# Review of Passive Design Strategies for Sustainable Development: A Focus on Energy Efficient Strategies for Tropical Climates

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**Abstract:** In tropical climates, where high temperatures and humidity levels pose challenges to energy efficiency, the adoption of passive design strategies becomes crucial. With the use of qualitative data, this study analysed secondary sources such as experiments and scholarly materials from reputable databases such as Google Scholar, ResearchGate, Scopus and Covenant University Repository. The systematic review of published literatures presented in themes examined how passive design strategies aid energy efficiency for a sustainable built environment in tropical buildings. 70 publications spanning the years of 2002-2024 were content analysed and descriptively presented. The findings showed that proper incorporation of passive design solutions is both advantageous to man and the environment. It further makes for reduced energy consumption in tropical buildings. The study recommended intentional designer responsibility, policy implantation and better innovative solutions.

**Keywords:** Passive design, Energy-efficiency, Tropical buildings, Sustainability, Built environment

## 1. Introduction

Building typologies vary, but residential and commercial buildings account for one-third of global energy use. Passive design strategies have become increasingly important in the quest for sustainable development, especially when it comes to improving building energy efficiency in tropical regions. According to [51], passive design strategies are a collection of techniques that make use of natural elements to lower energy consumption and increase thermal comfort in buildings. Additionally, [16] stated that these tactics take into consideration things such as building orientation, shade, natural ventilation, and the usage of thermal insulation materials. Buildings can significantly reduce their energy use and further the cause of sustainable development by incorporating passive design strategies [71].

[37] indicated that the implementation of passive solutions in existing buildings can result in enhanced thermal comfort and energy efficiency. Furthermore, there has been encouraging progress in improving building sustainability through the application of passive design strategies adapted to particular climatic circumstances, such as solar chimneys for natural ventilation in hot, arid locations [15]. The significance of passive design strategies as

mentioned by [28] in conjunction with renewable energy technologies like photovoltaic systems has also been emphasized by efforts to achieve zero energy buildings (ZEB) in tropical and humid climates. Through the integration of passive solutions with active technology, including solar water heaters and panels, buildings can attain energy self-sufficiency and simultaneously lessen their ecological footprint.

Energy efficient buildings are more common now more than ever as there is a growing need for habitable spaces that are eco-friendly [24]. According to [23], such spaces should address the visual, spatial, thermal, acoustic and air quality comfort of its users. As such, when energy consumed is greater than energy generated, it imposes a huge challenge for the government to cater for the needs of the people. This gives citizens more room to rely on pricey private power plants that have long-term detrimental effects on the environment and public health. That is why [54] suggested that ways on how generated energy consumption can be minimized should be explored. One of which is use of passive building elements that mitigate high energy consumption throughout the lifecycle of a building. Hence, in buildings, energy demands influenced by site characteristics, building orientation, organisation of space, building plan, building envelope and construction materials should be low [23]; [21]; [54]. These are not just passive building elements but in turn make for a sustainable and conductive environment for all.

On the subject of passive design strategies, existing studies were found to have been carried out with focus on traditional vernacular architecture, sustainable thermal comfort, cost effectiveness, retrofit buildings, residential buildings, economic benefits, solar design, garment factory, net plus energy houses, architectural identity, human design and ergonomic sustainability [50]; [74]; [22]; [45]; [61]; [65]; [63]; [67]. Relatively, studies found on energy efficiency focused on office buildings, construction materials, building envelope, construction knowledge and sustainability parameters [23]; [5]; [21]; [54]; [3]. Some other studies were found on tropical climate with focus on construction materials implications, existing building retrofits, cost effectiveness of active and passive design strategies, indoor overheating risk and cooling design [26]; [68]; [21]. This posed a literature gap regarding the relationship between passive design strategies, energy efficiency and tropical climates.

It is on this premise that this study looked into passive design strategies that facilitate energy efficiency for a sustainable built environment and determine how tropical buildings can apply such strategies. Passive design strategies emphasize a sustainable and energy-efficient approach to building design, which represents a paradigm shift in the field of architecture. [45] asserted that it is imperative to implement passive design solutions at the outset of architectural design, since they aid in reducing the building's energy consumption. Thus, the following objectives are established:

i. Examine passive design strategies for sustainable energy-efficient buildings; and
ii. Determine how they are applied in the design of tropical buildings.

