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Green Hotel Design Model: Integration of Balinese Architecture and Passive Cooling Systems

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ABSTRACT

The hospitality sector in Bali, a major contributor to the island's tourism economy, faces significant challenges in energy consumption, particularly due to reliance on air conditioning systems for thermal comfort. These systems account for over 60% of the total energy use in star-rated hotels. In contrast, traditional Balinese architecture has long utilized passive design strategies—such as cross ventilation, thermal-insulative local materials, and site planning in accordance with Tri Hita Karana philosophy—to achieve indoor comfort without active cooling. This research proposes a green building design model that integrates traditional Balinese architectural elements with modern passive cooling technologies. The study employs a mixed-methods approach: qualitative data were obtained from interviews with architects, hotel managers, and users; quantitative data were collected through energy consumption measurements (kWh/m²/year) before and after passive design interventions. Four hotel areas—Sanur, Kuta, Ubud, and Nusa Dua—were selected as case studies. Results show that cross-ventilation and traditional spatial arrangements can reduce indoor temperatures by an average of 3.2°C, lowering energy use by 20–30%. Integration with reflective coatings, thermal insulation, and double-glazed windows further improves energy performance, achieving up to 32.4% reduction. This model demonstrates strong acceptance by users and is contextually adaptive to coastal microclimates. The research contributes a validated, culturally grounded green design framework, bridging local wisdom with sustainable development imperatives in tropical tourism zones.

Keywords: passive design, balinese architecture, green hotel, energy efficiency, tropical buildings.

INTRODUCTION

The island of Bali as an international tourist destination has experienced very rapid tourism growth in the last two decades. Based on data from the Central Statistics Agency (BPS) of Bali Province, the number of foreign tourists visiting Bali reached more than 6 million people in 2019, with an average annual growth of around 8% since 2015 [1]. This growth has implications for the increased need for accommodation and tourism infrastructure, especially in the form of the construction of new hotels and the rejuvenation of existing hotels. However, this development has also triggered a significant increase in energy consumption, especially for the cooling system needs in hotel buildings operating in tropical climates such as Bali.

The hospitality sector in Bali is recorded as the second largest energy consumer in the tourism industry after transportation. The average energy consumption of star-rated hotels in the tropics reaches 450–700 kWh/m²/year, with more than 60% of this being used for air conditioning (HVAC) systems [2,3]. The dominance of active cooling systems, especially the use of air conditioning (AC), causes high carbon emissions and places a heavy burden on local electricity systems that still rely mostly on fossil energy [4–6]. The reliance on active cooling also ignores the potential of natural approaches that have long been applied in traditional Balinese architecture.

Traditional Balinese architecture has applied passive design principles that have been proven to be able to create thermal comfort without relying on mechanical technology. This approach includes the use of natural cross-ventilation, building orientation that pays attention to wind direction and solar intensity, and the use of local materials such as bamboo, wood, and clay bricks that have natural

thermal insulation properties [7–9]. These principles are in line with the philosophy of Tri Hita Karana which prioritizes harmony between humans and God (parahyangan), humans and others (pawongan), and humans and nature (palemahan) in spatial planning [10]. Unfortunately, today most modern hotels in Bali prioritize a global commercial and aesthetic approach by putting aside sustainable local design values and strategies.

This phenomenon opens up strategic opportunities to redesign hotel building design models that are not only energy-efficient but also based on local cultural identity. The integration of traditional Balinese architectural principles with modern passive cooling technology is seen as an innovative solution that is able to answer energy efficiency challenges while supporting the preservation of local culture. The urgency of this research lies in the effort to develop a green building design model that is contextual to the tropical and socio-cultural climate of Bali.

Various previous studies have proven the effectiveness of passive design in lowering energy consumption and improving thermal comfort in tropical buildings [6,11,12]. Nevertheless, there is a significant gap in studies that specifically explore the integration between traditional Balinese architecture and modern passive cooling systems in the context of green buildings. Most studies have only highlighted the technical aspects of passive design such as ventilation and materials without thoroughly examining the cultural values and spatial philosophies in Balinese architecture [9,13]. In addition, the design models developed are generally generic and have not taken into account the different microclimatic conditions in regions such as Sanur, Kuta, Ubud, and Nusa Dua [14]. Therefore, this research aims to answer the need for the development of green building design models that are not only energy-efficient but also culturally and contextually based on the characteristics of Bali's environment.

Referring to these backgrounds and gaps, the formulation of the problems raised in this study is: (1) How can the integration of traditional Balinese architectural elements with passive cooling systems reduce energy consumption in hotel buildings in Bali? (2) To what extent does the design strategy affect the improvement of thermal comfort and energy efficiency compared to conventional hotel design? (3) What is the ideal design model to optimally combine Balinese's local values with an eco-friendly technological approach?

