An-Najah University Journal for Research – A
Natural Sciences

Architectural Elements Shaping Thermal Comfort in Floating Houses on Tempe Lake

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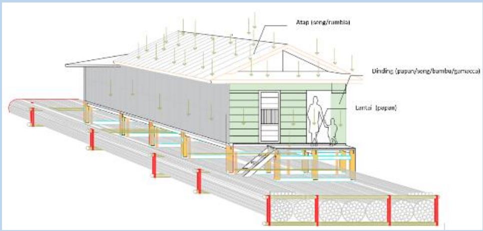
(Type: Full Article]. Received: 22nd Sep. 2025, Accepted: 3rd Nov. 2025, Published ××××, DOI: https://doi.org/10.xxxx

(Accepted Manuscript, In Press]

Abstract: The thermal comfort of buildings in tropical regions is influenced by multiple architectural factors, particularly in vernacular structures located in extreme environmental contexts. This study focuses on floating houses situated on Lake Tempe in South Sulawesi, Indonesia, where environmental conditions present challenges to maintaining indoor comfort. The research aims to identify architectural elements that affect thermal comfort in these houses and to evaluate their effectiveness using both qualitative and quantitative methods. The study was conducted on 11 floating house units selected through purposive sampling, taking into account variations in materials, spatial dimensions, building form, and opening design. Field data were collected through direct observation, interviews, and climate measurements, including indoor temperature and humidity. The analysis involved thematic coding of architectural characteristics and comparison with thermal comfort standards using tools such as the Mahoney Table and the Temperature Humidity Index. The results show that floating houses with cross-ventilation, minimal partitioning, breathable materials like wooden planks, and fabric ceilings exhibit better thermal performance. Conversely, the use of dense or layered wall materials without adequate ventilation increases indoor heat accumulation. The orientation of these houses is not fixed due to water currents and wind direction, which present a unique limitation in achieving optimal solar and wind exposure. This study concludes that passive design strategies, particularly well-placed openings, breathable materials, and open interior layouts, can significantly improve thermal comfort in floating dwellings. The findings offer practical guidance for the future design and construction of thermally comfortable floating houses in similar climatic and environmental settings.



Keywords: thermal comfort, floating house, passive design, natural ventilation, vernacular architecture, tropical climate, Tempe Lake

Introduction

Indonesia is nicknamed a maritime country because Indonesia's waters are wider than its land area, covering almost 2/3 of Indonesia's area [1]. Geographical conditions like this allow settlements in Indonesia to not only be located on lands but also settlement in water areas. Settlements in Indonesian water are quite widespread and have long existed in various water environments in Indonesia [2–4]. One of the water settlements can be found in the Tempe Lake area located in South Sulawesi, Indonesia. Tempe Lake is a water area rich in biodiversity and is used as a fishing area by the local community [5,6].

The presence of settlement on Lake Tempe is the result of adaptation to the need for settlements that bring residents closer to their work locations, namely as fishermen in the waters of Lake Tempe. Especially when the waters of Lake Tempe experience low tide, so that the distance between houses on land and fishing locations is further into the middle of the lake [6].

The house on the waters of Lake Tempe is also used as a residence. As a residential unit, of course, the house on Lake Tempe is a place to return to rest for its occupants after doing various activities outside the home. In order to function optimally as a place of rest, the house must have a comfortable atmosphere, because comfort and tranquility will be able to restore peace and tranquility to the occupants [7,8].

Psychologically, the thermal conditions in floating houses on Lake Tempe are not perceived as comfortable by the occupants, when it feels hot during the day and cold at night. Based on the results of measurements using a thermohygrometer, it is known that during the day the air temperature reaches 31,4oC and humidity 66% and 26,8oC with humidity 88% at midnight. In fact, physically, the floating house in Lake Tempe is also classified as a vernacular building, because it is built based on the behavior and needs of its community. As is known, vernacular buildings are usually built to engineer less than ideal environmental conditions by reducing various local climate discomforts [9,10].

Local climate greatly affects the indoor thermal environment in buildings. Therefore, it is necessary to carry out architectural design interventions so that the thermal comfort conditions of the building are in accordance with the needs of the occupants [11]. As is known, the local climate in Indonesia is included in the tropical climate zone with characteristics of high air humidity (can reach 80%), and relativity high air temperature (can reach up to 35oC) [12]. The seasonal zone in the Lake Tempe area in Wajo Regency is included in the 4-season type or is commonly called

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equatorial, namely a seasonal zone that has a climatological pattern with two peaks of rainfall [11].

Based on these climate conditions, the strategy that can be done to achieve thermal comfort is to lower the temperature during the day and increase it at night. Engineering to achieve thermal comfort can be done in various ways, namely with a mechanical approach, but this requires a lot of operational costs. The second approach is to condition the environment inside the building naturally through an architectural approach [10,13]. Even in many studies it has also been stated that environmental conditioning with an architectural approach can lead to energy savings [14,15].