With the use of a mono method qualitative research choice, this study provided insight into the various passive building elements that can be incorporated for energy-efficiency in the design of tropical buildings. The interpretivism philosophy adopted in this study highlighted existing literatures as case studies for an in-depth understanding on the study’s context. By evaluating the use of passive design strategies for energy-efficient buildings in a sustainable environment through empirical studies, the findings can be beneficial to people at different sectors such as policy makers, researchers, students and lecturers. This further promotes sustainable building practices in tropical regions. In keeping with international efforts to create a more sustainable environment, the study also supports three (3) of the Sustainable Development Goals (SDGs): the ninth target, "industry, innovation, and infrastructure," advocates for resilient in infrastructure, sustainable industrialization, inclusivity and innovation in the built environment; the eleventh target, "sustainable cities and communities," speaks to the habitability of human settlements that are inclusive, safe, sustainable and resilient; and the thirteenth target, "climate action," highlights the urgency of finding innovative solutions to climate change and its effects.

## 2. Materials and Methods

### 2.1 Research Design

Using a thematic analysis approach, comparable topics were grouped together to uncover reoccurring themes and patterns in the literature. The study looked at the nuances of these themes as well as additional information regarding the use of passive design strategies for tropical budlings that use less energy. The "results and discussion" section outlined the ten categories into which the passive design strategies were divided. With the use of a plate and figures to promote comprehension, a descriptive method was employed to present and discuss the findings.

### 2.2 Data Collection

This study used a qualitative research methodology to filter data from pertinent secondary sources in order to offer insights on the passive design strategies that promote energy efficiency in tropical climates. ***Table 1*** lists the number of data sources from peer-reviewed articles published between 2002 and 2024 that were obtained from reliable academic databases like Google Scholar, Scopus, ResearchGate, and Covenant University Repository. Terms like "Passive Design," "Energy-efficiency," "Tropical Buildings," "Sustainability," and "Built Environment" were utilized to ensure a comprehensive analysis of the topic.

**Table 1.** A Table Outlining the Number of Retrieved Articles from Utilized Databases

| SN | Database/Journal | No. of Papers |
|---|---|---|
| 1. | Google Scholar | 46 |
| 2. | Scopus | 31 |
| 3. | ResearchGate | 12 |
| 4. | Covenant University Repository | 17 |
|  | Total | 106 |

***Authors' Compilation (2024)***

### 2.3 Data Analysis

Out of the 106 articles that were initially deemed relevant, 70 were selected because they had a direct bearing on the subject of the study. From the papers, pertinent data on passive design techniques appropriate for the planning and construction of energy-efficient buildings in the tropics was extracted and subjected to content analysis. The systemic procedure used in this study is illustrated by an overview of the synchronization of publications gathered, evaluated, screened, and reviewed at each level, as shown in ***Figure 1.*** Primary studies were extracted in the initial search stage using titles, keywords, abstracts, and findings. Following assessment, there was agreement on the data extraction, and additional synchronization was carried out to filter out pertinent studies that answered the research question. This is the screening stage, which is step two. Stages three and four of the synthesis process complete the systematic data extraction process, preventing bias and appropriately formulating emerging themes related to the paper's content.

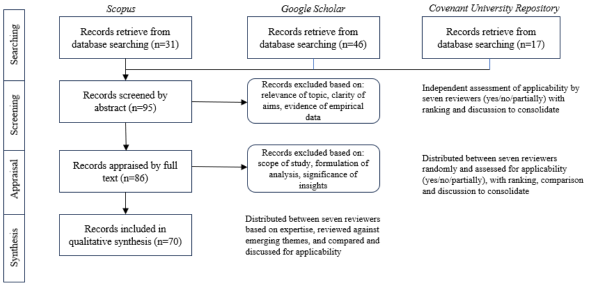

**Figure 1**. A Summarized Flowchart for the Selection and Analysis of Papers

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# 3. Result

## 3.1 The Concept of Passive Design

According to [12], passive design is the application of architectural principles that adjust to the local climate with the goal of achieving long-term indoor thermal comfort through natural means. [62] reiterated that the term "passive" denotes a defensive strategy, with buildings intended to shield residents from unfavourable local temperature conditions. Passive building designs are recommended to reduce internal heat radiation, enhance natural ventilation caused by prevailing winds and optimize natural daylighting, especially in hot and humid tropical locations.

The importance of passive building strategies is advantageous to architects and users alike. It is the responsibility of architects to develop designs that take into account basic climate requirements. In recent times, scholars such as [50] and [63] have underscored the significance of integrating passive building design strategies into contemporary structures situated in tropical regions. By maximizing the use of available natural resources, passive design strategies lessen the requirement for mechanical temperature control systems. It is not only a question of taste when these strategies are incorporated into traditional architectural methods; rather, it is a responsible step toward building structures that optimize resources, balance the built environment, and promote environmental sustainability [45].

