# Identification of Thermal Comfort Conditions in a Residential: A Case Study of a 2-Story Balinese Contemporary House in Batuan, Gianyar, Bali

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*ABSTRACT*

Housing is a fundamental human need that requires to offer its occupants the best possible safety and comfort. The Gianyar district of Bali is now home to a disproportionate number of structures of the Bali architectural style. The thermal comfort of modern Bali buildings is the subject of the bare minimum research, which makes it crucial to determine the thermal comfort of these structures as a foundational knowledge and point of reference for thermal studies of comparable structures. Using *Autodesk Ecotect Analysis 2011* software, the research was conducted by modeling spatial convenience and presenting quantitative descriptive data through data tabulation and graphics. The study's findings demonstrated that the Bali Contemporary Building Study facility in Mas Village, Gianyar, had thermal comfort levels that exceeded Indonesia's norms.

**Keywords:** *Contemporary House, Thermal Comfort*

## 1. INTRODUCTION

A house is one of the basic human needs, serving as an institution based on a series of considerations regarding the local cultural and climatic environment [1]. As a shelter, a house is required to provide protection and a sense of comfort to its occupants. In the article "Thermal Comfort in Tropical Architecture" [2], it is explained that the comfort sensation felt by humans is influenced by several aspects, including thermal comfort. The aspect of thermal comfort in a room is an essential study as it affects the mental condition as an expression of human satisfaction with the quality of a space, which includes temperature, air humidity, wind speed, and radiation temperature due to body metabolism [3].

The development of housing concepts has been occurring frequently, considering the trends that constantly change over time. Bali has been affected, with an increasing variety of designs blending the philosophical values of traditional architecture and modern architecture [4]. The concept known as Bali Contemporary Architecture essentially considers the impact of building development on the surrounding environment, which aligns with the principles of sustainable architecture. However, many Bali contemporary buildings have been found to raise issues in the thermal aspect. This is due to the increasing human needs and a tendency to prefer instant solutions, indicated by the use of modern technology that consumes more energy.

Gianyar was chosen as the location for this study because it is an area with the richest culture in Bali and one of the top three areas with the highest tourist visit interest [5]. As an area with a rich culture, Gianyar strives to maintain the existence of traditional Balinese architectural values in its buildings, including modern buildings that are still given local accents through the use of materials and ornaments.

Related research on thermal comfort has been widely conducted, such as the study on housing in Bandar Lampung [6]. This research aimed to clearly understand the thermal comfort level of residential buildings in densely populated areas through measurement methods using a digital thermometer and hygrometer or digital thermohygrometer and an anemometer to measure wind speed. The results showed that the house temperature ranged from 30°C to 33°C with humidity levels of 59-71% and wind speed of 0 m/s, concluding that the houses studied had thermal comfort levels far below the standard. A similar study was also conducted with the Salatiga Regional Library as the subject, using similar methods, namely digital measurements with a thermohygrometer and luxmeter to measure temperature, air humidity, and light intensity that affect the comfort level of the room. This research highlighted the importance of considering thermal comfort in creating spaces that function as environments for human activities in enclosed spaces [7].

Research using similar methods, namely simulations with *Autodesk Ecotect Analysis 2011* software, was conducted by reviewing a public building, a mosque in Bogor City [8]. The data collection method in this research still used direct measurement with digital tools, which were then translated into software data for *Ecotect* to enable digital thermal simulations. This study found that public mosque facilities still had ineffective thermal comfort, so modifications were made to the use of simulation materials, which proved effective in significantly increasing the interior thermal comfort of the building.

Research on thermal comfort in conventional buildings has been widely conducted using various methods, such as direct measurement, digital measurement, and software simulation. However, in Bali, the use of traditional-style buildings is still maintained, resulting in the dominance of Bali Contemporary building designs, which combine traditional Balinese architecture with modern elements. Studies on interior comfort conditions with a focus on thermal comfort in Bali Contemporary buildings are relatively rare, making this research important to conduct as it can serve as a reference for related studies, especially discussing the thermal conditions of Bali Contemporary buildings.

The purpose of this research is to understand the thermal conditions of Bali Contemporary residential buildings in the Gianyar area, Bali, using the simulation method with *Autodesk Ecotect Analysis 2011* software. The research will focus on the level of thermal comfort felt by the occupants when inside the room, explained using variables presented in tabulation and graphical forms. The research results will contribute to providing literature related to the thermal conditions of buildings with similar characteristics, especially those located in Gianyar, Bali.

