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Effectiveness of Passive Design Elements in a Malaysian Modernist Tropical Cottage

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Abstract

When the general population could afford mechanical cooling, everything changed. Modern designs that were not appropriate for the tropical region are slowly introduced, and the best way to control indoor thermal conditions is by mechanical cooling. This paper aims to assess the effectiveness of passive design elements in a tropical Modernist cottage on indoor thermal conditions by analyzing data obtained from fieldwork research. The building can be recognized by its simple cottage style, with a focus on practical functionality. Passive design principles are integrated into Modernist architecture to construct lasting, practical, and environmentally conscious buildings. The fieldwork research involves indoor thermal performance and ventilation data monitoring of three rooms within the cottage over an extended period. Through a comprehensive analysis, it is found that passive design elements within this Modernist cottage are effective for passive cooling during the day with closed windows and inactive fans. At night, it is advisable to open the windows for heat dissipation while keeping the fans switched off. It was observed that the ceiling fans kept the monitored room temperatures high as they circulate warm air downward instead of permitting it to flow through the ventilation blocks. Further, several design recommendations were made to improve indoor air flow and heat discharge for cooling. Although the fate of the studied Modernist tropical cottage is yet unknown, the knowledge gained through this study could improve the cooling of existing modern tropical houses through retrofits and strategic use of fans, while new houses should have suitable vents on the building envelope and roof for effective indoor cooling and less reliance on air-conditioning.

1.0 INTRODUCTION

Spatial planning for most contemporary residential houses in Malaysia disregards passive cooling strategies such as cross ventilation, permanent openings, stack effect and jack roof systems (M. Al-Tamimi, Syed Fadzil, & Wan Harun, 2011). Unfortunately, while developing new building designs, local climatic circumstances and the requirement for energy conservation are seldom considered because their main goal is to quickly meet extremely high housing demand. Due to this, new buildings generally have poor thermal performance, necessitating the use of mechanical ventilation and air conditioning, which increases energy consumption (Tatarestaghi, Ismail, & Ishak, 2018). Contemporary designs that are more suited for temperate climates have been introduced here in Malaysia by maximizing the number of units for profitability (Kamal, Ab Wahab, & Che Ahmad, 2004).

Architecture must play a vital role in reducing the energy consumption of buildings, especially when there is evidence that passive design is proven when adopted. In their research, Geetha and Velraj (2012) have created a comprehensive framework for strategies of passive cooling. In the framework, they identified three categories:

- Heat prevention/reduction (decreasing heat gain)
- Thermal moderation (modifying heat gain)
- Heat dissipation (removing internal heat)

Each category is divided into two approaches, which are factors that correlate with the category. Under heat prevention are microclimate and solar control. Thermal mass and night ventilation fall under thermal moderation, and with or without thermal energy, they fall under heat dissipation. This study focusses on the heat dissipation method, specifically natural ventilation, wind-driven ventilation, and single-sided ventilation. The reliance on active cooling in residential homes has increased over the years and is a contradiction to a more sustainable energy-efficient solution. As global climate is a major concern, the usage of active cooling increases carbon emissions and just adds more problems. Studies have shown that the building sector accounts for between 23% and 47% of total primary energy consumption in developed and developing countries worldwide (Chen, Tong, & Malkawi, 2017). 70% of energy used in residential houses is due to active cooling and electrical appliances which require heating. The air conditioner is the appliance that contributes the most to the overall quantities of electricity saved and used among minimum energy performance standard (MEPS) compliant appliances when compared to the other appliances (Salleh et al., 2018).

The increased demand for artificial cooling by air conditioning units to provide comfort would also mean increased energy usage and increased electricity cost to the occupants in a hot and humid climate like that of Malaysia (Daghigh, 2015). According to Ahmed et al. (2017), on weekends, the average energy usage is 25.8 kWh/day, whereas on weekdays, it is 21.9 kWh/day. The air conditioner alone uses 11.5 kWh/day. Active cooling has created residential designs that no longer consider the climate condition of the site, giving buyers no alternative but to use active cooling for indoor thermal comfort (Tuck et al., 2020). Large, fixed openings are introduced, emphasizing style rather than practicality. Design features such as ventilation blocks are introduced for literal aesthetic purposes rather than for improvements of natural ventilation. Architecture in Malaysia no longer needs to adapt to the tropical climate as it is currently designed with active cooling being the tool to control indoor thermal comfort. There is an insufficient study on residential buildings in this region that utilizes passive design strategies to improve internal comfort. There was a time when almost all designs in Malaysia adhered to the tropical climate, and it was expressed in the design up until the Modernist Movement, post-independence. During this period, progressive and functional Modernist architecture was adapted to the local climatic conditions and culture in search of a modern and unique national identity.

2.0 LITERATURE REVIEW

The built environment significantly contributes to carbon emissions and energy consumption, especially via the utilization of cooling systems in residential buildings. Passive design strategies have long been employed to reduce energy demand and improve thermal comfort, especially in tropical climates. However, with the effects of global warming becoming increasingly severe, the effectiveness of these passive methods has come into question. This literature review examines several key areas: the reassessment of passive cooling systems in light of climate change, carbon emissions from indoor human activities, thermal comfort in the tropics, ventilation strategies, the role of window openings and ventilation blocks, and the passive design elements used in Modernist architecture.

Global warming, primarily caused by anthropogenic activity like fossil fuel consumption and deforestation, has profoundly affected the Earth's climate. As temperatures rise, the effectiveness of passive cooling systems—once sufficient for maintaining indoor thermal comfort—has diminished. According to Houghton (2005), carbon dioxide is the most critical greenhouse gas contributing to this warming trend. As a result, relying solely on passive cooling methods is becoming less viable, particularly in the face of rising temperatures and more frequent extreme weather events like hurricanes.

The growing insufficiency of passive systems necessitates the incorporation of energy-efficient mechanical devices to enhance natural ventilation and cooling. According to Bezemer (2008), the key challenge now is how technology can assist passive ventilation methods. Gill et al. (2011) further emphasize that the built environment, particularly the residential sector, is a major contributor to energy consumption and carbon emissions. These developments suggest that a hybrid approach, combining passive systems with advanced mechanical ventilation technologies, may be necessary to achieve optimal indoor thermal comfort in a changing climate (Rahman & Al-Obaidi, 2019).

However, the impact of human activities on carbon emissions is particularly pronounced in residential buildings. The residential sector accounts for more than 30% of global carbon emissions and energy consumption, as noted by King et al. (2008) and Utley & Shorrock (2008). In Malaysia, over 20% of energy consumption is attributed to the residential sector, according to the International Energy Agency (2021). This figure has likely increased following the COVID-19 pandemic, which transformed many homes into temporary offices. With residents spending more time indoors, air-conditioning surged, driving up energy demand in residential areas (Mustapa et al., 2021). Although air conditioning was already becoming the dominant method for achieving indoor thermal comfort, particularly in tropical regions, this trend exacerbates the environmental burden of residential energy consumption. The need for passive cooling strategies, supplemented by low-energy mechanical aids, is therefore more urgent than ever, as energy use from human activities continues to rise (Rahman & Al-Obaidi, 2019).

As commonly accepted, thermal comfort is a critical factor in determining the livability of residential spaces, particularly in tropical climates where heat and humidity are persistent challenges. Thermal comfort is defined by ISO 7730 (1994) as the “condition of mind which expresses satisfaction with the thermal environment.” It is mostly affected by the indoor and outdoor temperature, relative humidity, air velocity, clothing, and human activity. In tropical countries like Malaysia, thermal comfort is subjective and varies greatly between individuals, especially when compared to residents of temperate climates (Reardon, 2008). In order to achieve thermal comfort, building designers must apply passive design principles that leverage natural resources such as wind and sunlight to provide comfort without mechanical cooling systems (Hassan & Ramli, 2010). However, these methods are often inadequate for hot and humid climates. Despite the development of numerous thermal comfort models over the past century, most are tailored for temperate regions and office environments. These models are often retrofitted for residential applications in tropical climates but fail to fully account for high humidity levels and unique climate conditions (Parsons, 2014; Nicol et al., 2012). Consequently, new standards for thermal comfort, specifically designed for tropical regions, are needed to address the challenges posed by the local climate (Rodriguez & D’Alessandro, 2019).