The main objective of this research is to develop a green building design model that integrates the principles of traditional Balinese architecture with modern passive cooling technology systematically and applicatively. This research is expected to provide benefits in three dimensions. First, academically, this research will enrich the treasures of tropical architecture and locality-based sustainable building with a multicontextual approach. Second, in practical terms, the resulting design model can be a strategic guide for architects, developers, and policymakers in the hospitality sector in implementing energy-efficient design based on culture. Third, culturally, this research contributes to the preservation of traditional Balinese architectural values through revitalization in sustainable modern building design.

The novelty of this research lies in the development of an integrative design model that synergizes traditional Balinese architectural principles (such as the Tri Mandala system, spatial orientation, cross ventilation, and local materials) with modern passive cooling technologies (such as thermal insulation, reflective coatings, and shading devices). The multicontextual approach by considering the variation of microclimates in Bali's four tourist areas makes this model adaptive and replicative. In addition, a holistic approach that not only targets energy savings but also considers aesthetic aspects, psychological comfort, and cultural preservation makes this model have strategic value in sustainable development. The empirical validation of the model through energy consumption measurements, thermal comfort tests, and user perception analysis provides additional scientific strength that distinguishes this study from previous studies.

Several studies show that passive design strategies are able to reduce energy consumption by up to 38% [6]. Traditional Balinese architecture has ecological value through spatial orientation, the use of natural materials, and a cross-ventilation system [3,7]. In the context of green buildings, passive design has been shown to lower room temperature by 3–4°C [8–10]. Another study states that the use of thermal coatings, insulation, and strategic openings also support energy efficiency [11,12].

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Concepts and Theories Supporting Research

This research is in the realm of *sustainable architecture* that emphasizes energy efficiency, environmental sustainability, and the preservation of local cultural values. One of the key approaches in sustainable architecture is passive design, which is an architectural strategy that utilizes the conditions of the surrounding natural environment to improve thermal comfort and reduce the need for mechanical energy such as air conditioning or heating [1]. Passive design includes techniques such as natural cross-ventilation**,** building orientation**,** thermal mass**,** thermal insulation**,** and natural lighting control **[2].**

Traditional Balinese architecture has applied the principles of passive design from generation to generation. The spatial system based on *the Sanga Mandala* and *Tri Mandala* produces a spatial structure that is open and adaptive to the tropical climate [3]. Building materials such as bamboo, clay bricks, coconut wood, and palm trees have good thermal characteristics, are able to resist heat and keep room temperature stable [4]. In addition, the Tri Hita Karana philosophy directs traditional architectural practices to maintain harmony between humans and nature. This philosophical basis is in line with the principle of green buildings [5].

Thus, the integration of Balinese architecture into green building design not only strengthens energy efficiency, but also maintains the values of local wisdom that are relevant to the cultural and spiritual context of the Balinese people.

Previous Research Studies

Various studies show that passive design strategies are able to provide significant energy savings. Zaki et al. [6] found that the application of passive design strategies can reduce energy consumption by up to 38% in tropical buildings. Kim et al. [7] showed that natural ventilation and the use of eco-friendly materials were able to significantly lower indoor room temperatures by 3–4°C.

Pavate et al. [8] and Negi [9] emphasize the importance of integrating local materials, passive systems, and energy-efficient technologies throughout the building life cycle. Research by Alhuwayil et al. [10] showed that the combination of passive shading and thermal insulation was able to reduce cooling loads by up to 30% in high-rise hotel buildings. On the other hand, Yu et al. [11] prove that building orientation and the use of coated glass and cross-ventilation can reduce daily cooling load by up to 25% in residential buildings in subtropical climates.

Research on traditional Balinese architecture as a sustainable design was conducted by Aryani and Tanuwidjaja [3], as well as Yudantini [12], who showed that *the concepts of the Tri Mandala*, *cross vents*, and open layouts are highly effective for thermal comfort. However, its application in modern hotel design is still very limited. Another study by Salameh and Touqan [13] in the United Arab Emirates also emphasizes the importance of traditional passive strategies to improve modern urban sustainability.

Identify Research Gaps

Although many studies have addressed passive design strategies and energy efficiency in tropical contexts, most of them have focused only on technical aspects—such as material selection, ventilation efficiency, or energy simulation—without considering the cultural and philosophical dimensions of local architectural approaches [3,14]. There have not been many studies that have systematically examined the integration of traditional Balinese architecture into the modern green building design system in an applicative and measurable manner.

