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Submission date: 03-Sep-2024 09:24AM (UTC+0700)
Submission ID: 2443542356
File name: Jurnal_Amalina_Sabela.docx (1.47M)
Word count: 4463
Character count: 24926

The Effect of Vernacular Adaptation on Thermal Energy in Semarang Architectural Houses

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Abstract. Semarangan vernacular houses mostly have acceptable thermal performance, primarily related to the roof design and its elements. However, some developments associated with the quality of comfort have already been in progress. We found modifications with an alternative opening in the roof. Testing is needed to determine whether this alteration of a vernacular house with roof modifications is suitable to synchronize to nature and culture for its sustainability. This research aims to assess the quality of the modification for the thermal and energy performance of Semarangan vernacular houses in responding to climate change based on innovation. We utilize an energy audit simulation using the SketchUp software and the Sefaira plugin extension to measure thermal shape and variables. The focused study analyzes the thermal performance of buildings through analysis of the building envelope and building shape from a conceptual model. We discover that vernacular modifications do not reveal any extreme differences. Further research is needed to examine some other types of modifications further. We have to ensure that any modification maintains the quality of the house's performance and even have to increase it.

Keywords *Vernacular, innovation, energy, thermal performance*

INTRODUCTION

Vernacular houses are proven to have good thermal performance in accommodating the comfort of their occupants. Vernacular architecture can also be seen as the "natural architecture" of a particular region, which refers to conditions, climate, and cultural potential so that it will be more harmonious with society and more responsive to its environment (Victor Papanek, 1995: 113–138). Vernacular architecture is known for its energy-efficient designs that creatively adapt to local natural conditions and use various climate-responsive strategies. For example, ventilation in indoor spaces is maintained high with wide building openings (windows and doors) facing the dominant wind direction, while the building's thermal mass is low to avoid discomfort at night due to stored building heat. In areas that are intensively exposed to sunlight, roofs with specific structures reduce heat gain from sunlight, providing particular shade and reducing the surface area to volume ratio. However, vernacular design may not be sufficient to maintain indoor thermal comfort because it has not been used much (Nguyen et al., 2011).

Vernacular building innovation has limitations that lie in the characteristics of the building form, which rarely accepts innovation from outside due to human needs and local material availability. So, the physical and aesthetic quality, shape, structure, and typology of the building are influenced by geographical conditions (Sani, 2015). Uniquely, this vernacular architectural house was built using methods and knowledge passed down from generation to generation and is adaptive to the local environment (Umar & Irmawati, 2019). Thus, not only the characteristics of the building form are factors limiting innovation, but also the methods and knowledge passed down from generation to generation, which also underlie the limitations of innovation in vernacular architecture. Pada penelitian ini, akan membahas mengenai inovasi yang terdapat pada rumah vernakular yang terletak di Kota Semarang, Provinsi Jawa Tengah, Indonesia.

Semarang is a city in a coastal area with a humid and warm climate, so people feel warm and hot and keep sweating (Purbaya, 2023). The city of Semarang is vulnerable to the impacts of climate change. In October 2023, Semarang experienced El Nino conditions, making it the hottest big city in North Java (Damiana, 2023). Facing this phenomenon, there is a vernacular architectural house in Semarangan, which is the case study in this research. Semarangan architecture is a combination of Indische Empire architectural styles with Tropical Javanese architecture; then a combination of Transitional architectural styles with Tropical Javanese architecture emerged; and most recently, there is a combination of Modern/Indic Colonial architectural styles with Tropical Javanese architecture. Semarangan architecture was created and developed over a long period and is part of the traditional popular culture of the city of Semarang. Therefore, Semarangan architecture has adapted well to the natural and social conditions in Semarang. This Semarangan vernacular house is one of the Semarangan houses that is still original or has minimal changes, with only a few remaining changes in scale and shape.

Figure 1. Semarangan vernacular houses and their roof shapes. (a) Facade of a Semarangan vernacular house. (b) The shape of the roof of a vernacular house.

Two Semarangan vernacular houses are case studies in this research, both with the Limasan roof typology. However, what is unique is that one of the two houses has a modified window opening on the pyramid roof. The addition of this element is not found in the surrounding vernacular house architecture. These two houses were chosen because they represent the Semarangan architectural typology of lower middle-class houses.

In contrast to the upper-class Semarangan houses, which at that time were to maintain indoor thermals, the Dutch built tall houses with wide ventilation openings. So, there is no need to doubt thermal comfort. The house is different from lower middle-class Semarangan houses, which have a small area and are short. This raises the question of how the thermal performance of a Semarangan house with a modified roof typology compares with a roof typology with an original shape. And whether these modifications also affect the thermal energy in the vernacular house building.