Ventilation plays a pivotal role in passive cooling strategies. Cross ventilation, which allows air to flow through a building by creating pressure differences between openings on opposite sides, is widely recognized as more effective than single-sided ventilation. Studies show that cross ventilation can significantly enhance indoor thermal comfort by increasing the rate of air exchange, reducing indoor temperatures, and improving air quality (ASHRAE, 2023). Despite these benefits, many residential designs, particularly in urban settings, rely heavily on single-sided ventilation. This approach limits air movement and reduces the potential for natural cooling (Ahmed, Kumar & Mottet, 2021). A study by Aflaki et al. (2019) demonstrated that the use of transom windows could increase air circulation by 27%, suggesting that even minor design modifications could improve ventilation in single-sided designs. However, maximizing cross ventilation remains the optimal strategy for passive cooling in tropical climates (Stasi, Ruggiero & Berardi, 2024).

Despite the lack of use in current building designs, ventilation blocks are a common architectural feature in tropical Modernist buildings, designed to enhance natural ventilation and improve indoor air quality. Despite their extensive utilization in 1960s Modernist architecture, there has been less investigation into their real effectiveness. Many studies have focused on the aesthetic and decorative functions of ventilation blocks, overlooking their potential to improve thermal comfort (Tuck et al., 2019). Schaetz (2013) suggests that ventilation blocks are primarily employed for privacy and rainproofing, yet their ability to enhance airflow and reduce heat gain warrants further investigation. Field measurements and empirical studies are needed to determine whether these blocks can be an effective passive cooling element in contemporary building designs.

Table 1. Summarizes an observation on passive design elements found on various Modernist houses in Petaling Jaya, Malaysia. (Source: Authors)

Modernist building typology	Orientation	Shading Device	Large Overhangs	Ventilation Blocks	Timber Louvres
Cottage 	Earlier developments were oriented in a north-south direction.	Concrete shading device	Yes	Yes	Visible at doors
Terrace 	Earlier developments were oriented in a north-south direction.	Concrete shading device	Yes	Yes	Visible at doors
Shophouse 	Layout according to road orientation	Concrete shading device	None	Ventilation blocks visible at above windows and utility areas (staircase)	None
Apartment 	Earlier developments are oriented in the North-South direction	None	None	Ventilation blocks visible at above windows and utility areas (staircase)	None

Window openings are critical in facilitating natural ventilation and reducing indoor temperatures. Properly positioned windows can promote cross ventilation, enhancing airflow throughout the building. Aflaki et al. (2019) note that strategically placed window openings not only improve indoor thermal comfort but also significantly reduce energy costs by minimizing the need for mechanical cooling. In tropical regions, windows are often combined with shading elements like overhangs or louvered screens to prevent heat gain while maintaining ventilation (Yusoff et al., 2023). Besides, night ventilation is another effective strategy for lowering indoor temperatures, particularly when paired with large openings that allow heat to escape during the cooler evening hours (Toe & Kubota, 2015). However, windows and walls must be adequately shaded to prevent solar radiation from increasing indoor temperatures during the day. This balance between allowing ventilation and reducing heat gain is a key consideration in passive design strategies for tropical climates.

Tropical Modernist houses are characterized by several passive design elements that enhance natural ventilation and thermal comfort. These include ventilation blocks, louvered openings, large overhangs, and spatial designs that promote cross ventilation. Ventilation blocks, positioned above windows, allow airflow while providing privacy and protection from rain. Similarly, louvered openings facilitate air circulation and can be integrated into doors, windows, and sliding panels (Yusoff et al., 2023). Large overhangs are another important design feature, used to protect buildings from direct sunlight and reduce heat gain. These structures create shaded areas that limit the amount of solar radiation entering the building, thus keeping interior spaces cooler (Gut & Ackerknecht, 1993). Finally, the spatial arrangement of rooms in Modernist houses—often oriented north-south to minimize heat exposure—maximizes cross ventilation, reducing the need for mechanical cooling systems (Nordin, Ismail & Ariffin, 2019). These design elements, widely used in the mid-20th century, are now recognized as sustainable solutions for improving indoor environmental quality and reducing energy consumption. Table 1 summarizes an observation on passive design elements found on various Modernist houses in Petaling Jaya, Malaysia. As architects and urban planners look to the past for inspiration, these passive cooling strategies continue to offer valuable lessons for designing energy-efficient homes in tropical regions.

Petaling Jaya was selected as the base location for this study as it was first developed in response to an urgent need for mass housing in the early 1960s. Using Ebenezer Howard’s garden city concept as an inspiration, buildings in Petaling Jaya new township were developed using the then popular Modernist architecture with various housing typologies similar to those introduced in Howard’s garden cities (Hassan, 2005). This was done to address the growing urbanization and population influx in Kuala Lumpur. Despite Petaling Jaya’s origin as a new town and manufacturing hub, it has matured into a thriving city with many new high-rise buildings and condominium developments over the past few years, threatening the existence of its calm 1960s Modernist housing clusters. Petaling Jaya has become a highly sought-after residential location for the Greater Kuala Lumpur area.

Therefore, the aim of this study is to assess the effectiveness of passive design elements in a tropical Modernist cottage, considering the changing climate. While the widely accepted and researched strategies such as cross ventilation, window openings, and ventilation blocks remain crucial, they are no longer sufficient on their own. Therefore, the objectives of this research are to investigate the integration of mechanical aids and to explore the design elements' efficacy that are needed to create thermally comfortable, energy-efficient residential buildings in the tropics.

3.0 METHODOLOGY

Previous studies employed field measurements at various tropical housing typologies to determine the passive cooling techniques and ventilation effectiveness (Toe & Kubota, 2015; Aflaki et al., 2019; Sadafi et al., 2011; Tuck et al., 2019). Similarly, the purpose of this quantitative study was to investigate the effectiveness of passive design building elements in enhancing thermal comfort. However, this study was conducted on a single tropical Modernist cottage that was constructed in the 1960s and located in Petaling Jaya, close to Kuala Lumpur in Malaysia. Climatically, Ahmad & Szokolay (2007) describes Kuala Lumpur as being hot and humid throughout the entire year. This climate can be summarized as follows:

- The daytime maximum temperature of 30–35°C with an annual mean temperature of about 27 °C.
- The range of average monthly temperature is about 1–3°C.
- The average diurnal temperature variation is about 8°C.
- The annual precipitation is 1500 mm.
- Inland areas are generally windless, which leads to thermal stress during the day.
- Solar radiation intensity varies widely with cloudy conditions.

This house was selected to analyze the optimization of passive design methods. For this research, aspects such as location, orientation, spatial layout, and the efficient application of passive design components are all taken into consideration. Selecting a layout for a terrace house or flat might restrict the number of orientation options available and make it more difficult to accomplish successful cross-ventilation. Below are the other case study selection criteria for this study:

- Having the original design elements and almost no renovation towards the building may alter the design intention of the original layout.
- Each space within the cottage is designed to achieve a level of cross-ventilation, with openings on two or more sides of the space.
- Having additional adaptive elements in line with the Modernist Movement in Malaysia, such as louvered doors, ventilation blocks above windows, a ventilated roof, as well as concrete ledge/awning above the windows.
- Unoccupied as it would maintain regularity in terms of the usage of space in terms of the proposed scenarios.

- Having a cluster of residential buildings of the same layout and approximately similar location and thermal conditions in the event of needing to replicate the data for confirmation.
- The residential buildings are all oriented at a north-south orientation to minimize heat gain and maximize natural ventilation.

3.1 Case Study House Selection

Considering the selection criteria above, many Modernist houses in Petaling Jaya were scouted but most were either occupied or dilapidated. Eventually, the authors selected a two-story cottage (as shown in Figure 1) which was once occupied by professors close to the Universiti Malaya campus. It was built in the late 1960s and is in its original condition, with no additional renovation work done on the exterior. This house has passive design features that comply with the selection criteria. There was a reinforced concrete overhang ledge as a sun-shading device on the western side of the living room. All windows are equipped with ventilation blocks above them, and the first-floor bedrooms include a minimum of two windows on different sides, facilitating cross ventilation.

Figure 1. (Left) Selected house. Source: Authors. (Right) House location. Source: JPPHB UM.

3.2 Experiment Apparatus and Setup

Each area was monitored using HOBO U12-012 Temp/RH/Light data loggers, which were outfitted with integrated sensors for temperature, relative humidity, and light intensity, in addition to a connected air velocity sensor (T-DCI-F900-S-O). The HOBO U12-012 has a temperature precision of ± 0.35°C within a range of 0° to 50°C; and a relative humidity accuracy of ±2.5% to ±3.5% within 10% to 95% RH range. In addition, the air velocity sensor can measure wind speed within the range of 0 to 5 ms-1, with an accuracy of ±0.015 ms-1, equivalent to ±3% of the reading. To ensure the accuracy and consistency of the data loggers, all deployed units recorded indoor temperature and relative humidity over a 24-hour period and compared.