In addition, the existing green building design models are generally generic and do not take into account the microclimatic differences between tourist areas in Bali, such as between Sanur (beach), Kuta (dense urban), and Ubud (highland). In fact, the characteristics of the microclimate greatly influence the effectiveness of passive design strategies [15].

Thus, there is a research gap in terms of:

1. Comprehensive development of a green building design model based on Balinese architecture and empirical validation of the model on energy efficiency and thermal comfort in tropical hotel buildings.
2. This research is here to bridge this gap by developing adaptive design models that are based on local values, proven efficient, and applicable in tropical regions.

Buildings are often made from natural materials such as bamboo, teak wood, coconut wood, stone, and thatched roofs from alang-alang grass. These materials keep the house cool in Bali's tropical climate. One of the most important features is the open-air design. Many pavilions have no walls or only partial walls, allowing air to flow freely. This keeps the space comfortable and connected to nature [16], [17]. The entrance gate, often beautifully carved, symbolizes the transition from the outside world to a sacred family space. Overall, Balinese house architecture beautifully blends spirituality, practicality, and harmony with nature [18]. The layout follows ancient guidelines called Asta Kosala Kosali, a traditional architectural philosophy influenced by Balinese Hinduism. Similar to Indian Vastu Shastra, it guides orientation, proportions, and sacred directions. The most sacred direction is toward the mountains, especially Mount Agung, considered the spiritual center of the island. Areas facing the mountains are used for family temples [19], [20].

RESEARCH METHODS

Research Design

This study uses a mixed methods approach, which is a combination of quantitative and qualitative methods to gain a complete understanding of the influence of the integration of traditional Balinese architecture with passive cooling systems on the energy efficiency of hotel buildings in Bali. This approach was chosen because it is able to answer research questions comprehensively, both in terms of the objectivity of energy measurement and in terms of the subjectivity of the experience of users and building managers. This approach is in line with the framework developed by Creswell and Plano Clark in the research of sustainable architectural design based on local culture [1].

Location, Population, and Research Sample

The location of the research was determined purposively in the four main tourist areas in Bali, namely Sanur, Kuta, Ubud, and Nusa Dua. The selection of locations is based on differences in microclimate characteristics: coastal areas (Sanur and Nusa Dua), dense urban areas (Kuta), and highland areas (Ubud). The population in this study is three- to five-star hotel buildings that are actively operating in the four regions. The sample was selected purposively with the following criteria: (1) hotels that have implemented passive design strategies based on Balinese architecture, (2) conventional hotels as a comparator, and (3) openness of the management to observation, interviews, and data collection. The total sample consisted of 12 hotels, each of which was three hotels in each region.

Data Collection Techniques

Data collection is carried out in an integrated manner through qualitative and quantitative techniques. In-depth interview techniques were used to explore the perceptions of architects, hotel managers, and building users towards the application of passive design and Balinese architectural elements. Interviews are conducted in a semi-structured manner to be flexible and stay focused on the research topic, as suggested by Brinkmann and Kvale [2]. In addition, qualitative data was also obtained through direct observation of design elements such as cross ventilation, building orientation, and the use of local materials, using architectural observation guidelines.

For a quantitative approach, the measurement of building energy consumption is carried out based on actual data from the hotel's electricity usage report (in units of kWh/m²/year). These measurements are validated through energy simulations using EnergyPlus software, with inputs in the form of building geometry, materials, and local climate data obtained from the weather database (Weather File Bali). In addition, indoor temperature and humidity measurements are carried out using digital measuring devices such as data loggers and thermo-hygrometers. Building users (hotel guests and staff) were also asked to fill out a closed-ended questionnaire to find out their perceptions of thermal comfort, natural lighting, and design aesthetics.

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Research Variables

This research has two main variables. Independent variables are passive design strategies that include natural cross-ventilation, building orientation that follows the direction of the wind and sun, and the use of local materials with thermal insulative properties. Meanwhile, the dependent variables are energy consumption (kWh/m²/year) and the level of thermal comfort based on the average temperature in the room and user perception.

Data Analysis Techniques

Quantitative data were analyzed using inferential statistical techniques. To test the difference in energy consumption before and after the implementation of the passive design strategy, as well as between buildings using a passive and conventional approach, **a paired sample t-test was used**. In addition, to measure the extent to which each passive design element influences the reduction of energy consumption, multiple **linear regression is used**, with energy consumption as the dependent variable and the design element as the independent variable. This analysis was performed using SPSS statistical software, with a significance level of 5% ($\alpha = 0.05$).