The main objective of this research is to find out how vernacular innovations in Semarangan house roof modifications affect energy and thermal performance. This research uses descriptive and quantitative methods. The stages in this research are: 1) identifying the typology of Semarangan vernacular houses; 2) knowing thermal comfort from directly measuring the temperature and humidity of vernacular houses. 3) Carry out a simulation using SketchUp software with the Sefaira plugin to see shading details that affect indoor thermal. The hope of this research is to contribute to understanding effective climate design strategies in vernacular houses for empirically maintaining human comfort and health. As well as providing recommendations for preserving vernacular innovations, both privately owned and those designated by local governments as cultural heritage.

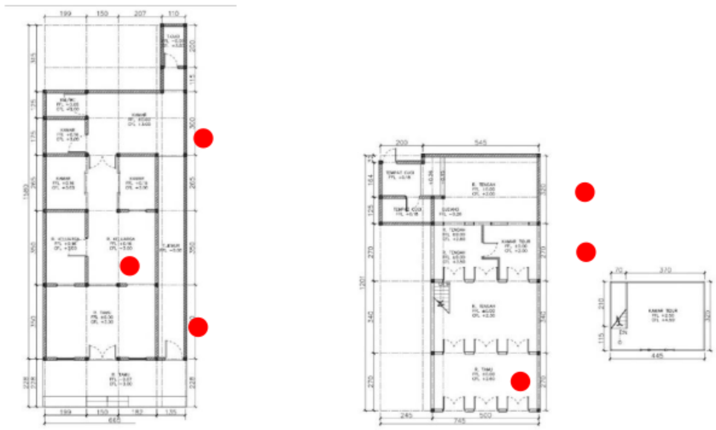
METHODS

The case study in this research is located on Jalan Kauman Krendo No. 16, which is called Semarangan Traditional Vernacular House, and Jalan Kauman Timur no. 90, which is called the Semarangan Traditional Vernacular Modification House in Kauman Village, Semarang City, Central Java Province, Indonesia. The samples taken were two traditional Semarangan vernacular houses, which are traditional houses designated by the Semarang City Government as houses that will be selected as cultural heritage houses. The chosen house is supported by evidence from homeowners with official letters from the City Government. Another reason for choosing this house is that its typology is still original and has minimal changes. Up to now, there are very few Semarangan vernacular houses that are still standing with their authenticity and the owner's efforts to preserve them even though, in terms of space requirements, they require changes so that the house can still accommodate the needs of their occupants along with the times that have passed. Apart from that, its location is located around the cultural heritage area, namely close to Johar Market, Aloon-Aloon, Kauman Grand Mosque, and Kauman Grand Mosque, Semarangan.

This research uses a descriptive quantitative method by conducting a field survey to collect primary data through photo documentation, drawings, and measurements to draw existing house buildings. This research seeks to find out the influence of vernacular innovation on the shape of the roof, which not only influences the facade's appearance but also the thermal and energy performance of this Semarangan vernacular house. Semarangan vernacular houses in this study are categorized into Semarangan vernacular houses and Semarangan vernacular modified houses. Semarangan vernacular house, namely a vernacular house with an original shape with a pyramid roof typology. Meanwhile, the Semarangan vernacular innovation house is a house that has the same roof shape as the Semarangan vernacular house, namely a pyramid roof but with modified window openings equipped with eaves on the joglo roof.

The stages in this research are as follows: 1) Identify the typology of Semarangan vernacular houses. Then, one of the architectural typologies of Semarangan, which is the case study in this research, will be looked at more closely, focusing on the case of innovation carried out by one of the residents of Seamarang. Measurements were carried out at Semarangan vernacular houses and compared with those that had been modified so that they could be compared directly; 2) knowing thermal comfort from directly measuring the temperature and humidity of vernacular houses. 3) Carry out a simulation using SketchUp software with the Sefaira plugin to see shading details that affect indoor thermal.

To see the thermal performance in the two vernacular house case studies, this research was carried out using thermal variable measurements using thermal equipment. The thermal variables measured are air temperature and air humidity. The two thermal variables are variables that are considered more influential than other variables. Measurements were carried out using a temperature datalogger tool, with data collection every 10 seconds for 24 hours. Measuring instruments were placed at three points in each case study house: the living room, bedroom, and kitchen. To make it easier to process data, temperature and humidity data from measurements will be taken every 60 minutes, starting at 08.30 and in multiples. Analysis uses graphs of air temperature and air humidity. Thermal comparisons are carried out using descriptions from the graphs that have been created. Thermal comfort analysis is based on thermal comfort standards from several researchers.



(a) (b)

Figure 2. Semarangan vernacular house plan and roof shape. (a) Original Semarangan vernacular house plan. (b) Modified Semarangan vernacular house plan

Performance-Based Design (PBD) is a building design that considers building performance. PBD is a process that is repeated by assessing the sustainability of how a building performs, what factors influence the building's performance, and how they affect the building's performance to achieve better goals. This research uses a performance-based design application, namely SketchUp modeling with the Sefaira plugin extension, to analyze and simulate the thermal performance of buildings through analysis of the building envelope and building shape by creating a conceptual model with geometric shapes in such a way as to carry out energy analysis effectively and provide a general picture of thermal transmission.