Section A-A (Living)

Figure 2. Case study house ground floor (left) and first floor (right). (Source: Authors)

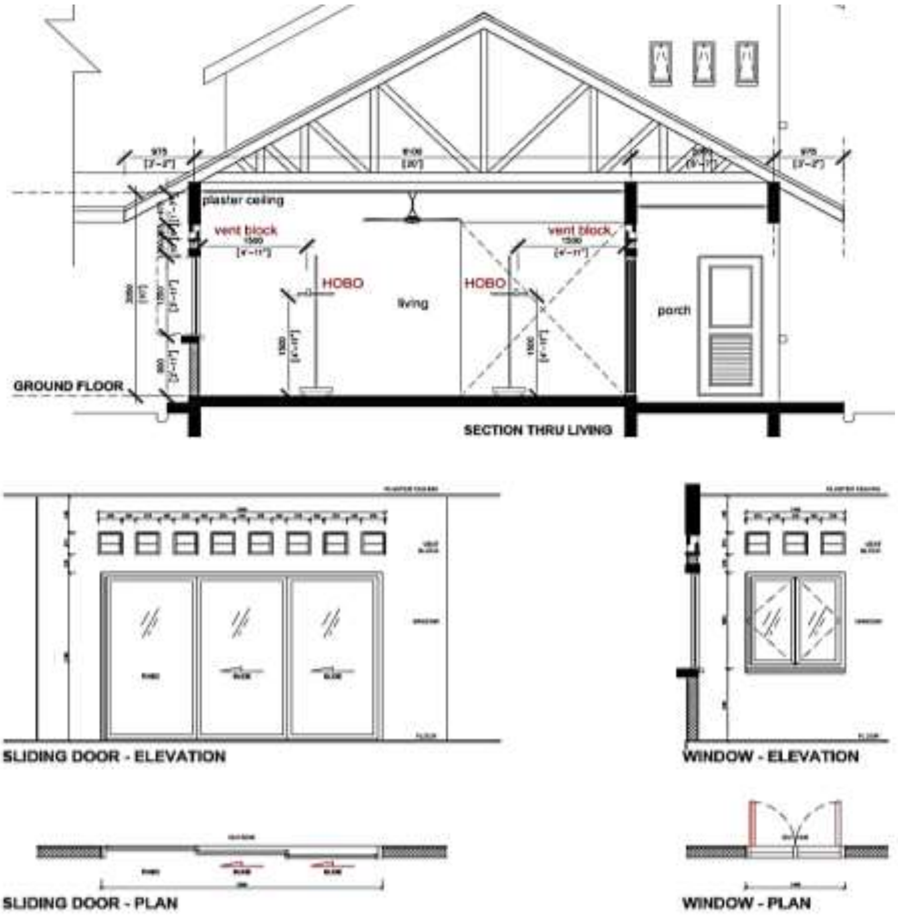


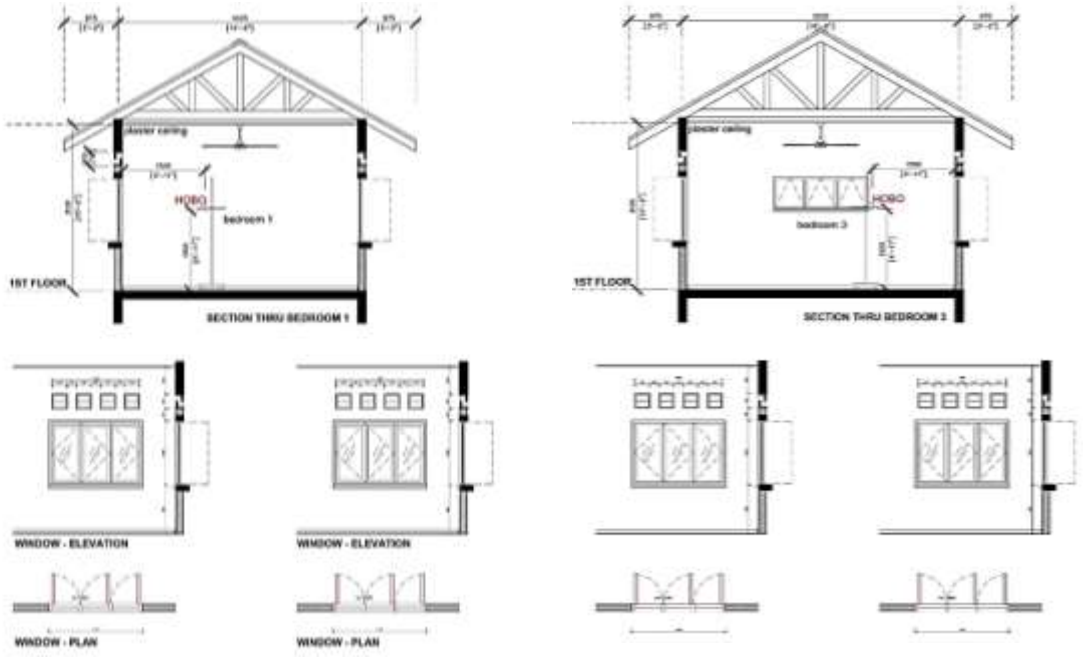
Figure 3. Monitoring equipment setup in the living room on the ground floor (section A-A) and ventilation block design. (Source: Authors)

In line with the rules for interior environmental monitoring, the data loggers were attached to a retort stand at a height of 1.5 meters above ground and positioned 1.5 meters away from the openings (as illustrated in Figures 2, 3 and 4). As a result of limitations imposed by the equipment, the measurements were conducted sequentially.

For data measurement, the passive design element of the ventilation block that is situated above the windows (as shown in Figure 5) that are closed is the only means of cross-ventilation of the internal spaces. As a means of putting passive cooling solutions into action, the control (Scenario 0) is formed purposefully by including ventilation blocks above the windows in the design of the building when it was first constructed. When monitoring and comparing the effectiveness of daytime and nighttime performance, it was necessary to take readings of the temperature and relative humidity inside the building, as well as readings of the air velocity inside the building.

The four scenarios below were monitored for five days each at 1-minute intervals from 28 April 2021:

a. Scenario 0 (Control): windows closed, fan off.
b. Scenario 1: windows open, fan off. This scenario is to maximize cross-ventilation and its effect on indoor thermal comfort.
c. Scenario 2: windows closed, fan on. This scenario is to determine if the wind flow is significantly better with a minimal active design solution such as the ceiling fan. Windows are closed to test the effectiveness of the elevated air velocity and how it impacts the indoor temperature.
d. Scenario 3: windows open, fan on. This would be the optimum scenario to maximize natural ventilation and achieve the best outcome for indoor thermal comfort.



Section C-C (Bedroom 3) Section B-B (Bedroom 1)

Figure 4. Monitoring equipment setup in bedrooms 1 and 3 (Sections B-B & C-C) on the first floor and ventilation block design. (Source: Authors)

To determine which scenario is the most likely to be successful, data from each scenario (T0, T1, T2, and T3) as well as (RH0, RH1, RH2, and RH3) are evaluated and measured. After that, they were compared to the data that corresponds to the outdoor temperature (To) and outdoor relative humidity (RHo) that was collected by a weather station located on top of a building 1.5 kilometers away. Following that, the information that was acquired for the living room was compared with the information that was gathered from bedrooms 1 and 3 to determine whether location and orientation would constitute a significant variable. It is important to take into consideration the arrangement of the space between the ground floor and the first floor in relation to the thermal comfort of the inside of the building. Specifically, this is because the ground floor is designed with an open layout, and the dining area and one side of the living room both have sliding doors that go out to the garden. It was anticipated that there would be heat gain through the building materials, notably in bedroom 1, which was exposed to both morning and afternoon sun.

When determining appropriate levels of thermal comfort, it is common practice to make use of the ASHRAE Standard 55 as a point of reference. It has been proven in previous studies that there is a minimum variance of one degree Celsius in the preferred level of thermal comfort within an interior space between individuals (Fanger, P.O. & Langklide, G. 1975). Due to the subjective nature of thermal comfort, which differs from person to person depending on their tolerance, acclimatization, and clothing, it was decided that the selected case study should involve a unit that was not occupied by any people. Furthermore, this guarantees that the data obtained from a variety of settings will continue to be constant and will not be influenced by the presence of the inhabitants.

