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Passive Design Strategy in Vernacular House of Samin, Indonesia

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Abstract

Vernacular architecture embodies passive design principles and strategies to create comfortable dwellings. This study investigates the impact of passive design strategies on temperature comfort in Samin vernacular houses. Visual observation is employed to assess the suitability of house elements based on passive design criteria. At the same time, field measurements are conducted to evaluate comfortable temperature conditions using data loggers over one month. The research focuses on the Original Samin house and the New Samin house situated in Klopoduwur Village, Blora Regency, Central Java, Indonesia. The visual observation reveals that the roof volume, slope, and thin walls with low conductivity in both Samin houses align with passive design principles. The New Samin house also incorporates other passive design strategies, including an east-west building orientation with the long side perpendicular to the wind direction, an open-plan room layout, and varying floor heights. The temperature comfort performance in both houses falls within the neutral temperature range during 16 hours. The New Samin house exhibits the largest daytime air temperature decrease at 5.5°C, while the Original Samin house experiences the largest nighttime decrease at 0.7°C. The evolution of passive designs in Samin vernacular houses encompasses considerations such as building proportion and width, terrace width, positioning and size of window openings, vegetation, and shading elements.

INTRODUCTION

The concept of sustainable development has gained significant importance in contemporary architectural practices, particularly in regions experiencing rapid environmental changes (Sargazi & Tahbaz, 2022; Elaouzy & El Fadar, 2022). In Indonesia, the planning of built environments is confronted with pressing issues such as escalating environmental degradation and the energy crisis. Exploring and advancing passive design solutions that mitigate environmental damage and promote low energy consumption is crucial. To achieve sustainable built environments, it is imperative to harness the potential of local resources and prioritize indigenous knowledge of materials and construction techniques passed down through generations (Widera, 2021; Hu et al., 2023). The wealth of knowledge encapsulated within vernacular architecture holds a rich history of achieving optimal comfort with minimal energy usage (Ozarisoy, 2022; Yang et el., 2022). In this context, comfort within buildings is achieved through passive design principles that rely less on artificial systems and embrace eco-friendly materials. Climate-responsive design elements, such as roofs, walls, and floors, play a vital role in adapting to local climatic conditions, considering factors like solar radiation, rainfall, and wind (Nguyen et al., 2019; Nasir & Kamal, 2021). The primary objective is to provide a thermally conducive environment by regulating temperature, humidity, and airflow. Indonesia boasts diverse vernacular dwellings shaped by social, cultural, and natural influences. It can also be witnessed in other countries, such as India, with the use of local materials, labor, and culture (Nasir & Kamal, 2021).

An exemplary illustration of a vernacular dwelling that exemplifies the principles of harmonizing with nature can be found in the Samin Vernacular House in the hot and humid lowland area of Blora, Central Java. These houses, prevalent in the Blora Regency and its surroundings, are closely associated with the cultural and teaching principles propagated by Samin Surosentiko since 1890. These principles emphasize the prohibition of dishonesty and a commitment to mutual assistance within the community. Samin community dwellings are typically arranged in clusters, facilitating communication and interaction among residents. Primarily constructed with wood, these houses seldom feature brick walls. The spatial configuration is straightforward, encompassing a living room, bedrooms, and a kitchen. Livestock pens are integrated into the houses, while communal bathrooms are separate entities. The evolution of these houses reflects the community's endeavours to develop passive design solutions that cater to the hot microclimate conditions prevalent in the area. Two types of houses can be observed: the original Samin houses, constructed approximately a century ago, and the newer Samin houses, built around forty years ago. Investigating the impact of changes in architectural elements on the thermal comfort conditions of these houses proves to be an intriguing research focus. Kamal (2012) and Farooq et al. (2020) also conducted similar research in hot and humid climates. This study aims to assess the degree of compatibility between the passive design elements and the temperature comfort performance in Samin Vernacular Dwellings through meticulous observation and field measurements of both the Original Samin House and the New Samin House. Based on the Indonesian climate zone, the research location is included in the temperature zone with high air temperatures throughout the year and there is no clear seasonal cycle, while based on the wind zone, Indonesia has a high wind speed character that provides passive cooling potential from May to November with a peak in August (Putra et al., 2022). The urgency of this research can be compared to prior research on passive design strategies conducted by Dili et al. (2011), Victoria et al. (2017), Prasetyo and Astuti (2017), Zune et al. (2021), Miranda et al. (2021), Sun et al. (2023) and Hu et al. (2023).

Multiple researchers have investigated the knowledge of passive design strategies, which encompass various principles. These include longitudinal orientation (Beccali et al., 2018; Prasetyo, 2016; Sardjono, 2011) and consideration of wind direction (Nguyen et al., 2011; Agugliaro, 2015). Additional strategies include slender massing and the incorporation of verandas (Nguyen et al., 2011; Nugroho, 2012; Zune et al., 2021; Sun et al., 2023), steeply sloped roofs, lightweight materials, roof openings, and 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 wall types (Nugroho, 2012; Prasetyo & Astuti, 2017), appropriate placement and size of openings (Beccali et al., 2018; Victoria et al., 2017), raised floors with specific heights and floor gaps (Prasetyo & Astuti, 2017; Sardjono, 2011; Victoria et al., 2017), and landscaping featuring shading plants, particularly on the west side (Nugroho, 2018; Prasetyo, 2016; Yang et al., 2022). According to Miranda et al. (2021), passive cooling methods have protective mechanism, including heat absorption and dissipation. Heat protection through the use of microclimate applications (landscape, aquatic element vegetation) and sun protection (shading, aperture) while heat absorption depends on material properties (Hu et al., 2023).

