



## ***Thermal Comfort Evaluation of Low-Cost Rental Flats in a Coastal Tropical Area***

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### **Abstract**

*Low-cost rental flats in Indonesia face significant thermal discomfort challenges due to high humidity and reliance on natural ventilation. This study evaluates the thermal environment of Kampung Nelayan II Sungailiat low-cost rental flat to understand housing quality in humid tropical coastal areas. Using a quantitative approach, measurements of air temperature, humidity, and wind speed were conducted in 11 residential units. Data were analyzed using the Thermal Humidity Index (THI) and CBE Adaptive Method. Results reveal a discrepancy: THI categorized all units as uncomfortable, while CBE (Center for the Build Environment) simulations identified eight units as comfortable. Discussion suggests that while THI is a useful indicator of heat stress, it is limited in accounting for human physiological adaptation and airflow. The study concludes that the CBE Adaptive Model is more suitable for evaluating local thermal tolerance. Design strategies must prioritize passive cooling, specifically optimized building orientation and cross-ventilation.*

**Keywords:** center for the build environment adaptive method; low-cost rental flats; thermal comfort; thermal humidity index

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## **1. INTRODUCTION**

Low-cost rental flats (*rusunawa*) are designed as a housing policy instrument to provide decent and affordable housing for low-income communities, especially in densely populated urban areas (Rahayu & Winandari, 2025; Viska & Mukhsin, 2021). The construction of low-cost rental flats is not only intended to address land constraints and quantitative housing needs, but also to provide adequate environmental quality for residents. According to the Indonesian statute 20/2011, the establishment of vertical housing needs to ensure the provision of livable housing, including its comfort, health, welfare, and sustainability of the

area as part of the effort to attain the economic, social, and cultural resilience (Undang-Undang Republik Indonesia Nomor 20 Tahun 2011 Tentang Rumah Susun, 2011). However, various studies show that low-cost vertical housing in developing countries often faces spatial quality issues, particularly related to thermal comfort in spaces due to limited unit size, domestic activity density, and minimal support from artificial air conditioning systems (Aderinsola et al., 2025; Fitriaty et al., 2024). These conditions make thermal comfort a crucial issue in evaluating the quality of vertical housing, especially in humid tropical regions such as Indonesia. This is particularly true for coastal areas in Indonesia.

In practice, coastal low-cost rental apartments are designed with a typical approach that does not take into account the local climate characteristics and specific needs of coastal communities, thus potentially causing more serious thermal comfort problems than similar housing in non-coastal areas. Therefore, this study focuses on evaluating thermal comfort in low-cost rental flats housing located in coastal areas. With a common building layout that mostly applies to the hotel or commercial apartment building with the mechanical air conditioning systems, the design for the low-cost vertical housing in Indonesian coastal areas are often disregarding the requirement for thermal comfort for the low socio-economic demographic that mostly relies on the natural building cooling system from the coastal weather and forcing them to adapt with the unsuitable building layout. In addition to the over-generalized design made by the housing provider, such negligence in the design process also comes from the lack of understanding on how the thermal comfort are being assessed for the low-cost vertical housing and simply relies on the low-income tenants' behavior to adapt with the discomfort. This research aims to shed light on the coastal and low-cost vertical housing's building performance by assessing the thermal comfort of the fisherman's vertical housing in Sungailiat city, Bangka Island, Indonesia.

### **1.1. Thermal Comfort and Standards**

The comfort of residential spaces cannot be separated from the quality of the physical environment within the space, one component of which is thermal comfort. Thermal comfort is understood as a subjective condition in which individuals feel satisfied with their thermal environment, which is formed through the interaction between physical parameters of the space and human adaptive responses (Bridgette et al., 2026). In the context of residential buildings, the main parameters that affect thermal comfort include effective temperature, relative humidity, and wind speed. In Indonesia, these parameters are normatively referred to in the Indonesian National Standard SNI 03-6572-2001 concerning Procedures for the Design of Ventilation and Air Conditioning Systems in Buildings (Badan Standarisasi Nasional (BSN), 2001), which specifies the range of thermal