[49] highlighted that passive or natural approaches were employed to obtain desired thermal comforts in work spaces for improved productivity prior to the arrival of active/mechanical cooling and heating technology. But more and more individuals are choosing energy-driven mechanical devices these days, which rely significantly on high energy input to maintain thermal comfort. These devices have high heat production which raises the ambient temperature and increases the risk of climate change and global warming, particularly in tropical regions. A great source of historic knowledge that can influence modern sustainable design practices is vernacular architecture. Through the examination of passive design strategies found in traditional architecture, designers can get valuable knowledge about how to adapt to regional climates and maximize the use of available resources [50]. This blending of traditional knowledge with contemporary design concepts emphasizes how crucial it is to approach sustainable development with consideration for the surrounding context.

Using the innate qualities of the local climate and surroundings, passive design strategies provide a comprehensive approach to sustainable building design. Effective shading and solar management strategies are crucial elements of passive design in regions with intense sunlight [39]. The study of shade examines vegetation, louvers, and overhangs as means of reducing heat gain and blocking direct sunshine. By strategically positioning shading devices to lessen the demand for mechanical cooling systems, passive design lowers energy usage. According to [56], sunlight entering buildings through roof and wall holes causes discomfort and indoor overheating, especially in office buildings, which lowers productivity. This shows that the influence of energy efficiency achieved through passive design can have a positive effect on users.

It has been demonstrated that implementing passive design strategies greatly enhances building performance in terms of thermal comfort and energy economy. Buildings can attain optimal performance without heavily depending on mechanical systems by including aspects like orientation, shade, natural ventilation, and thermal mass, as explained by [55]. As mentioned by [73], these strategies are essential to the idea of sustainable architecture since they not only help save energy but also enhance occupant comfort and well-being. These strategies can result in significant reductions in cooling energy usage, enhancing the resilience of structures to environmental fluctuations [6]. Designers can customize passive solutions to meet the unique climatic circumstances of tropical places by concentrating on functions like storing, avoiding, delaying, and removing heat.

### 3.2 Climatic Characteristics of Tropical Regions

The distinct climatic patterns seen in tropical countries, which are defined by their location between the Tropics of Cancer and Capricorn, have a substantial impact on many elements of human existence, including building design and performance. The main climatic features of these areas were examined in this section, with focus on patterns of temperature and humidity, solar radiation and wind, and how these factors affect building performance.

**Temperature and Humidity Patterns:** High temperatures and humidity necessitate effective thermal comfort strategies to ensure occupant well-being. Tropical regions are renowned for their consistently high temperatures throughout the year. [9] noted that average temperatures often exceed 26°C, with minimal diurnal and seasonal variations. This thermal constancy is attributed to the consistent solar radiation intake due to the region's geographical location.

Concurrently, humidity levels in tropical regions are notably high, contributing to a warm and humid climate. Relatively, [19] noted that diurnal temperature fluctuations are more significant than seasonal variations in many tropical locations. Research by [18] indicated that relative humidity frequently surpasses 70%, fostering a conducive environment for microbial growth and human thermal discomfort. The interplay between temperature and humidity results in a high wet-bulb temperature, which significantly impacts human thermal comfort and building energy consumption.

Furthermore, the distribution of temperature and humidity within tropical regions is influenced by factors like altitude, proximity to water bodies, and prevailing wind patterns [19]. For instance, coastal areas tend to experience higher humidity due to evaporation from the ocean, while inland regions may exhibit lower humidity levels. Understanding these regional variations is crucial for effective building design and adaptation strategies

**Solar Radiation and Wind Patterns:** Tropical regions are characterized by intense solar radiation, with solar angles remaining relatively high throughout the year [18]. This is due to the near-vertical sun angle This abundant solar energy presents both opportunities and challenges for building design. While it can be harnessed for passive solar heating and energy generation, it also necessitates effective shading and insulation strategies to mitigate overheating.

Wind patterns in these regions are influenced by large-scale atmospheric circulation systems, such as the Intertropical Convergence Zone (ITCZ)., a low-pressure belt that shifts seasonally and Tropical Cyclones (TCs), atmospheric heat engine which is self-sustained and originated in tropical oceans. [31]

underscored the role of the ITCZ in determining prevailing wind directions and speeds. Such wind analysis highlighted rainfall trends and varying weather phases that characterise climate region. Additionally, [42] concluded that tropical oceans in coastal regions experience recurrent landfall of TCs which is of negative impact to human life and other species.