These criteria have been expanded through recent studies on passive design in vernacular buildings located in tropical regions. Given Indonesia's high housing demand and increasing energy requirements, there is a need for design solutions that incorporate passive cooling strategies derived from vernacular dwellings. Assessing and contrasting the performance of passive designs concerning thermal environmental conditions in Indonesian vernacular dwellings involves evaluating strategies for temperature comfort and air temperature reduction. Some of these design elements and strategies can be applied to modern dwellings, provided that appropriate requirements and regulations are adhered to. While the Samin Vernacular Dwellings may have undergone certain modifications over time, specific approaches to passive design have endured and remain functional and adaptable in the present era.

METHODS

The research methodology involves qualitative and quantitative assessments, employing visual observation and measurements of air temperature conditions. Visual observation evaluates the effectiveness of passive design strategies implemented in house objects. At the same time, a quantitative assessment of temperature comfort conditions is conducted through measurements of air temperature and its variations.

The research focuses on the Samin Vernacular Dwellings situated in the village of Klopodhuwur, Blora Regency, within the province of Central Java. This location is selected because it is one of the few remaining settlements of the Samin community where original houses still exist. Within the village, two types of Samin houses are present. The first is the Original Samin House, which has existed since the village's establishment and remains the only remaining house of its kind. The second type is the original Samin house that has undergone renovations and is referred to as the New Samin House (Fig. 1).

The Original Samin House and the New Samin House are located close to each other, precisely at coordinates 7°02'16" South latitude and 111°24'24" East longitude (Fig. 2). The average air temperature in this area is 29.2°C, with an average humidity of 82%. Prevailing winds predominantly originate from the northeast direction. Both houses continue serving as living spaces, featuring a similar rectangular floor plan with a living area and a cattle pen. The roof design of these buildings is hipped, and there is a front terrace.

Fig. 1. Original Samin House (top) and New Samin House (bottom) as Research Objects
(Source: author)

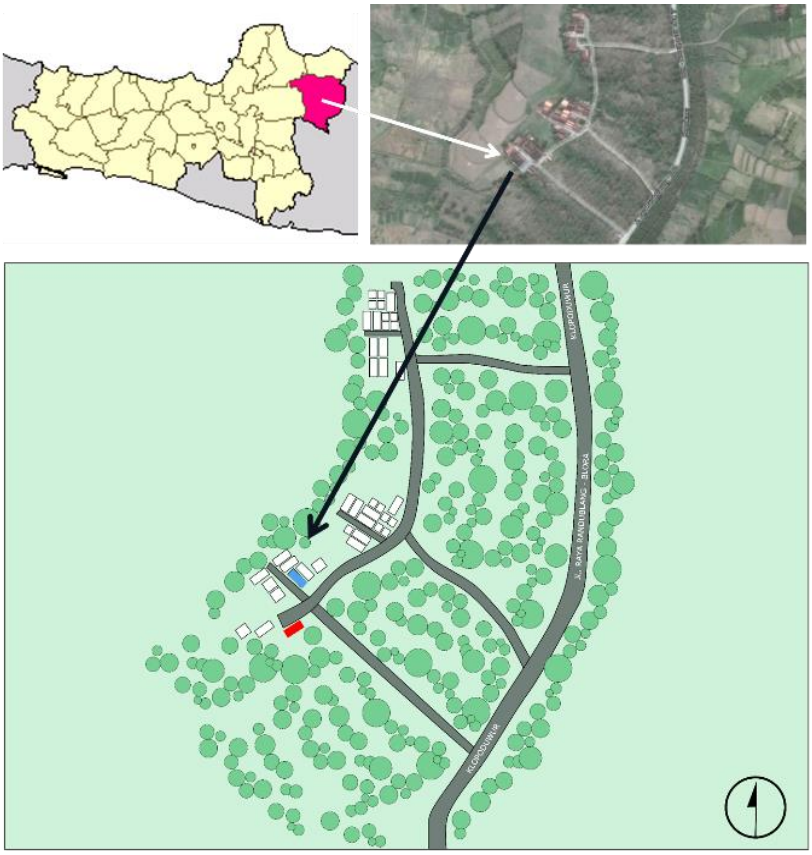


Fig. 2. Location of Research Case Studies
(Source: Images acquired from Wikipedia, Google Earth and author)

Visual data encompasses all building elements associated with passive design, including roofs, spaces, walls, floors, and landscaping. Direct observation is conducted by visually describing both houses based on their architecture, which is subsequently analyzed. The observed variables encompass orientation, construction period, floor plan, building elevations and sections, materials used, and the surrounding environmental conditions.

Air temperature measurements are taken within the house and on the house terrace, with sensor placement as illustrated in Fig. 3. The measurements are conducted using an RC-4HC data logger, which boasts an accuracy of up to 0.1°C and 1%. Data is recorded every hour from March 27th to April 30th, 2019.

Visual observation analysis involves evaluating the compatibility between the existing architectural elements in each house and the passive design criteria. Thermal environmental measurements are analyzed by assessing the air temperature conditions within comfortable temperatures. The discussion of passive design strategies entails comparing the results of visual observations, measurements, and previous research to establish the significance of the relationship between these factors.

