PASSIVE COOLING STRATEGIES

Current Status and Drivers of Integration into Policy and Practice within ASEAN's Building Sector

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Foreword: ACE

As the ASEAN region continues to experience rapid economic growth and urbanization, the demand for energy, particularly for space cooling, is projected to rise significantly. The ASEAN Centre for Energy (ACE) recognizes the critical need for sustainable solutions that address this growing energy demand while mitigating environmental impacts. In this context, passive cooling strategies emerge as a vital component of our approach to energy efficiency in the building sector.

This report, "Passive Cooling Strategies: Current Status and Drivers of Integration into Policy and Practice within ASEAN's Building Sector," serves as a comprehensive overview of the current landscape of passive cooling practices across ASEAN member states. It highlights the importance of integrating these strategies into national policies and building designs to enhance energy efficiency and reduce greenhouse gas emissions.

We acknowledge the collaborative efforts of various stakeholders, including government agencies, industry experts, and international organizations, in advancing the adoption of passive cooling techniques. By sharing knowledge and best practices, we aim to foster a culture of innovation and sustainability within the region.

As we move forward, it is essential to highlight the role of passive cooling strategies in developing resilient, energy-efficient buildings that support the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021-2025 goals. This report outlines the key drivers and policy challenges in implementing these strategies, including their impact on energy consumption. We call for collaboration among all stakeholders to address these challenges and work towards the sustainability of the building sector.

Beni Suryadi

Acting Executive Director

ASEAN Centre for Energy

Foreword: ESCAP

The ASEAN region is at the forefront of the sustainable cooling challenge. Climate change is driving rising temperatures and increasing the frequency of heat waves, while cities are expanding and urban populations continue to grow. Economic growth and rising incomes are enabling households and businesses to adopt energy-intensive cooling systems, further straining energy systems and leading to increased cooling-related emissions.

There is a growing urgency to provide access to thermal comfort, which is essential for health, well-being, productivity, and learning. However, the reliance on mechanical cooling systems to meet these needs places a heavy burden on energy infrastructure and contributes to rising greenhouse gas emissions.

Passive cooling strategies optimize a building's interaction with the environment to minimize the inputs from active cooling. Passive cooling approaches utilize architectural design to minimize heat gain, and utilize advanced materials, thereby offering avenues to reducing dependence on energy-intensive active cooling. This approach not only helps to lower greenhouse gas emissions but also enhances the resilience and well-being of communities, particularly as they face the impacts of climate change.

This report, "Passive Cooling Strategies: Current Status and Drivers of Integration into Policy and Practice within ASEAN's Building Sector," prepared by the ASEAN Centre for Energy (ACE), is a timely and valuable contribution to our regional understanding of passive cooling. It highlights the importance of passive cooling in the ASEAN context, provides a comprehensive overview of current policies and regulations supporting passive cooling, and offers targeted recommendations for regional and national policy and planning to promote the adoption of these low-energy and low-carbon approaches. In addition, the findings and recommendations presented in this report align with achieving the objectives of the ASEAN Plan of Action for Energy Cooperation (APAEC), the Sustainable Development Goals (SDGs), and the Paris Agreement.

ESCAP, with funding offered by Energy Foundation China, is proud to have supported this collaborative effort, and we extend our gratitude to the authors, reviewers, and all contributors who have made this report possible. We look forward to continued partnership with ASEAN member states, ACE, and other stakeholders to advance the adoption of passive cooling strategies, thereby fostering a sustainable future for the ASEAN region.

ESCAP
Economic and Social Commission for Asia and the Pacific

Hongpeng Liu

Director, Energy Division

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)

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Abbreviations and Acronyms

Abbreviation	Full Name
ACE	ASEAN Centre for Energy
APAEC	ASEAN Plan of Action for Energy Cooperation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
IEA	International Energy Agency
LEED	Leadership in Energy and Environmental Design
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
SHGC	Solar Heat Gain Coefficient
UHI	Urban Heat Island
UN	United Nations
VGBC	Vietnam Green Building Council
WWR	Window to Wall Ratio

Executive Summary

The ASEAN region is experiencing rapid economic growth and urbanization, leading to a significant increase in energy demand, particularly for space cooling. This surge in energy consumption poses challenges for sustainability and environmental impact, necessitating the exploration of innovative solutions. Passive cooling strategies in building design and construction emerge as a vital component in addressing these challenges, offering a means to enhance energy efficiency in buildings while reducing reliance on active cooling systems.

A pressing need for sustainable energy solutions exists in the ASEAN region, considering the anticipated rise in energy demand for space cooling. It establishes passive cooling strategies as a critical approach to enhancing energy efficiency and reducing environmental impacts, thereby addressing the dual challenges of energy consumption and climate change.

The implementation of passive cooling strategies in the ASEAN context face both challenges and opportunities due to the region's hot and humid climate. While high temperatures (25°C to 35°C) and humidity levels (often exceeding 70%) complicate cooling efforts, they also inspire innovative design solutions. Most importantly, high performance building envelopes with insulated roofs, walls and window glazing offer the greatest benefits in terms of maintaining comfortable indoor temperatures and reducing cooling loads. Where appropriate, natural ventilation can be harnessed through strategic building orientation and window placement, reducing reliance on mechanical cooling. Shading devices, high thermal mass materials, and reflective surfaces can effectively mitigate solar heat gain and reduce building energy use intensity. By leveraging these strategies, ASEAN countries can address their unique climatic challenges while promoting sustainable, culturally relevant building practices that improve comfort and reduce energy consumption.

Through the use of simulation parameters such as Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), and unmet hours, the report presents valuable insights into thermal comfort across different climatic conditions. The findings indicate that both passive cooling and hybrid scenarios significantly enhance thermal comfort compared to base cases. Additionally, the active design scenario provides the most consistent thermal comfort, although it may lead to increased energy consumption. Furthermore, passive cooling strategies applied to a baseline building design result in lower PPD values, suggesting that fewer occupants are dissatisfied with the thermal conditions. Reducing unmet hours is also essential for improving overall comfort and requires identifying areas for design improvement. These strategies are crucial for optimizing passive cooling strategies, particularly in subtropical climates.

The report also addresses significant policy challenges that impede the broader adoption of passive cooling strategies, including regulatory inconsistencies and a lack of enforcement mechanisms. To overcome these challenges, it offers actionable recommendations, such as the development of comprehensive building codes that incorporate passive cooling principles and the establishment of training programs for architects and builders. These initiatives are essential for creating a supportive regulatory environment that encourages the integration of passive cooling techniques.

In conclusion, the report underscores the importance of embedding passive cooling strategies within the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021-2025. It calls for sustained collaboration among stakeholders to tackle existing challenges and promote sustainable building practices. The findings reveal that passive cooling strategies are underutilized despite their significant potential to reduce energy consumption and greenhouse gas emissions. Therefore, the report advocates for a transformative shift towards sustainable building practices through the adoption of passive cooling strategies, which are vital for achieving energy efficiency and environmental sustainability in the ASEAN region.

I. INTRODUCTION

I.1 Introduction to Passive Cooling Principles and Design Approaches

In the ASEAN region, the demand for space cooling is becoming increasingly urgent due to the effects of climate change, urban population growth, and the expansion of the built environment. One largely overlooked strategy for addressing this demand is passive cooling.

Passive cooling is a design approach that utilises natural processes to maintain comfortable indoor temperatures while reducing reliance on active mechanical systems like air conditioners, which require electricity. As the world moves towards strengthening energy security, adopting practices that aren't dependent on conventional energy consumption becomes critical. Passive cooling methods are more resilient in the face of energy scarcity as they leverage architectural design, materials, and environmental conditions to reduce heat gain and enhance heat dissipation (Yu *et al*., 2020). In buildings, passive design strategies offer an effective and sustainable approach to enhance occupant comfort while reducing cooling load and electricity consumption related to active cooling systems.

The comprehensive application of passive design in building envelopes is a crucial strategy. Firstly, this approach incorporates insulation, for example, in roofs, walls and window glazing units. Proper insulation helps keep heat out during the summer and, in regions with climates that experience cooler temperatures, retain warmth, contributing to overall energy efficiency. Secondly, the use of reflective surfaces on roofs and walls that reflect rather than absorb solar energy significantly reduces heat gain. Thirdly, implementing shading devices such as overhangs, louvres, and vegetation can block direct sunlight from entering the building, further minimising heat gain.

Another key passive cooling strategy for buildings not employing active cooling systems and in regions experiencing mild outdoor temperatures is natural ventilation. This involves designing buildings to maximize airflow by using windows, vents, and openings to create cross-ventilation, which helps expel warm air and bring in cooler air. Another important technique is the use of thermal mass. Materials such as concrete, brick or stone can absorb and store heat during the day and release it at night when temperatures drop, helping to regulate indoor temperatures. Night cooling utilises cooler nighttime air to ventilate the building and lower indoor temperatures, often facilitated by opening windows or using thermal chimneys.

