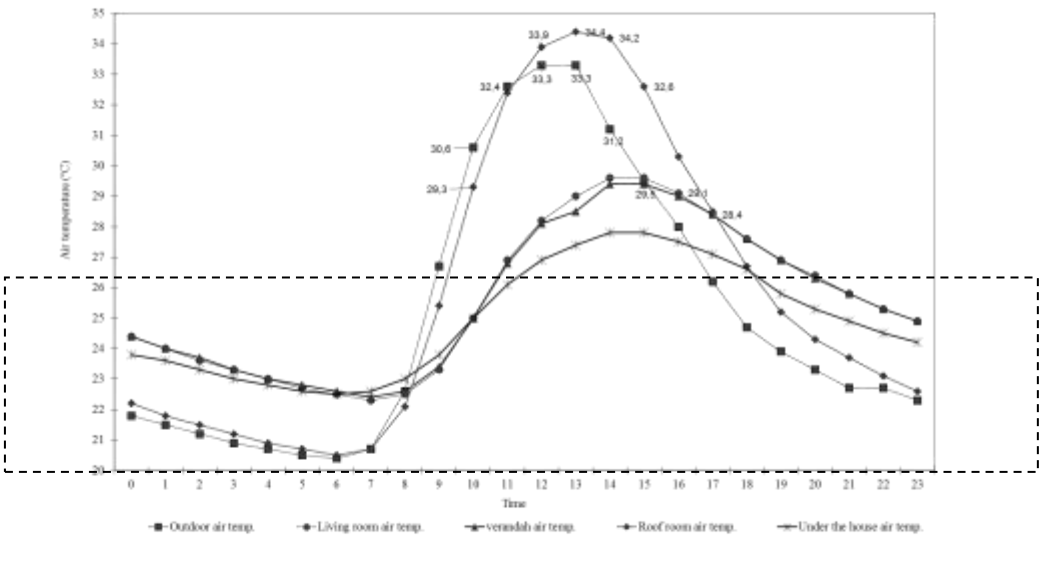

***Figure 5**.* Average Air Temperature in compare to Comfortable Air Temperature at Gadang Jopang Manganti House (author documentation)

The difference in peak air temperature between the building environment and the outside environment can be used to calculate the time lag of building elements; for example, if there is no difference or it is zero, the conductivity of building elements is low. This is consistent with Dili et al (2011). At the Gadang Jopang Manganti House, the peak outdoor air temperature occurred at 12.00, as did the roof space. While the peak air temperature in the dwelling space, verandah, and below is one hour cooler, the peak air temperature in the commercial space, verandah, and below is one hour cooler. This indicates that the roof space is less conductive than the other spaces. The shroud of the dwelling space is made of two layers of wood, whereas the roof is made of thin zinc. As a result, conductivity value of the wall is greater than the roof.

Cooling Climate Bioclimatic Design's Effect on Natural Cooling

The natural cooling rate of the building is indicated by the magnitude of the decrease in the value of the outside air temperature and the temperature inside the building. At 11.00, the basement's air temperature drops by the maximum of 6.5°C. Natural cooling time under the dwelling room is 8 hours at 4.1°C, significantly longer than the 3.7°C and 3.8°C decrease in air temperature caused by the dwelling room and verandah, respectively.