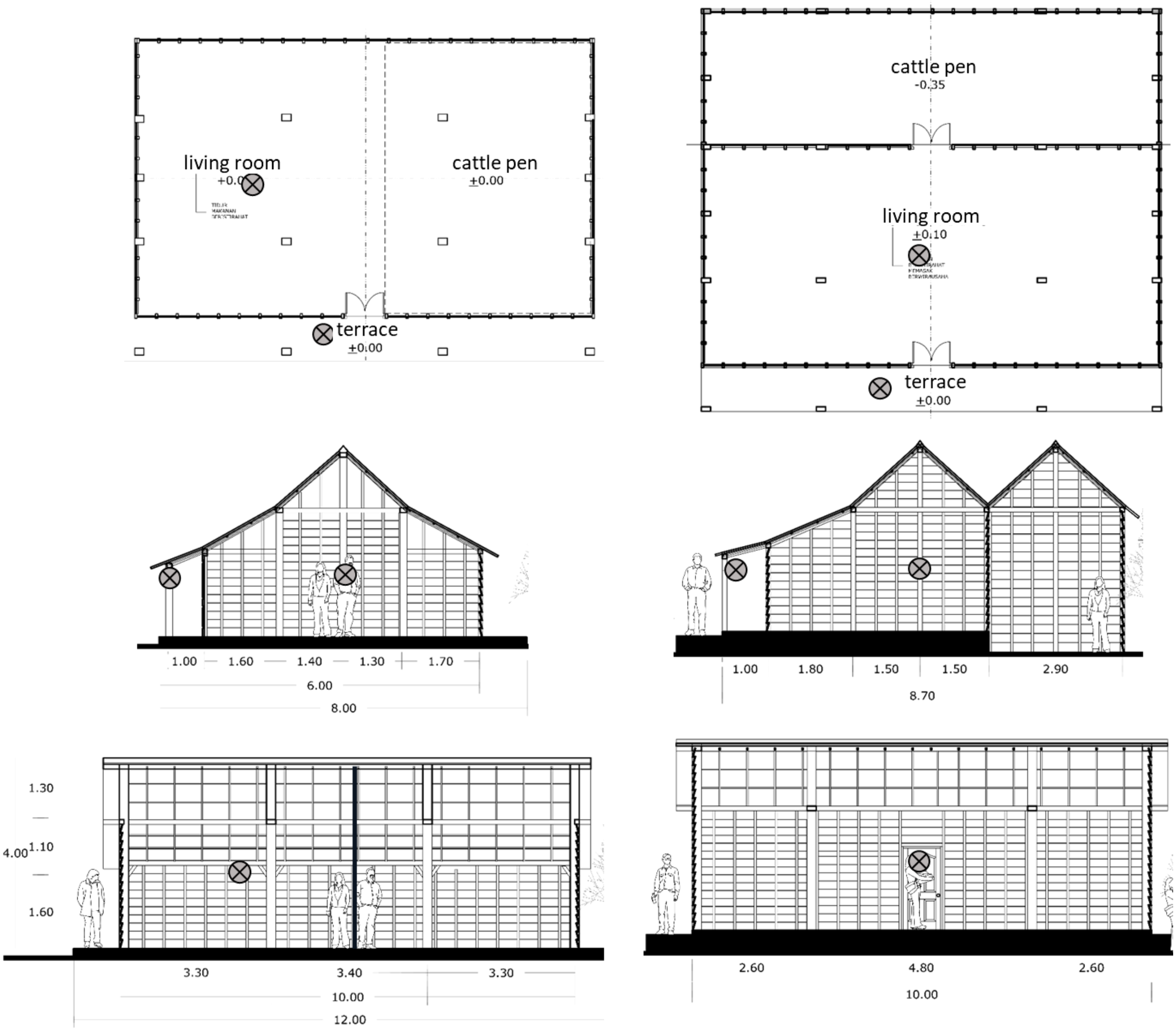


Fig. 3. Placement Points of Measurement Devices
(Source: author)

RESULTS AND DISCUSSION

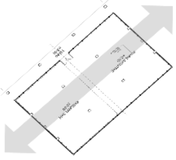
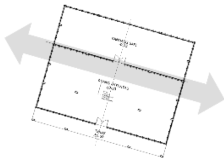
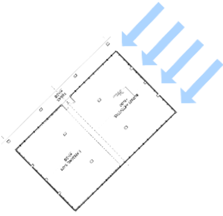
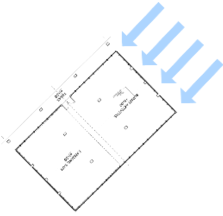
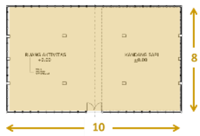
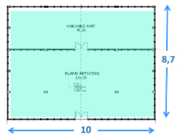
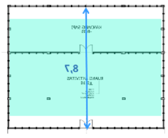
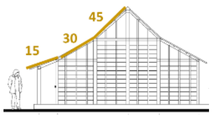
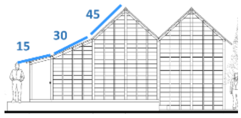
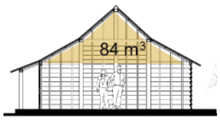
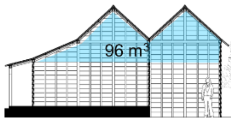
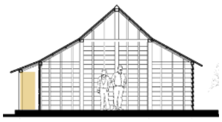
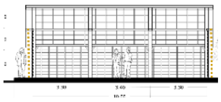
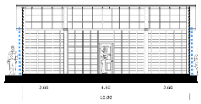
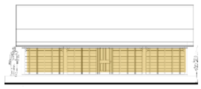
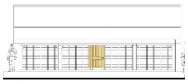
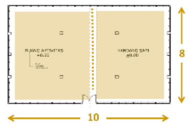
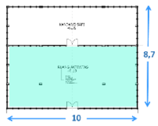
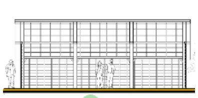
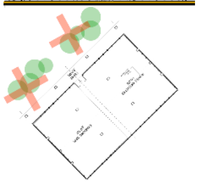
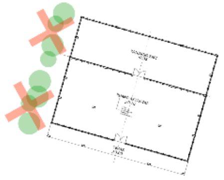
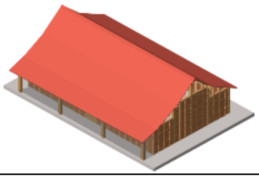
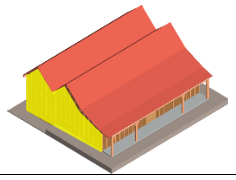
Passive Design Elements in Samin Vernacular Houses