Lastly, evaporative cooling leverages water evaporation to cool the air and is a strategy best applied in hot and dry climates. This can be achieved through water features, misting systems, or wet surfaces. By incorporating these techniques, buildings can maintain more comfortable temperatures with less reliance on energy-intensive cooling systems, leading to greater energy efficiency and reduced environmental impact.

While the strategies outlined above are highly effective, it is important to recognise that they are not universally applicable to all climates and building types. For instance, the effectiveness of insulation and thermal mass is significantly influenced by local climate conditions; in regions with high humidity and minimal temperature variation, thermal mass might not provide the intended cooling effect.

Similarly, natural ventilation is most beneficial in areas with mild outdoor temperatures and good air quality but can be counterproductive in regions with high pollution levels or extreme temperatures. Reflective surfaces and shading devices are more suited to regions with intense solar exposure, while evaporative cooling is effective primarily in hot, dry climates where humidity levels are low. Therefore, when designing energy-efficient buildings, it is essential to tailor these passive design strategies to the specific environmental context and the intended use of the building to maximise their effectiveness and avoid unintended consequences.

I.2 Benefits of Passive Cooling Strategies

- **REDUCE ENERGY USE INTENSITY IN BUILDINGS**

The implementation of passive cooling strategies can reduce the need for energy-intensive air conditioning systems by utilising passive design, materials, and natural processes to regulate indoor temperatures. Passive cooling techniques, such as insulation, reflective surfaces, shading, natural ventilation, and thermal mass, can significantly lower the cooling load of a building. This reduction in cooling load leads to lower electricity consumption, which is crucial to reduce the building sector's demand on energy systems and the environment and is particularly beneficial in regions with high energy costs and limited energy resources. Improved energy use intensity translates to lower operational costs for building users.

- **REDUCE CARBON EMISSIONS**

Passive cooling strategies contribute to the reduction of greenhouse gas emissions by decreasing reliance on mechanical cooling systems. In Southeast Asia, where a significant portion of electricity is generated from fossil fuels, the reduction in energy consumption directly leads to lower carbon dioxide emissions. This is crucial in the effort to mitigate climate change, as buildings account for 23% of the region's total energy use and 23% of associated emissions (IEA, 2022c). By curbing the carbon footprint of buildings, passive cooling supports environmental sustainability. Lowering the reliance on mechanical cooling systems not only reduces operational emissions but also lessens the demand for energy production, which, in Southeast Asia is often carbon-intensive. As a result, passive cooling strategies deployed in existing and new construction plays a critical role in the broader strategy to reduce overall greenhouse gas emissions and combat global warming.

Case Study in Southeast Asia: In Cambodia, the National Cooling Action Plan integrates passive cooling solutions into national building regulations. This includes policy interventions, demonstration projects, and capacity building to reduce reliance on mechanical cooling and subsequently lower carbon emissions. The project aims to achieve a cumulative reduction of approximately 0.5 MtCO2eq by 2030, showcasing the Significant impact of passive cooling on emission reductions (Cool Coalition, 2024).

- **SUPPORT FOR ACHIEVING NATIONAL EFFICIENCY AND CLIMATE OBJECTIVES**

Many Southeast Asian countries have established ambitious national energy efficiency and climate goals as part of their commitments under international agreements such as the Paris Agreement. Implementing passive cooling strategies aligns with these objectives by promoting sustainable building practices and enhancing overall energy performance of the building sector. Countries like Cambodia, Indonesia, Thailand and Vietnam, have integrated energy efficiency targets into their national policies, recognising the building sector as a major energy consumer. Passive cooling can significantly contribute to achieving these targets by reducing the energy consumption of buildings, thus supporting national energy efficiency goals.

Furthermore, passive cooling enhances the resilience of buildings and their occupants against climate change impacts, such as rising temperatures and increasing frequency of heatwaves. By mandating the design of buildings that naturally maintain comfortable temperatures, countries can improve the quality of life for their citizens while alleviating the strain on energy infrastructure during peak demand periods. This dual benefit of improving living conditions and increasing energy security underscores the importance of passive cooling in national climate strategies.

Case Study in Southeast Asia: Vietnam's Green One UN House exemplifies the integration of passive cooling to meet national efficiency and climate objectives. The building features a range of passive design elements, including high-performance glazing, shading devices, and natural ventilation, contributing to a 28.8% reduction in energy use compared to conventional buildings (VGBC, 2018). This results in annual energy savings of around 110,000 kWh and a reduction of approximately 250 tonnes of CO2 emissions per year (United Nations Viet Nam, 2018).

COUNTRY	ENERGY EFFICIENCY TARGET
Brunei Darussalam	Reduce total energy consumption by 63% by 2035 compared to BAU scenario
Cambodia	• 10% energy reduction in all sectors compared to BAU by 2030 • Achieve less than 8% transmission and distribution losses • 15% energy intensity reduction in industry sector by 2030 • 15% increase of bus engine efficiency by 2030
Indonesia	• Energy Elasticity < 1 by 2025 • 1% energy intensity reduction per annum up to 2025
Lao PDR	• 10% total final energy consumption reduction by 2030 compared to BAU • 20% total final energy consumption reduction by 2040 compared to BAU
Malaysia	8% demand growth reduction by 2025, equivalent to 233 GWh of electricity savings over 2016-2025
Myanmar	• Reduce 12% of energy consumption from BAU by 2020 • Reduce 16% of energy consumption from BAU by 2025 • Reduce 20% of energy consumption from BAU by 2030
Philippines	• 3% reduction in energy intensity across key economic sectors • At least 10% energy saving on electricity from all sectors by 2040, based on 2016 BAU
Singapore	Energy Intensity reduction by 35% in 2030, compared to 2005 level
Thailand	Reduce energy intensity (TFEC/GDP) by 30% in 2036, compared to 2010
Vietnam	• 5-7% energy saving in 2019-2025 • 8-10% energy saving in 2019-2030 • Reduce power loss to less than 6.5% by 2025 and less than 6% by 2030

Figure I-1. Energy Efficiency Targets of ASEAN Member States (ASEAN Energy Database System, 2020)

Notes: BAU (Business as Usual Scenario), TFEC (Total Final Energy Consumption), GDP (Gross Domestic Product)

II. CURRENT TRENDS IN THE ASEAN BUILDING SECTOR AND THE RISING DEMAND FOR COOLING

II.1 Building Floor Space Trends and Projections

As human population worldwide is projected to continue rising for another fifty to sixty years (United Nations, 2024), Southeast Asia expects a total population of 791.7 million people by 2050, a 124.6 million increase from the year 2020 (ACE, 2022). Thereupon, the demand for building spaces will surely follow. Not only is the total number and floorspace of residential building spaces expected to increase, but this growth will also manifest in the non-residential sector as well. This phenomenon will be even more prevalent in big cities that serve as the centre for economic and societal activity.

Approximately half of ASEAN population was reported to be urban citizens in 2020 (ASEAN, 2022). According to the ASEAN Sustainable Urbanisation Report (ASEAN, 2022), this number is estimated to continue rising until 405 million people out of 726 million reside in urban areas in 2030. As of 2020, Cambodia and Myanmar are among the least urbanised countries in Southeast Asia with 24.2% and 31.1% of their population as city-dwellers respectively, while countries like Singapore (100%) and Brunei Darussalam (78.2%) are among the most urbanised (ASEAN, 2022). For the following years, urban migration in ASEAN will continue to bring individuals to big cities, increasing the need for building spaces to accommodate the growing number of people.

In 2015, the total floor area of buildings globally amounted to 223.4 billion m^2, with 15.6 billion m^2 of those attributed as the total building area in Southeast Asia (GlobalABC, IEA, and UNEP, 2016). This total is predicted to reach 23.8 billion m^2 by

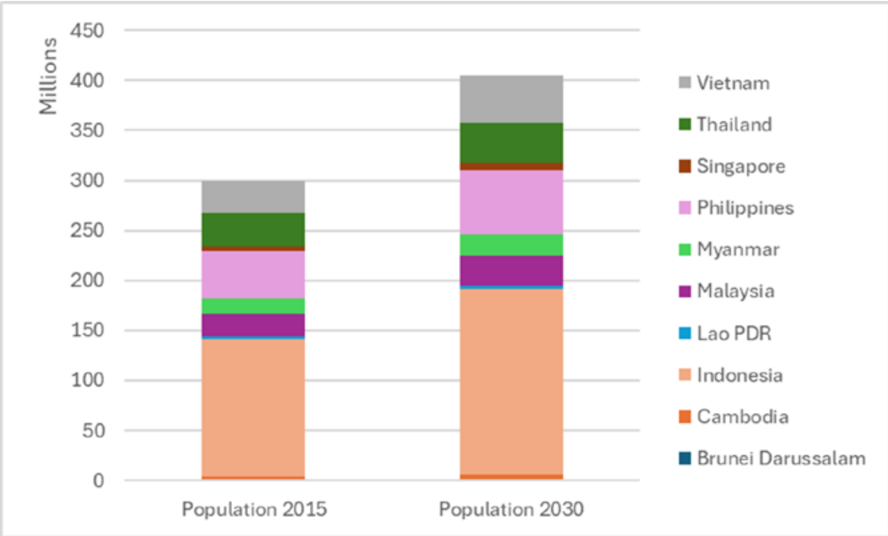

Figure II-1. **Comparison of Urban Population across ASEAN Countries in 2015 and 2030 (ASEAN, 2022)**

2030, and by 2050, the total area of building floor spaces across Southeast Asia will have doubled (GlobalABC, IEA, and UNEP, 2016). Naturally, this expansion of floor area will result in the subsequent rise of energy demand in the buildings sector as well. How much energy demand will increase depends largely on how buildings will be designed and constructed.