comfort. Although compiled as technical guidelines for design, this Indonesian National Standard (SNI) is still widely used as a reference for evaluating the thermal conditions of buildings in architectural and built environment research in Indonesia (Mulfakli et al., 2025; Shelviana et al., 2023). In addition, the international standard ASHRAE 55:2020 is also widely used as a reference in assessing thermal comfort. ASHRAE 55: Thermal Environmental Conditions for Human Occupancy is the most widely used international guideline for determining thermal environmental conditions that are acceptable to most building occupants. This standard stipulates that thermal comfort is influenced by a combination of environmental and personal factors, with the main parameters including air temperature, relative humidity, and wind speed, as well as metabolic factors and clothing type (Kahir, 2024; Noor Fitri Indah P & Hariyadi, 2023).

### **1.2. Thermal Comfort in Coastal Areas**

Coastal areas in Indonesia are generally inhabited by fishing communities, port workers, and other informal sectors. These communities have limited access to adequate housing, so the construction of low-cost flats in coastal areas is an important strategy to reduce slums in coastal areas and improve the quality of life of coastal communities (Viska & Mukhsin, 2021). In coastal areas, achieving the thermal comfort conditions recommended in these standards poses greater challenges. High outdoor temperatures throughout the day, intense solar radiation, and relative humidity that tends to be above 70% cause residential spaces to easily accumulate excess heat and humidity. Although sea breezes have the potential to improve natural ventilation, fluctuations in wind direction and speed often cannot guarantee stable airflow within residential units, especially in multi-story buildings with less than optimal mass configurations (Rufaida, 2024). As a result, the thermal conditions of public housing units in coastal areas are often outside the normative comfort range, especially in the morning, afternoon, and evening, thereby increasing the risk of thermal discomfort for residents.

In public housing, this condition is exacerbated by the limitations of artificial ventilation systems due to residents' limited purchasing

power and building operational cost considerations. Most public housing is designed with a high dependence on natural ventilation, so that the quality of the thermal environment inside the room is greatly influenced by outdoor climate conditions, building orientation, opening configuration, housing density, and the intensity of domestic activities inside the unit (Gunawan, 2024; Surya Ananta & Suryabrata, 2024; Suwarno & Prayitno, 2021).

In addition to the above factors, the limited size of public housing units further complicates the issue of indoor comfort. The relatively small size of the units encourages high-intensity domestic activities in a confined space, which has the potential to increase internal heat load and worsen the thermal conditions of the space. In the context of coastal areas, this problem is even more complex due to the dynamic nature of fishing communities, which tend to carry out domestic and productive economic activities in the same living space, such as repairing nets, processing catches, and storing fishing equipment (H. et al., 2019). These activities contribute to an increase in internal heat load and humidity, thereby significantly impacting the comfort of the space and the quality of life of its occupants. From a sustainability perspective, spatial comfort is an important indicator of housing quality because it is directly related to Indoor Health and Comfort (IHC) in the Green Building approach. IHC 6 emphasizes the importance of creating thermal comfort by maintaining stable air temperature and humidity in conditioned rooms to increase the productivity of building users (Felly et al., 2024; GBC Indonesia, 2013).

Based on these conditions, empirical measurements of air temperature, relative humidity, and wind speed inside public housing units in coastal areas are an important step in objectively understanding the quality of thermal comfort in spaces.

### **1.3. Thermal Humidity Index (THI)**

The Thermal Humidity Index (THI) is an analytical method used to determine thermal comfort levels in a region by combining two main climate parameters: air temperature and relative humidity. This index provides an objective picture of the effects of heat conditions on humans, which are closely related to health

and work productivity (Harmin et al., 2025; Rahmadyani & Fahri, 2024). This index is particularly relevant in tropical climates such as Indonesia, which is characterized by heat and humidity year-round. The application of the THI spans various research scales, ranging from comfort analysis in high-rise buildings and transition zones (thresholds) to environmental quality assessments in public open spaces such as city parks and town squares (Harmin et al., 2025).