Architecturally, environmental conditioning inside a building can also be done by considering the placement of the building (orientation of the building to the sun and wind), the use of architectural and landscape elements and the use of materials/building materials that are in accordance with the characteristics of the local climate [16,17]. As noted by Al-Qeeq [18], although thermal comfort methods on an architectural scale are well developed, techniques applied on a broader urban scale still need to be consolidated to promote climate responsive design. Another opinion states that the technique that can be done to achieve this is by modifying climate factors, human body heat exchange and building components [2]. There is a close relationship between thermal comfort and the architectural and construction characteristics of the building, such as layout, spatial dimensions (including height), window-wall ratio, external shading, and the thermal envelope properties of the building [19].

Since the Lake Tempe floating house is located in the middle of the water, not all of these architectural elements can be used to regulate the thermal environmental conditioning. The Lake Tempe floating house stands on a bamboo raft floating on the water. In order not to drift, the house to rotates continuously. This rotation causes the orientation of the house to constantly change. So the building orientation factor needs to be studied further so that it can be used as a design in achieving thermal comfort in floating houses [20].

In addition, the position of the floating house in the middle of the waters causes there to be no vegetation around the floating house that can function as shade or barrier against sunlight and wind, so that the shading/shadow effect can only be obtained from the building itself. Essa and Ihissou [21] also emphasize that the relationship between land surface temperature, material characteristics, and environmental context is complex, particularly in extreme climates, suggesting that similar dynamics may occur in humid tropical zones where water and surface materials influence local temperature distribution. This then becomes a limitation in research related to architectural elements that form thermal comfort in the floating house of Lake Tempe.

Previous studies have examined thermal comfort in various vernacular and tropical contexts. Bodach, Lang, and Hamhaber [17] identified climate-responsive strategies in Nepalese vernacular buildings, while Toroxel and Silva [10] reviewed passive solar heating and cooling systems based on traditional design principles. Other researchers have emphasized the role of passive architectural elements, such as cross-ventilation, shading, and material selection, in achieving energy efficiency and thermal comfort [15,16]. In Indonesia, Rahman and Kojima [22] examined thermal comfort in lanting (floating) houses in Banjarmasin and found that dense wall materials and limited openings increased indoor heat accumulation. Similarly, Muqoffa et al. [22] analyzed natural ventilation in Javanese vernacular houses and highlighted the effectiveness of breathable materials and cross-ventilation for improving indoor comfort.

Although these studies provide valuable insights into passive design strategies, research that specifically addresses floating dwellings located in open-water environments remains scarce. Most existing studies focus on land-based vernacular houses or amphibious structures with fixed orientations and vegetative surroundings. Floating houses on Lake Tempe differ fundamentally because they lack stable orientation due to water and wind dynamics and are fully exposed to solar radiation without external shading. These unique environmental and physical conditions make conventional passive design strategies less applicable and reveal a distinct research gap in understanding how architectural elements perform in such dynamic settings.

Addressing this gap, the present study investigates the architectural elements that influence thermal comfort in floating houses on Lake Tempe. It aims to identify how design factors, such as building orientation, openings, materials, and form, affect indoor thermal conditions and how these can be optimized through passive design. Using field observations, climatic measurements, and comparative analysis with the Mahoney Table and Temperature Humidity Index (THI), this study contributes new empirical evidence to tropical architectural research. The findings are expected to inform future design strategies for floating and water-based dwellings in similar climatic environments.

Materials and Methods

This study uses a qualitative approach with a case study method to identify architectural elements that contribute to thermal comfort in floating houses of Lake Tempe. The case study method is a study of an object, situation or condition of an individual or group of people, or in this case, a building or a series of buildings in a settlement. By using case studies, research can refer to actual situations, with a researcher having the opportunity to make a series of observations [23].

The object of the study was floating houses in Lake Tempe, namely 11 units as samples. The selection of samples was taken using a non-probabilistic purposive sampling technique, where not all units in the population have the same opportunity to become samples [24], depending at least on the ability of the researcher's manpower, funds and time; the narrowness of the observation area of each subject, because it is related to amount of data; the size of the risk borne by the researcher [22]. The number of floating house units taken as samples was 10% of the total population of floating houses in Salotengnga Village, Sabbangparu District, Wajo Regency. Based on data from the Wajo Regency Bapedalda, the number of floating houses in the area was 115 units. The selection of samples was based on certain criteria that were relevant to the study such as construction type, size/dimensions, building materials, types and sizes of openings, and the shape and façade of the building.