The Original Samin House, built over a century ago, has dimensions of 7x10 meters. It features a saddle-shaped roof with a 45° slope and 1.6-meter-high walls made of horizontally arranged teak wood measuring 15-20 mm thick. On the west side, the house lacks windows and has a soil floor. On the other hand, the New Samin House, which underwent modifications approximately 30 years ago, faces south. It has a larger floor area of 77 m2, measuring 7.7 x 10 meters. The roof design is also saddle-shaped with a 45° slope, and an additional similar roof is added at the back. The wall height remains the same as the Original Samin House, utilizing wooden boards less than 5 cm thick. Like its counterpart, it lacks windows but features a raised floor of plastered cement measuring 15 cm in height. The main differences between the two houses lie in the roof design, raised floor, and building orientation.

The suitability of the Original Samin House and the New Samin House to the criteria of passive design in vernacular architecture serves as the basis for evaluation. Table 1 outlines similarities in the level of suitability between the two houses, including building mass proportions, building width, roof slope, presence of a terrace, thin walls, low wall material conductivity, and absence of openings and natural shading.

The building mass proportion refers to the ratio of the building's width to its length. The Original Samin House has a proportion of 8:10, while the New Samin House has a proportion of 8.7:10. Both houses exhibit nearly identical proportions as the New Samin House evolved from the Original Samin House with the addition of an animal pen at the back. However, the proportions of both houses tend to be box-shaped (1:1.25) rather than rectangular, which could be better for tropical buildings (1:3).

Table 1. Level of Compatibility of Passive Design Elements in the Original Samin House and the New Samin House

Passive Design Criteria	Original Samin House	New Samin House
East-West Orientation		
Long side of the building faces the direction of the wind		
Width-to-length ratio is 1:3		
Slender floor plan not exceeding 12 meters for a height of 3 meters		
Roof wit a slope >30°		
Larger roof volume is preferred		
Presence of terrace or veranda		
Thin walls with good ventilation		
Low thermal conductivity of materials		
Presence of window openings around the building		
Minimal use of room partitions		
Difference in floor heights		
Presence of natural shading		
West side of the building is shaded		

The floor plan width for both the Original Samin House and the New Samin House is 8 meters and 8.7 meters, respectively. According to passive design criteria, which do not prioritize slim buildings, the assessment of building slimness is determined by the ratio of wall height to building width. With a wall height of 3 meters, the optimal width for ventilation and natural lighting is four times that or approximately 12 meters. As both houses have a wall height of 1.6 meters, the optimal width should be 6.4 meters. However, the Samin houses have a roof height of 2.4 meters, higher than the wall height, and feature three roof slopes. These slopes vary 15° for the terrace, 30° for the edges, and 45° for the centre. The 45° slope represents the main roof and meets the passive design criteria (>30°). Each house has a one meter wide terrace, which is suitable considering the relatively low wall height. The walls of the Original Samin House are made of 1 cm thick horizontally arranged teak wood, while the New Samin House utilizes 3 cm thick wooden boards arranged similarly. The tight arrangement of wooden elements without ventilation gaps results in poor air circulation within the building. Both houses exhibit relatively low wall material conductivity (wood material and not thick), allowing heat absorption and dissipation. Neither house incorporates ventilation openings, relying solely on door openings at the front of the house. This indicates that both houses are typical Javanese vernacular houses from the past, which do not make extensive use of windows and instead rely on the porous nature of the walls, such as the utilization of woven bamboo. The absence of windows and bamboo-woven walls restricts airflow within the building.

The observed Samin community settlement, serving as the subject of observation, features a linear arrangement of houses with minimal spacing between them, resulting in limited front yards. Each house possesses a small yard area, with no shading plants present. This characteristic applies to both the Original Samin House and the New Samin House. No shading elements are found on the west-facing side of the houses.

Distinguishing features between the Original Samin House and the New Samin House include solar and wind orientation, roof volume, interior walls, and floor height. The Original Samin House has a long side stretching from southwest to northeast, resulting in a larger northern side exposed to sunlight. In contrast, the New Samin House extends from west to east, with the west side of the building relatively less exposed to solar radiation. The orientation of the houses to wind direction also differs. The New Samin House positions its long side to face the prevailing wind direction from the northeast, facilitating better airflow around the building. On the other hand, the Original Samin House features a short side facing the incoming wind, which directly hits the building wall.