RESULTS

Semarangan Architectural Typology

According to Sidharta (1997), several innovations by Dutch architects in design responding to the tropical climate were: open verandas at the front, back, or around the building; Wide overhangs to protect wall and window surfaces from direct sunlight and rain; a ceiling height of 4m and natural ventilation above doors and windows; Tropical garden with sufficient trees (Handiniti, 2010). The earliest Semarangan architectural styles it was influenced by a combination of Indisce Empire architectural styles with Tropical Javanese architecture, then a combination of Transitional architectural styles with Tropical Javanese architecture emerged, and the latest is a combination of Modern/Indic Colonial architectural styles that focus on lighting. Natural ventilation in the building, combined with tropical Javanese architecture.

(a) (c) (d)

Figure 3 . Upscale Semarangan vernacular house. (a) High and wide openings of Semarangan vernacular houses. (b) The roof shape of an upscale Semarangan vernacular house. (c) The terrace forms an upscale Semarangan

Javanese architecture was born and lived because of Javanese society. Traditional Javanese houses have three levels: traditional houses of original form and conventional houses with majestic shapes still maintain their original shape, but certain exclusive ornaments that ordinary people cannot use are starting to appear. Traditional dwellings have modern shapes; Javanese traditional values are no longer taken into account; the application of Javanese architecture is only for the architectural beauty of the building. Based on the various types, Javanese architecture is classified into five types: village, Limasan, and Joglo, as in the image below.

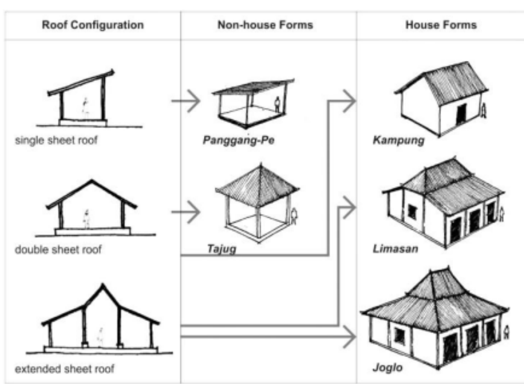


Figure 4 . Primary traditional forms of Javanese buildings (Idham, 2018).

Tipologi Studi Kasus

In traditional Semarangan vernacular houses, the most common roof forms are gable roofs, a combination of gable roofs and shields, shield roofs and joglo roofs, and other roof forms typical of Javanese architecture. On the roof, there are extended eaves as an adaptation to the tropical climate, then decorated with Javanese ornaments on the plank and the edge of the roof. As in the following picture, the roof shape is a combination of a shield roof and a joglo roof.

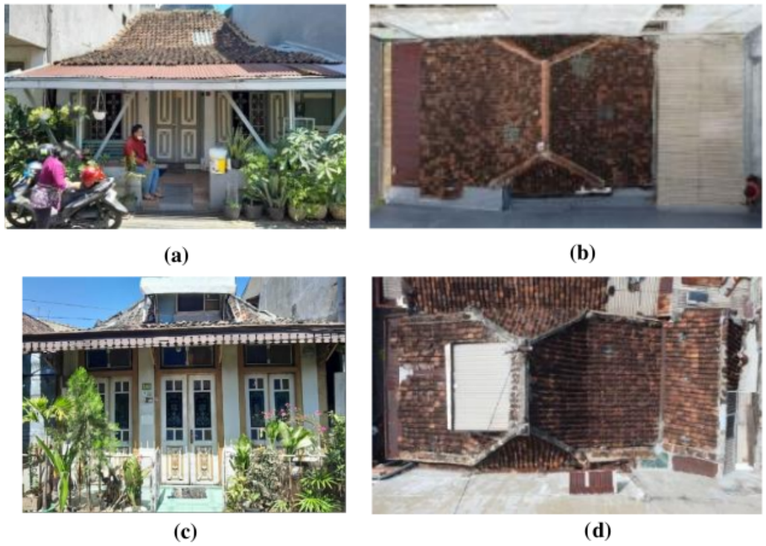


Figure 5 . Semarangan vernacular houses and their roof shapes. (a) Facade of a Semarangan vernacular house. (b) The shape of the roof of a vernacular house. (a) Facade of a Semarangan vernacular house. (b) Roof shape of Semarangan vernacular house.

M ... tural style, w ... ront terrace ... tics, which are heavily influenced by Colonial and Javanese architecture. The door frame has a height of more than 210 cm with double doors with two leaves as an adaptation of Colonial architecture. The frame is made of wood and has ornaments, trellises, and glass panels in the vents. This ornament was used solely for the aesthetic value of the building and the availability of materials at that time.