The type of data needed in this study is adjusted to the variables of architectural elements and thermal comfort. The following are some important elements that can improve thermal comfort [25], such as:

1. Buiding orientation and layout: Determining the orientation of the building based on the sun can help optimizing sunlight exposure to increase natural heating and cooling according

to seasonal needs. Strategic room placement and open space design also promote better airflow, which contributes to temperature regulation.

2. Building opening: effective natural or mechanical ventilation systems facilities air circulation, remove excess heat, and maintain thermal comfort. Design features such as openable windows, vent, or skylights support natural ventilation strategies. Cross ventilation is very effective in increasing indoor air circulation, helping to reduce temperature and humidity. Facing or crossing windows and doors allows for better air flow. Window types such as vertical sliding eindows and nako windows can increase wind speed and air distribution in room.
3. Building materials: choosing the right building materials can affect the heat transfer and cooling within a building. For example, using materials with high thermal capacity can help balance indoor temperatures. This includes using building materials that have good thermal insulation. Using the right thermal insulation materials can help maintain comfortable interior temperatures. Combining materials with high thermal mass, such as concrete or stone, helps regulate indoor temperatures by absorbing and releasing heat slowly, balancing temperature fluctuations.
4. Roof Design: applying a cool roof that reflects sunlight or a green roof that provides additional insulation can reduce heat absorption, resulting in a cooler indoor environment. Using a roof with additional ventilation or insulation can reduce heat entering the house. Materials such as ceramic tiles or metal roofs with an insulating layer can be good choices. In addition, applying insulation to the ceiling, roof vents, and a heat-shielding layer on the outer surface of the roof can improve thermal comfort in the building.
5. Building form: the shape and geometry of a building affects its energy efficiency and thermal comfort. Studies show that certain shapes, such as rectangular buildings with an east-west orientation, can optimize energy consumtion and increase comfort in certain climates..
6. Use a vegetation: planting various types of vegetation around buildings can create a shady and cool atmosphere, helping to lower the ambient temperature and increase thermal comfort.

Due to the position of the floating house in the middle of water, there is no vegetation around the floating house that can function as shade or barrier against sunlight and wind. So the shading/shadow effect can only be obtained from the building itself. This then becomes a limitation in research related to architectural elements that form thermal comfort in the floating house of Lake Tempe.

Meanwhile, the thermal comfort variable data is climatological data in the Tempe Lake Area. Climatological data for the Tempe Lake area were obtained from the Automatic Weather Station (AWS) operated by the Meteorology, Climatology, and Geophysics Agency (BMKG) located in Bontouse, Wajo Regency, at the location point of Tempe Station, namely at longitude 120º02'17,9" East Longitude and Latitude 04º08'15,3" South Latitude, and is at an altitude of 30 meters above sea level. The location of the Automatic Weather Station (AWS) used in this study is shown in Figure 1. The AWS automatically records air temperature, relative humidity, wind speed, and solar radiation at regular intervals using digital sensors connected to a data logger. The recorded data are transmitted in real time via GSM or satellite telemetry to the BMKG central server in Jakarta, where they are processed and validated before public release [26,27]. The climatological data analyzed is the regional climate data in the Lake Tempe area in a one-year period, namely from January to December 2023.

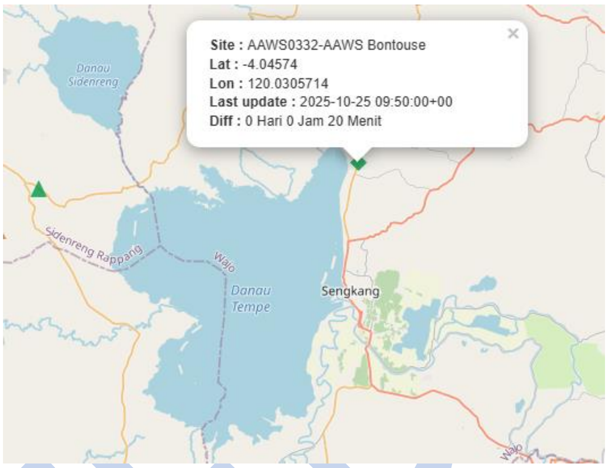


Figure (1): Position of Automatic Weather Station (AWS) towards Lake Tempe (Source**:** https://awscenter.bmkg.go.id).