While wind speeds are generally lower compared to temperate regions, the consistency and directionality of tropical winds can impact building ventilation and cooling strategies. A study conducted by [53] emphasized that wind-induced changes will occur in the future due to the growing global climate. This shows the importance of considering wind patterns in building orientation and ventilation design. Proper alignment of buildings with prevailing wind directions can enhance natural cooling and reduce reliance on mechanical systems.

**Impact on Building Performance:** The distinct weather patterns found in tropical areas provide major difficulties for building performance and design. High temperatures and humidity can lead to thermal discomfort, increased energy consumption for cooling, and accelerated deterioration of building materials [59]. Effective thermal control techniques are necessary to preserve indoor comfort in high temperatures and humidity. Building orientation, insulation, ventilation, and shading are important components in minimizing heat gain and reduce energy use, as discussed by [56]. To address these issues, researchers and practitioners have explored various design strategies, including passive cooling techniques, insulation, ventilation, and the use of appropriate building materials.

Solar radiation, while a renewable energy source, can also contribute to building overheating if not managed appropriately. [67] underscored the importance of solar radiation analysis in building design to optimize daylighting and minimize solar heat gain. Moreover, the combination of high temperature, humidity, and solar radiation creates favourable conditions for mould growth and material degradation. The need for durable and moisture-resistant building materials as asserted by [35] ensures the longevity of buildings in tropical environments.

Wind patterns can be harnessed for natural ventilation, providing cooling and improved indoor air quality. However, [53] cautioned that wind direction and speed variations should be considered to prevent unwanted wind effects, such as wind-driven rain and discomfort. But due to human activity, tropical climates have been changing, mostly in terms of perceived patterns and temperature. This has had detrimental implications on both terrestrial and aquatic biotas as well as unfavourable socioeconomic effects on people [9].

Furthermore, the interaction between climate and building performance is influenced by factors such as building orientation, ventilation, and energy systems. [56] accentuated the importance of passive energy design considering both climatic conditions and occupant requirements. Hence, understanding the climatic characteristics of tropical regions is essential for developing sustainable and resilient building design. By carefully considering temperature and humidity patterns, solar radiation, and wind conditions, architects and engineers can create buildings that provide optimal thermal comfort, energy efficiency and durability.

### 3.3 Passive Design Strategies for Sustainable Energy-Efficient Buildings in Tropical Climates

Climate comfort, ventilation, and daylighting are all included in the passive design concept. The concept recognizes that a building can create liveable areas by using natural materials and climate conditions, as opposed to mainly depending on mechanical systems. In particular for tropical climates, the architectural use of passive design strategies for energy-efficient buildings represents an interdependent synergy of sustainability and operational performance. Because tropical climates present unique challenges for building performance and design, careful planning must be included to ensure a reduced environmental effect. The following are more detailed ways that the incorporation of passive design strategies can lower energy usage and lessen the environmental effect of tropical buildings:

**Site-Specific Factors:** Passive design promotes individual solutions based on site-specific features in relation to climate conditions. Incorporating passive design solutions begins with a thorough analysis of site-specific variables. Passive design solutions are very flexible and guarantee that buildings blend in with their surroundings, optimizing resource use and performance, independent of the climate, as explained by [26].

[14] have underlined the importance of comprehending the indigenous native climate, terrain, and environmental circumstances, since this opens up opportunities to investigate a wide range of methodologies. Ventilation, heat transmission, and outdoor thermal comfort are all impacted by wind patterns, which are defined by their predominant directions and speeds. Building layout, construction, and landscaping are all influenced by site analysis, which provides the foundation for using passive design concepts successfully.

Architects as iterated by [43] are becoming more and more focused on architectural orientation as they try to use natural resources like sunshine and wind. By considering the unique characteristics and climate of each location, the application of passive design strategies is inherently site-specific. Buildings now more than ever are being designed to minimize energy use and maximize efficiency by integrating with their surroundings through a customized approach such as passive design.

**Natural Ventilation and Daylighting:** Two thirds of greenhouse gas emissions worldwide are attributed to the energy sector, with lighting accounting for the second-highest energy consumption in the construction sector [58]. Natural ventilation and daylighting are two crucial components of passive architecture that raise energy efficiency in buildings. By utilizing the sun's path, passive lighting, commonly referred to as daylighting, reduces the need for artificial lighting. This focuses on ways to maximize the amount of natural light that enters interior rooms, thereby declining the necessity for artificial illumination.

According to [40], the principles of natural ventilation also emphasize creating openings for the flow of fresh air to enhance indoor air quality without the need of mechanical systems. Stack ventilation and cross ventilation are two well-known passive ventilation techniques. By making openings on opposing sides of a structure, cross-ventilation allows air to circulate and naturally cools the area. The idea behind stack ventilation is that heated air rises and causes a pressure differential, which in turn propels airflow as shown in ***Plate 1***. In addition to their benefits for air quality, cross ventilation also helps to maximize natural light in interior areas, as stated by [68].