Figure 5. Ventilation block used in the case study cottage and the location of *brise soleil* and vent blocks below the roof on the western wall of the living room. (Source: Authors)

4.0 RESULTS AND DISCUSSION

Consistent data collection was conducted for each scenario throughout the course of three consecutive days. Every scenario had a total of 4320 temperature readings taken, which were then averaged on an hourly basis until the result was determined. All four scenarios are shown in Table 2, which shows the average as well as the variability of the living room and bedrooms 1 and 3, respectively. Among the three rooms, the living room has the lowest mean temperature, while bedroom 1 has the highest mean temperature. Tables 3 and 4 present a more in-depth study of the daytime and nighttime data. When the fan is on, there is a rise in temperature for both S1 and S3, which follow the same pattern. It is observed that the ventilation block is most effective for S3, followed by S0, when the fan is not operating. From the box plot in Figure 6 below, the living room temperature range is less volatile compared to bedroom 1, located on the first floor, for all scenarios. A similar pattern is observed for relative humidity as shown in Figure 7.

Table 2. Overall indoor temperature (Ti) (ºC) for the living room and bedrooms 1 and 3.

	Mean	StDev.	Mean	StDev.	Mean	StDev.	Mean	StDev.
Scenario	S0		S1		S2		S3	
Living Room	27.88	0.70	28.15	0.76	27.85	1.24	28.24	1.09
Bedroom 1	28.77	1.21	29.62	1.48	28.58	1.84	28.82	1.55
Bedroom 3	28.09	0.88	28.68	1.01	28.15	1.43	28.33	1.06

Note: **S0** – Fan Off, Windows Closed, **S1** – Fan On, Windows Closed, **S2** – Fan Off, Windows Open, **S3** – Fan On, Windows Open.

Table 3. Daytime (0800 hrs – 1900 hrs) indoor air temperature (Ti) (ºC) data for the living room and bedrooms 1 and 3.

	Mean	StDev.	Mean	StDev.	Mean	StDev.	Mean	StDev.
Scenario	S0		S1		S2		S3	
Living Room	28.27	0.67	28.63	0.66	28.64	1.31	28.68	1.22
Bedroom 1	29.51	1.12	30.55	1.24	29.82	1.84	29.56	1.65
Bedroom 3	28.53	0.93	29.29	0.90	29.06	1.50	28.74	1.17

Note: **S0** – Fan Off, Windows Closed, **S1** – Fan On, Windows Closed, **S2** – Fan Off, Windows Open, **S3** – Fan On, Windows Open.

Table 4. Nighttime (2000 hrs–0700 hrs) indoor air temperature (Ti) (⁰C) data for the living room and bedrooms 1 and 3.

	Mean	StDev.	Mean	StDev.	Mean	StDev.	Mean	StDev.
Scenario	S0		S1		S2		S3	
Living Room	27.49	0.47	27.66	0.50	27.07	0.37	27.81	0.74
Bedroom 1	28.04	0.78	28.69	1.04	27.34	0.57	28.08	1.00
Bedroom 3	27.66	0.55	28.07	0.69	27.23	0.45	27.92	0.76

Note: **S0** – Fan Off, Windows Closed, **S1** – Fan On, Windows Closed, **S2** – Fan Off, Windows Open, **S3** – Fan On, Windows Open.

Each of the selected areas is orientated in a manner that is distinct from the others. Bedroom 1 (B1) is located on the northern side of the house, bedroom 3 (B3) is located on the eastern side of the structure, and the living room is located on the western side of the house. In addition to a sliding door on the south side of the building, the living room features windows that are positioned on the north and west sides of the building. The windows on the western side of the building are topped with a concrete *brise soleil*. The windows in bedroom 1 (B1) are located on the walls to the east and west, whereas the windows in bedroom 3 (B3) are located on the walls to the north, east, and south. It is possible to produce passive cooling through the application of cross-ventilation, and doing so has been confirmed through several simulations. With the windows closed and the fan turned off, the temperature in the living room can remain relatively consistent throughout the day and night during the control scenario (S0). With a maximum temperature of 29.32°C and a minimum temperature of 26.66°C, the average temperature is 27.88°C.

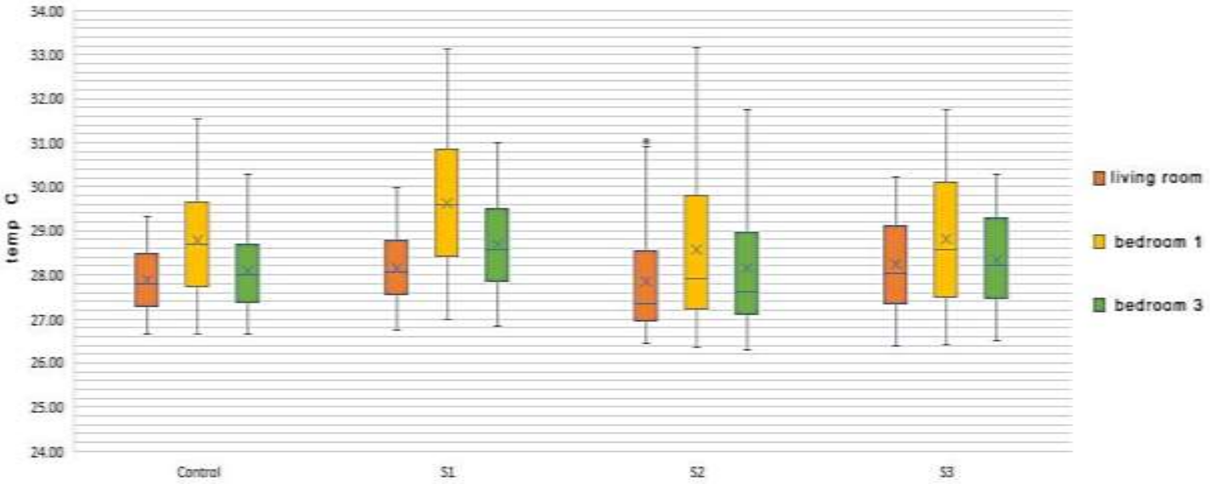


Figure 6. Box plot of indoor temperature according to scenarios for all three spaces.

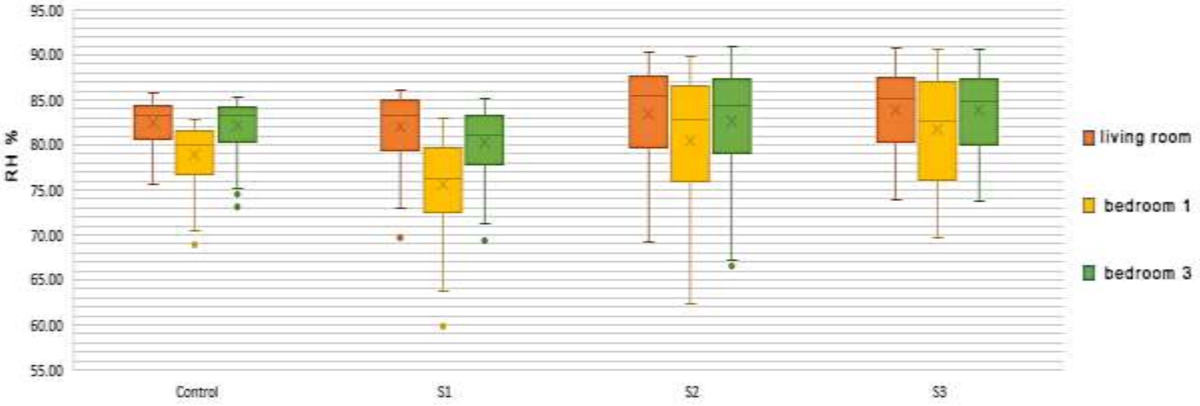


Figure 7. Box plot of relative humidity (RH) according to scenarios for all three spaces.