### **1.4 CBE (Center for the Built Environment) Thermal Comfort Tool**

Thermal comfort is an important aspect in building design, especially in tropical climates such as Indonesia. Thermal comfort directly affects health, productivity, and space quality, while also being a determining factor in building energy efficiency (Lestari et al., 2022). Therefore, thermal comfort evaluation is an essential part of sustainable architecture and green building studies, especially in buildings that rely on natural ventilation.

One widely used approach is the CBE Thermal Comfort Tool developed by the Center for the Built Environment (CBE), University of California, Berkeley. This tool is used to analyze thermal comfort levels based on environmental parameters and user characteristics, either through the PMV or Adaptive Method approach (Adi Prabawa et al., 2023; Kahir, 2024; Zuraihan, Cut Azizah, 2024). In Indonesia, CBE has been applied in various architectural studies to evaluate the thermal performance of residential houses, vernacular buildings, and public facilities, and has been proven to comprehensively describe the thermal conditions of a space.

PMV predicts the average thermal sensation of humans on a scale of  $-3$  (cold) to  $+3$  (hot), taking into account six main variables: air temperature, average radiation temperature, relative humidity, wind speed, metabolic rate, and thermal resistance of clothing. This model produces PMV and PPD (Predicted Percentage of Dissatisfied) indices (Rahmadyani & Fahri, 2024). The PMV approach is recommended for buildings with mechanical ventilation systems (air conditioning) and relatively stable thermal environments. ASHRAE Standard 55 states that PMV is suitable for use in air-conditioned

buildings with strict temperature control (ANSI/ASHRAE, 2017).

The adaptive method was developed based on global field data showing that humans are able to adapt to the thermal environment through physiological, behavioral, and psychological mechanisms. This method links the comfortable temperature in a room to the average outside air temperature, thus reflecting the adaptive response of building users. The adaptive method is recommended for evaluating the thermal comfort of buildings that rely on natural ventilation. This approach refers to ASHRAE Standard 55, which recommends the use of the adaptive method for naturally ventilated buildings that do not use artificial or mechanical ventilation. This method links comfort temperature to outdoor climate conditions, making it more suitable for tropical buildings (ANSI/ASHRAE, 2017).

In simulations using the CBE Thermal Comfort Tool Adaptive Method, the main parameters used include indoor air temperature, outdoor air temperature, and wind speed. These three parameters play a dominant role in influencing the perception of thermal comfort. Research (Qodir et al., 2020) shows that the adaptive method is able to represent the comfort perception of users of naturally ventilated buildings more accurately than the PMV approach.

Therefore, the use of the CBE Thermal Comfort Tool based on the adaptive method is a relevant, contextual, and applicable approach for evaluating the thermal comfort of tropical buildings without mechanical ventilation in Indonesia, as well as supporting the design of sustainable buildings oriented towards user comfort (Kahir, 2024).

This study aims to contribute to the discussion on the applicability of thermal comfort standards in tropical residential buildings, particularly in naturally ventilated low-cost housing. Static standards such as SNI 03-6572-2001 define fixed temperature thresholds that may not fully represent occupants' thermal perception in humid tropical climates. Therefore, this study compares the Thermal Humidity Index (THI) with the CBE Adaptive Method to examine whether an adaptive thermal comfort approach better reflects occupants' thermal tolerance in

low-cost rental flat in coastal tropical area. This study is expected to serve as a reference for the design of similar housing in the future, particularly with regard to thermal comfort. Thus, ensuring can be taken into consideration.

## 2. METHODS

### 2.1. Research Methods

The method used in this study is quantitative, which aims to obtain a comprehensive image of the thermal conditions of dwelling in Low-Cost Rental Flats Housing in a Coastal Tropical Area, with a case study of Low-Cost Rental Flats or *Rumah Susun Sederhana Sewa (Rusunawa) Kampung Nelayan II Sungailiat*. A quantitative approach was chosen because it allows for standardized, measurable, and numerically analyzable measurements of physical environmental variables based on thermal comfort parameters established in applicable standards. In the initial stage, observations and measurements will be conducted in the field to collect building data, such as building orientation and openings, as well as thermal comfort data, such as air temperature, air humidity, and wind speed. Then, from the results of the observations and measurements, two thermal measurement systems will be approached, namely using the Thermal Comfort Index (THI) and the CBE Adaptive Method simulation. Through this approach, the research will produce empirical data from the calculation of THI values and CBE simulations from field measurements to be identified and analyzed for their level of compliance with standards. The flowchart for this study is as follows (Figure 1):