The first house, a Semarangan vernacular house, has an original form with a pyramid roof. Brick-material walls with a thickness of 15 cm are used. The floor uses tile flooring. It has a ceiling with a slope that follows the slope of the roof of the house, except at the top of the pyramid, where the ceiling covers the ceiling in a flat position. The frames and windows are made of teak wood. On the windows, there are iron bars with typical Semarangan carvings. There is no glass in the window opening. Several openings in the room at the back of the house are part of the renovation at the back. There are taller buildings on the right and left sides of the house. However, on the left side of the house, there is a 60-cm-wide space along the left side, called "Lengkong.".

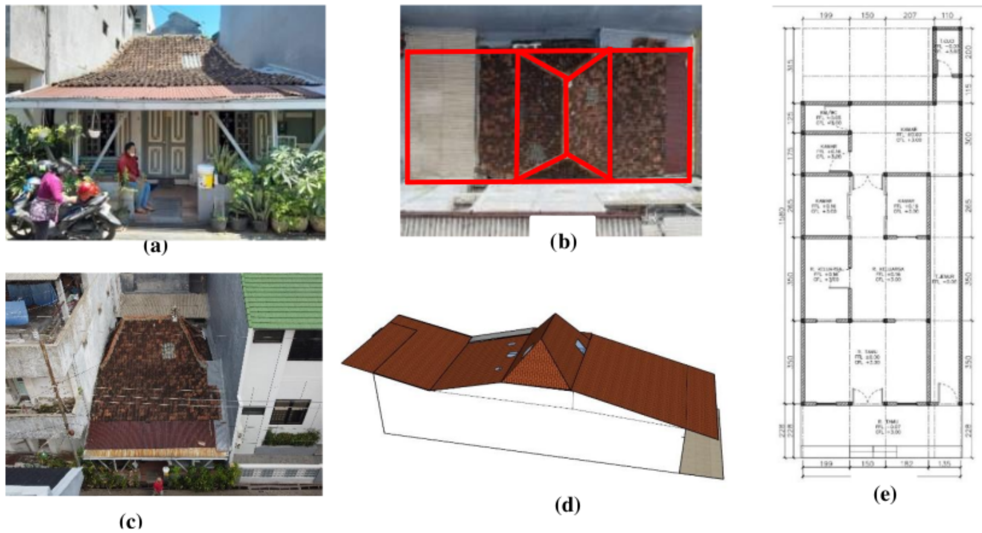
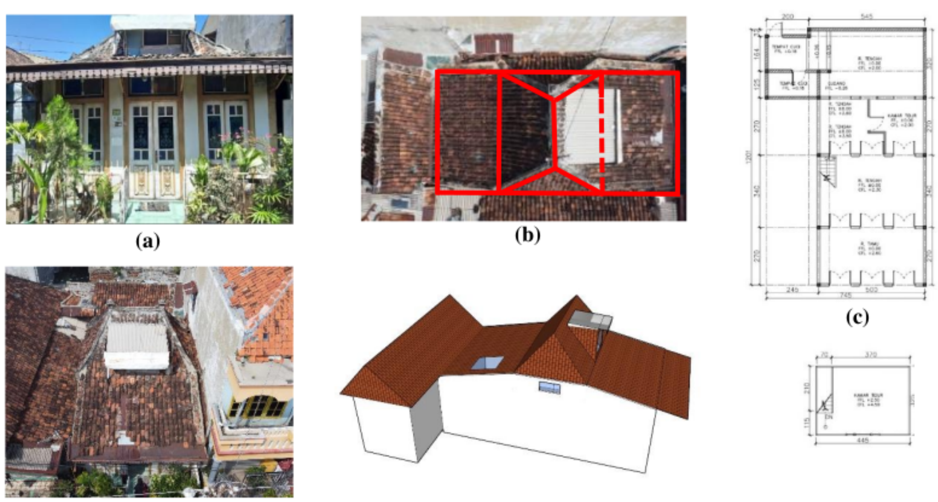


Figure 6. Typological analysis of original Semarangan vernacular houses. (a) The facade of a Semarangan vernacular house in its original form. (b) Roof shape of Semarangan vernacular modified house. (c) Typology of pyramid roofs on vernacular houses in Semarangan, original form. (d) Modeling of Semarangan vernacular house in original form (e) Plan of modified Semarangan vernacular house in original form

include, instead of windows, equipped with eaves on the windows. Using wooden walls with a thickness of 2–3 cm. This house is the same as the Semarangan vernacular house, which has a ceiling with a slope that follows the slope of the roof, except for the top of the Joglo building, where the ceiling covers the ceiling in a flat position. The frames and windows are made of wood with glass. There is an opening in the room at the back of the house, especially near the bathroom. There is also a longan on the right side of the house.