Roof volume represents a crucial criterion for passive design in hot and humid areas, as it aids in controlling heat buildup caused by solar radiation. Larger roof volumes offer more significant advantages. The New Samin House boasts a roof volume of 96 m3, surpassing the roof volume of the Original Samin House (84 m3). Both houses' roof volumes approach the living space volume, which amounts to 128 m3 for the Original Samin House and 139.2 m3 for the New Samin House, averaging 66%. The passive design criterion for the space involves the absence of partition walls that impede the removal of hot air from the building. The Original Samin House includes interior partition walls to separate the living area from the livestock area. At the same time, the New Samin House lacks such partitions since the livestock area has been relocated to the rear of the house. Another disparity between the two houses lies in the 15 cm raised floor present in the New Samin House. The floor of the Original Samin House remains at ground level without any height difference from the yard. The New Samin House features a raised, plastered cement floor measuring 15 cm in height, mitigating the risk of flooding in the area. Consequently, based on visual observations regarding the suitability of passive design strategies, the New Samin House exhibits a higher compatibility with passive design principles than the Original Samin House. These observations can be linked to the measurements of temperature comfort performance between the two houses.

Air Temperature Conditions in Samin Vernacular House

The average outside temperature is 28.5°C, with the highest recorded temperature of 39.5°C at 13:00 and the lowest temperature of 22.3°C at 07:00. There is a relatively large difference between the lowest and highest temperatures, amounting to 17°C. In the living space of the Original Samin House, the average air temperature is 28.4°C, with maximum and minimum values of 40.7°C and 21.9°C recorded at 13:00 and 06:00, respectively. The temperature range in the terrace area of the Original Samin House (16.8°C) is lower than that of the living space (18.8°C). This initial indication suggests that the terrace space in the Original Samin House exhibits more stable air temperature performance compared to the living space.

The New Samin House shows the same average air temperature as the Original Samin House, which is 28.4°C, with the highest and lowest values recorded at 34.2°C and 25°C at 13:00 and 06:00, respectively. The lower average maximum air temperature in the New Samin House indicates better passive design performance during daytime. Meanwhile, the higher average minimum temperature suggests that the existing passive design can maintain a stable thermal environment. In the terrace area of the New Samin House, the average air temperature is the same as that of the terrace in the Original Samin House, with a slightly higher average maximum temperature of

0.4°C. Thus, the interior space of the New Samin House is more stable compared to its terrace area, contrasting with the condition of the Original Samin House.

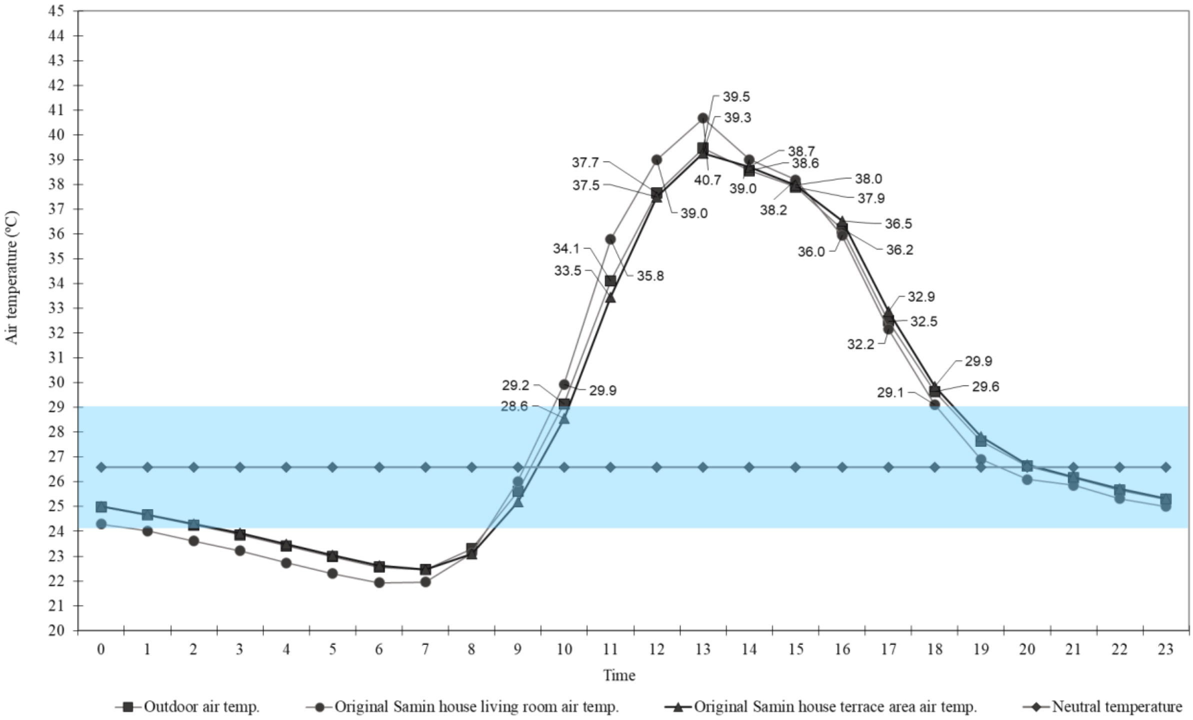


Fig. 4. The Air Temperature Condition of The Original Samin House Against The Neutral Temperature Zone Per Hour for 30 Days of Measurement
(Source: author)