The steps in analyzing data are as follows:

1. Qualitative Descriptive Analysis
   - Qualitative data were analyzed using thematic coding techniques to identify pattern and architectural elements that support thermal comfort.
   - Categorize architectural elements found in the field.
   - Interpret the relationship between these elements and thermal comfort parameters.
2. Quantitative analysis (supporting)
   - Quantitative data were analyzed descriptively to compare the measurement results with the analysis result using the Mahoney Table and the calculation of the Temperature Humidity Index (THI) using the Nieuwolt equation with the formula:

$$\mathrm{THI} = 0.8 \times \mathrm{T} + \left(\frac{RH \ x\ T}{500}\right) \qquad (1)$$

where: THI = Temperature Humidity Index

T = Air Temperature (ºC)

RH = Relative Humidity (%)

   - Mapping the results of temperature, humidity and air circulation measurements in the form of graphs and tables.
   - Compare physical data with the comfort classification based on temperature and humidity formulated by Nieuwolt as follows:
     - THI < 29 ºC; comfortable;
     - THI = 29 – 30.5 ºC; uncomfortable;
     - THI > 30.5 ºC; very uncomfortable;
   - Comfort standards for tropical areas according to SNI 03-6572-2001:
     - Comfortable cool, between effective temperature 20.5ºC ~ 22.8ºC.
     - Optimal comfort, between effective temperatures 22.8ºC ~ 25.8ºC.
     - Comfortable warm, between effective temperature 25.8ºC ~ 27.1ºC.
3. Data Triangulation

- Combine the results of observations, interviews, and measurements to ensure the validity of the findings.

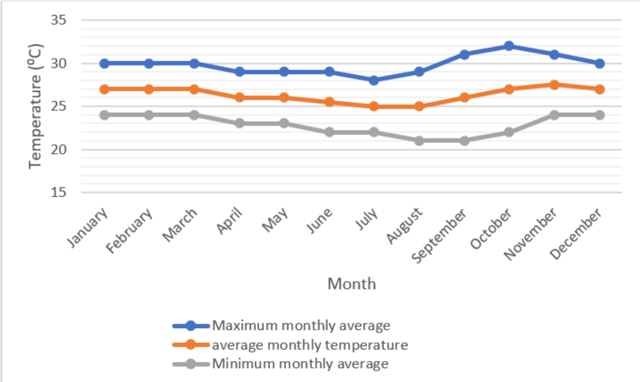
4. Interpretation of Results
   - Linking occupant perception data with physical data to assess the effectiveness of architectural design applied.

Identify relevant passive design principles and provide design recommendations for improving thermal comfort using Mahoney Table analysis.

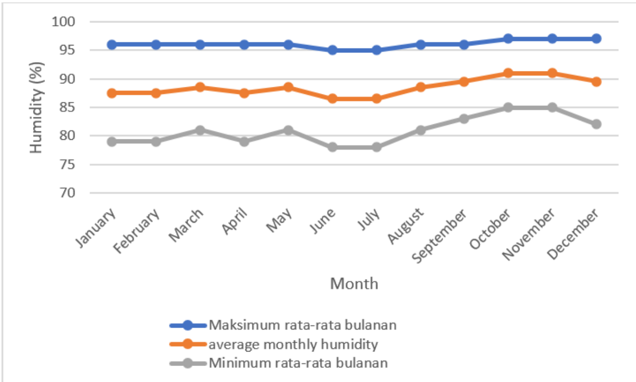
Results and Discussion

Climate Conditions of The Tempe Lake Area

The analysis of climate conditions in the Tempe Lake Area began with the collection of climatological data. The variables measured included air temperature, humidity, rainfall, wind speed, and solar radiation intensity. Data were obtained through two approaches: (1) direct measurements inside a floating house over a 24-hour period, and (2) annual climate records from January to December 2023, provided by the Meteorology, Climatology, and Geophysics Agency (BMKG) of South Sulawesi. The climate data are presented in figure 2 and were subsequently analyzed using the Mahoney Table and the Temperature Humidity Index (THI) to determine the thermal conditions of the Lake Tempe region.



(a)



(b)

Figure (2): Climate Conditions at Lake Tempe (a) Air Temperature and (b) Relative Humidity
Source: compiled by the authors.

The analysis using the Mahoney Table (table 1) indicated that the average maximum temperature reached 32ºC, while the minimum temperature was 24ºC. The average annual temperature (TRT) was 28ºC, with an annual range (RRT) of 8ºC. The average relative humidity ranged between 88% and 92% and persisted throughout the year. Because the mean humidity exceeded 70%, the region was classified as group 4 humidity, with comfort limits of 22-27ºC during the day and 17-21ºC at night. Overall, the climate conditions in the Tempe Lake area were classified as exhibiting hot thermal stress, particularly during daytime hours. Normal thermal stress was observed anly at night, and even then only in the months of August - September.

Table (1): Result of Climatological Data Analysis for The Tempe Lake Area using The Mahoney Table.