(d) **(e)**

Figure 7. Typological analysis of Semarangan vernacular modified houses. (a) Semarangan vernacular modified house facade. (b) Roof shape of Semarangan vernacular modified house. (c) Typology of pyramid roofs on Semarangan vernacular modified houses. (d) Modeling of a Semarangan vernacular modified house (e) Plan of a Semarangan vernacular modified house

An essential factor that must be considered in building construction is indoor thermal comfort. Indoor thermal comfort is achieved using mechanical cooling systems, which are energy-intensive and environmentally damaging. However, this only happened in traditional buildings after the advent of modern AC systems. Thermal comfort is achieved by designing buildings to suit local climate conditions. For example, in hot areas, buildings are built with roof designs that are able to reduce heat gain from sunlight and provide shade with a ratio of surface area to building volume.

Thermal comfort in Semarangan architecture

The thermal performance of the building will contribute to the thermal comfort of the occupants. Thermal comfort and performance have been distinguished by several researchers. Thermal performance relates to how a building creates comfortable variables, while thermal comfort is the standard of comfort obtained from building occupants (Zhang et al., 2018). Thermal performance will produce an optimal building design. Architects will try to create zero-energy buildings, one of which is by creating efficient ventilation (McArthur, 2020). Natural ventilation is one way to get to zero energy. Apart from ventilation, vernacular house sheathing materials are also considered capable of creating energy savings and are considered an aspect of sustainability (Hermawan et al., 2022).

Thermal comfort is achieved by designing buildings to suit local climate conditions. For warm and humid tropical areas, ventilation in indoor spaces is maintained high, with wide building openings (windows and doors) facing the dominant wind direction, while the thermal mass of the building is low to avoid nighttime discomfort due to stored heat (Samuel et al., 2017). One way to maintain indoor thermal comfort is with passive cooling techniques on the roof of the house with ceiling insulation (Toe & Kubota, 2015). This is supported by Huang et al. (2016), who found that this passive solution has proven to be effective in improving indoor thermal comfort even though it has not yet achieved adaptive thermal comfort. Interestingly, this condition is accompanied by a relatively high level of satisfaction and tolerance for lower thermal comfort expectations because residents appreciate the sentimental value of these traditional houses.

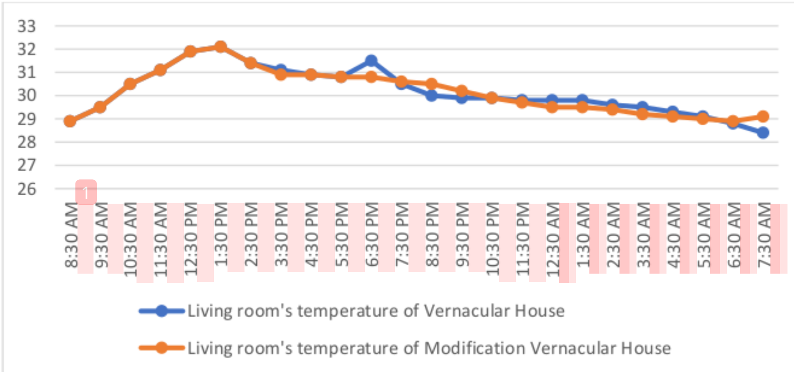


Figure 8. Temperature graph of the Living rooms of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

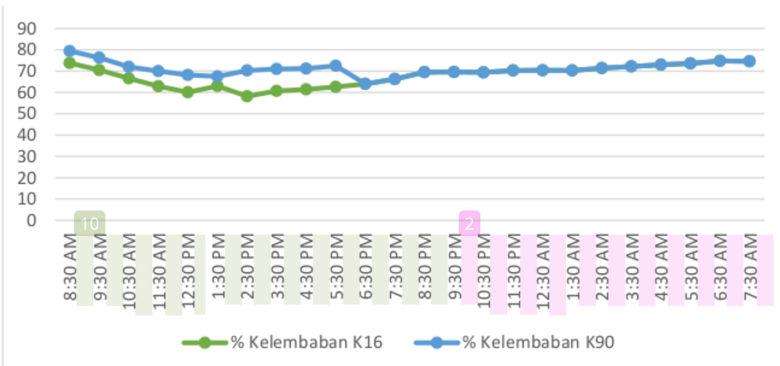


Figure 9. Humidity graph of the Living rooms of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

The air temperature obtained from the results of thermal measurements in the Semarangan vernacular house in the living room obtained maximum temperature data, namely 33.4°C at 14:45 and maximum humidity 75.7%RH at 08:00. Minimum temperature data is 28.4 °C at 07:00, and minimum humidity is 57.7% RH at 14:30 WIB. The average temperature is 30.5 °C, and the average humidity is 67.9% RH. Meanwhile, the results of thermal measurements in the vernacularly modified house in the living room obtained maximum temperature data of 32.2 °C at 10.00 and maximum humidity of 80.8% RH at 10.00. The minimum temperature data was 28.7 °C at 12:00, and the minimum humidity was 64.9% RH at WIB. The average temperature is 30.1 °C, and the average humidity is 74.4% RH.