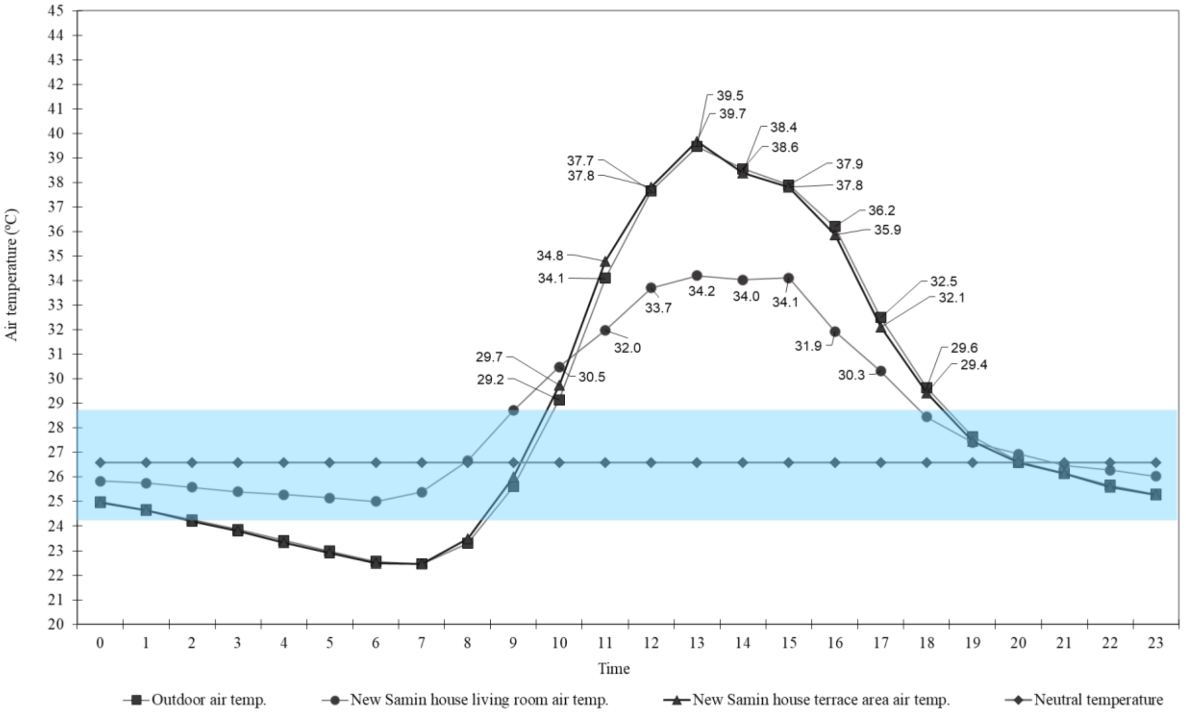


Fig. 5. The air Temperature Condition of The New Samin House Against The Neutral Temperature Zone Per Hour for 30 Days of Measurement
(Source: author)

Performance of temperature comfort in Samin Vernacular Houses is based on neutral temperature or comfortable temperature at the location, which is 26.6°C, with a comfortable zone range between 24.2°C and 29.1°C. However, when compared to the comfortable temperature according to Karyono (2001), there is a larger range, from 23.2°C to 30.2°C. The average air temperature outside both Samin houses (28.5°C) falls within the comfortable range, but there are specific times that are uncomfortable (from 10:00 to 18:00). The percentage of time that the original Samin house is in a comfortable condition is 66.7%, which is 16 hours out of a total of 24 hours, with discomfort occurring from 10:00 to 17:00. The new Samin house has the same comfort conditions in terms of duration (16 hours) and time range. The difference lies in the average uncomfortable temperature, which is 32.6°C, or 5.7°C lower than the original Samin house.

The Influence of Passive Design on Air Temperature Reduction in Samin Vernacular Houses

The performance of building air temperature reduction can be calculated by looking at the difference between outdoor and indoor air temperatures. If the result is positive, it indicates a temperature decrease, while a negative result indicates a temperature increase. The largest temperature decrease in the new Samin house is 5.48°C at 13:00, with an average of 0.2°C throughout the day and 3°C during the daytime. The temperature decrease in the original Samin house occurs at night, with the highest value being 0.73°C at 19:00. The timing of temperature decreases affects the temperature comfort in each house. From nine to ten in the morning, neither the old Samin house nor the new Samin house experience a drop in air temperature (Fig. 6). Cooling of the living space in the new Samin house occurs during the daytime, while cooling in the original Samin house occurs at night, commonly referred to as nighttime cooling. The influence of the cooling timing shows that the nighttime cooling technique in the original Samin house provides a lower comfortable temperature (24.5°C) compared to the average comfortable air temperature during daytime cooling in the new Samin house (26.3°C). Based on these results, knowledge about nighttime cooling can be learned from the original Samin house, while daytime cooling can be obtained from the new Samin house.