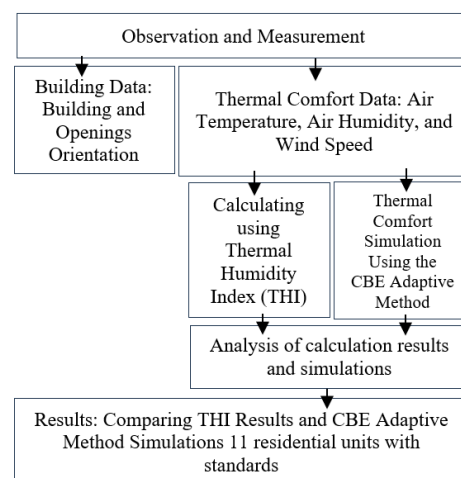


Figure 1. Research Framework

## 2.2. Research Location

This research was conducted at the *Kampung Nelayan II Sungailiat Low-Cost Rental Flats (Rusunawa)* (Figure 2), which were built in 2018. This location was chosen based on the characteristics of the building as low-income vertical housing that relies on natural ventilation without the use of mechanical ventilation such as air conditioning. In addition, the location of *Kampung Nelayan II Sungailiat Low-Cost Rental Flats* was chosen because it is located on the coastal area. Thus, by examining the air temperature, humidity, and wind speed in the residential units, this study is expected to provide a comprehensive picture of the thermal comfort quality of the space in the low-cost rental flats so that it can be used as a basis for design recommendations and management of vertical housing that is more responsive to the tropical climate and coastal areas.

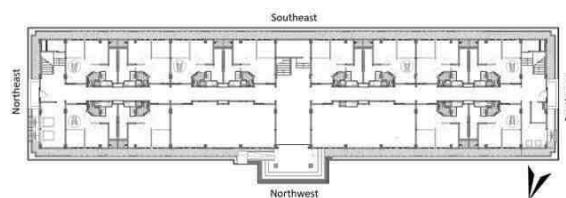


**Figure 2.** Existing Condition of *Kampung Nelayan II Sungailiat Low-Cost Rental Flats (Rusunawa)*  
Source: Google Maps.

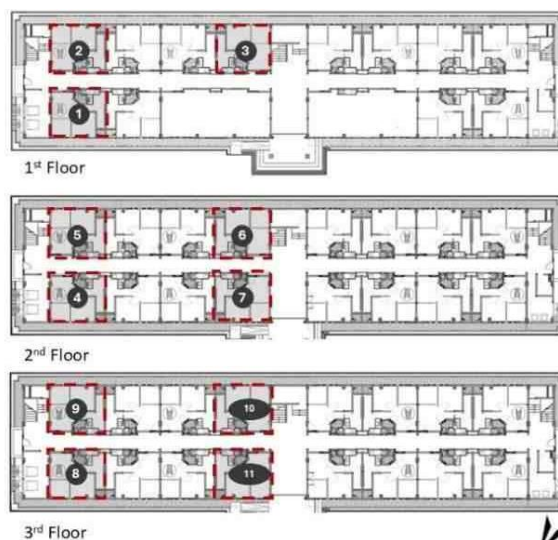
*Kampung Nelayan II Sungailiat* low-cost rental flat consists of 3 floors with each building unit covering an area of 36 m<sup>2</sup>. This building faces northwest with maximum building openings facing southeast and northwest. This is because the orientation of each unit's openings faces southeast or northwest (Figure 3). However, on the northeast, southwest, and northwest sides, there are also doors and windows as entrance areas for user and air circulation.

The sample units used in this study consisted of 11 residential units (Figure 4) located on the right wing of the building or northeast of the building, considering that the temperature measurements were taken at 11:00 a.m. when the sun was shining on the east side. These 11 residential units are divided into 3 residential units on the 1st floor, 4 residential units on the

2nd floor, and 4 residential units on the 3rd floor (Figure 4). The residential units selected as samples are those adjacent to the staircase on the northeast side and those adjacent to the staircase in the center of the building. This is to observe that residential units close to stairwell openings function optimally in terms of thermal comfort.