## 2. THEORY AND METHODS

### 2.1 Theory

1. Bali Contemporary Architecture

According to the Indonesian Dictionary, the word "contemporary" is an adjective referring to the present time. Therefore, contemporary architecture can be defined as current architecture prevalent in certain regions that consistently follows the times, characterized by freedom of expression, innovation, and the merging of architectural styles. In Indonesia, contemporary architecture has developed through a combination of tropical modern elements and local elements. Thus, Bali Contemporary Architecture can be defined as architecture that grows, evolves, and can be sustained in Bali, which later became known as Bali architecture [9]. Traditional Balinese architecture is used as the basis for Bali Contemporary Architecture, which is then adapted to the changing times to produce more expressive designs. Bali Contemporary Architecture considers the impact of building development on the surrounding environment, aligning with the principles of sustainable architecture. The characteristics of Bali Contemporary Architecture include:

a. Keeping up with advancements in science and technology without losing its original identity.
b. Using modern local standards, methods, and materials that reflect the essence of Balinese buildings.
c. Building typology has evolved, no longer limited to traditional Balinese building types but adapting to Balinese architectural rules.
d. Utilizing sunlight for natural lighting, cross ventilation, and thermal comfort.
e. Integration with the environment: Bali Contemporary Architecture emphasizes integrating buildings with their surroundings by considering the landscape, flora, and surrounding topography.
f. Considering indoor air quality, including proper ventilation systems and using raw materials that do not contain harmful substances. Using natural light and proper temperature control is also important for making the space comfortable.
g. Incorporating green elements such as gardens, ponds, and plants into architectural elements to enhance the environmental quality and create a balance with the natural environment. Choosing plants suitable for the local climate and using an effective irrigation system should be considered.

2. Space Comfort

According to the Indonesian Dictionary, comfort can be defined as coolness, a state of comfort, and freshness. However, it is challenging to define comfort entirely because it directly impacts each individual's perception [10]. A space must meet several basic comfort requirements to be functional. These include air comfort (temperature, humidity, circulation, and pollution levels), movement comfort (ergonomics, circulation), and sensory comfort for the eyes and ears (lighting, acoustics). Additionally, space comfort also includes the psychological aspect of the users and social comfort, which supports the conduciveness of activities within the space.

3. Thermal Comfort

Thermal comfort includes temperature, humidity, wind speed, and radiation temperature generated by body metabolism. Good thermal comfort can reduce the risk of illness, increase productivity, and reduce the energy needed to heat or cool a room. As a result, the thermal comfort of buildings is critical, especially in tropical environments like Indonesia, where temperatures and humidity levels can be very high.

Thermal comfort is the condition of satisfaction with the thermal environment expressed in thought patterns [11]. Air temperature, mean radiant temperature, humidity, and wind or air movement are the physical standards of thermal comfort. In equatorial regions, the comfort limit ranges between temperatures of 22.5°C to 29.5°C and relative humidity of 20-50%. The wind speed comfort standards are as follows: 0.25 m/s is comfortable without feeling air movement; 0.25 m/s to 0.5 m/s is comfortable without feeling air movement; 1.0 m/s to 1.5 m/s is light airflow, making it uncomfortable; and above 1.5 m/s is uncomfortable [12].

Climatic variables affecting thermal needs include air temperature, mean radiant temperature, relative humidity, wind speed, and air movement in the space [13]. At air temperatures of 26°C-30°C, human endurance begins to decline, falling within the comfortable warm standard. At temperatures of 33.5°C-35.5°C, the environmental conditions become difficult for the body and environment to tolerate [14]. The thermal comfort standard for

Indonesia is regulated in SNI 03-6572-2001 [15], which states that the thermal comfort standard in Indonesia must be between temperatures of 20.5°C and 27.1°C.

**Table 1.** An Example of a Table

| **Temperature** | **Comfort Condition** |
|---|---|
| 20.5°C – 22.8°C | Cool Comfortable |
| 22.8°C – 25.8°C | Optimal Comfort |
| 25.8°C – 27.1°C | Warm Comfortable |

Another factor that affects thermal comfort is air humidity. Air humidity is the water vapor content in the air. If the air temperature in the room is higher than 70% or lower than 40%, humidity will affect the body's heat dissipation, causing discomfort. Wind speed, which is the movement of air caused by forces due to pressure and temperature variations, also affects thermal comfort [16]. Additionally, thermal comfort is influenced by body metabolism and indoor activities [7]

## 2.2 Methods

This study employs a quantitative descriptive method, focusing on reviewing the thermal conditions of buildings using *Autodesk Ecotect Analysis 2011* simulations and field measurements for data validation. The quantitative method typically presents data in numerical form to describe the research results. Descriptive research aims to create a factual description of the phenomena occurring. Quantitative descriptive research is a method that aims to objectively describe a situation using numbers, from data collection, interpretation, and presentation of results [17]. Quantitative research is based on positivism and is used to study samples and populations [18]. The quantitative data generated from the simulations will be reviewed based on the standard references for thermal comfort, presented in tables and images. The object of study is a building with contemporary Balinese style located in Mas Village, Ubud, Gianyar, where measurements were taken for detailed dimensions to create 3D modeling using SketchUp software.