***Plate 1. High Level Window for Stack Ventilation***

Passive daylighting as mentioned by [22] has physiological and psychological benefits that directly affect occupant health, circadian cycles, and productivity in addition to lowering energy load. Studies such [68] and [11] showed that by strategically positioning windows and skylights, passive design ventilation reduces the need for artificial lighting while facilitating the flow of fresh air. In order to minimize the demand for cooling, cross-ventilation must be optimized in the design of windows, vents, and openings. Vertical shafts and atriums can be used to improve stack ventilation in tropical structures, which will improve cooling and air flow [4].

Every indoor space creates its own macroclimate, and its efficacy is greatly influenced by elements such as air, light, and circulation. A crucial component of interior environments, ventilation depends not only on large openings but also on how interior spaces are arranged to allow for enough airflow [69]. When designing for natural ventilation, openings must be placed strategically, prevailing wind directions must be taken into account, and airflow impediments must be kept to a minimum. These factors contribute to optimizing natural ventilation's efficacy.

**Building Orientation and Layout:** Buildings account for 40%–50% of primary energy consumption worldwide making the housing and construction industry the largest electricity consumer and a major contributor to carbon dioxide emissions [41]. Because building orientation and pattern density have a basic impact on energy consumption, architects and builders, as highlighted by [24], are essential in encouraging energy conservation in society. Strategically positioned rooms and open floor plans are two aspects of building layouts that facilitate thermal comfort and ventilation. Passive cooling solutions might function better when they are laid out well. In a similar vein, [56] investigated how building orientation and the ratio of windows to walls affected the energy efficiency of tropical buildings. Their findings demonstrated how crucial it is to optimize building layout in order to reduce solar heat gain and increase natural ventilation.

Reducing cooling loads requires building orientation that maximizes use of prevailing winds and minimizes direct solar exposure. Appropriate alignment can minimize heat gain and enhance natural ventilation. Scholarly sources have conducted a thorough investigation on the effects of building orientation on energy usage [24]; [23]; [56]; [54]. In addition, the amount of direct sunlight that reaches the building facade depends on the angle of the building and the wall's bearing, as enumerated by[36].

According to [25], the best orientation happens when the main axis of the building makes a 0º angle with respect to the North. Furthermore, because the east and west receive twice as much sun radiation as the north and south, [56] determined that placing the building along the east-west axis can reduce solar heat absorption throughout the structure. Nonetheless, it is critical to state clearly what possible energy-saving benefits any design project may have. This is why because if they all include the same building typology, each design project has something special to offer that sets it apart from the others.

**Building Form:** The components that make up a building's form are mostly determined by orientation, massing, thermal mass, and site-specific aerodynamics. Passive design strategies which address characteristics like massing, proportion, scale, style, materials, and usefulness, can be included into a building's form. This element is critical to achieving the goals of sustainable design, making it more important than just beautiful design [38]. In order to reduce energy consumption, the form of the structure must be carefully considered while designing for energy efficiency. Building geometry is known to play a significant role in influencing energy use. A methodology was established by [33] to evaluate the effects of modifications in building geometry and materials on energy consumption. They discovered that the building's vertical and horizontal proportions are equally responsive to specific material characteristics that affect energy usage using two different types of sensitivity assessments.

When designing a building, it is best to keep the buildings outside surface area to volume ratio as small as possible, ideally emulating a hemisphere [52]. The design of the structure as noted by [10] can affect a number of elements that affect how much heating and cooling is needed. Climate is one of them. A building's form should adapt to the unique climate of the place where it is located. This explains why some building forms are more common in some areas than other possible forms. For example, building form in places with considerable yearly rainfall are different from those in arid and hot climates. Furthermore, the avoidance of energy loss through the building envelope should be taken into consideration while designing building shapes.

**Building Fenestration:** The location of windows has a significant impact on how much energy a structure uses. By limiting the amount of light and air that enters the building from the outside, they help to manage the quality of the air inside, especially depending on the location of the building. The impact of varying window sizes and degree on peak loads and energy requirements for heating and cooling in a well-insulated building was examined by [29]. They found that while bigger windows may increase energy efficiency, they may also increase peak loads throughout cold seasons. They also observed that while excessive solar transmittance hampered summer performance, windows with low thermal transmittance performed better when combined with high solar transmittance.