**Figure 3.** Building Orientation of *Kampung Nelayan II Sungailiat Low-Cost Flats (Rusunawa)*



**Figure 4.** 11 Residential Units

## 2.3. Data Collection

Data collection in this study consisted of primary and secondary data collection. Primary data collection was conducted through direct observation, physical environment measurements, and visual documentation of the 11 residential units as research objects (Figure 5). Field observations aimed to identify the existing conditions of the buildings, including building orientation, opening orientation, and architectural elements that could potentially affect thermal conditions and air movement inside the buildings. Physical environment measurements were carried out to obtain quantitative data using digital meters and digital anemometers to obtain data on air temperature, air humidity, and wind speed (Figure 5).

In addition, photographic documentation was used as supporting data to reinforce the observation results and provide a visual description of the physical condition of the building. Secondary data was collected from scientific literature in the form of accredited journal articles, statute and reference books related to the topic of thermal comfort. This literature was used to reinforce the theoretical basis of this study.



Figure 5. (a) Digital Measuring Device; (b) Digital Anemometer Measuring Device

### 2.4. Thermal Humidity Index (THI) and CBE Thermal Comfort

This research using Thermal Humidity Index (THI) as a calculation method and using CBE Thermal Comfort Tool as simulation method. Technically, the THI value is calculated using the Niewolt formula (Azzahra & Kartikawati, 2021; Isnoor et al., 2021):

$$THI = 0.8 \times T + ((RH \times T) / 500) \dots\dots\dots [1]$$

where THI is the Thermal Humidity Index; T is Air Temperature (°C); and RH is Humidity (%).

The application of the Thermal Humidity Index (THI) encompasses comfort analysis in high-rise buildings, green open spaces (GOS), and urban environments. The addition of shade-providing vegetation or specific plants, such as snake plants, has proven effective in improving THI values by lowering temperatures through the absorption of solar radiation and evapotranspiration (Hanifah et al., 2019). Research shows that the development and enhancement of vegetation are effective in reducing the THI value to create a cooler microclimate (Azzahra & Kartikawati, 2021). For tropical climates, comfort categories are generally divided into three criteria (Table 1).

Table 1. Thermal Humidity Index Criteria

No	Criteria	THI Value
1	Comfortable	21 < THI < 24
2	Fairly Comfortable	25 < THI < 27
3	Uncomfortable	THI > 27

Source: Ardiyansah et al., 2024.

In addition, this study also utilized a simulation tool, namely the CBE Thermal Comfort Tool with the Adaptive method (Figure 6). The Adaptive method was chosen because the 11 residential units do not have air conditioning. For this simulation, the required data are air temperature and air velocity. Therefore, a simulation will be conducted for each of the 11 residential units using the CBE Thermal Comfort Tool to determine whether the thermal comfort results meet the ASHRAE standard 55-2023.

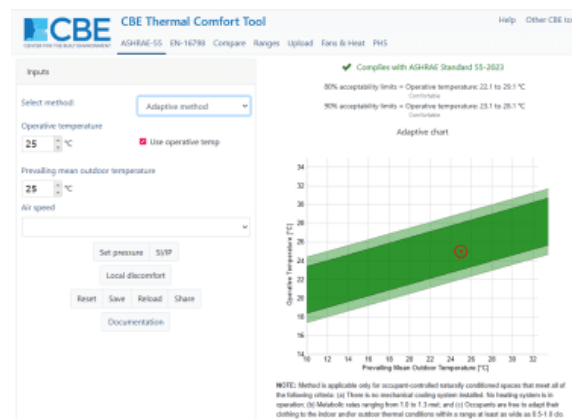


Figure 6. Adaptive Method: CBE Thermal Comfort Tool

Source: <https://comfort.cbe.berkeley.edu>.

### 3. RESULT AND DISCUSSION

Based on field measurements using measuring devices, measurements were obtained for 11 residential units with parameters of air temperature, air humidity, and wind speed. Each residential unit was measured by measurement tools inside the room, namely in the living room, and outside the room, namely in the front corridor of the residence. The following are the results obtained (Table 2).