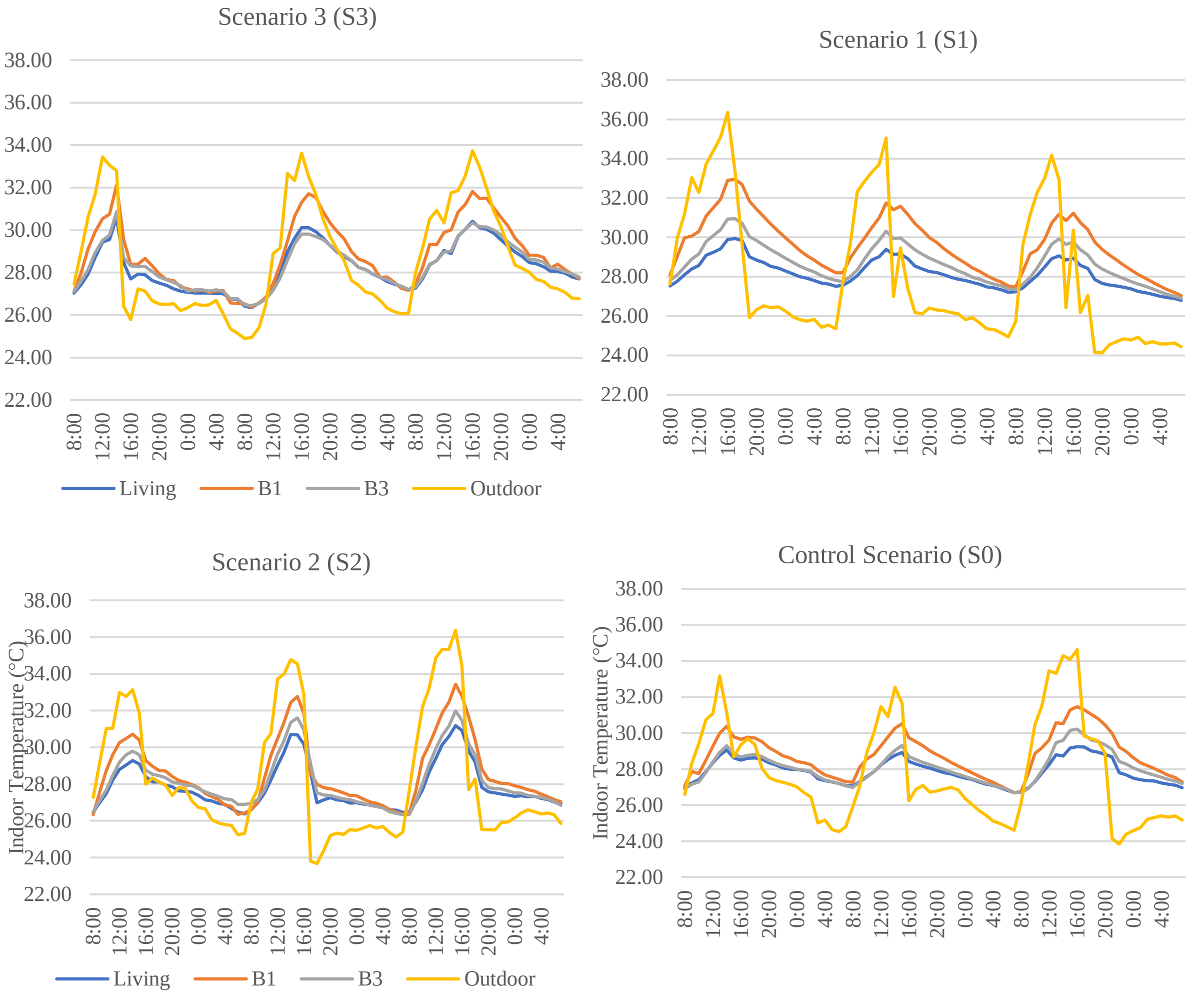


Figure 8. Indoor temperature readings in the living room, and bedrooms 1 and 3 for all scenarios.

There is a greater degree of variation in the temperature swings that occur between day and night in this room, in contrast to bedroom 1 (B1). The alignment of bedroom 1 (B1) is the reason for this, as it causes the north wall of the room to be directly exposed to sunlight throughout the entire day. As a result, the north wall causes heat to be emitted into the room. Bedroom 3 can make use of its location on the east side of the building, which shields it from the sun that comes from the west and enables it to receive cross ventilation from the north to the south. In its entirety, the construction features components of shading that are consistent, the majority of which take the shape of roof overhangs. The overhangs, on the other hand, have a minor impact because of their short height and their inability to adequately shade the windows and cool the air in the surrounding area. The only difference is the concrete *brise soleil* that is placed on the wall against the western side of the living room. The amount of solar radiation that enters the living room from the west is reduced because of this, which leads to a reduction in the amount of heat that is accumulated.

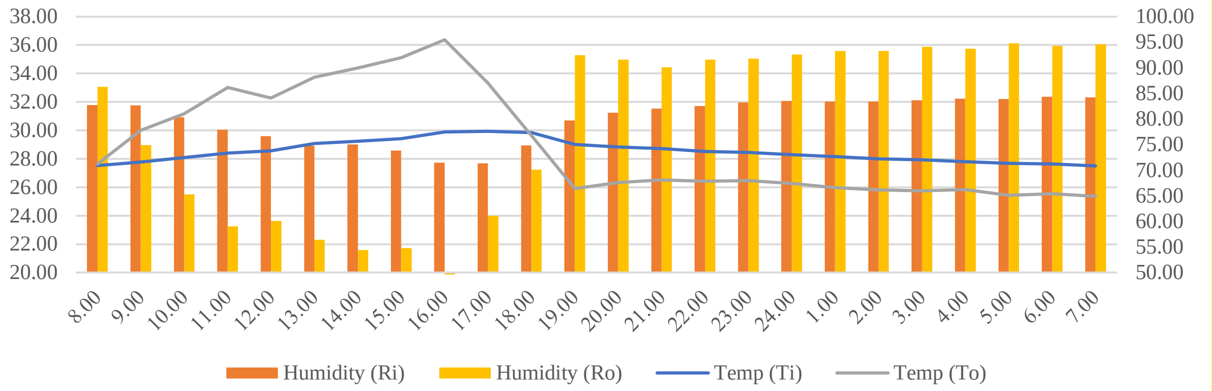


Figure 9. Correlation between T_i and T_o with R_i and R_o living room in control scenario (S0).

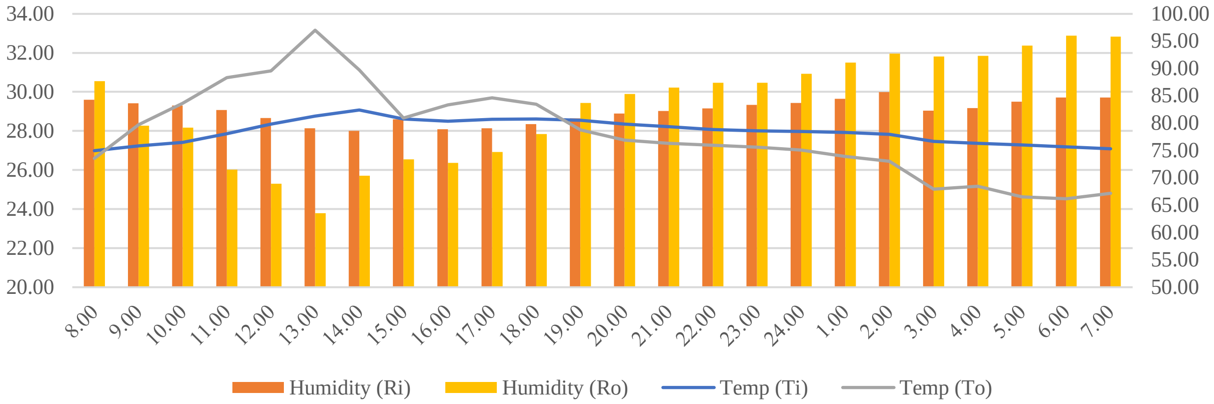


Figure 10. Correlation between T_i and T_o with R_i and R_o living room in scenario 1 (S1).

Figure 9 shows further analysis and illustrates the behavior of relative humidity and temperature both inside and outside throughout the course of a period of twenty-four hours in the living room during the control scenario (S0). The relative humidity inside the living room is less variable than the relative humidity outside, and it is not affected by changes in the relative humidity outside. When the fan is turned on during scenario 1, there is a slight increase in the humidity level inside, as shown in Figure 10. Further, it is found that there is a strong negative Pearson correlation between temperature and relative humidity in the living room, bedrooms 1 and 3, respectively with an $r(288) = -.891, -.943$, and $-.923$; $\rho = <0.001$. Indoor temperatures tend to decrease while the indoor relative humidity increases.

Besides, the impact of the ceiling fan is evident in both the living room and bedroom 1, where the indoor temperature is somewhat elevated while the fan is operational, irrespective of whether the windows are closed or open. Figures 11 and 12 show the impact of the ceiling fan, where in the control scenario, both day and night temperatures indicate a relatively faster temperature decrease than in scenario 1, where the ceiling fan is turned on. It is believed that the ceiling fan would circulate hot air that was accumulated throughout the day. They also indicate a minor lag in the decrease of temperature inside the examined areas. It has been extensively proven that ceiling fans are an effective method to enhance convective heat dissipation (and evaporative heat dissipation in the presence of perspiration) in hot and humid regions.