[60] looked into how triple-glazed, low-emissivity windows' dimensions and placement affect the amount of energy needed for heating and cooling. According to their findings, well-insulated walls and a functional ventilation system meant that window size had no bearing on the amount of energy needed. Aiming for energy efficiency requires careful consideration of factors like window placement, size, and arrangement, which affect the amount of incoming radiation.

[2] studied the effects of several window models on the amount of daylight that is created in a space. They found that, for the same opening area, square windows produced noticeably greater daylight factors than vertical windows and marginally higher daylight factors than horizontal windows. In addition, they observed that windows placed higher permitted more light to enter the back of the space than windows placed in the middle. It is noteworthy that attaining the ideal equilibrium in solar radiation intake necessitates meticulous evaluation of four fundamental elements: window dimensions, form, orientation, and suitable glazing choice.

**Solar Control and Shading:** A shading system's main objective is to protect a building's transparent areas from unwelcome solar radiation [4]. There are several sorts of these systems, including as moveable, fixed, and other configurations. Shade-producing structures like pergolas, louvers, and overhangs lessen heat accumulation and direct sunlight gain inside buildings. Reducing cooling energy use and preserving indoor comfort are two benefits of effective shade design. Controlling solar radiation is therefore essential for lowering heat gain and energy usage.

[13] examined the impact of shading devices on the thermal performance of buildings in a variety of climates and latitudes, as they have an impact on a building's energy usage. Their research showed that, in office settings with different climates, shading devices considerably improve thermal performance and save energy. This demonstrated how adding solar collectors to horizontal louver shading systems could improve a building's energy efficiency. [47] proposed potential classes for sun shading systems, as shown in ***Figure 2***.

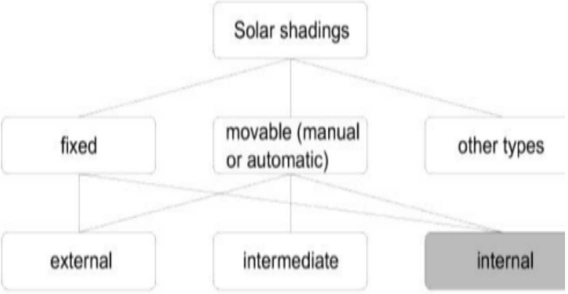

***Figure 2: Possible Classification for Solar Shading Systems [47]***

**Type of Glazing:** Due to its ability to control the amount of solar radiation that enters interior areas, glazing is essential for energy management in buildings. According to [34], windows are responsible for 20–40% of buildings' energy waste. Windows have a major impact on the overall energy performance of a structure and are essential to its design. A window's energy efficiency depends on a number of variables, including air leakage from airtight installations and frames, solar transmittance of the glazing, and thermal transmittance. The glazing system is one of these factors that is particularly important in determining the energy efficiency of windows.

The size, arrangement, and placement of windows are important elements that can significantly impact a building's energy efficiency in addition to glazing technologies. Therefore, the optimal window design necessitates balancing a number of criteria, such as the window's unique features, orientation, dimensions, kind of glass, and surrounding environmental factors. According to research by [70], selecting the appropriate glass is another practical way to limit the amount of solar radiation that enters a building. This strategy becomes especially crucial in areas where heating and cooling demands are high. As a result, when choosing the type of glazing, it's imperative to take the building's unique climate into account.

**Integration of Building with Landscape:** The architect's use of passive design architecture is seen in how well buildings blend in with their environment. According to [20], every design project should take into account the skilful blending of developed structures with green spaces. For instance, adding plant and natural components to the building envelope through the use of green roofs (see ***Figure 3***) and walls offers insulation, lowers stormwater runoff, and creates habitat for wildlife. Furthermore, green walls boost thermal comfort, attractiveness, and air quality.

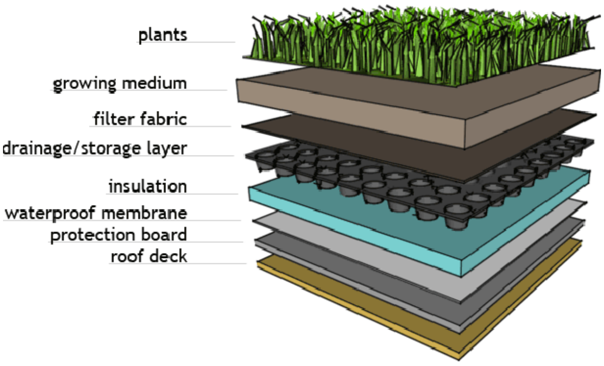

***Figure 3: Detail of a green roof [46]***

According to [64], using sustainable building materials reduces environmental effect and encourages resource conservation. Examples of these materials include recycled content, locally sourced materials, and low-emission products. In general, sustainable water management techniques including permeable pavement, on-site water treatment, and rainwater collection also save water usage and lessen the negative effects of stormwater runoff on the environment [56]. [46] discussed the use of native plants in landscape design to save water use, lessen maintenance needs, and maintain local biodiversity. Native plants are more resilient and sustainable options since they can adapt to the local soil and climate.