Table 2. Field Measurement Result

Residential Unit Number	Air Temperature		Air Humidity		Wind Speed	
	A	B	A	B	A	B

1	29.4	28.2	72.9	82.0	1.5	1.5
2	28.8	29.6	85.5	80.1	0.0	0.0
3	29.5	29.1	80.2	82.0	0.7	0.0
4	29.8	29.2	81.1	76.5	0.1	0.0
5	29.2	29.3	79.2	82.1	0.2	0.0
6	29.3	29.6	77.3	78.1	0.2	0.0
7	28.9	29.5	83.9	79.9	0.0	0.0
8	29.5	28.9	77.0	79.4	0.0	0.1
9	28.7	28.9	78.0	79.4	0.0	0.1
10	30.3	30.4	74.3	75.3	0.1	0.0
11	30.4	30.1	74.7	75.0	0.1	0.3

**Description:**

A: Indoor Unit

B: Outdoor (Corridor)

After obtaining the measurement results in the field, the Thermal Humidity Index (THI) value was calculated using the Niewolt formula. The following are the THI calculation results (Table 3).

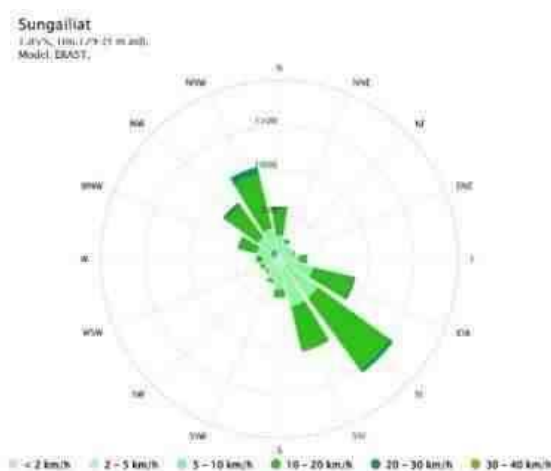
**Table 3.** Thermal Humidity Index (THI) Calculation Result

Residential Unit Number	Air Temperature (T) °C		Air Humidity (Rh) %	THI Calculation	Comfort Category
	Indoor Unit	Indoor Unit	Indoor Unit	Indoor Unit	Indoor Unit
1	29.4		72.9	27.8	Uncomfortable
2	28.8		85.5	28.0	Uncomfortable
3	29.5		80.2	28.3	Uncomfortable
4	29.8		81.1	28.7	Uncomfortable
5	29.2		79.2	28.0	Uncomfortable
6	29.3		77.3	28.0	Uncomfortable
7	28.9		83.9	28.0	Uncomfortable
8	29.5		77.0	28.1	Uncomfortable
9	28.7		78.0	27.4	Uncomfortable
10	30.3		74.3	28.7	Uncomfortable
11	30.4		74.7	28.9	Uncomfortable

Based on the THI calculation results, it was found that the comfort category for indoor spaces in 11 residential units was classified as uncomfortable. This was due to the fact that the

THI calculation results exceeded the standard of 27. Based on this data, in fact, the calculation figures for each residential unit relative to the THI standard were not too far off, ranging from 27.4 to 28.9. Providing openings, such as windows or louvers, for air circulation in the stairwell area could be one recommended alternative to improve natural ventilation in the residential units. Given the current existing conditions, the stairwell is enclosed with no openings. Consequently, the air entering the building is not very dominant and significantly affects the relatively high temperature and humidity measurements in each room. This should be considered a potential issue, given that the stairwell is located on the southeast side, where the prevailing wind flows from the southeast.

Based on the wind rose graph from MeteoBlue (Figure 7), the southeast direction is the orientation that receives the most wind flow, so this wind flow certainly contributes to a decrease in temperature inside the dwelling.