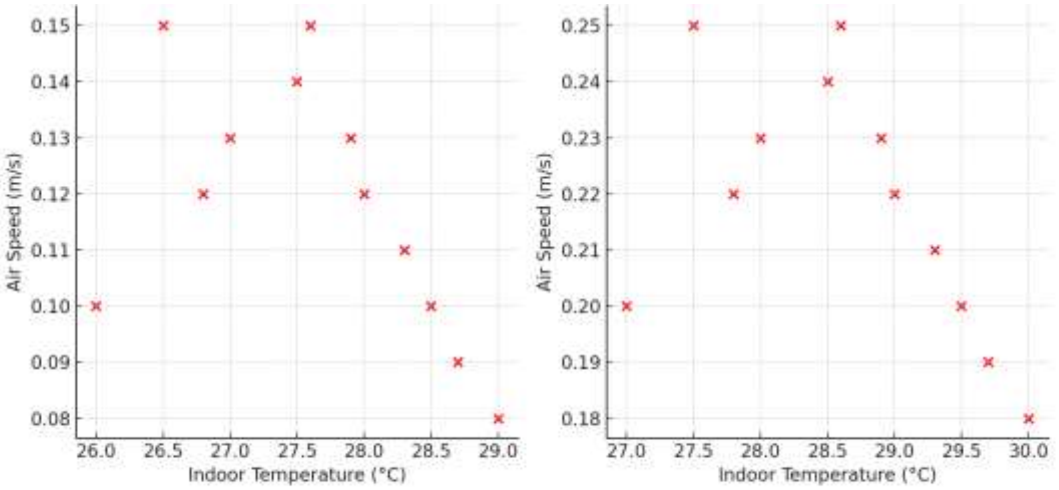


Figure 11. Correlation between indoor temperature and air speed in the living room during the control scenario (S0) (left) and scenario 1 (S1) (right).

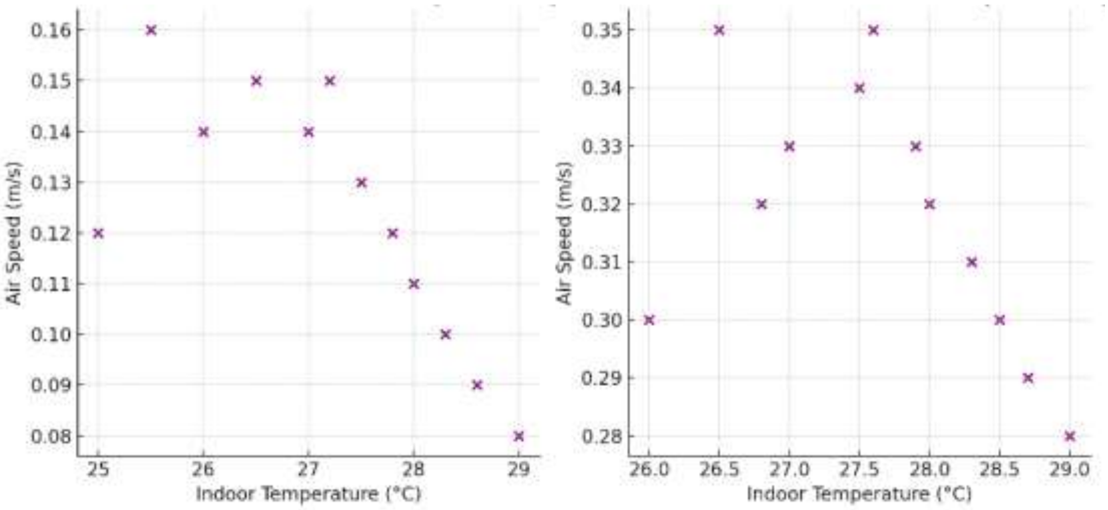
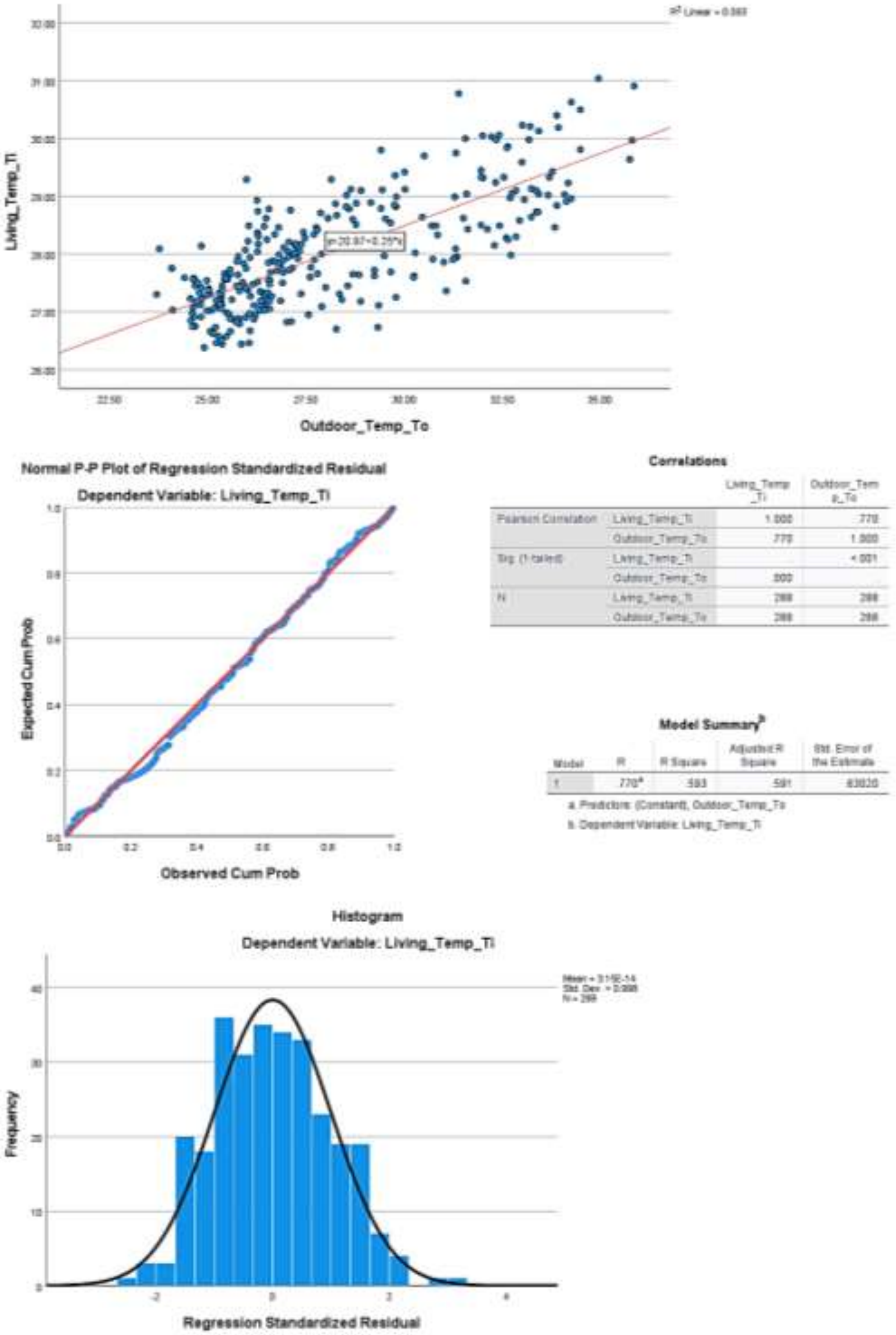


Figure 12. Correlation between indoor temperature and air speed in bedroom 1 during the control scenario (S0) (left), scenario 1 (S1) (middle), and scenario 2 (S2) (right).

An ANOVA test was conducted to examine the correlation between the variables. The results reveal that there is no statistically significant relationship between the temperature and relative humidity in the living room. The ANOVA results, as compiled in the appendix, revealed significant differences in both living room temperatures (F (3, 284) = 2.827, p = .039) and relative humidity (F (3, 284) = 2.907, p = .035) among the groups. However, no significant differences were found in outdoor temperature (F (3, 284) = 0.820, p = .483) or outdoor relative humidity (F (3, 284) = 0.089, p = .966). Similarly, as shown in Table 4.6, there were significant differences in both bedroom 1 temperature (F (3, 284) = 6.409, p =<.001) and relative humidity (F (3, 284) = 14.244, p =<.001). There were no significant differences in outdoor temperature or outdoor relative humidity. Consistently, significant differences were observed in bedroom 3 temperatures (F (3, 284) = 4.078, p = .007) and relative humidity (F (3, 284) = 7.400, p =<.001). Meanwhile, there were no significant differences in outdoor temperature and relative humidity. Therefore, these findings suggest that variations in living room, bedrooms 1 and 3 conditions (change in scenarios) may impact temperature and relative humidity level, while outdoor conditions may remain relatively consistent across groups.