	J	F	M	A	M	J	J	A	S	O	N	D	TRT
Maximum monthly average	30	30	30	29	29	29	28	29	31	32	31	30	**28**
Afternoon comfort: above	27	27	27	27	27	27	27	27	27	27	27	27	
Afternoon comfort: below	22	22	22	22	22	22	22	22	22	22	22	22	
Minimum monthly average	24	24	24	23	23	22	22	21	21	22	24	24	
Night comfort: above	21	21	21	21	21	21	21	21	21	21	21	21	
Night comfort: below	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	
Thermal stress: night	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**N**	**N**	**P**	**P**	**P**	

Note: P (hot): if the average temperature is above the limit.
N (comfort): if the average temperature is within the limit.
D (cold): if the average temperature is below the limit.
Source: compiled by the authors.

Based on the temperature and humidity data presented above, the monthly average temperature range from 25ºC to 27,5ºC, while the average relative humidity throughout 2023 remained between 88% to 92%. These data were then analyzed using the Nieuwolt equation to obtain the results presented in Table 2.

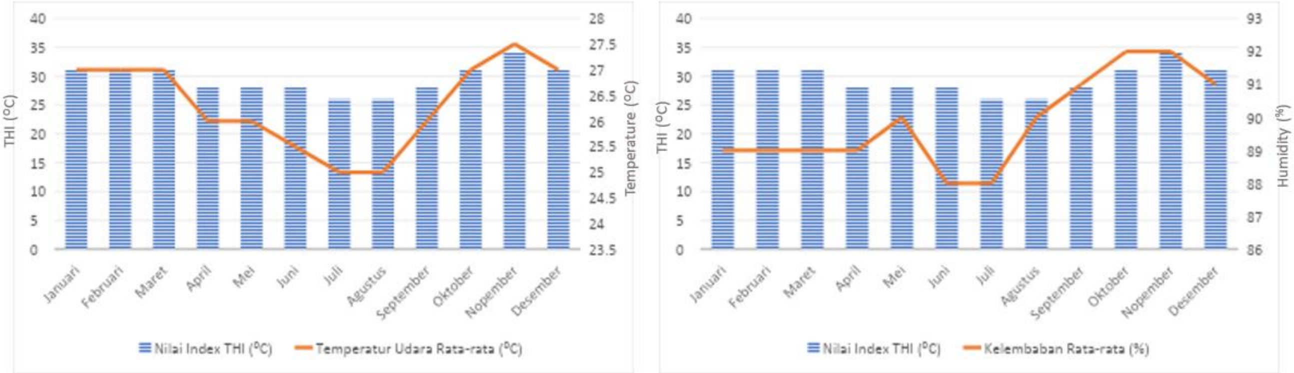
The THI analysis indicated that index values in the Tempe Lake area ranged from 26°C to 34°C. The minimum value of 26°C occurred in July–August, while the maximum value of 34°C was recorded in November.

Figure 3 illustrates that increase in the THI values are directly proportional to increase in air temperature. By contrast, variations in average relative humidity have little influence on THI values. The analysis indicates that the Tempe Lake area falls within the comfortable classification from April to September, while the remaining months are categorized as wery uncomfortable.

Table (2): THI Index Values for The Tempe Lake Area.

Month (Year 2023)	THI Index Value (ºC)
January	31
February	31
March	31
April	28
May	28
June	28
July	26
August	26
September	28
October	31
November	34
December	31

Source: compiled by the authors.



(a) (b)

Figure (3): Relationship between (a) Average Air Temperature and THI Values, and (b) Average Relative Humidity and THI Values
Source: compiled by the authors.

Overall, the results obtained from both analytical tools suggest that the climate conditions in the Tempe Lake area are generally characterized by hot thermal stress, despite occasional periods of comfort. The Mahoney Table analysis provides several design recommendations for floating houses: adopting open-plan layouts to maximize wind penetration, maintaining interior spaces without partitions to support continuous air circulation, and positioning openings on the north and south façades at approximately human height and oriented toward prevailing winds. These openings should be protected from rainfall. In addition, lightweight roofing materials with thermal insulation and adequate rainwater drainage are strongly recommended.

Analysis of Architectural Elements Affecting Thermal Comfort

Data on architectural elements were collected from 11 floating houses included in the study. The information was grouped into six categories: building orientation, building form and layout, building openings, building materials, roof design, and vegetation and external shading.

Architectural characteristics are summarized in Table 3, which presents data on building shape, dimensions, materials, and the ratio of openings to interior volume. Building openings are typically located on the left and right sides of the houses, while the front side remains closed, as it faces prevailing winds.

The 11 floating houses examined in this study exhibit variation in architectural elements, particularly in room dimensions, building materials, and openings, as outlined in Table 3. Their corresponding thermal conditions are presented in Figure 4.

Table (3): Architectural Elements of the Floating Houses.