**Figure 7.** Windrose Graph in Sungailiat City  
Source: meteoblue.com, 2026.

In addition, another internal factor is the arrangement of the building's interior. In some units, residents frequently hang laundry near openings, thereby obstructing airflow into the building and causing the air temperature and humidity to rise (Figure 8). This is due to the limited space available for drying clothes outside the residential units, so residents tend to hang laundry inside the units and near openings to facilitate drying. Ideally, a communal drying area should be provided outside the residential

units, while still ensuring the safety of the laundry. In general, the THI measurement results for these 11 residences are not too far from the fairly comfortable THI standard of

$25 < \text{THI} < 27$ . Several active and passive strategies can be implemented to reduce temperature and humidity so that the residences can meet the fairly comfortable THI standard.



**Figure 8.** Existing Openings in Residential Unit

In addition to THI measurements, this study also conducted simulations using the CBE Adaptive Method. These simulations aimed to assess the thermal comfort of tropical buildings without mechanical ventilation. In these simulations, both temperature and air velocity were utilized. However, air velocity was divided into four categories: 0.3 m/s, 0.6 m/s, 0.9 m/s, and 1.2 m/s. Thus, during measurements, air velocity values were predominantly at 0.0 m/s; therefore, in this simulation, the smallest value of 0.3 m/s was selected, considering that according to the Beaufort scale, the 0–0.3 m/s range still falls within the same category, namely calm (Aji & Cahyadi, 2015). Here is the result of CBE Adaptive Method simulations:

Table 4 and Appendix 1 present the results of a thermal comfort simulation using the CBE Adaptive Method. Each row represents a different thermal condition scenario, after which the system evaluates whether the condition falls within the comfort zone (comfortable) or is too warm.




Of the total 11 residential units simulated using the CBE Adaptive Method, eight units (residential unit 1, 2, 3, 4, 5, 6, 7, 9) were classified as comfortable with an average temperature of 28 °C, although when compared with the THI comfort category standard, the average indoor temperatures still fall outside the prescribed thermal comfort range. The other 3 units, namely residential units no. 8, no. 10, and

no. 11, were classified as too warm (Table 5). Based on the indoor and outdoor air temperatures of these 3 units, the air temperature was quite high compared to the other units. Moreover, residential units 10 and 11 reached temperatures above 30°C, which exceed the thermal comfort range. Consequently, these units were classified as too warm in the simulation results, a condition that was further reinforced by the very low air velocity or minimal wind speed within the residential spaces.

**Table 4.** CBE Adaptive Method Simulation Result and Comfort Category

Residential Unit Number	Comfort Category
1	Comfortable
2	Comfortable
3	Comfortable
4	Comfortable
5	Comfortable
6	Comfortable
7	Comfortable
8	Too Warm
9	Comfortable
10	Too Warm
11	Too Warm

**Table 5.** CBE Adaptive Method Simulation Result by Residential Unit Number

Floor	Residential Unit Number
1 <sup>st</sup> Floor	
2 <sup>nd</sup> Floor	
3 <sup>rd</sup> Floor	

However, essentially, looking at the CBE Adaptive Methods graph, all units are on the verge of becoming too warm. If temperatures continue to rise and wind speed remains at 0, residential units will tend to become too warm when using the CBE Adaptive Method simulation. Therefore, several approaches are needed to lower indoor and outdoor temperatures, such as adding natural shade—like trees—around Low-Cost Rental Flats (Azzahra & Kartikawati, 2021). Given the existing conditions, there are no canopy trees that can serve as shading elements.

Based on the results of the thermal comfort evaluation above, there is a significant difference between the Thermal Humidity Index (THI) approach and the CBE Adaptive Method. Based on THI calculations, all residential units were identified as uncomfortable, while the

simulation results using the CBE Adaptive Method showed that the majority of units were still within the comfort zone, except for three units that were outside the thermal comfort limits. This difference in results shows that the approach used in assessing thermal comfort greatly affects the interpretation of indoor environmental conditions, especially in residential buildings in humid tropical climates.

THI is a thermal comfort index developed based on the relationship between air temperature and relative humidity. This index is widely used in thermal environment studies due to its simplicity in calculation and its ability to describe the level of heat stress felt by humans. However, the main limitation of THI lies in its inability to take into account factors such as airflow velocity or windspeed and the user's ability to adapt to local climatic conditions. As a result, the application

of THI in tropical residential buildings tends to produce stricter classifications of discomfort, especially in environments with high temperatures and humidity. This condition is in line with the findings of several studies which state that static indices such as THI are less able to represent the actual comfort perception of occupants in humid tropical climates.