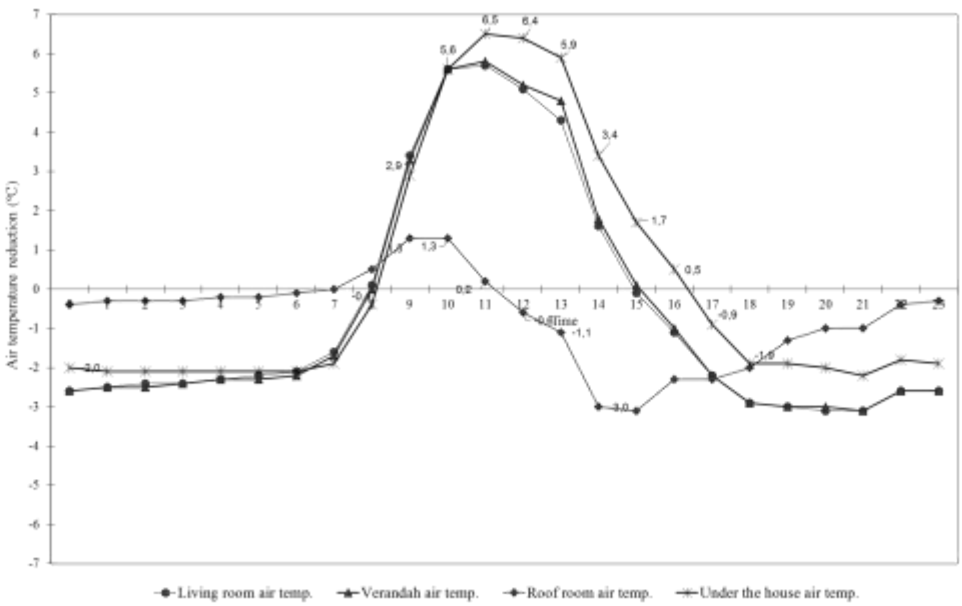

Figure 6. The decrease in air temperature at the Gadang Jopang Manganti House (author documentation)

Recommendation of Bio-climatic Design Elements

The relationship between local wisdom and the level of comfort in air temperature in the Gadang Jopang Manganti House demonstrates the influence of bio-climatic design elements on the performance of natural comfort as a form of bio-climatic wisdom in Minangkabau architecture. In comparison to other rooms, the air temperature is more comfortable in the underground space. This is because the stage's porous walls on all four sides and the stage's height allow for constant airflow (Victoria et al, 2017). Things related to local wisdom has been named differently based on the level of floor height, the first level is called by Tingkat while the second level is called as Anjuang. Anjuang in the ujuang section is a place for weaving and Anjuang at the base is a place for playing, traditional ceremonies and receiving guests.

The most significant temperature reduction occurred in the underground and dweilling spaces, which was influenced by the suitability of the building's south-facing orientation and the use of solar radiation protection, as explained by Daemei et al (2019). This performance is also related to the peak air temperature in each room, and it can be seen that the underground space and the dwelling have a one-hour difference, indicating that the use of double walls made of wood can increase the time lag. This is in contrast to the terrace space, which is typically open, resulting in a low conductivity value for the material. The double wall in the Gadang Jopang Manganti house's bioclimatic wisdom is referred to as the use of sasak bugis or woven bamboo, which is installed on the outer layer of the wall to protect it from the sun and rain.

While the air temperature in the residential room is comfortable, there are times during the day when conditions are uncomfortable, between 11.00 and 18.00. This is due to the narrow width of the window opening shading elements and the non-shading nature of the shade trees. Beccali et al. (2018) emphasized the value of shade in bioclimatic structures. Another issue is that the humidity level in both outdoor and indoor spaces remains above the health standard of greater than 80%. Climate-responsive design elements that contribute to this are non-absorbent roof and floor materials, as determined by Hema et al (2017). This occurs as a result of a change in the roof material. In the past, the Gadang house's bioclimatic wisdom dictated thatched roofs arranged in layers. The use of palm fiber roofs enables the house's air to remain cool and comfortable despite the scorching heat. The fibers are left on the sagars and are vertically arranged. This is because the Minangkabau community believes that technically the role of the Sagar-Sagar is to strengthen and beautify the expanse of the palm fiber roof.

4. Conclusion

The study of bioclimatic wisdom in Minangkabau architecture with the case study of the Gadang Jopang Manganti House yields two major conclusions regarding the suitability of tropical bioclimatic elements and the thermal environment's performance. The orientation of the building mass and openings; the placement and form of a single uninsulated residential space; and a large roof space all contribute to the Gadang Jopang Manganti House's tropical bioclimatic suitability. The slope and eaves of the roof; the shade tree; the transition space, as well as the height and type of stage floor, are all quite appropriate. The outstanding thermal environment performance is defined by an average monthly air temperature that is within comfortable limits, as well as daytime natural cooling. Thus, the overall performance of the residential space's thermal environment is comfortable. However, one aspect of the thermal environment performance has been overlooked, namely the air's high average humidity. Bioclimatic wisdom development at the Jopang Manganti Gadang House in the future will focus on natural cooling and optimizing natural ventilation to remove moisture from the building.

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