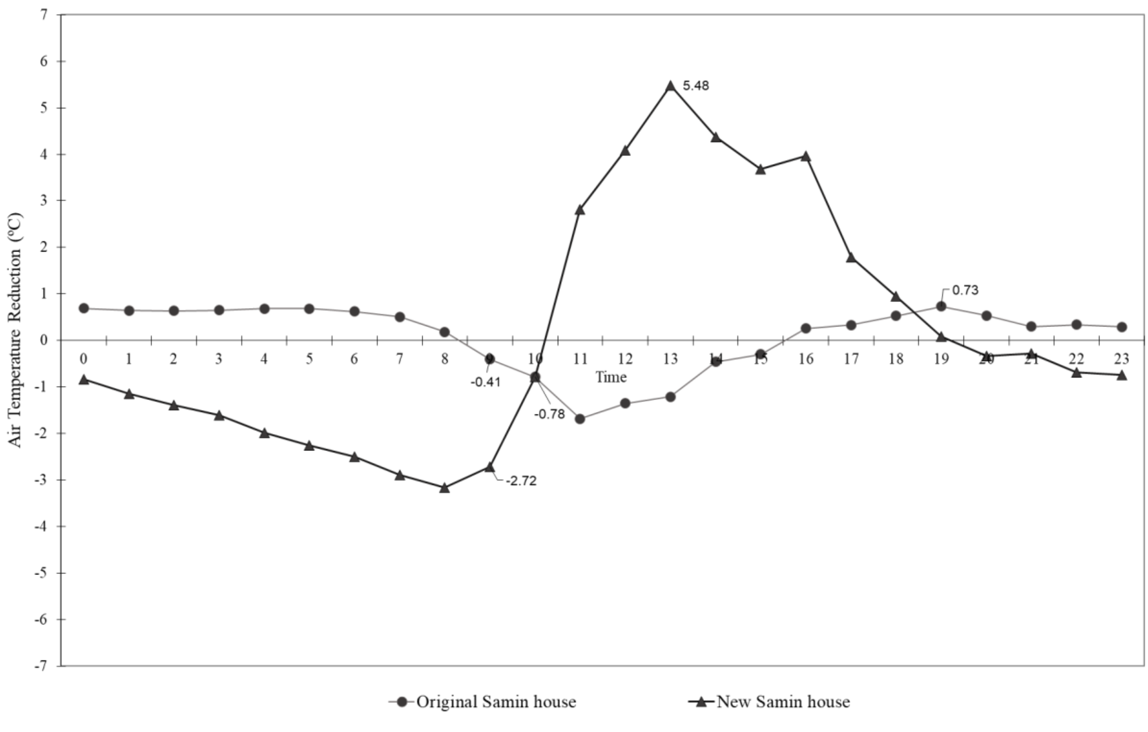


Fig. 6. Performance of air temperature reduction in the Original Samin House and the New Samin House (Source: author)

The Relationship Between The Suitability of Passive Design Elements and Air Temperature Reduction

The suitability of passive design elements in relation to temperature cooling performance can be explained through the level of influence of building orientation, roof volume and slope, and wall material on temperature comfort and passive cooling. A comparison of the passive cooling performance of both houses shows that the New Samin House performs better than the Original Samin House during the daytime. This indicates that the west-east orientation of the New Samin House, perpendicular to the wind direction, has an impact on temperature cooling performance.

Large roof volume and steep slope have been proven to provide a temperature comfort of 28.4°C in both houses. A larger roof volume can store and prevent heat from spreading to the living space below, as stated by

Nugroho (2018). Similarly, Zune et al. (2021) claim that the utilization of extensive shading device is the primary component of passive architecture in the tropics. However, the roof of the New Samin House is still not optimal in providing temperature comfort to the living space below. This is because there are no roof openings that allow hot air to escape and be replaced by cool air (Victoria et al., 2017).

As mentioned by Sun et al. (2023), terraces are typical of space cooling technique in traditional buildings in humid hot climates, and their existence in both dwellings has an impact on the effectiveness of lowering air temperature. The main component of this study object, if it were wider, might anticipate extremely hot and humid weather conditions and serve as a buffer zone for the development of a thermal environment that meets the demands of residents.

On the other hand, during the nighttime, the passive cooling performance of the Original Samin House is better. The visual difference lies in the use of Teak wood as the wall material in the Original Samin House and wooden boards in the New Samin House. Wooden boards have higher conductivity than Teak wood, which means they retain heat for a longer time and release it during the night. This causes the temperature in the New Samin House to be warmer than the Original Samin House, as mentioned by Prasetyo and Astuti (2017), who state that the use of wooden boards creates a more adaptive air temperature condition. This is further supported by the claims made by Miranda et al. (2021) and Hu et al. (2023), who state that the primary method of passive cooling is through heat absorption, particularly through the use of materials with the capacity to delay or adjust peak heat periods.

These results are related to the temperature peak differences in each room to understand the influence of material time lag, as done by Dili et al. (2011). The peak temperature in the outer and inner rooms of both the original and new Samin houses occurs simultaneously at 13:00 (Fig. 7). This indicates that the time lag for each house is 0, which means the conductivity of the material for the walls and roof is relatively low.

In hot humid climates, the main dominant strategies are wall thermal property elements followed by window material, window to wall ratio; ventilation (Hu et al., 2023).