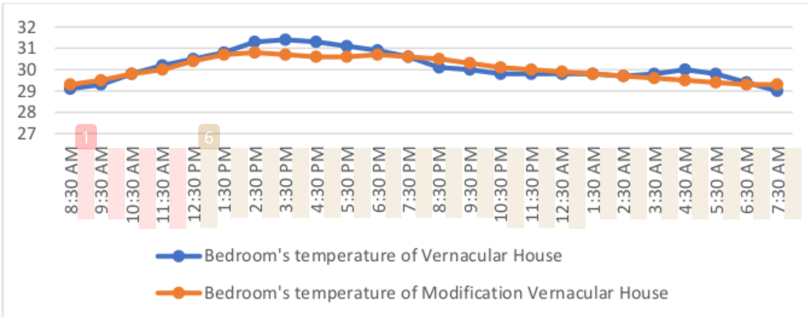


Figure 10. Temperature graph of the Bedrooms of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

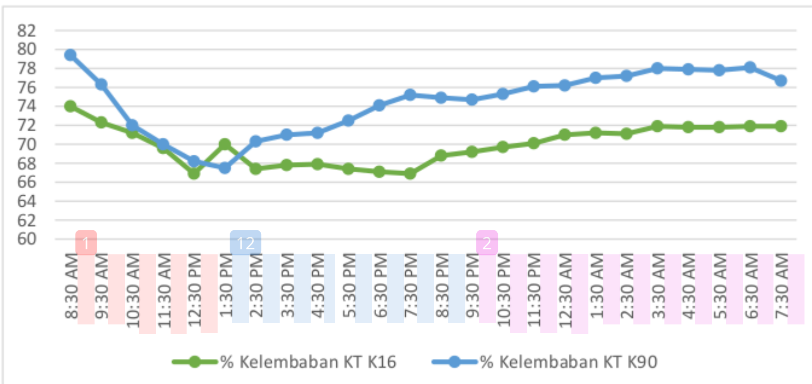


Figure 11. Humidity graph of the Bedrooms of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

Based on the graph of thermal measurement results in the Semarangan vernacular house in the bedroom, the maximum temperature data was obtained; namely 31.4°C at 14:30–15:30, and the maximum humidity was 74% RH at 08:30. Minimum temperature data is 29°C at 07:30 and minimum humidity is 65.8% RH at 19:00 WIB. The average temperature is 30.1 °C, and the average humidity is 69.9% RH. Meanwhile, the results of thermal measurements in the vernacular modified house in the bedroom obtained maximum temperature data of 30.8 °C at 14:30 and maximum humidity of 79% RH at 08:30. Minimum temperature data was 29.3 °C at 06:30, and minimum humidity was 73.8% RH at 13:30 WIB. The average temperature is 30 °C, and the average humidity is 76.1% RH.

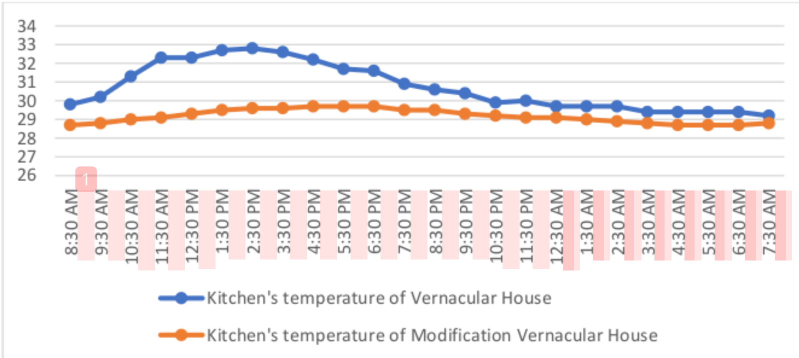


Figure 12. Temperature graph of the kitchens of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

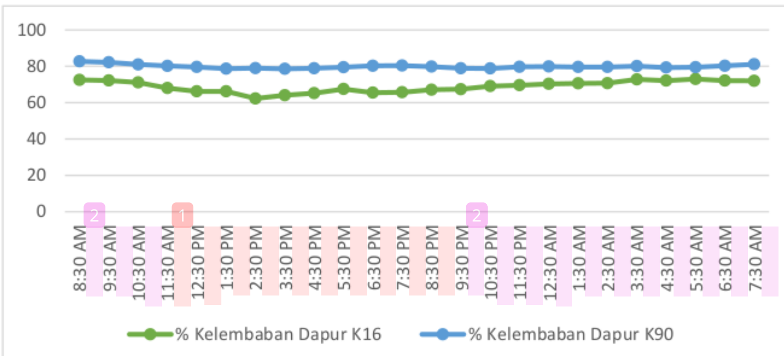


Figure 13. Temperature graph of the kitchens of both Semarangan traditional vernacular house and Seamarangan traditional Modification Vernacular House