The additional areas of building floor space coupled with rising temperatures will mean a higher demand for space cooling. With expanding floor spaces to cover, the region must expect an escalating number of energy-intensive ACs installed and in operation. Specific strategies to slow the growth in energy demand have never been more critical.

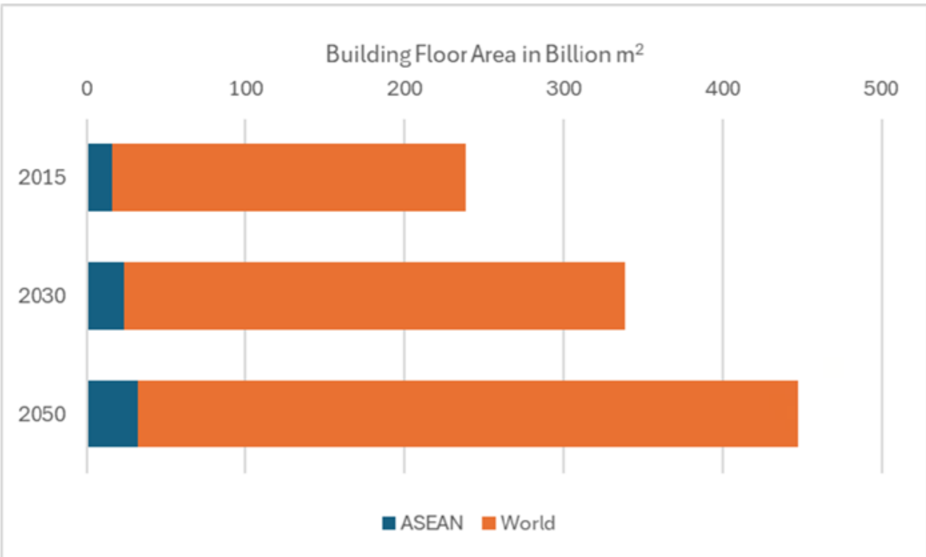

Figure II-2. **Share of ASEAN's Building Floor Area in the Global Scene (GlobalABC, IEA, and UNEP, 2016)**

II.2 Space Cooling Penetration Rates and Projections

Year by year, ownership of air conditioners among other types of cooling devices continues to rise, with the latest data from 2016 reported by the International Energy Agency showing a total of 1.622 billion air conditioners installed globally (IEA, 2018). This number is a staggering hike compared to the number of installed ACs recorded in 1990 that barely amounted to 700 million units worldwide (IEA, 2018). Though one thing persists about the penetration of air conditioners throughout the years, and that is the fact that residential sector remains the biggest contributor to the number of AC units installed, comprising of 1.093 billion units in 2016 while commercial sector claims the rest (IEA, 2018).

This escalating trend for space cooling penetration can also be found in ASEAN. Since the year 2000, Southeast Asia has experienced a continuous rise in ownership of AC units (IEA, 2022b). However, the increase in the penetration rate of air conditioners in Southeast Asia is still not as rapid as other regions (ACE, 2022). ACE reported in the 6th ASEAN Energy Outlook that on average, merely 18% of households across ASEAN owned an AC in 2019. This number pales in comparison to countries like Japan or Korea whose ownership rates have both exceeded 85% (ACE, 2020).

Although logically ASEAN should have a higher amount of installed AC units due to the region's relatively warmer climate, the low percentage of ownership suggests that there are other aspects affecting the rate of space cooling penetration, e.g. economic growth and income levels. This is why the rate of AC penetration varies widely across nations, with Brunei Darussalam, Singapore, and Malaysia—the wealthiest ASEAN Member States (AMS)—having more than 75% ownership rates, surpassing the other AMS significantly (ACE, 2020). It is also why countries with strong economic dynamism such as China or the United States have a very high space cooling penetration rate (EIA, 2022; IEA, 2022a).

As the economy grows, the stock of air conditioners in AMS is projected to continue rising, amounting to 300 million units in 2040 (IEA, 2022a). By then,

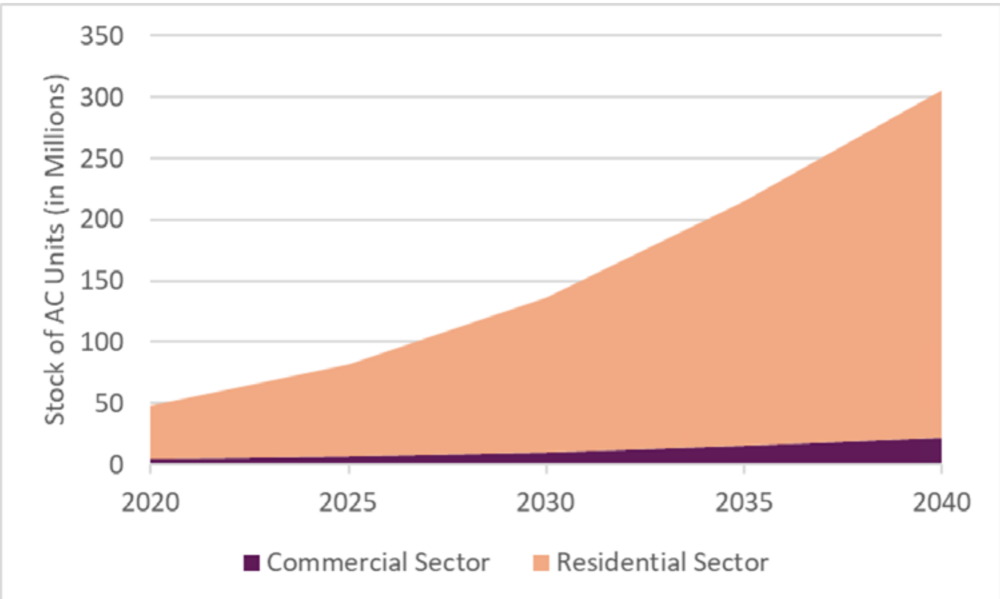

Figure II-3. **Projected Stock of AC in ASEAN from 2019-2040 (IEA, 2019)**

the share of households in ASEAN with space cooling is expected to reach 60%, and Indonesia alone will be responsible for approximately half of the region's growth (IEA, 2022a).

Aside from the region's strengthening economy, escalating urbanisation and people seeking a better quality of life will also be a few key drivers in the increasing penetration rate of space cooling. Without meaningful interventions, the rate of space cooling penetration in AMS will keep rising exponentially, multiplying the stock of AC units in the region by more than five times its stock in 2019 by 2040 (IEA, 2019).

II.3 Space Cooling-Related Energy Demand Trends and Projections

Annual energy consumption in Southeast Asia continuously increased through 2000-2020 (IEA, 2022b). This trend aligns with the population and economic growth that Southeast Asia has and will continue to experience for the next several years. Across the previous two decades, oil remained the largest contributor to the energy supply even if its percentage in the energy mix lessened every single year. At the same time, the share of renewable energy rose from 13.13% or 2.1 EJ in 2000 towards 17.53% or 5.1 EJ in 2020. Along with it, the share of traditional biomass plummeted drastically. This finding reflects the region's progress and commitment to cultivating energy transition.

Under the existing policies, the total energy consumption in Southeast Asia is projected to reach 922 Mtoe by 2040 (ACE, 2022). Currently, buildings alone are responsible for 23% of the total final energy consumption in the region (IEA, 2022a). Among the other sectors, the buildings sector will experience an escalation in its total final energy consumption, growing by around 60% by 2030 and 120% by 2040 (ACE, 2020). Space cooling will be responsible for the bulk share of the growing energy consumption.

III. PASSIVE COOLING STRATEGIES WITHIN THE ASEAN CONTEXT

III.1 Rising Demand for Space Cooling in the ASEAN Context

Most ASEAN people live in areas in which average daily temperatures exceed 25 °C. Even when and where temperatures are lower, high humidity levels increase perceived temperatures. Space cooling needs in ASEAN are among the highest in the world, with an average of over 1,500 cooling degree days per year (IEA, 2019). Comfort provided by air conditioners is available to only a fraction of the population today, with less than 20% households having an air conditioner. Fans are much more common at an average of 1.5 units per household. With increasing income, purchasing an air conditioner is high on the list of priorities for many households and businesses.