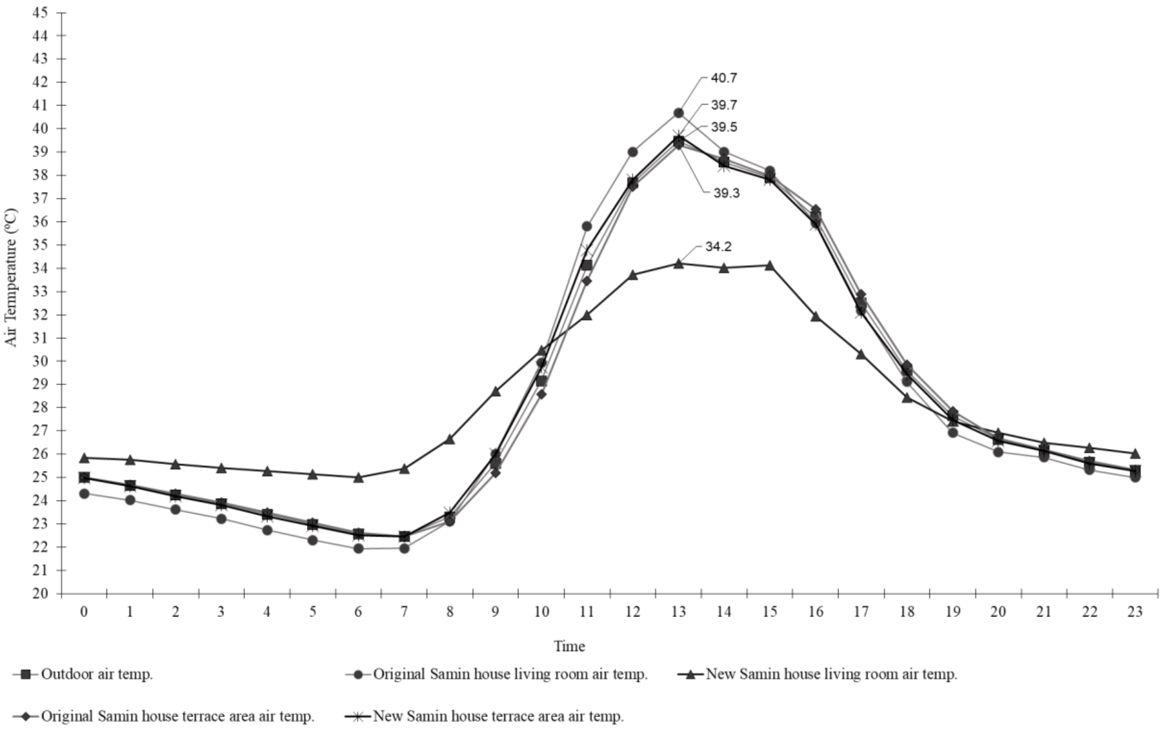


Fig. 7. Comparison of Air Temperature in the Original Samin House and the New Samin House
(Source: author)

The knowledge of passive design in Vernacular Samin houses includes the strategy of passive cooling during the daytime in the New Samin House through the application of a large-volume roof, low-conductivity walls, orientation of the longest side perpendicular to the wind direction, minimal use of dividing walls, and a roof slope greater than 30°. The development of passive design in Vernacular Samin houses is approached through visual observations that have not been fully implemented, such as building proportions and width, window openings, and shading. The appropriate building proportion is a rectangular shape, maintaining a width-to-length ratio of 1:3, with the width of the building not exceeding 4 times the height of the space (Nugroho, 2019). Ventilation openings should be added, facing the wind direction, with a size of 5-10% of the floor area. Additional vegetation or shading elements should be provided on the western side of the building. This is in line with Yang et al. (2022) suggestion that using landscape components is an effective method to protect vernacular structures from solar radiation.

CONCLUSION

The investigation of passive design strategies in the Samin vernacular house yielded three key findings. Firstly, the study confirmed the suitability of passive design criteria in both the Original Samin house and the New Samin house. Secondly, it examined the performance of temperature comfort and passive cooling in these two house types. Lastly, the research established a significant relationship between the application of passive design elements and passive cooling performance, providing a foundation for the future development of Samin vernacular houses.

The Samin house exhibits several elements well-suited for passive design, including its large volume (84-96m3), sloped roof (45°), and low conductivity walls (thick wooden boards). Similarly, the New Samin house demonstrates passive design compatibility through its west-east building orientation, aligned with the sun's movement, and the arrangement of its long side perpendicular to the wind direction. Moreover, the absence of room dividers and elevated floors further contribute to its passive design effectiveness.

However, certain discrepancies in passive design elements were observed between the two house types. These include variations in building proportions and width (1:1,25), narrower terraces (1 m), the absence of window openings, and the lack of vegetation on the west side of the building.

To evaluate passive cooling performance, the study considered the average air temperature, which measured 28.4°C, falling within the neutral temperature range of 24.1-29.1°C. Notably, the New Samin house exhibited the most significant decrease in air temperature during the day, reaching 5.5°C, whereas the Original Samin house demonstrated a decrease of 0.7°C at night.

The research also identified a clear relationship between implementing specific design elements and passive cooling performance. Notably, volume elements, roof slopes exceeding 30°, walls with low conductivity, east-west orientation, the longest side of the building perpendicular to the wind direction, minimized wall barriers, and raised floors were found to enhance passive cooling effectiveness. Further exploration of these elements is necessary within a broader context.

In conclusion, this investigation sheds light on the suitability of passive design criteria in the Samin vernacular house, examines the performance of temperature comfort and passive cooling in two house types, and establishes a relationship between passive design elements and cooling effectiveness. These findings contribute to the ongoing development of Samin vernacular houses and underscore the significance of incorporating passive design strategies for sustainable and comfortable living environments.

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