Based on the graph of thermal measurement results in the Semarangan vernacular house in the kitchen room, the maximum temperature data was obtained, namely 32.9 °C at 14:30 and the maximum humidity of 73% RH at 05:30. Minimum temperature data was 29.1 °C at 7.30, and minimum humidity was 62.1% RH WIB. The average temperature is 30.7 °C, and the average humidity is 68.8% RH. Meanwhile, the results of thermal measurements in the vernacular modified house in the kitchen room obtained maximum temperature data of 29.7 °C at 16:30–18:30 and maximum humidity of 82.7% RH at 08:30. Minimum temperature data was 28.7 °C at 05:30, and minimum humidity was 78.5% RH at 15.30 WIB. The average temperature is 29.1 °C, and the average humidity is 79.8% RH.

Table 1. Recapitulation of Air Temperature and Humidity

Case study	Room	Lowest temperature °C	Highest temperature °C	Lowest Humidity %	Highest Humidity %
Original Vernacular	Living room	28.4	32.1	60.1	74.8
	Bedroom	29	31.4	66.9	74
	Kitchen	29.2	32.7	64.1	73
Innovation Vernacular	Living room	28.9	32.1	64	79.4
	Bedroom	29.3	30.8	67.5	79.4
	Kitchen	28.7	29.7	78.6	82.7

Based on the table above, the lowest temperature mostly comes from the original vernacular house, 28.4°C in the living room, with a relatively small temperature difference, and the highest temperature of 31.2°C occurs in the two case study houses. In hot areas, the lowest temperature is the most desired by residents, while the highest is the temperature that residents do not like. In Indonesia, most of them are coastal cities. However, there are also mountainous areas, both of which have different comfort standards. In mountain areas, the standard thermal comfort for residents is 27 °C. Meanwhile, the comfort standard for residents in the coastal area is 29 °C (Hermawan et al., 2019).

The results of the comparison of temperature and humidity in these two case studies show that the house with vernacular modifications has a temperature difference that is relatively less extreme compared to the original vernacular house. Some traditional buildings can maintain thermal comfort, but others cannot (Pamungkas & Ikaputra, 2020). From this data, the existence of vernacular innovations on the roof still allows its existence to be preserved as part of the architectural characteristics of Semarangan.

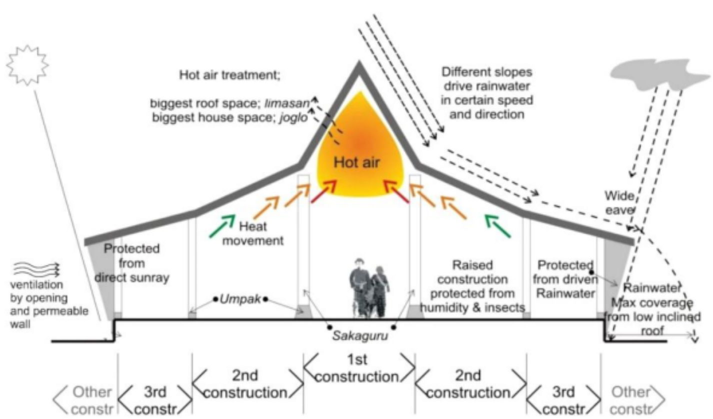
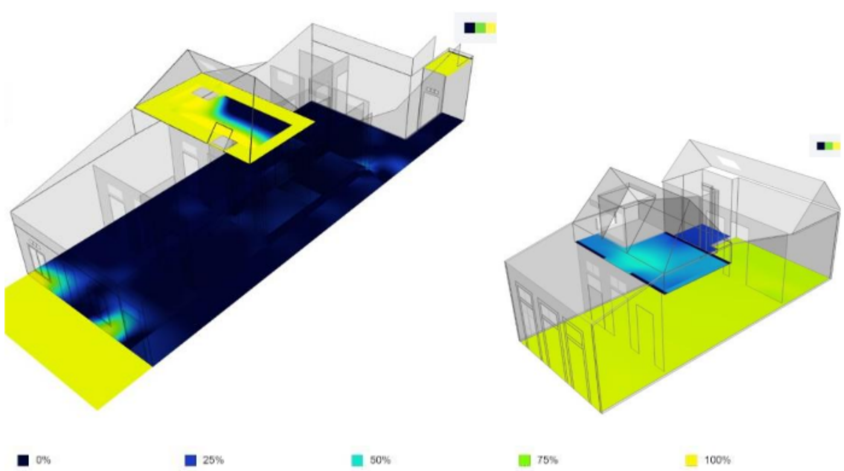


Figure 12. Construction form and acclimatization of Javanese houses (Idham, 2018).