Sample Code	Floating House Unit	Dimensions	Material	Opening
S1		P = 10 m L = 3 m T = 2 m	Roof: zinc Ceiling: fabric Walls: wooden boards	5 %
S2		P = 10,35 m L = 3,75 m T = 1,8 m	Roof: zinc Ceiling: Walls: zinc (front), wooden planks (right), gamacca (left)	3 %
S3		P = 10 m L = 4,5 m T = 1,85 m	Roof: zinc Ceiling: Walls: zinc	3 %
S4		P = 10 m L = 3 m T = 1,85 m	Roof: zinc Ceiling: Walls: bamboo (used fishing gear)	3 %
S5		P = 9,5 m L = 3,75 m T = 1,8 m	Roof: zinc Ceiling: plywood Walls: gamacca (outside), plywood (inside)	3%
S6		P = 12 m L = 4 T = 2	Roof: zincalum Ceiling: Walls: wooden planks (bottom), gamacca (top)	5 %
S7		P = 9 m L = 4 m T = 1,85 m	Roof: zinc Ceiling: fabric Wall:gamacca	3 %

Sample Code	Floating House Unit	Dimensions	Material	Opening
S8		P = 8 m L = 4 m T = 1,9 m	Roof: zinc Ceiling: Walls: zinc (front), bamboo (side)	2 %
S9		P = 9,8 m L = 3,9 m T = 1,8 m	Roof: zinc Ceiling: fabric Wall: bamboo	3 %
S10		P = 10 m L = 4 m T = 2 m	Roof: zinc Ceiling: Wall: Gamacca	5 %
S11		P = 8,25 m L = 3,15 m T = 1,76	Roof: zinc Ceiling: Walls: board (front), zinc (side)	3%

Source: compiled by the authors.

Based on the measurement data, the highest temperatures were recorded between 15:00 and 16:00, ranging from 30.72 °C to 36.29 °C, while the lowest temperatures, between 25.40 °C and 26.13 °C, occurred between 04:00 and 10:00. Relative humidity values ranged from 67.27% to 89.36% at their highest, and from 38.31% to 69.64% at their lowest. The maximum temperature was observed in sample S5, which reached 36.29 °C at 16:00 with a corresponding humidity of 42.96%. In contrast, the minimum temperature was recorded in sample S1 at 25.40 °C, with a relative humidity of 85.19%.

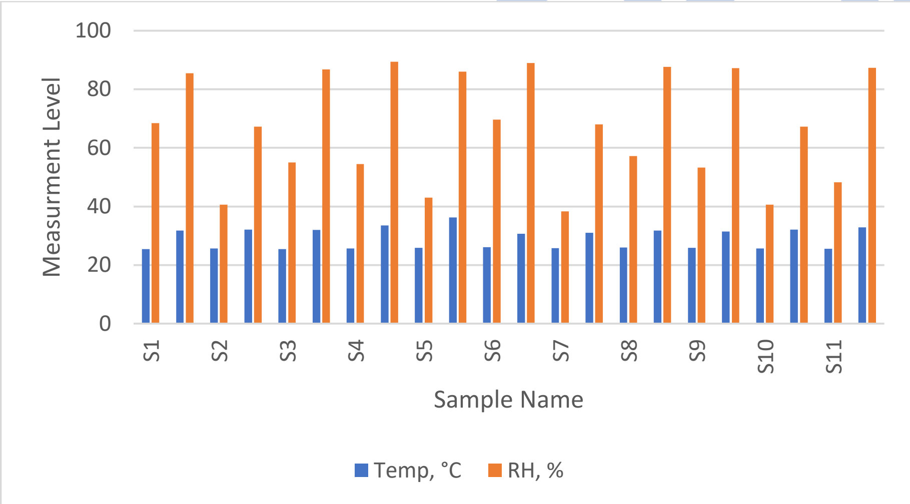


Figure (4): Minimum and maximum Temperature and Humidity values for each research sample.
Source: compiled by the authors.

The elevated temperatures observed in sample S5 are primarily attributed to its layered wall construction. The exterior wall is made of *gamacca* (woven bamboo), while the interior wall is covered with plywood, which restricts airflow and reduces natural ventilation. In addition, the plywood ceiling is integrated with the inner wall, further limiting the effective area of openings for air exchange. Although the ceiling provides some insulation against heat transfer from the zinc roof, it significantly reduces ventilation efficiency, contributing to higher indoor temperatures.

In contrast, the lower temperatures observed in sample S1 are attributed to the use of wooden planks installed crosswise, with gaps between each plank that function as ventilation openings and facilitate smoother air circulation. Additionally, a gap between the wall and the fabric ceiling further enhances airflow, as illustrated in Figure 5.

1.