Correlations

		Living_Temp_Ti	Outdoor_Temp_To
Pearson Correlation	Living_Temp_Ti	1.000	.770
	Outdoor_Temp_To	.770	1.000
Sig. (1-tailed)	Living_Temp_Ti		<.001
	Outdoor_Temp_To	.000	
N	Living_Temp_Ti	288	288
	Outdoor_Temp_To	288	288

Model Summary[b]

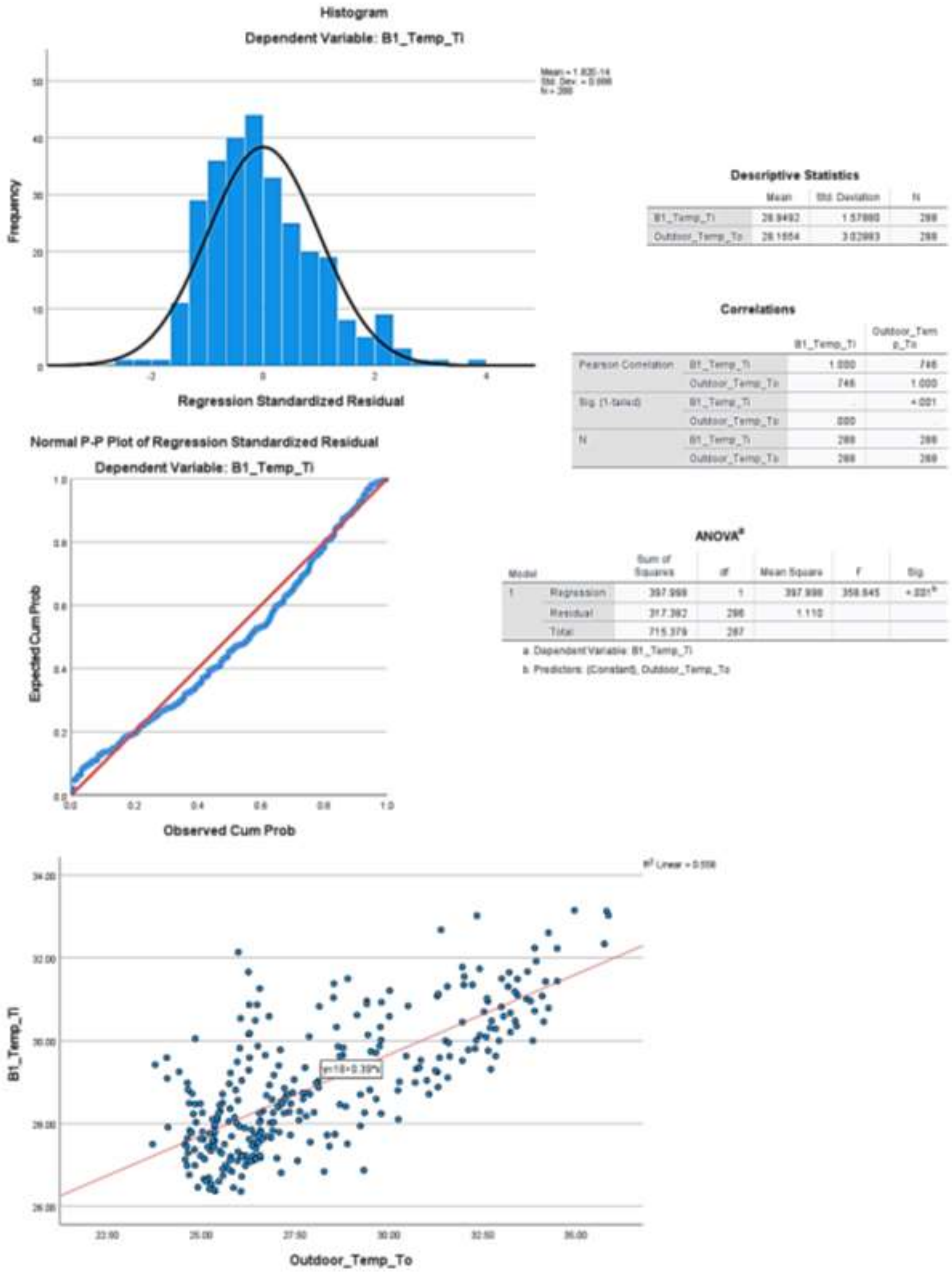
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.770[a]	.593	.591	.83020

a. Predictors: (Constant), Outdoor_Temp_To

b. Dependent Variable: Living_Temp_Ti

Figure 13. Scatter plot and Pearson correlation of the living room.

A simple linear regression analysis was conducted to determine if the outdoor temperature significantly predicted the living room and bedrooms 1 and 3 temperatures. Results shown in Figures 13, 14 and 15 indicate that there was a substantial positive correlation between the temperature inside and outside throughout the day. We found that there was a positive association between the rising temperatures outside and the temperatures inside. On the other hand, the correlation was affected by the insulation and heating and cooling systems that were in place, which influenced the delay in temperature variations between the surroundings of the outer environment and the internal environment. The outdoor against living room, bedrooms 1 and 3 temperatures overall regression are statistically significant (R2 living room = 0.593, F (1, 286) = 416.241, P =<.001); (R2 bedroom 1 = 0.556, F (1, 286) = 358.645, P = <.001); (R2 bedroom 3 = 0.537, F (1, 286) = 331.719), respectively.



Descriptive Statistics

	Mean	Std. Deviation	N
B1_Temp_Ti	28.9492	1.57880	288
Outdoor_Temp_To	28.1654	3.02983	288

Correlations

		B1_Temp_Ti	Outdoor_Temp_To
Pearson Correlation	B1_Temp_Ti	1.000	.746
	Outdoor_Temp_To	.746	1.000
Sig. (1-tailed)	B1_Temp_Ti	.	<.001
	Outdoor_Temp_To	.000	.
N	B1_Temp_Ti	288	288
	Outdoor_Temp_To	288	288

ANOVAª

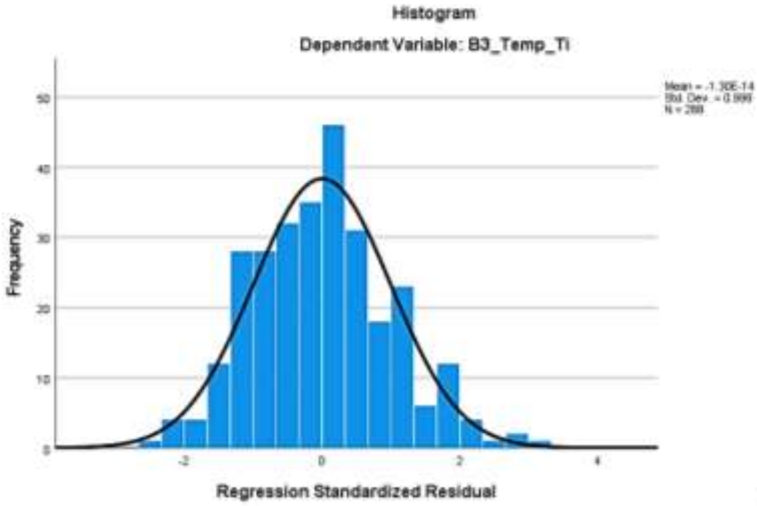
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	397.998	1	397.998	358.645	<.001ᵇ
	Residual	317.382	286	1.110		
	Total	715.379	287			

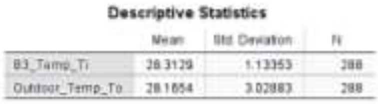
a. Dependent Variable: B1_Temp_Ti

b. Predictors: (Constant), Outdoor_Temp_To

Figure 14. Scatter plot and Pearson correlation of bedroom 1.