The air temperature inside vernacular house buildings has been proven to create thermal comfort for occupants. Air circulation in the house can be achieved through ventilation openings both from windows and holes above the windows, with aesthetic elements in the form of wooden ornaments typical of Semarangan architecture. In general, Limasan houses have good thermal conditions because the space inside the home is large enough to support the creation of a stack effect. Even though the rooms in the two case study houses are partitioned, with walls covering only a height of 210–240 cm and not covering the ceiling, this condition supports the creation of a stack effect in the highest room supported by a pyramid-shaped roof, provides good thermal insulation, keeping the cool air at a livable level. This performance is further assisted by a permeable clay tile roof, which releases hot air (Idham, 2017).

Result of simulation with Sefaira



(a) (b)

Figure 13. Shading details on vernacular houses (a) Shading details on Semarngan vernacular houses. (b) Detail of shading in the Semarngan vernacular modified house.

Figure 13 above is a simulation result that shows the shading details of the two vernacular houses based on the quality of lighting, which will be explained in more detail in the following table:

Table 2. Simulation result of detail shading

Mostly Lit (%)	**Value of Vernacular**	**Value of Vernacular Innovation**
Underlit	89	17
Well Lit	1	35
Overlit	10	47

Table 2 shows a detailed shading comparison of the two vernacular houses. The results demonstrate that insufficient lighting occurs in Semarangan vernacular dwellings by 89%. Meanwhile, good lighting occurs in Semarangan vernacular-modified houses by 35%. Likewise, excessive lighting also occurs in Semarangan vernacular-modified houses. Based on this data, it shows that modifications to the roof by providing window openings have an impact on the light entering the home, bringing a more excellent presentation. However, on the other hand, it also has the effect of excessive lighting based on empirical calculations with software.

Table 3. Energy audit result with Sefaira

Indicator (Unit)	**Energy Standards for Vernacular**	**Energy Standards for Vernacular Innovation**
Baseline	ASHARE 90.1 - 2013	ASHARE 90.1 - 2013
Wall insulation W/(m^2 K)	Poorly Insulated 36,62	Poorly Insulated 54,62
Floor Insulation W/(m^2K)	Insulated 52,80	Insulated 22,20
Roof insulation W/(m^2K)	Well Insulated 146,49	Well Insulated 100,79
Solar Heat Gain (SHGC)	Reflective 0,25	Reflective 0,4

Ventilation Rate (L/S)	Typical ventilation 14,99	Typical ventilation 14,99

Table 3 shows data from an energy audit of the two vernacular houses. There are ten indicators in an energy audit, but in this study, the researchers focused on five indicators related to thermal performance. The baseline is based on ASHRAE 90.1 in 2013. The data in The three above shows that the two vernacular houses have the same assessment categorization. Starting from wall insulation, both of which have poor insulation study, the Semarangan vernacular house at 36.62 W/m2 K, and the Semarangan modified vernacular house at 54.62 W/m2 K. Floor insulation in the insulated category, with VS houses at 52.80 W/m2 K and MVS houses at 22.20 W/m2 K. The result between the two is more than half. The roof is well-insulated, with VS houses 146.49 W/(m2 K) and MVS houses 100.79 W/(m2 K). Solar heat gain is in the reflective category with a VS house of 0.25 SHGC and an MVS house of 0.4 SHGC. Meanwhile, the ventilation rate has the same category and number of ratios, namely 14.99 L/S.

Based on the energy audit that has been obtained shows no significant differences. The differences only exist in the value coefficients, not in the categories of assessment indicators. Furthermore, this energy audit correlated with the results of temperature and humidity measurements at three points: the living room, bedroom, and kitchen in the Semarangan Vernacular House and the Semarangan Vernacular Modified House.

CONCLUSION

Based on the building typology analysis results based on the shape of the roof, the two case study houses have a Semarangan vernacular house typology with a pyramid roof. The prominent characteristics of the Semarangan vernacular house are the wide and high ventilation openings and the eaves on the terrace, which are pretty wide. Based on thermal measurement data and simulations, the vernacular modification does not show any extreme differences in results, which means there is only a slight difference at the lowest temperature with very little temperature difference. Meanwhile, the highest temperature reached 32.1 °C in the two case study vernacular houses. Furthermore, the simulation results show that changes in the shape of the roof, or what in this research is called roof modifications of vernacular houses, affect the level of thermal radiation inside vernacular dwellings. However, the existing opening design also shows a climate-responsive context. Because the presence of openings in the roof allows air circulation, it will have an impact on indoor thermal comfort.

Thus, the two stages, measurement, and simulation, show that the results enable vernacular modifications to remain maintained. This concept of air movement and architecture is the main or essence of Semarangan architecture with the Archipelago Architecture concept. As a nation with a history that relies on science, technology, and cultural values, we must maintain the heritage of our ancestors, who have proven their ability to adapt to the archipelago's climate. Therefore, further research collaboration between the government and professionals is needed so that house construction in Indonesia can implement an identity and increase performance per current developments.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18