The significant increase in air conditioner (AC) usage among households has been driven not only by improvements in economic conditions but also by the growing demand for thermal comfort among occupants. As incomes rise, more households can afford to invest in AC units to maintain comfortable indoor temperatures, especially in regions with hot and humid climates like the ASEAN countries. Unfortunately, this surge in AC adoption has several negative consequences. It leads to higher energy consumption, which strains the electricity grid and increases operational costs. Moreover, the widespread use of air conditioners contributes to environmental concerns, such as increased greenhouse gas emissions.

On the other hand, achieving thermal comfort in a more sustainable and cost-effective manner involves balancing the use of air conditioning with passive cooling strategies. Thermal comfort is the state of comfort in an indoor environment, where the temperature, humidity, and airflow are within a pleasant range for most occupants (Fanger, 1970).

For several decades, adaptive thermal comfort studies have been conducted, and the results have shown that people in different climate zones have different thermal preferences (Fanger, 1970; De Dear, 2004; Sikram, Ichinose and Sasaki, 2020). Based on a study of adaptive thermal comfort in Southeast Asian countries, the comfort temperatures in air-conditioned areas were found to be up to 25.6°C in Malaysia, 26.3°C in Indonesia, and 26.4°C in Singapore, while the average operative temperatures of these countries were 24.4°C, 25.9°C, and 23.2°C, respectively (Damiati *et al.*, 2016; Sikram, Ichinose and Sasaki, 2020).

Temperatures in the ASEAN region regularly exceed thermal comfort levels. Passive cooling strategies integrated into building design and construction help maintain lower indoor temperatures, therefore reducing cooling loads and the amount of energy needed to bring indoor temperatures to a comfortable level.

III.2 Passive Cooling in Hot and Humid Climates

Passive cooling strategies have increasingly become a focus as an alternative approach to cooling and ventilating indoor spaces, driven by a movement towards more sustainable architecture. The main principle in implementing passive cooling in hot and humid climate mostly depends on the architectural passive design features of a building. Therefore, it is essential to understand the factors that give significant influence in the implementation of passive cooling.

• BUILDING ENVELOPE

The building envelope is the essential component of a building, and its design and construction determine the amount of heat able to enter the building through conduction, convection and radiation. Therefore, it will be the main determinant of the amount of energy needed to remove heat from interior spaces to the exterior environment, as well as the comfort level of building occupants (Okba, 2005; Sadineni, Madala and Boehm, 2011).

The building envelope consists of non-transparent components (e.g. roof and walls) and fenestration systems (e.g. windows) that separate the interior of a building from the external environment. The building envelope provides protection from elements of the external environment such as heat, radiation, wind, rain, noise, pollution, and others. Building envelope design has an important role in reducing cooling and lighting energy consumption.

OTTV is one of the parameters used to assess a building envelope, specifically to calculate an average heat transfer rate of a building through envelope components, such as opaque walls and window glass. There are three main modes of heat transfers in a building, i.e conduction through walls, conduction through openings, and radiation through openings. Even though heat transferred through glass windows has been proven to generate the highest heat to enter a building, it is still important to prevent heat transfers through other building elements.

Insulations will be essential for hot climate regions in preventing heat gains from the environment. Insulations should be installed on surfaces most exposed to heat gains originating from solar energy, such as roof. Glazing materials will also contribute to the effective insulation of a building. Glazing that prevents heat from penetrating a building but at the same time transmits high value of light is preferable in regions with hot climate. Moreover, it is not recommended for buildings to have an expansive glazing area.

• BUILDING ORIENTATION

Optimized building orientation is also an important passive cooling strategy, especially in hot and humid climates. Proper building orientation can significantly reduce a building's cooling load by minimizing direct solar heat gain and maximizing natural ventilation (Chen, Yang and Zhang, 2018). In hot and humid climates, the goal is to orient the building in such a way that it reduces exposure to intense sunlight while utilizing existing winds to increase cross ventilation (Haase and Amato, 2009).

By aligning the longer side of the building along the east-west axis, as shown in **Figure III.1** below, the structure minimizes direct sun exposure on the largest surfaces, thereby reducing heat gain during the hottest part of the day. This orientation ensures that the shorter sides, which receive less sunlight, face the intense morning and evening sun, thereby minimizing heat buildup in the interior. Based on the findings of a study in a tropical climate, buildings should avoid having large window openings on the east and west sides (La Roche *et al.*, 2001). This is because these

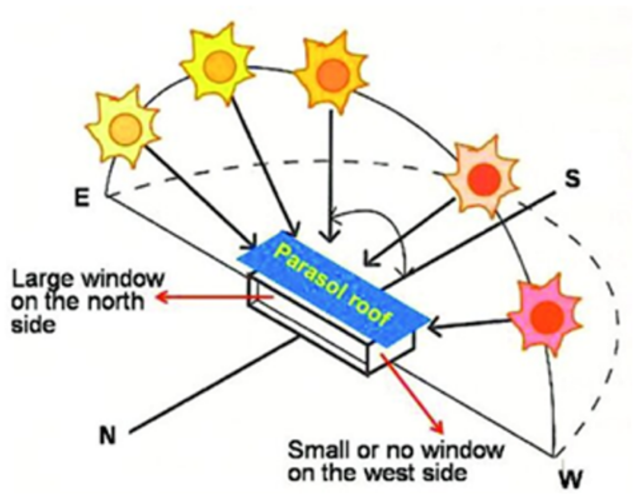

Figure III-1. **Building Orientation and Window Design to Minimize Solar Heat Gain (Nawawi and Ahmad, 2012)**

sides receive nearly twice as much solar radiation compared to the north and south elevations.

Additionally, strategically placing windows and openings to catch prevailing winds can enhance natural ventilation. Where indoor temperatures surpass outdoor temperatures due to heat build-up in buildings, the use of this approach helps to expel hot air and introduce cooler outdoor air, thus improving indoor thermal comfort without mechanical cooling systems. Incorporating features such as extended roofs, verandas and shaded courtyards also help shield buildings from direct sunlight and create cooler outdoor spaces that further contribute to passive cooling.

- **MATERIAL SELECTION**

Choosing the right materials is crucial in passive cooling strategies for buildings located in hot and humid climates. The goal is to select materials that can effectively mitigate heat gain, enhance thermal comfort, and reduce the need for mechanical cooling systems.

In hot and humid climates, materials with high thermal mass, such as concrete, brick, and stone, play a significant role. These materials absorb heat during the day and release it slowly during cooler periods, helping to stabilize indoor temperatures. This process, known as thermal inertia, reduces temperature fluctuations and maintains a more consistent and comfortable indoor environment without the need for active cooling.

Natural and sustainable materials such as wood, bamboo, and rammed earth are also gaining popularity for their thermal properties and environmental benefits. These materials provide natural insulation and often have lower embodied energy compared to traditional building materials, contributing to overall energy efficiency and sustainability.

III.3 Technologies and Architectural Design Elements

- **WALL MATERIALS**

High Thermal Mass Materials

High thermal mass, combined with appropriate insulation, plays a crucial role in passive cooling strategies, particularly in the hot and humid climates typical of ASEAN countries. Materials with high thermal mass, such as concrete, brick, and stone, can absorb heat during the day and release it slowly at night.

Insulation is a material or layer that reduces the rate of heat transfer between the inside and outside of a building. While high thermal mass absorbs and stores heat, insulation helps to minimize the unwanted transfer of heat. In the context of ASEAN countries, where outdoor temperatures can be very high, insulation is crucial to prevent external heat from entering the building during the day. It helps to reduce heat gain by conductivity, thereby minimizing the amount of heat that enters a building and reducing the reliance on mechanical cooling systems.

By utilizing high thermal mass and insulation, buildings can reduce their reliance on air conditioning, leading to lower energy consumption and operational costs. During the day, the combination of high thermal mass and insulation keeps indoor spaces cooler by absorbing less heat, through reducing the rate at which outdoor heat penetrates the building.

- **OPENINGS**

Low E-Glazing Materials

Low-e windows reflect infrared radiation from the sun, keeping the interior of the building cooler. This is particularly beneficial in ASEAN countries, where the intense sun can cause significant heat gain in buildings.

Double Glazing

Double glazing is a window system that uses two panes of glass separated by a gap, which is usually filled with air or an inert gas like argon. This gap acts as an insulating barrier between the interior and exterior environments. The air or gas-filled gap between the panes acts as an insulating layer that reduces the amount of heat that can pass through the window. This helps to keep the interior cooler during hot weather, which is crucial in the ASEAN region. Further strategy is to combined installation of solar film and double glazing. A retrofit project in Singapore was found that additional low-e coating reduces annual HVAC energy consumption by up to 20% (Somasundaram, Thangavelu and Chong, 2020)

Shading Devices

By blocking or filtering direct sunlight, shading devices reduce the amount of solar radiation that enters a building. This helps to keep indoor temperatures lower, reducing the reliance on air conditioning systems.