**Figure 1.** SketchUp 3D Model

The data needed in this study are categorized into:

1. Primary Data, obtained through direct observation of the research object, including building dimensions, existing building conditions, and building thermal comfort values.
   a. Building Dimensions
   This contemporary Balinese architecture building is located in a residential area with moderate population density. The building has two floors with dimensions of 8 x 13

meters. The total area of the building is Data on building dimensions is useful in creating 3D models in *SketchUp* and *Ecotect* software. The dimensions were measured in detail using a tape measure and laser measurement tools to provide accurate simulations, ensuring that the simulation data obtained is not merely speculative.

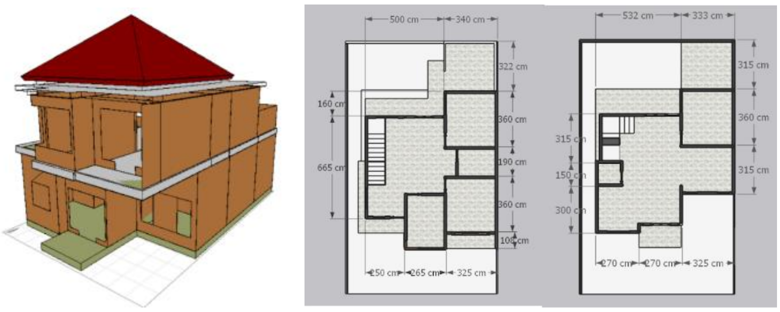


**Figure 2.** Floor Plan and Perspective View

b. Building Condition Data

This building with contemporary Balinese architecture style uses artificial ventilation in the form of air conditioning (AC) to support thermal comfort in the interior. The building has an existing condition facing south, where this orientation is best for blocking solar heat [19]. The openings are predominantly on the southern side or the front of the building, which also features a strong Balinese architectural facade.

2. Secondary Data, obtained from reference sources based on relevant literature studies that support and relate to the research. The research method using *Ecotect* software requires secondary data, including average regional temperature values, average hottest times, and standards used as references for thermal comfort levels.

a. Weather Data

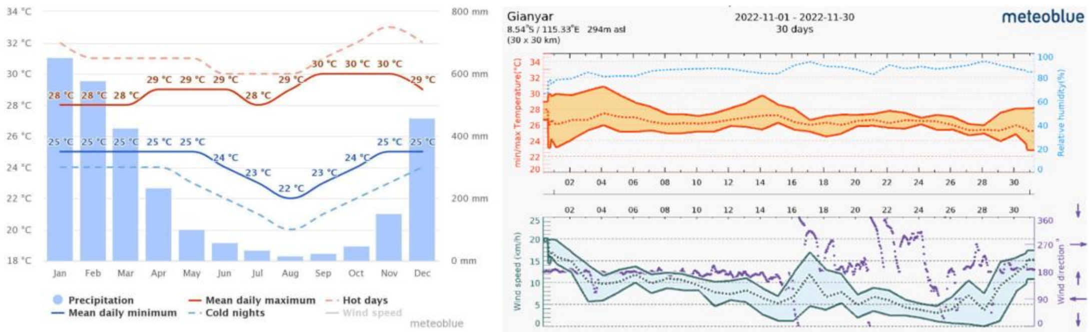


**Figure 3.** Gianyar Regency Weather Chart

The research is based on the weather conditions of the study object, reviewed from the source meteoblue.com, which indicates the average hottest temperature in Gianyar occurs in November, averaging around 30°C with a peak temperature reaching 33°C (Figure 3). The research was conducted at noon when the sun was at its peak (12:00). The highest relative humidity in November was recorded at 92%, with the highest wind speed at 18 km/h.