In contrast, the CBE Adaptive Method simulation was developed based on the concept of human thermal adaptation, which recognizes that the perception of comfort is influenced by an individual's ability to adjust to environmental conditions through physiological, psychological, and behavioral mechanisms. This model is particularly relevant for naturally ventilated buildings, where occupants have the flexibility to adjust openings, use fans, adjust clothing, and modify activities. Therefore, the comfortable temperature range in the adaptive model is broader and is considered more representative of real conditions in the field, especially in tropical dwellings. The results of this study indicate that the adaptive approach is able to describe the thermal tolerance of local communities more realistically than the static approach.

#### **4. CONCLUSION**

The difference in results between THI and CBE Adaptive Method in this study shows that the evaluation of thermal comfort in tropical climates cannot rely solely on physical environmental parameters. An adaptive approach is important because it considers the dynamics of occupant behavior and local climate conditions. The finding that almost all units were in a comfortable condition according to the adaptive model indicates that the building design and natural ventilation system applied were still able to support the achievement of thermal comfort due to the tenants' behavioural capacity to adapt with the thermal comfort ranges, even though the THI rated them as uncomfortable.

The three residential units that were still outside the adaptive comfort zone were suspected to be influenced by several design and environmental factors, including unfavorable building orientation, high exposure to direct solar radiation, limited cross ventilation, and the position of the units on the upper floors, which

received heat accumulation from the roof. In addition, the quality of building envelope materials, such as walls and roofs, also plays an important role in influencing heat transfer into the room. In addition, vegetation can act as a barrier and canopy, creating a more shaded and comfortable environment and surroundings.

The particular result on the housing unit facing the south-east direction on the third floor that can attain the most comfortable thermal situation due to its orientation in receiving the benefit of coastal wind indicates the importance of architectural design for the passive thermal comfort. These findings have important implications for tropical residential architectural design strategies, particularly for low-cost rental flats (*rusunawa*). Passive design optimization should focus on improving cross ventilation, controlling solar radiation through shading devices, selecting materials with good thermal performance, and adjusting the orientation of building masses. Thus, rather than relying on the general building layout templates such as the 6x6 m housing unit used by the vertical housing in this study, future tropical apartment/flats can creatively improvise the layout better: i.e. designing a unit with a south east-north west cross-ventilation corridor with a 3x12m layout, maximizing unit orientation to face the wind direction, maximizing sun-shading in the east-west façade, etc. These strategies have been proven to improve thermal comfort without relying on mechanical cooling systems, thus aligning with the principles of green buildings and energy efficiency.

Overall, the results of this study confirm that the CBE Adaptive Comfort Model is more suitable for evaluating the thermal comfort of residential buildings in humid tropical regions, especially in buildings with natural ventilation. Meanwhile, the use of THI remains relevant as an initial indicator of environmental heat stress, but it needs to be combined with an adaptive approach to obtain a more comprehensive picture of thermal comfort. The integration of these two methods is expected to produce more accurate and applicable design recommendations in efforts to improve the quality of sustainable housing.

## AUTHOR CONTRIBUTION

The first author (RF) served as the primary conceptualizer of the research and the journal article. The first author conducted surveys, field observations, and field measurements. This author was also responsible for developing the writing framework, conducting the literature review, and drafting the journal article—from the introduction, methods, and results and discussion sections, through to the conclusion.

The second (AS) author assisted the first author in conducting surveys and field observations. The second author was involved in compiling the literature review and in the journal writing process.

The third author (AR) collaborated with the first and second authors in compiling the literature review. The third author also contributed to the journal writing and refined the manuscript.

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APPENDIX 1

Residential Unit Number	CBE Adaptive Methods Simulation Result	Comfort Category
1		Comfortable
2		Comfortable
3		Comfortable
4		Comfortable
5		Comfortable
6		Comfortable
7		Comfortable
8		Too Warm
9		Comfortable
10		Too Warm
11		Too Warm