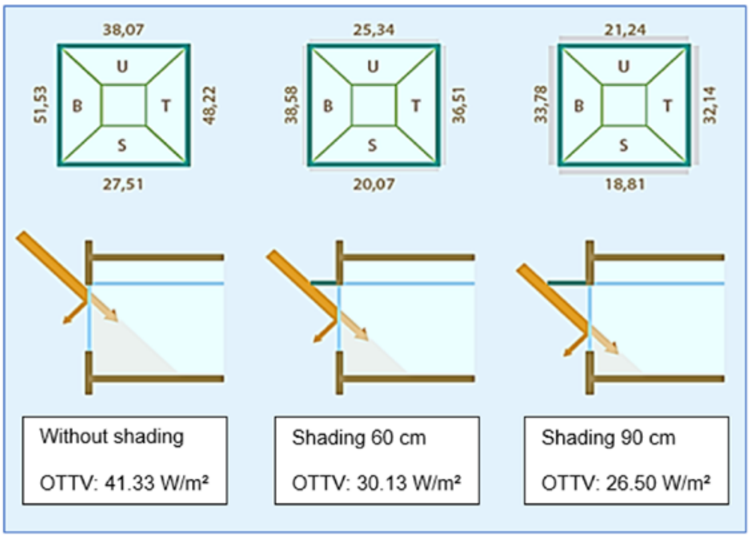

Figure III-2. Effect of Shading Devices (Purwitasari, 2019)

Figure III-3. Sample of Shading Device for Commercial Buildings

- **COOL ROOF**

Reflective Coating

A cool roof with reflective coating is an effective passive cooling strategy that can significantly reduce the heat load on buildings in the hot and humid climates typical of ASEAN countries. This strategy helps to maintain lower indoor temperatures, reduce energy consumption, and improve overall comfort.

A cool roof refers to a roof that is designed to reflect more sunlight and absorb less heat than a standard roof. Cool roofs can be made from highly reflective types of paint, sheet covering, or highly reflective tiles or shingles. Reflective coatings reduce the energy needs of a building by decreasing the incoming solar irradiation to the building shell. Various studies have been conducted quantifying the decrease in cooling energy needs in a variety of building types (Synnefa, Santamouris and Akbari, 2007; Androutsopoulos, Stavrakakis and Damasiotis, 2017).

The cool roof application was observed on a public-school building and the results showed that, ten days after the application, the reduction of the daily mean indoor air temperature below the cool roof ranged in 1.3-2.3^{o}C and 1.6-1.9^{o}C as provided by measurements and simulations, respectively. In terms of annual energy consumption, a reduction of up to 30% in cooling demand was estimated in summer (Androutsopoulos, Stavrakakis and Damasiotis, 2017).

The impact from using cool roof coatings on the cooling loads and the indoor thermal comfort conditions of residential buildings were investigated. The results showed that increasing the roof solar reflectance reduces cooling loads by 18–93% and peak cooling demand in air-conditioned buildings by 11–27%. The indoor thermal comfort conditions were improved by decreasing the hours of discomfort by 9–100% and the maximum temperatures in non-air-conditioned residential buildings by 1.2–3.3°C. These reductions were found to be more important for poorly or non-insulated buildings. (Synnefa, Santamouris and Akbari, 2007)

- **NATURAL VENTILATION**

Cross Ventilation

Cross ventilation occurs when air flows between two opposite or adjacent openings, such as windows or vents, within a building. The difference in air pressure between the windward (wind-facing) and leeward (opposite to the wind) sides of the building creates this airflow. The fresh air enters through one opening and exits through the other, creating a cooling breeze that flushes out warm, stale air.

While natural ventilation reduces the need for air conditioning, leading to lower energy consumption and operational costs, it can introduce harmful pollutants like particulate matter, NOx, and VOCs into buildings in urban areas with high levels of air pollution, compromising indoor air quality and potentially affecting health. Additionally, natural ventilation, such as opening windows or vents, can allow external noise from traffic or other sources to enter the building, creating an uncomfortable environment for occupants.

III.4 Modelling Approach: Passive Cooling Modalities

In the ASEAN context, hot and humid climates are prevalent, creating a distinctive set of challenges and opportunities for implementing passive cooling strategies. The high temperatures, often ranging from 25°C to 35°C, combined with humidity levels that frequently exceed 70%, necessitate effective cooling solutions to maintain thermal comfort in buildings. This climate profile complicates passive cooling strategies, as the constant heat and moisture can lead to discomfort and reduced air quality. However, these conditions also present unique opportunities for innovative design approaches.

For instance, the abundance of natural ventilation can be harnessed through strategic building orientation and window placement, promoting airflow and reducing reliance on mechanical cooling systems. Additionally, the use of shading devices, such as overhangs and vegetation, can effectively mitigate solar heat gain, creating cooler indoor environments. Emphasizing high thermal mass materials and reflective surfaces further enhances energy efficiency and indoor comfort. By leveraging these strategies, the ASEAN region can address the challenges posed by its hot and humid climate while fostering sustainable building practices that are both environmentally friendly and culturally relevant.

To assess the effectiveness of these passive cooling strategies, we conducted building thermal simulations using DesignBuilder under the following scenarios:

- **100% PASSIVE COOLING**

100% passive cooling aims to reduce the number of discomfort hours by utilizing natural ventilation, thermal mass, and shading strategies to maintain comfortable indoor temperatures without relying on mechanical cooling systems. This approach not only enhances occupant comfort but also promotes energy efficiency and sustainability in building design.

Features:

✓ Higher thermal mass materials (including insulation)
✓ Cool roof (using reflective coating)
✓ Better windows thermal profile
✓ Architectural shading
✓ Reduced window-wall ratio (WWR)
✓ Cross Ventilation
✓ No VAC system

- **ACTIVE DESIGN**

Passive design focuses on optimizing building elements to minimize the need for active cooling systems. By applying passive design principles, building cooling loads can effectively be reduced, thereby lowering energy consumption and operational costs associated with air conditioning, while also maintaining indoor thermal comfort.

Features:

✓ Uses VAC system
✓ Higher thermal mass materials (including insulation)
✓ Cool roof (using reflective coating)
✓ Better windows thermal profile
✓ Architectural shading
✓ Reduce WWR

- **HYBRID**

Hybrid strategies integrate passive design and mechanical ventilation to achieve optimal thermal comfort. Hybrid approaches are particularly useful in climates where passive strategies alone may not be sufficient during extreme weather conditions.

Features:

✓ Higher thermal mass materials (including insulation)
✓ Cool roof (using reflective coating)
✓ Better window thermal profile
✓ Architectural shading
✓ Reduced WWR
✓ Cross ventilation
✓ Use mechanical ventilation (ceiling fan)

III.5 Modelling Results: Passive Cooling Strategies across Urban and Rural Settings and Varying Climatic Zones

To assess the effectiveness of passive cooling strategies, the study conducted building thermal simulations using DesignBuilder. The method in performing building thermal simulations is shown in the following flowchart.

In order to evaluate the opportunity and effectiveness of passive cooling strategies, there were 4 (four) locations selected to represent the ASEAN weather condition, 2 (two) locations represent area that experience tropical weather condition and 2 (location) at subtropical area.

Singapore and Balikpapan are two locations selected to represent area with tropical weather conditions, and both of this area located near the Equator. Singapore represents an urban area and Balikpapan represents a rural area. For subtropical weather conditions, Ha Noi and Sa Pa were selected, Ha Noi represent an urban area, and Sa Pa represents a rural area. The location of those selected areas is depicted in **Figure III-5**.

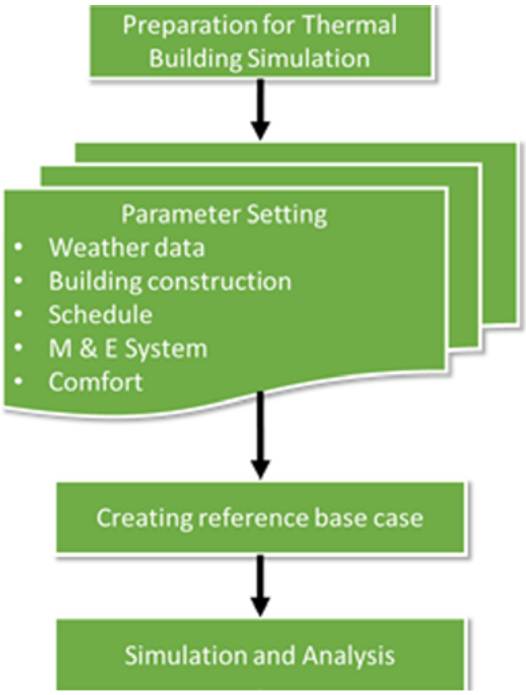

Figure III-4. **Flowchart Thermal Building Simulation**

Figure III-5. **Selected Locations for Building Thermal Simulation**

• WEATHER PROFILE

The difference of latitudes in the selected locations result in the difference of hourly outside dry bulb temperature of each location[1]. The figures below show the profile of hourly dry bulb temperature for all the selected locations.

The weather profile of each location is shown in **Table III-1**.