**Table 2.** Weather Data for November 2023 in Gianyar Regency

| Time Interval | Temperature | Humidity | Wind Speed |
|---|---|---|---|
| 06.00 – 21.00 | 24-33° C | 50 – 92% | 3 – 18 km/h |
| **Average** | 30°C | 87% | 11,4 km/h |

b. Reference Standards

This study aims to identify the thermal comfort level of a building with contemporary Balinese style located in Mas Village, Gianyar. Identification requires references to validate whether the analysis activities align with thermal comfort standards. In Indonesia, there is SNI 03-6572-2001, which contains thermal comfort standards in Indonesia, which must be between temperatures of 20.5°C and 27.1°C, with a humidity percentage ranging from 40% to 80%. Further details reveal comfortable temperature ranges: 20.5°C - 22.8°C gives a cool comfortable impression, 22.8°C - 25.8°C represents optimal comfortable temperatures, and 25.8°C - 27.1°C provides a warm comfortable sensation [15].

Simulations using *Ecotect Analysis* 2011 were conducted with spatial comfort tests producing values for Mean Radiant Temperature (MRT), Predicted Mean Vote (PMV), Percent Dissatisfaction (PPD), Required Air Velocity (RAV), and Solar Gains, detailed as follows:

1. Mean Radiant Rate (MRT)
   MRT indicates the radiant heat between humans and their environment. It shows the comfort level affected by the surface temperature of the building and its surroundings.
2. Predicted Mean Vote (PMV)
   PMV is an index introduced by Professor Fanger from the University of Denmark to represent feelings of warmth or coldness on a scale from +3 to -3.
3. Percent Dissatisfaction (PPD)
   PPD is a value measuring the level of dissatisfaction people feel in a given situation or environment.
4. Required Air Velocity (RAV
   RAV is the airspeed that affects humidity and room pressure.
5. Solar Gain
   This details the heat load received from solar radiation.

**Table 3.** Relationship Between PMV, PPD, and Thermal Sensation

| PMV | THERMAL SENSATION | PPD (%) |
|---|---|---|
| +3 | Hot | 100 |
| +2 | Warm | 75 |
| +1 | Slightly Warm | 25 |
| 0 | Neutral | 5 |
| -1 | Slightly Cool | 25 |
| -2 | Cool | 75 |
| -3 | Cold | 100 |

The simulation testing was conducted in conditions as similar as possible to the existing ones, accurately and actually inputting data on ventilation, activities, and activity schedules in each room. The spatial comfort testing will reveal values representing the comfort level experienced by room users. The *Ecotect* simulation results will provide data on MRT, PMV, PPD, RAV, and Solar Gains. There is a relationship between the PMV and PPD data with the sensations felt by room users, as shown in Table 3 [20]. This relationship data is based on related previous studies, relevant for this study.

## 3. RESULTS AND DISCUSSION

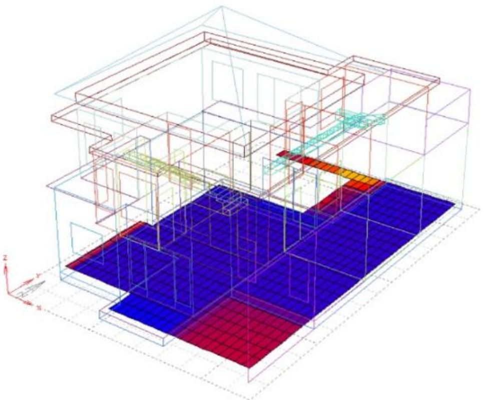

**Figure 4.** MRT Analysis

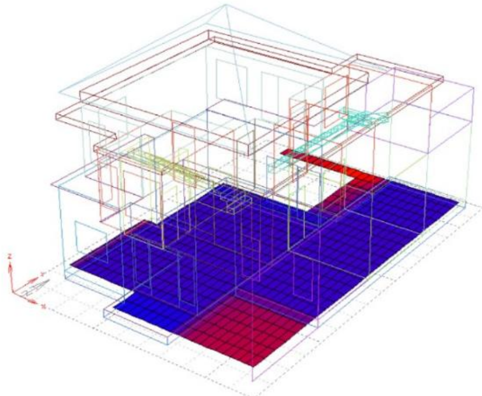

**Figure 5.** PMV Analysis

The MRT (Mean Radiant Temperature) analysis on the study object using *Ecotect* software produced an average value of 19.26°C, as shown in Figure 4. The simulation indicates discomfort when viewed from the SNI 03-6572-2001 standard. This discomfort sensation arises because the surface radiation temperature felt by room users is below the comfortable standard, which is 20.5°C. The PMV simulation conducted on the building showed a value of -1.94 PMV, as shown in Figure 5. When linked to the thermal sensation felt by room users, as per Table 2, the sensation experienced is slightly cold.