**Insulation and Reflective Materials:** By reflecting sunlight away from the building, reflective coatings lessen the amount of heat that the sun absorbs. This method lowers the amount of cooling energy needed while preserving colder interior temperatures. Reflective and permeable materials are the mainstay of insulation in tropical regions because they reduce heat gain. The goal of architectural interventions like cool roofs, green roofs, and reflective surfaces as mentioned by [67] is to reduce the amount of heat absorbed by the sun.

Since most heat gain in tropical climates happens at the top of structures, it is critical for the roof to be well- insulated. Air is a good insulator, especially on roofs that have high ridges (jack roofs, for example), which increase the stack effect [32]. In addition, air-gap roofs, like parasol roofs, are advised to aid in the removal of heated air and encourage cross-ventilation. In hot and humid climes, many tropical countries—often categorized as third world countries—face regular power outages and load shedding. According to [56], the increasing load shedding scenario has forced many people to rely on operational energy for heating and cooling their homes and workplaces because of the extreme heat radiation. This increases the ecological footprint of such budlings.

Solar control techniques are used in roof design as part of passive building design. Heat reflection and shading can be facilitated by various roofing configurations and materials, as well as colour. The colour scheme used on a building's outside can affect how much solar radiation is absorbed or reflected. According to [64], small, unventilated buildings in Israel with white walls had summer temperatures that were around 3ºC cooler than those with grey walls. They found that, on average, black roofs retained lower moisture levels than white roofs. [66] investigated how using a new kind of paint could reduce energy use in various climes. Coatings with mineral microparticles were shown to act as thermal insulation, resulting in a 20% decrease in energy usage.

Because the tropics present a difficult environment that makes living circumstances in densely crowded cities extremely uncomfortable, residents' working time is largely consumed managing these conditions [48]. Regretfully, these circumstances are made worse by elements that contribute to climate change, such as industrialization, population development, and rising carbon dioxide emissions. ***Figure 4*** illustrates how insulation was placed on the outside of building walls by [1].

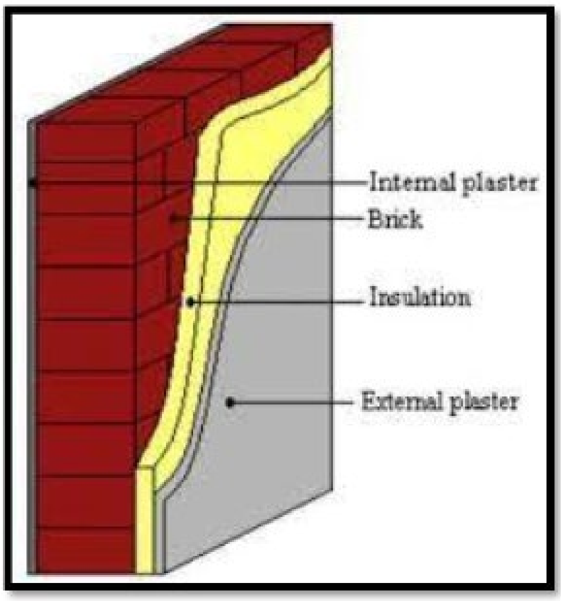

***Figure 4: Insulation placed on the exterior surface of the wall [1]***

**Thermal Mass Utilization and Thermal Insulation:** The capacity of a material to absorb and hold heat is referred to as its thermal mass. High thermal mass materials assist to regulate indoor temperatures in tropical climates by absorbing surplus heat during the day and releasing it at night when it's colder. When the temperature inside the thermal mass is lower than the surrounding air, it absorbs heat from the interior air and releases it back into the interior air when the outside temperature rises. According to [72], this theory enables the material mass of buildings to store solar heat gains, minimizing energy consumption for climate management and regulating temperature swings.

Brick and concrete are common building materials used for thermal mass in tropical regions. A well-planned thermal mass can lessen the requirement for mechanical cooling and raise the comfort level inside. Numerous elements, such as the climate, building orientation, window sizes, insulation levels, ventilation systems, load profiles, and occupancy patterns, affect a structure's thermal mass efficiency. Thermal mass works best in settings where there is a noticeable difference in temperature between day and night [30].