Consequently, the psychrometric charts profile for thermal comfort condition will also different based on the weather profile. Psychrometric chart presenting hourly data on dry bulb temperature and humidity for each location are provided in **Figures III-7**, **III-8**, **III-9**, **and III-10**.

1 The Dry Bulb Temperature refers basically to the ambient air temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air

The chart is generated based on provide weather data, and hourly weather parameter, such as dry bulb temperature, wet bulb temperature and relative humidity

Figure III-7 shows the psychrometric chart for Singapore. The hourly dry bulb temperature ranged between 24°C and 33°C, and the relative humidity is almost above 70% throughout the year. These values agreed with the **Table III-1**. The weather profile of Singapore is apparently similar to Balikpapan, which is depicted in **Figure III-8**, except that the average relative humidity of Balikpapan is lower.

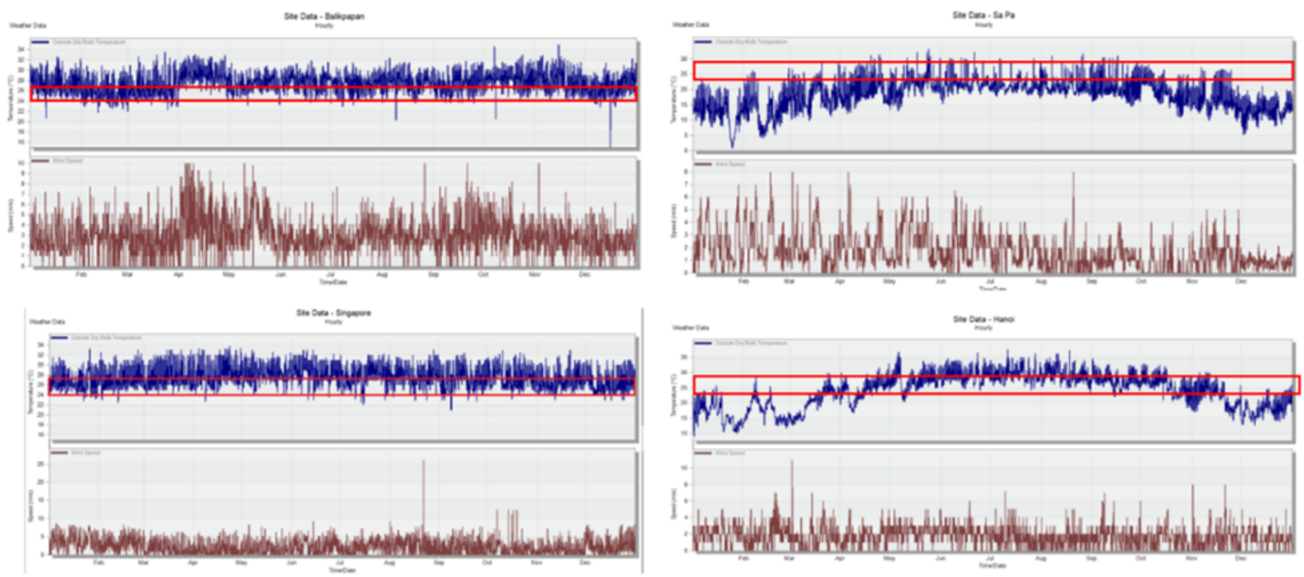

Figure III-6. **Outside Dry Bulb Behaviours of Balikpapan (Above-Left), Sa Pa (Above-Right), Singapore (Bottom-Left), and Hanoi (Bottom-Right)**

Table III-1. **Selected Location for Building Simulation**

	Urban		Rural	
Location	Singapore	Ha Noi	Balikpapan	Sa Pa
Climate	Tropical	Sub-Tropical	Tropical	Sub-Tropical
Max DBT	33.47	36.64	34.06	32.70
Average DBT	27.46	23.94	27.41	18.18
Min DBT	21.58	9.61	20.83	0.86
Average Humidity	75.54%	62.71%	69.76%	60.84%

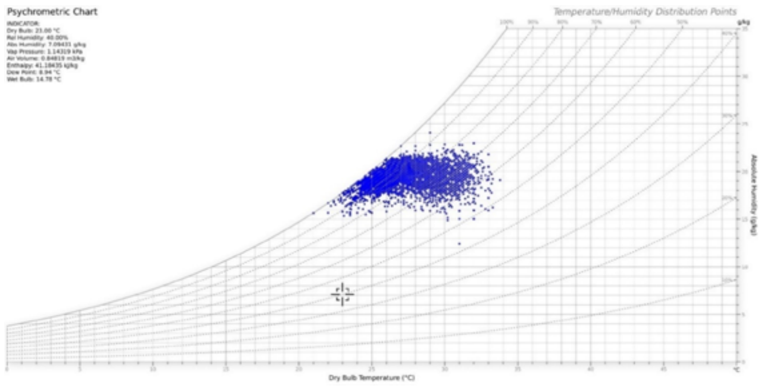

Figure III-7. **Psychometric Chart for Singapore Weather Data**

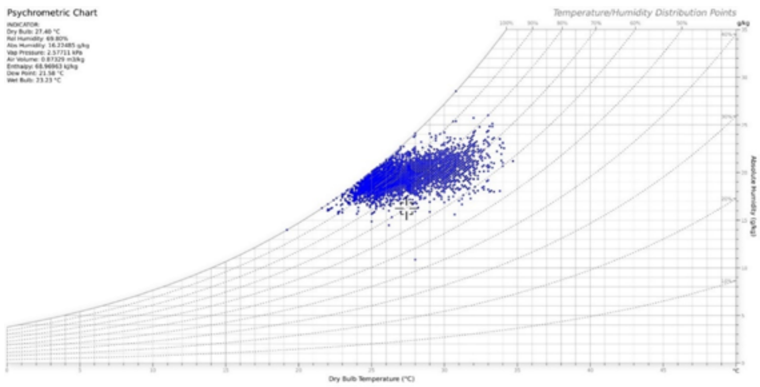

Figure III-8. **Psychometric Chart for Balikpapan Weather Data**

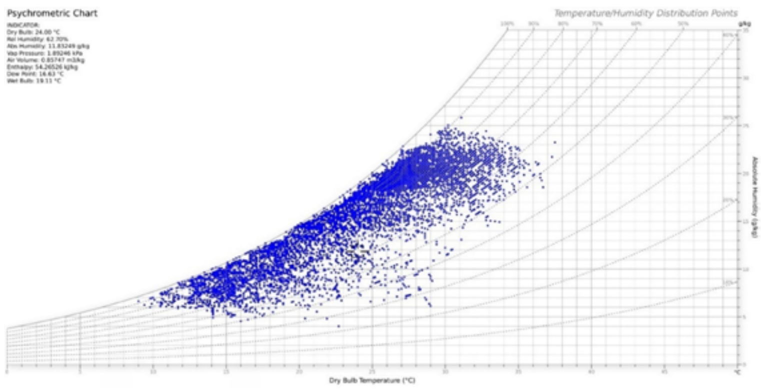

Figure III-9. **Psychometric Chart for Ha Noi Weather Data**

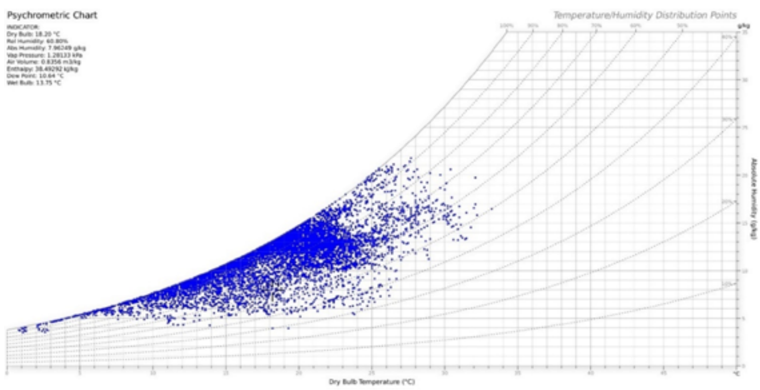

Figure III-10. **Psychometric Chart for Sa Pa Weather Data**

Figure III-9 and **Figure III-10** show the hourly condition in Ha Noi and Sa Pa, respectively. Both of those locations are shown to have lower average dry bulb temperature and relative humidity. The range of hourly weather condition of Ha Noi and Sa Pa is wider than that of Singapore and Balikpapan, and this presents an opportunity to implement passive cooling strategies.

• BUILDING GEOMETRY

The 3D geometry model used in building thermal simulations refer to Case 600 of ASHRAE Standard 140-2017. The model is modified in such way that represents residential buildings prototype in ASEAN to create a reference case file. **Figure III-11** presents the building geometry for Base Case simulation and **Figure III-12** shows the building geometry with passive cooling strategies.

• INPUT PARAMETERS

Table III-2 presents the input parameters for each scenario. In passive cooling strategies, while reducing window-wall ration (WWR) helps to lower the cooling load, it is also important to ensure adequate daylighting is maintained. Daylight or natural lighting from the sun has a substantial impact on natural functions and is considered central to human's wellbeing. Daylighting not only benefits in an efficient use of energy in built environments; it also influences human's circadian rhythm and outside view for building's occupants (Wong, 2017).