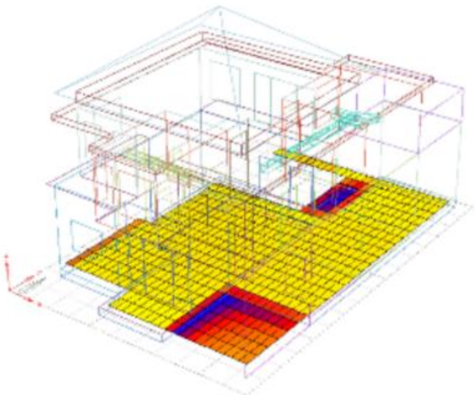

**Figure 6.** PPD Analysis

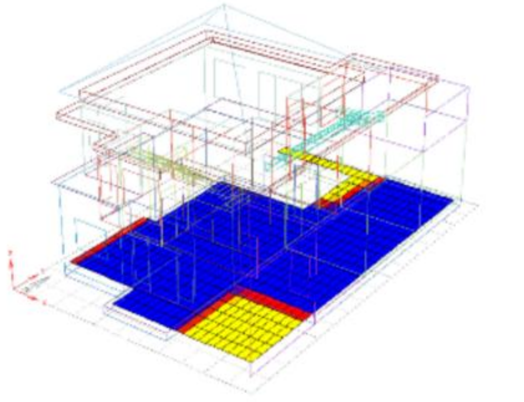

**Figure 7.** RAV Analysis

The PPD analysis of the building showed a value of 90.03, as seen in Figure 5, indicating a high level of dissatisfaction among the building's occupants and users. This PPD simulation suggests that the occupants feel cold when inside the building. The RAV (Required Air Velocity) simulation in this building produced an average value of 0.37 m/s, as seen in Figure 6. This indicates that the interior space has good indoor air movement. The average solar gains value showed an average of 35.31 watts, indicating the heat load experienced by the building from solar radiation.

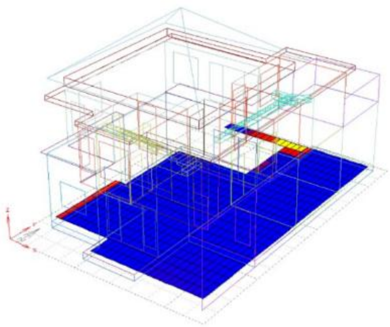

**Figure 8.** Solar Gain Analysis

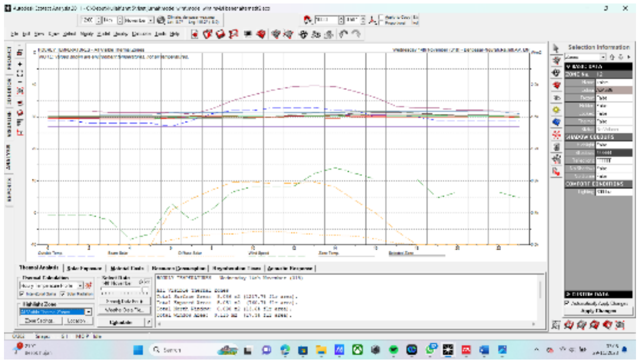

**Figure 9.** Temperature Chart for Each Room

**Table 4.** An Example of a Table

| | MRT | PMV | PPD | RAV | Solar Gains |
|---|---|---|---|---|---|
| Value | 19,26°C | -1,94 PMV | 90,03 | 0,47 m/s | 35,51 watts |
| Explanation | Below standard | Slightly cool | Uncomfortable | Quite good | Neutral |

Based on the simulation results, it was found that the MRT value indicates temperatures below the SNI standard. The PMV and PDD conditions of the building show that the building has a less comfortable thermal condition, as seen in Table 3. The Rav and solar gains conditions have quite good values, so overall, this contemporary Balinese building still has a less comfortable thermal condition according to the *Ecotect* simulation.

## 4. CONCLUSIONS

The contemporary Balinese residential building located in Mas Village, Gianyar, has thermal comfort values outside the standard thermal comfort range in Indonesia. Although the building has employed artificial ventilation to support thermal comfort, these efforts have not yet achieved optimal comfort conditions. This study's results, based on the *Ecotect* simulation, were influenced by limited input variables, neglecting environmental factors such as surrounding vegetation and the context of nearby buildings. Future research can further investigate and propose design solutions that improve the building's thermal conditions, taking into account the surrounding environmental context.

## 5. ACKNOWLEDGEMENTS

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