Using a combination of materials or a single material, thermal insulation reduces heat transfer by radiation, convection, and conduction into and out of a building. [7] looked at studies on the effects of thermal insulation on buildings' energy and environmental efficiency. Correctly installed thermal insulation on a building's exterior can drastically reduce energy use and its negative environmental implications. Expanded polystyrene (EPS), phenolic foam, and rockwool insulation were the three insulation materials evaluated and contrasted in terms of their environmental effects by [75]. They examined sixteen distinct environmental impact categories over a thirty-year period in order to identify the insulation with the lowest environmental impact. In fourteen of the sixteen categories they looked at, they discovered that EPS had the least negative effects on the environment.

Many initiatives have been made to investigate the possibility of using thermal insulation in buildings to save energy. The effects of using external wall insulation on energy consumption and indoor thermal conditions were studied by [17]. According to the results, there was a 23.5% summertime energy savings in the energy-efficient chamber compared to the basic chamber's energy use. Furthermore, [75] studied the effect of wall insulation thickness on the annual energy consumption for heating and cooling in China's different climates. The findings suggested that adding more insulation to external walls, especially in areas outside that face all directions in Beijing's climate, could result in a significant decrease in energy use. This demonstrates that creative methods for using natural materials as insulation in buildings can be accomplished.

## 4. Discussion

Different regions have different tropical climates, therefore passive design solutions must be adjusted. Passive measures are influenced by local factors such as cultural traditions and microclimates when designing and implementing them. The efficient application of passive design techniques in tropical regions has been shown in a number of projects. Buildings for residential, commercial, and institutional use that effectively use thermal mass, natural ventilation, and shading strategies are some examples. The comparative analysis of several passive design solutions revealed in this study is the relative efficacy of these strategies in tropical regions. Each strategy's success is influenced by various factors, including the type of building, its location, and its particular climate.

In addition to saving energy expenses, energy-efficient buildings provide their residents with the best possible living and working conditions. The goals of passive building strategies are to improve user comfort, boost output, and utilize less energy from sources like electricity and natural gas. For instance, how well green roofs work in tropical locations to reduce inside temperatures and increase building energy efficiency. Additionally, compared to existing buildings, an optimal design strategy reduces solar heat gain by having larger north-facing windows and fewer south-facing windows. The overall sustainability of the structure is improved by the insulation and cooling advantages that come with green walls and roofs, which also provide aesthetic value and support biodiversity.

Performance-oriented passive design strategies are becoming more and more important as the subject of sustainable architecture develops. Passive design strategies like orientation, shading, and natural ventilation can therefore be integrated to maximize energy efficiency and minimize the need for mechanical heating and cooling systems. Additionally, using landscaping elements like trees and plants reduces solar heat gain and provides shade. As a result, using natural materials like bamboo, stone, and wood strengthens the bond between the structure and its environment. To help decision-makers achieve energy-efficient targets through a thorough design process, simulation-based optimization techniques should be investigated [44]. Furthermore, new opportunities for improving the efficacy of passive envelope solutions in low-energy building designs should be presented by developments in enclosure systems and materials [8].

## 5. Conclusion

Implementing passive design presents a number of difficulties, including high upfront costs, material availability, and cultural opposition to novel ideas. It is imperative that these obstacles be removed in order to promote passive design strategies more widely. A comprehensive approach to building sustainability can be achieved by fusing active systems, such solar panels and energy-efficient appliances, with passive architecture. These integrations should be the subject of future studies in order to achieve overall energy efficiency. Advanced materials, smart building technology, and integrated design strategies are emerging themes in passive design. These developments could improve passive techniques' efficacy in tropical regions. To further understand emerging technologies, passive design strategies' long-term effectiveness, and how to integrate them with other sustainability measures, more research is required.

It is clear that using passive design techniques can help create sustainable cities, as this research promotes the three (3) Sustainable Development Goals (SDGs) listed in the introduction. An environment like this makes it possible for everyone to live in a human settlement that is resilient and safe. Furthermore, using more natural lighting and ventilation methods lowers a building's carbon footprint, which helps to lessen the effects of climate change.

In conclusion, the climatic features of tropical areas, such as elevated temperatures, elevated humidity, strong sun radiation, and particular wind patterns, present unique difficulties for building performance. In tropical areas, constructing buildings that are both comfortable and energy-efficient requires a thorough understanding of these environmental conditions. Subsequent investigations ought to concentrate on creating innovative construction methods and technologies that cater to the particular requirements of tropical areas.

## Conflict of Interest

The authors disclose that there is no conflict of interest.

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