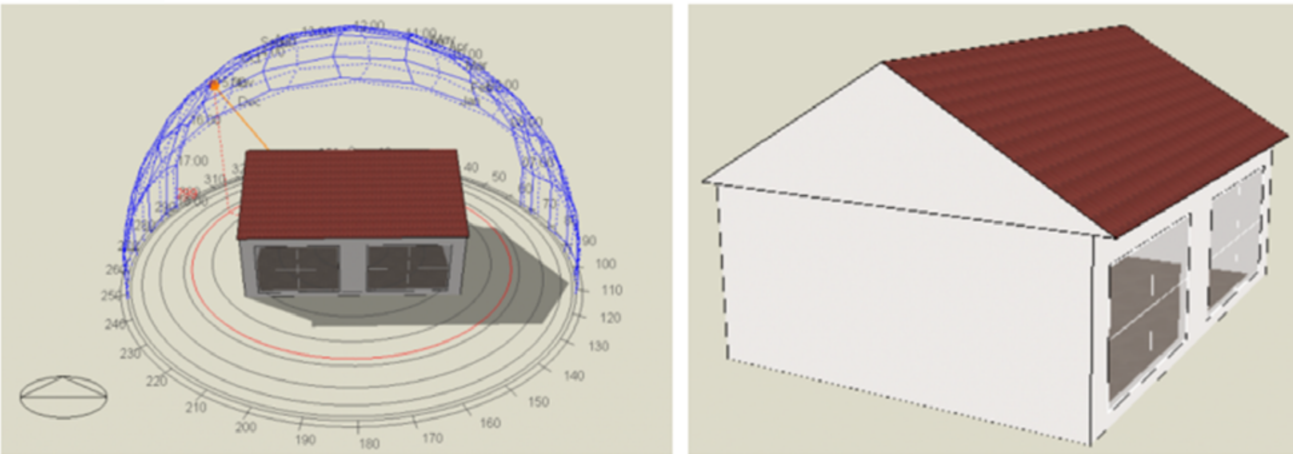

Figure III-11. Building Geometry for Base Case Simulation

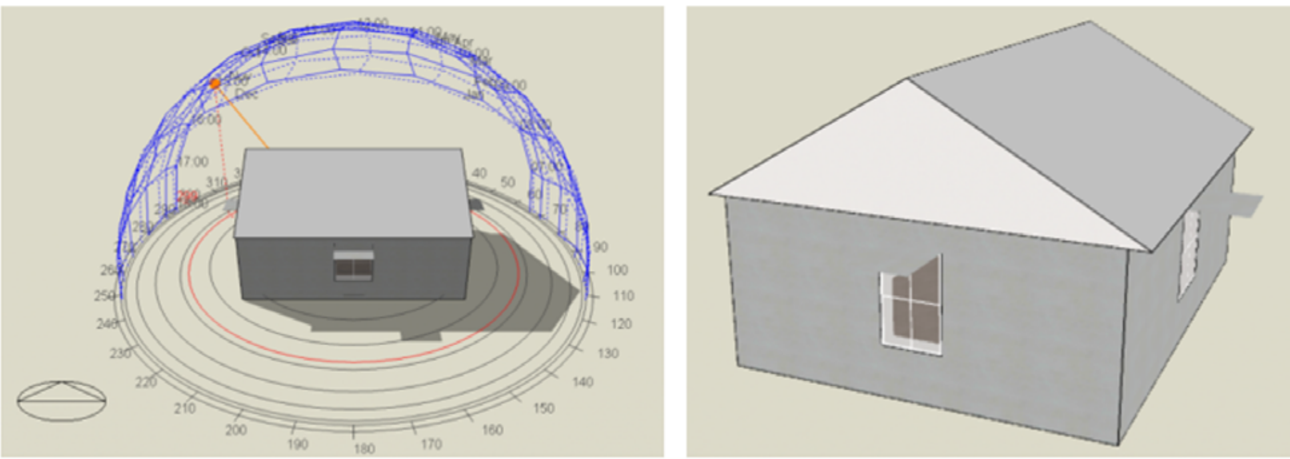

Figure III-12. Building Geometry with Passive Cooling Strategies

Table III-2. Input Parameters for Each Scenario

Scenario	Base Case	100% Passive Cooling	Active Design	Hybrid
Building Orientation	South (0°)			
HVAC	No	No	Yes	No
Mechanical Ventilation	No	No	No	Yes
Natural Ventilation	Yes	Yes	No	Yes
Building Envelope				
Wall Material	Lightweight concrete	Lightweight concrete with insulation		
Thickness (mm)	100	200	200	200
u-value (W/sqm.K)	1.164	0.708	0.708	0.708
Glazing Material	Clear Glass	Single Low-e		
Thickness (mm)	6	6	6	6
SHGC	0.819	0.720	0.720	0.720
Light Transmission	0.881	0.811	0.811	0.811
u-value (W/sqm.K)	5.778	3.779	3.779	3.779
WWR	14%	10%	10%	10%
East Façade	0%	10%	10%	10%
South Façade	54%	10%	10%	10%
West Façade	0%	10%	10%	10%
North	0%	10%	10%	10%
Cross Ventilation	No	Yes	No	Yes
Shading Device	No	Yes (Overhangs)	Yes (Overhangs)	Yes (Overhangs)
Roof Material	Clay tiles	Clay tiles	Clay tiles	Clay tiles
Reflective Coating	No	Yes	Yes	Yes
Type	Pitched Roof	Pitched Roof	Pitched Roof	Pitched Roof
u-value (W/sqm.K)	2.930	2.851	2.851	2.851

• SIMULATION RESULTS AND ANALYSIS

For evaluating thermal comfort, the following parameters are used:

Predicted Mean Vote (PMV)

PMV predicts the average thermal sensation of a group of people based on environmental factors such as air temperature, humidity, and clothing insulation. PMV values range from -3 (cold) to +3 (hot), with 0 indicating neutral comfort.

Predicted Percentage of Dissatisfied (PPD)

PPD estimates the percentage of occupants likely to feel dissatisfied with the thermal environment based on predicted thermal sensation. PPD is derived from Predicted Mean Vote (PMV) calculations that provides a quantitative measure of discomfort among building occupants. Lower PPD values indicate higher overall comfort, as fewer occupants are expected to be dissatisfied with the thermal conditions.

Unmet Hours

Unmet hours quantify the duration during which indoor temperatures deviate from desired comfort levels. This parameter measures the cumulative hours per year that indoor conditions fall outside predefined comfort thresholds. Higher unmet hours suggest more frequent periods of discomfort, highlighting potential areas for improvement in building design or HVAC system performance.

- **TROPICAL CLIMATE: URBAN AREA (SINGAPORE)**

Thermal Comfort Condition

The PMV graph indicates that both the 100% Passive Cooling and Hybrid scenarios enhance thermal comfort compared to the Base Case in an urban tropical climate. Among these, the active design scenario provides the most consistent thermal comfort with the least variability in Predicted Mean Vote (PMV).

The PPD graph also shows that both the 100% Passive Cooling and Hybrid scenarios improve thermal comfort compared to the Base Case in an urban tropical climate. The active design scenario can achieve the lowest PPD, but it also has a wider range of values. This indicates that the PPD can be lowered only when the air conditioner is operating.

Cooling Load and Cooling Energy Demand

Table III-3 shows that the implementation of passive cooling can reduce significantly cooling load and cooling energy demand.

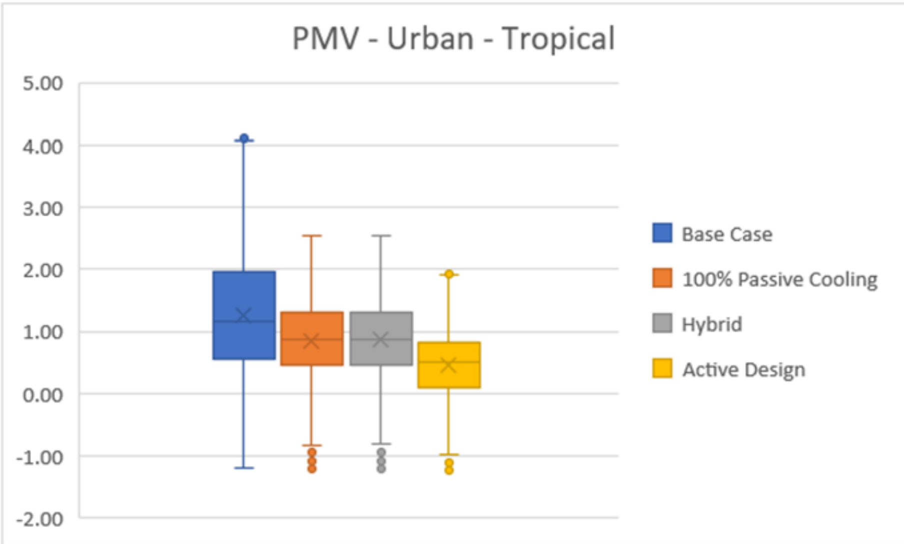

Figure III-13. PMV Results Tropical Climate: Urban Area (Singapore)