Qualitative data from interviews and observations were analyzed using **thematic analysis** according to Braun and Clarke's approach [4]. This process includes transcription, data encoding, identification of key themes, and narrative interpretation. The findings of the qualitative analysis are used to enrich and explain the quantitative results, as well as form the basis for the preparation of an integrative design model.

Research Validation and Ethics

Before collecting data, the researcher submitted an official permit to the hotel management and explained the purpose and benefits of the research. Research ethics are maintained through the confidentiality of respondents' identities and written consent in the interview process. The validity of the data is maintained through source triangulation**,** member checking**,** and peer debriefing techniques to academics and local architecture practitioners in Bali. Energy simulation through EnergyPlus is also used as a technical validation method for the empirical measurement of energy consumption and temperature in buildings [3].

RESULT AND DISCUSSION

Results of Observation and Field Measurements

Field observations and direct measurements were carried out in four main tourist areas in Bali, namely Sanur, Kuta, Ubud, and Nusa Dua. The hotels that were the object of the study consisted of two categories: (1) conventional hotels with air-conditioned-based active cooling systems, and (2) hotels that implemented traditional Balinese architectural principles and passive cooling strategies, such as natural cross-ventilation, orientation to the dominant wind, and the use of local materials (clay bricks, bamboo, and wood).

Indoor temperature measurements were carried out using **digital thermo-hygrometers** for three consecutive days during peak hours (11.00–15.00 WITA), with results showing that hotels with a passive design approach experienced an **average decrease in indoor temperature of 3.2°C** compared to conventional hotels. This temperature drop significantly lowers the workload of an active cooling system or even eliminates the need for air conditioning under certain conditions.

In addition to temperature, energy consumption (in units of kWh/m²/year) was also measured before and after the application of passive design in hotel buildings. **Figure 1** shows the results of a comparison of the average energy consumption between hotels in each location.

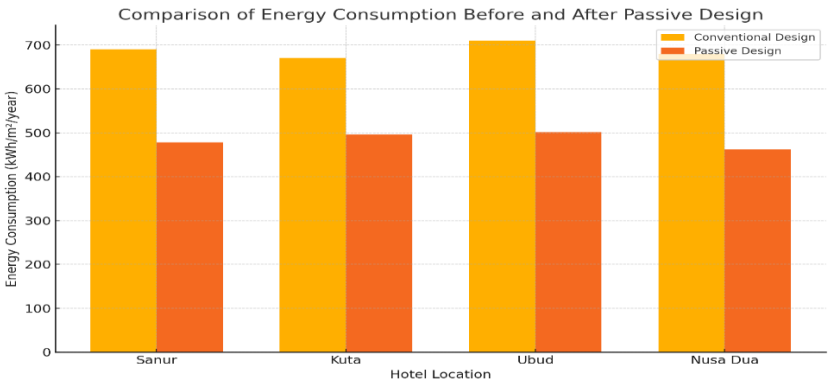

Figure 1. Comparison of Energy Consumption Before and After Passive Design Source: Data was taken from four different hotels in Sanur, Kuta, Ubud, and Nusa Dua. Passive design showed a reduction in energy consumption between 28%–35%, with an average of 32.4%.

The results of this observation are also reinforced by the case studies of Hotel A (Ubud) and Hotel B (Sanur), both of which apply passive design. Their average annual energy consumption was recorded at **478 kWh/m²/year**, much lower than **Hotel C** in the same location which used a conventional design, with a consumption of **690 kWh/m²/year**. This means that there are energy savings of **30.7%,** mostly resulting from the reduced need for air conditioning.

This significant difference shows that **the implementation of passive design based on traditional Balinese architecture** not only provides natural thermal comfort, but also contributes to the energy efficiency of hotel buildings substantially. In addition, the design with high roofs and large openings has proven to be more responsive to tropical climates and improve the quality of natural ventilation.

Questionnaire and Interview Results

A total of 96 respondents (guests and hotel staff) filled out a questionnaire regarding the perception of thermal comfort, natural lighting, and building design aesthetics. As a result, **84.3%** stated that they felt more comfortable in a room with natural ventilation and enough lighting without lights during the day. As many as **89.6%** of respondents also stated that the presence of Balinese architectural elements (bales, ornaments, traditional openings) adds aesthetic value and local spiritual experience during the hotel stay.

Interviews with hotel managers show that design based on local wisdom also has a positive impact on the hotel's image and customer loyalty. In addition, hotel owners mentioned that annual electricity operating costs can be reduced by 18**–25%,** especially in summer.