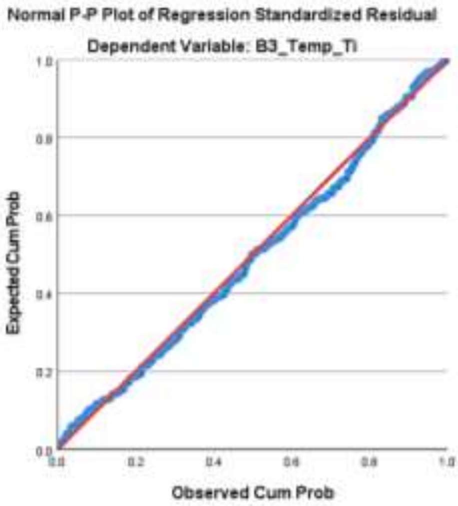
It was discovered that the relationship between the relative humidity within and the conditions outside was more complex than previously thought. Indoor humidity levels in well-insulated environments were only marginally affected by the humidity of the surrounding environment, which resulted in a consistently stable range (Jin et al., 2023). On the other hand, there was a more evident link between the humidity conditions inside the building and the conditions outside the building in regions that had less insulation (Kumar et al., 2020). The case study house is inadequately insulated, resulting in a notable similarity between the external and internal relative humidity levels.





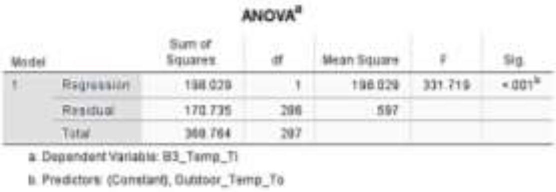
Descriptive Statistics

	Mean	Std. Deviation	N
B3_Temp_Ti	28.3129	1.13353	288
Outdoor_Temp_To	28.1654	3.02883	288



Correlations

		B3_Temp_Ti	Outdoor_Temp_To
Pearson Correlation	B3_Temp_Ti	1.000	.733
	Outdoor_Temp_To	.733	1.000
Sig. (1-tailed)	B3_Temp_Ti		<.001
	Outdoor_Temp_To	.000	
N	B3_Temp_Ti	288	288
	Outdoor_Temp_To	288	288



ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	198.029	1	198.029	331.719	<.001[b]
	Residual	170.735	286	.597		
	Total	368.764	287			

a. Dependent Variable: B3_Temp_Ti

b. Predictors: (Constant), Outdoor_Temp_To

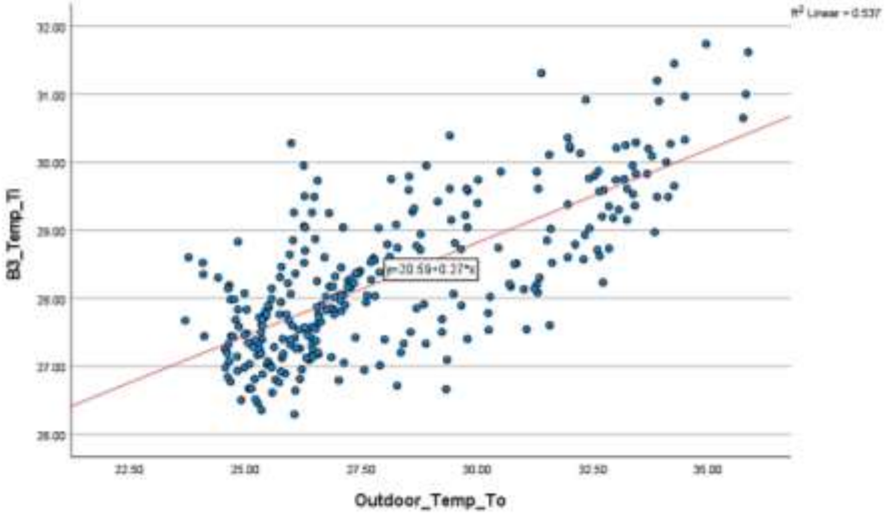


Figure 15. Scatter plot and Pearson correlation of bedroom 3.

This research aimed to assess the effectiveness of passive design elements in a tropical Modernist cottage house through examining the indoor thermal performance and the influence of mechanical ventilation. Passive design elements utilized to regulate the building's internal temperature include concrete *brise soleil* positioned above windows and beneath roofs, ventilation blocks, louvered doors, and strategic building orientation along with window placement to enhance cross-ventilation. A case study involved an experiment done throughout several areas of a Modernist cottage, with four scenarios established to assess the efficacy of the passive design components incorporated in the building's architecture. Data was collected over three days and three nights for each scenario and compared to external weather conditions. Data analysis confirms that passive design components regulate indoor temperature well, albeit under varying conditions. The data indicates that temperature regulation is optimal during the day when windows are closed and the fan is switched off, representing the control scenario. This demonstrates the efficacy of the ventilation blocks positioned above the windows. It additionally enhances during the nighttime hours. When the windows are open, the indoor temperature rises to a degree but rapidly decreases at night. Temperatures vary, but not as markedly due to the humidity. The data acquired when the ceiling fan is on, regardless of whether the window is closed or open, is quite remarkable. The temperature did not decline as anticipated, particularly at night. The data indicates that heat dissipates more slowly when the ceiling fan is operational, mostly because the fan circulates warm air downward instead of permitting it to flow through the ventilation blocks. Passive design features are useful to some extent. Nonetheless, they are significantly influenced by external conditions, including the surrounding environment, building orientation, and regional humidity. Overall, this study achieved its aim and objectives despite the passive design elements are not as efficacious as the authors initially expected, particularly during the day.

5.0 CONCLUSION

The data gathered during the day and evening were analyzed to assess the relationship between relative humidity and its effect on the building's indoor operational temperature. This was achieved by comprehensive analysis. It can be concluded that passive design elements are an effective approach to passive cooling but with potential for enhancement through several methods:

A hybrid strategy entails implementing various cooling scenarios at different periods. The research findings demonstrate that the control scenario, characterized by closed windows and an inactive fan throughout the day, is the most efficient approach for cooling the building. This strategy is recommended to minimize solar radiation and hot air infiltration while the ventilation blocks facilitate air circulation. At night, it is advisable to open the windows while keeping the fan off. This is the suggested line of action to enhance air exchange indoors. It is customary to close windows during the daytime to minimize solar radiation entering the building. Conversely, they are open to facilitating heat dissipation and enhancing airflow, hence leading to a reduction in internal temperature. The findings indicate that relative humidity significantly affects the enhancement of cross-ventilation and air circulation in enclosed spaces. The disparity in humidity levels between indoor and outdoor environments amplifies air pressure differences, hence enhancing cross-ventilation and promoting air circulation.

When the cooling element is configured horizontally, such as a table fan or a standing fan, it may be more suitable to utilize it as an active cooling solution compared to a ceiling fan. This may further improve cross-ventilation. The utilization of a ceiling fan extends heat retention within the enclosed space compared to when the fan is turned off. This suggests that the fan disrupts the natural stack effect, allowing hot air to exit through the ventilation openings. The installation of an extractor fan will help the removal of hot air from the room.

Augmenting the implementation of passive design measures to diminish the influx of solar heat into the structure. To do this, ventilation apertures must be incorporated into the ceiling. These apertures would extract warm air from the interior spaces and create a stack effect, enhancing the egress of hot air via the roof. Additional vent blocks must be installed on the roof to effectively remove hot air, as the existing vent blocks are inadequate for expediting the process. This insufficiency leads to the accumulation of heated air within the roof, thereby causing the ceiling to become hot.

To augment the quantity of ventilation blocks used in the design. The existing quantity of vent blocks utilized restricts cross-ventilation. The positioning of ventilation blocks can be analyzed to facilitate the ingress of air into the space rather than depending on the venting of hot air from the ventilation blocks. The positioning of vent blocks is crucial for enhancing cross ventilation. The inclusion of additional vent blocks beneath the window facilitates the circulation of cool air within internal areas while preventing the ingress of radiative heat.

The existing ventilation block design restricts cross-ventilation to minimize rain ingress into the building. Ventilation blocks can be designed to establish pressure differentials between the exterior and interior, facilitating the intake or expulsion of air, contingent upon their orientation.

To enhance the cooling strategy for the roof. The existing ventilation blocks employed to discharge the hot air gathering on the roof are inadequate for proper cooling. The architecture of the roof can be enhanced by incorporating a ceiling vent or a jack roof system to optimize air circulation and exchange rate within the structure. These enhancements to the roof design will reduce heat transfer from the roof to the areas beneath.

Nevertheless, further research using computer simulations and experiments, particularly on ventilation blocks, are essential to determining their true potential in modern architecture. The same could be done with the effect of various fans on the indoor air flow. Finally, the methodology applied in this study could also be replicated on other tropical Modernist houses to get a wider understanding of the efficacy of their passive design elements.

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