(a)

(b)

(c)

(d)

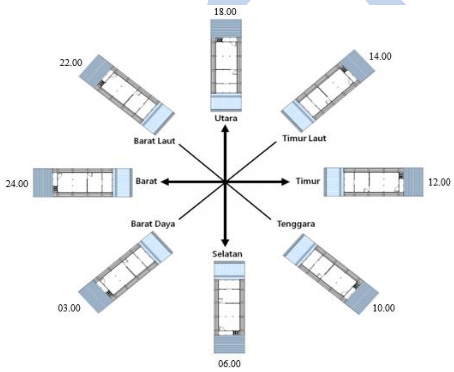
Figure (5): Architectural elements of selected samples: (a) Exterior of S5, (b) Interior of S5, (c) Exterior of S1, and (d) Interior of S1
Source: compiled by the authors

1. Building orientation

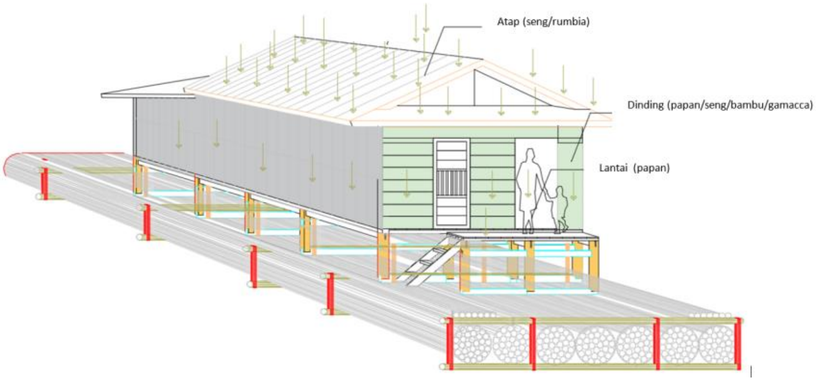
All floating house units exhibited similar orientation patterns, characterized by irregular positioning that shifts in response to wind direction and water currents (Figure 5a). The orientation changes continuously over a 24-hour cycle. Observations showed that at approximately 08:00 WITA, when the wind moved from north to south, houses tended to face north. By 10:00 WITA, as the wind shifted 90 degrees, the houses reoriented to the southwest. During midday, when the sun was directly overhead and the wind came from the west, the houses rotated to face west. In the evening, the wind gradually shifted from west to east, causing the houses to realign until dawn, when they returned to their original orientation. These continuous changes are caused by the combined effects of water currents, waves, and wind deflection. Observations showed that this continuous movement alters solar exposure throughout the day. When houses face west during the afternoon, indoor temperature peak above 34ºC due to direct solar gain. The absence of a stable orientation reduces the potential for consistent cross ventilation, increasing heat accumulation during calm weather periods.

2. Building form and layout

As shown in Figure 5(b), the shape of the floating houses generally follows the traditional Bugis architectural style, reflecting community knowledge and adaptation to environmental conditions on Lake Tempe. The houses typically have a square floor plan averaging 10 m × 3.5 m, smaller in area than traditional Bugis houses, and feature a saddle-shaped roof. Most units employ an open-plan interior with single open spaces that allowed air to flow freely. Units with minimal internal partitions achieved better thermal conditions because air circulation was uninterrupted. although some include a small enclosed room functioning as a bedroom. Houses with subdivided rooms experienced localized heat buildup, particularly during the afternoon. The study found a clear correlation between open-plan layouts and reduced THI values, indicating improved comfort levels.



(a)



(b)

Figure (5): (a) Orientation of the Floating Houses, and (b) Shape of the Floating Houses
Source: compiled by the authors

3. Building openings

Openings are critical in achieving natural ventilation. Houses with larger and cross-positioned openings (such as S1, S6, and S10) maintained lower average indoor temperatures (26–28°C) compared with houses with limited openings (S3, S5, and S8), where temperatures often reached above 35°C. Building openings are typically located on the left and right sides of the houses, while the front side remains closed, as it faces prevailing winds. The effective window-to-wall ratio ranged from 2% to 5%, and even small gaps between wooden planks contributed significantly to airflow. Figure 7 illustrates the various opening configurations, with samples S1 and S6 demonstrating the most efficient cross-ventilation patterns.

(a) (b) (c) (d) (e) (f)

Figure (7): Types of Opening in Research Sample
Source: compiled by the authors

4. Building materials

Material selection strongly influenced indoor temperature. Units with breathable materials, particularly wooden planks and bamboo, showed lower thermal accumulation, as air could pass through the material gaps. In contrast, zinc and plywood combinations, as found in S5, restricted ventilation and caused heat entrapment. The fabric ceiling in some units (e.g., S1 and S9) served as a thermal buffer that reduced direct heat transfer from zinc roofing but maintained sufficient permeability for ventilation.

5. Roof Design

All samples used pitched zinc roofs typical of Bugis Architecture, but variations in material and ceiling treatment affected thermal behavior. Zinc-alum roofs with added ceiling layers (S6) exhibited slightly lower indoor temperature compared to standard zinc. However, fully enclosed ceiling reduced air exchange, trapping heat beneath the roof plane. The addition of small vent openings near the ridge line improved exhaust ventilation in a few cases.