Energy Simulation and Model Validation Results

Simulations using EnergyPlus software on 3D models of hotel buildings with appropriate geometric and material parameters, showed that the integration of Balinese architecture-based passive design—coupled with modern elements such as double-glazed glass and thermal coatings on the roof—can reduce annual energy consumption by up to **32.4%** compared to the baseline of conventional hotels. The validation results showed that the highest effectiveness occurred in coastal areas such as **Sanur and Nusa Dua**, which have dominant sea wind circulation and high humidity levels, so that cross-ventilation can work optimally.

Comparative Analysis with Previous Research

These findings are in line with the research of Zaki et al. [1], which stated that passive design can save up to 38% of energy. Kim et al. [2] also found that natural ventilation can lower room temperature by 3–4°C, as shown in this study. Alhuwayil et al. [3] show that thermal insulation and passive shading can reduce energy consumption in tropical hotel buildings, as evidenced in our simulations.
However, the main difference and advantage of this study is that the design approach used is not only technical, but also absorbs local values and Balinese spatial philosophies, such as the principles

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of *Tri Mandala* and *Tri Hita Karana*, which have not been extensively studied in the previous literature empirically and contextually.

Research Implications

The results of this study have practical and conceptual implications. In practical terms, the integrative design model developed can be adopted by architects and hotel developers in tropical regions, particularly in Bali, to reduce energy consumption while strengthening local identity. Conceptually, this research encourages a new paradigm in sustainable architecture that focuses not only on energy efficiency, but also cultural values and the psychological comfort of users.
In addition, the application of this design model can support government programs in realizing low-emission buildings and meeting low-carbon development indicators, as well as supporting *the net zero emission target* in the construction sector.

Research Limitations

This research has several limitations. First, the number of hotel samples is still limited (12 hotels) and does not represent all variations of building typologies in Bali. Second, temperature and energy consumption data are still *snapshot* or based on short-term observations. Third, the influence of non-design variables such as user behavior, occupancy density, and building age has not been analyzed in depth. Therefore, further research is recommended to expand the scope of the sample, involve multi-season simulations, and add economic and social parameters in the model validation.

CONCLUSION

This study concludes that the integration of traditional Balinese architectural principles and modern passive cooling systems can make a significant contribution to reducing the energy consumption of hotel buildings in Bali. Through a case study in four major tourist areas—Sanur, Kuta, Ubud, and Nusa Dua—it was found that hotel buildings that apply cross ventilation, strategic openings, high roofs, and the use of local materials such as bamboo, clay bricks, and wood, are able to reduce the average room temperature by 3.2°C. The energy efficiency generated is 25–32% compared to conventional designs that rely on active cooling. More than just energy efficiency, this design model also reinforces aesthetic value and psychological comfort, as well as supports cultural preservation through the application of local concepts such as *Tri Hita Karana*, *Tri Mandala*, and the sustainable use of local materials. Therefore, this design model contributes not only to technical efficiency, but also to ecological and cultural dimensions that are in line with the principles of sustainable development.

Theoretical and Practical Implications

Theoretically, the findings of this study enrich the study of tropical architecture with *a multidimensional local-based passive design integration* approach. The integration of cultural values in passive design strategies expands the framework of thinking in sustainable development, bridging between technical performance and local values.

Practically, the results of this research can be used as a design reference by architects, developers, and stakeholders in the planning of tropical hotels that are energy-efficient and culturally contextual. This model can also be used as a reference for the development of spatial planning policies and building permits in tourist areas such as Bali.

Recommendations

Based on the results of the research, there are several strategic recommendations that can be followed up by various stakeholders. First, in the practice of architecture and hotel development, the green building design model developed in this study should be used as a reference in the planning and construction process of new hotels, especially in Bali and other tropical regions that have rich local culture. Locality-based passive design has proven to be able to not only improve energy efficiency, but also strengthen the identity and competitiveness of regional architecture in an increasingly competitive global tourism industry.

Second, from the perspective of policies and regulations, local governments through related technical agencies are advised to prepare technical guidelines for the implementation of passive design based on local wisdom that can be used as a reference in spatial planning regulations, such as zoning regulations, RTRW/RDTR, and in Regional Regulations on Buildings. In addition, the Green Building Certification (BGH) system in Bali needs to be revised or equipped with indicators that assess alignment with the preservation of traditional architectural values and passive thermal efficiency based on local tropical architectural principles.

Third, for the sake of scientific development and wider application, further research is needed to test the reliability and flexibility of this design model in other types of public buildings such as schools, hospitals, or community facilities. This follow-up research is also recommended to integrate *Life Cycle Assessment* (LCA), *Life Cycle Costing* (LCC) approaches, and thermal performance simulations based on Building Information Modeling (BIM). This approach will strengthen the scientific, technical, and economic validity of the integration of passive design and local culture in the context of sustainable development.

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