6. Vegetation and external shading

Due to their position in the middle of the lake, the floating houses lacked surrounding vegetation that could provide shade or filter wind. As a result, direct solar radiation was the main external thermal load. The absence of natural shading underscores the importance of optimizing other passive elements, especially openings and breathable materials, to compensate for this limitation.

Discussion

The climate of the Tempe Lake area, as determined through analysis using the THI index and the Mahoney Table, falls within the comfortable classification from April to September, while the remaining months are categorized as very uncomfortable. The Mahoney Table analysis therefore suggests several design specifications for floating houses: adopting open interior layouts to maximize wind penetration, maintaining single, nonpartitioned spaces to ensure continuous air movement, and placing openings on the north and south façades at approximately human height on the windward side. These openings should be protected from rainfall. In addition, lightweight roofing materials with thermal insulation and adequate drainage are recommended.

The identification of architectural elements across the 11 floating houses reveals that their orientation is not fixed but shifts with wind direction and water currents. Observations show that the side of the building facing the wind is usually the front, where walls are generally kept closed except for doors used as circulation points. Openings are instead concentrated on the sides, often in the form of gaps between crosswise wooden planks or between bamboo elements.

Among the 11 research units, the most thermally comfortable house was sample S1, which featured gaps between wooden planks functioning as ventilation openings, along with a fabric ceiling that reduced heat transfer from the zinc roof. Its open interior layout further enhanced air circulation.

The findings of this study are expected to serve as a reference for selecting appropriate architectural elements in the design of floating houses to achieve optimal thermal comfort. Improved comfort in floating houses not only enhances daily living conditions but also reduces potential health risks. Excessively high indoor temperatures can cause problems such as excessive sweating, fatigue, and skin irritation. Therefore, creating acceptable and comfortable indoor environments is essential for supporting the health, emotional well-being, and overall quality of life of residents

Conclusion

This study examined the architectural elements that influence thermal comfort in floating houses on Lake Tempe, South Sulawesi. Climate analysis and field observations revealed that thermal conditions in these dwellings are shaped primarily by design features such as orientation, the size and placement of openings, wall and roof materials, and interior spatial layout. Although the local climate is characterized by high daytime temperatures and humidity, certain configurations were able to maintain more comfortable indoor conditions. In particular, houses constructed with breathable materials such as wooden planks, designed with cross-ventilation through strategically placed openings, and organized with open interior layouts demonstrated improved thermal performance.

The findings underscore the value of passive design strategies in mitigating the challenges of extreme tropical climates. Site-related constraints—including the absence of vegetation and the continuous rotation of houses due to wind and water currents—make the optimization of internal architectural features especially critical. The study recommends lightweight insulated roofing, open-plan interiors without partitions, and protective openings placed at human height on windward façades. These strategies can enhance indoor comfort, safeguard resident health, and contribute to sustainable housing solutions for water-based communities.

Future floating house design and renovation efforts should prioritize such passive approaches as cost-effective alternatives to mechanical cooling systems, particularly in tropical regions facing comparable environmental challenges.

Disclosure Statement

- **Ethics approval and consent to participate:** This study was reviewed and approved by the main supervisor and co-supervisor. Formal approval from an institutional ethics committee was not required for this research. All participants were informed about the objectives of the study, and informed consent was obtained prior to their participation.
- **Consent for publication:** Consent for publication was obtained from all participants whose data, images, or other personal details are included in this manuscript. In the case of underage participants, consent was obtained from their parent or legal guardian.
- **Availability of data and materials:** The datasets supporting this study are presented within the text and figures of the manuscript. Additional data may be obtained from the corresponding author upon reasonable request.
- **Author's contribution:** The authors confirm their contributions to the study as follows: study conception and design: Armiwaty, Nurul Jamala; methodology and field investigation: Armiwaty, Baharuddin Hamzah; data analysis and interpretation: Armiwaty, Rosady Mulyadi; draft manuscript preparation: Armiwaty. All authors reviewed the results, contributed to the discussion, and approved the final version of the manuscript.
- **Funding:** This research was self-funded by the authors and did not receive external financial support from any granting institution.
- **Conflicts of interest:** The authors declare that there is no conflict of interest regarding the publication of this article.
- **Acknowledgements:** I would like to express my deepest gratitude to my promoter, Prof. Nurul Jamala, and my co-promoters, Prof. Baharuddin Hamzah and Dr. Rosady Mulyadi, for their invaluable guidance, continuous support, and insightful feedback throughout the course of this research. Their expertise, encouragement, and patience were instrumental in shaping both the direction and the quality of this study. I am sincerely thankful for their commitment and mentorship at every stage of the research process.

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