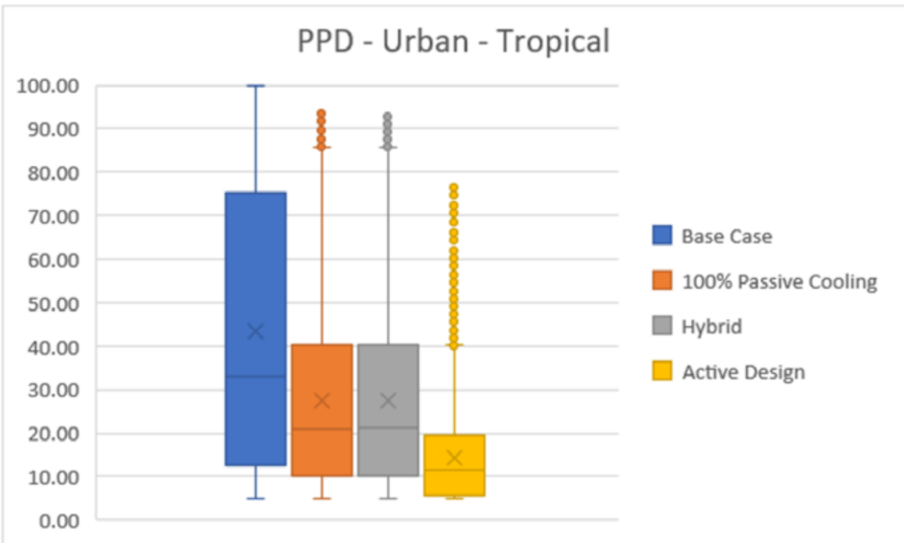

Figure III-14. PPD Results Tropical Climate: Urban Area (Singapore)

Table III-3. Cooling Energy Demand Tropical Climate: Urban Area as the Effect of Passive Cooling

VAC Scenario	Without Passive Cooling	With Passive Cooling
Unmet Hours during Occupied	117 Hours	61 Hours
Cooling Load	6.85 kW	5.38 kW
	23,372.20 BTUh	18,356.56 BTUh
Conditioned Area	48 Sqm	48 Sqm
Cooling Load	486.92 BTUh/sqm	382.43 BTUh/sqm
Cooling Load Reduction		**21.46%**
Cooling Energy Demand	104.44 kWh/sqm	60.63 kWh/sqm
Cooling Energy Demand Reduction		**41.95%**

Figure III-15 shows the sensitivity analysis of varying glazing material (SHGC) and window-to-wall ratio (WWR) on cooling load in an urban tropical environment. Using glazing materials with higher SHGC values leads to a higher cooling load. This is because these materials allow more solar heat to enter the building, increasing the cooling demand. Increasing WWR also results in a higher cooling load. This is due to more solar heat gain through larger window areas.

- **TROPICAL CLIMATE: RURAL AREA (BALIKPAPAN)**

<u>Thermal Comfort Condition</u>

The PMV graph indicates that both the 100% Passive Cooling and Hybrid scenarios enhance thermal comfort compared to the Base Case in a rural tropical climate. Similar to urban tropical climate, the active design scenario shows the most consistent thermal comfort with the least variability in Predicted Mean Vote (PMV) in rural environment.

The PPD graph presents that both the 100% Passive Cooling and Hybrid scenarios improve thermal comfort compared to the Base Case in a rural tropical climate. The active design scenario achieves the lowest PPD, but it also has a wider range of values. This indicates that the lower PPD can be achieved only when the air conditioner is running.

<u>Cooling Load and Cooling Energy Demand</u>

Table III-4 shows that the implementation of passive cooling can reduce significantly cooling load dan cooling energy demand.

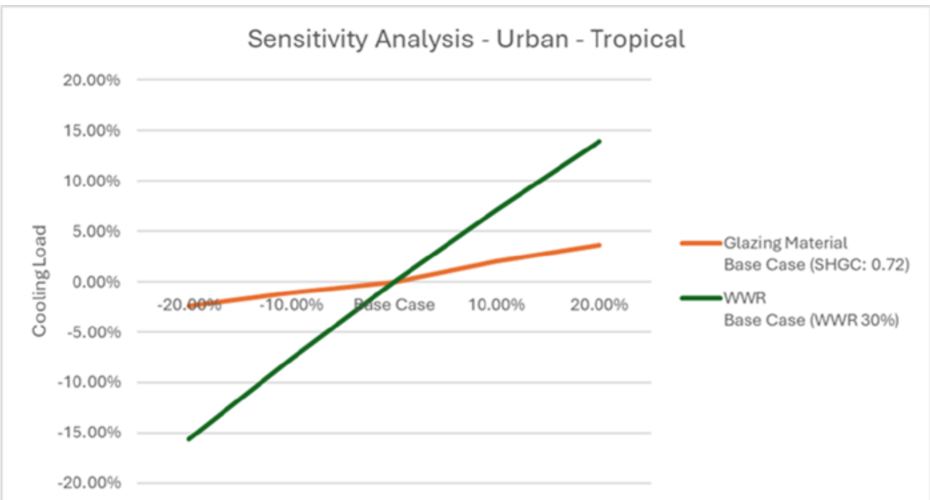

Figure III-15. Sensitivity Analysis Tropical – Urban Area (Singapore)

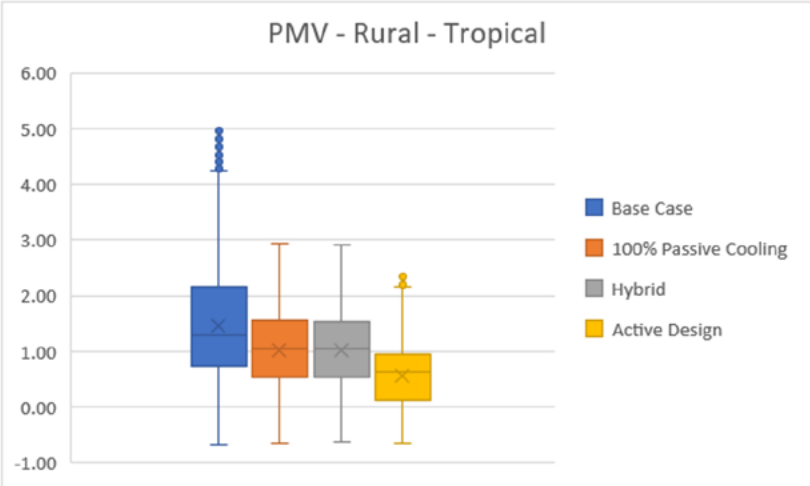

Figure III-16. PMV Results Tropical Climate: Rural Area (Balikpapan)

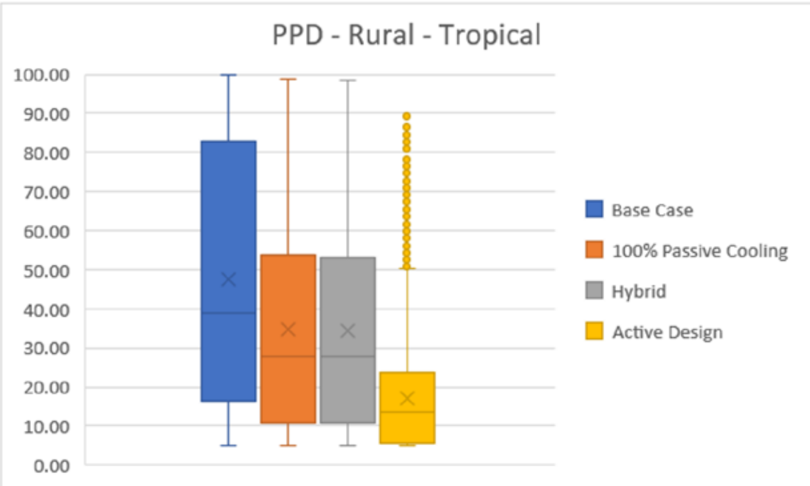

Figure III-17. PPD Results Tropical Climate: Rural Area (Balikpapan)

Table III-4. Cooling Energy Demand Tropical Climate: Rural Area as the Effect of Passive Cooling

VAC Scenario	Without Passive Cooling	With Passive Cooling
Unmet Hours during Occupied	120 Hours	80 Hours
Cooling Load	7.12 kW	5.69 kW
	24,293.44 BTUh	19,414.28 BTUh
Conditioned Area	48 Sqm	48 Sqm
Cooling Load	506.11 BTUh/sqm	404.46 BTUh/sqm
Cooling Load Reduction		**20.08%**
Cooling Energy Demand	115.00 kWh/sqm	74.25 kWh/sqm
Cooling Energy Demand Reduction		**35.43%**

Figure III-18 shows the sensitivity analysis of varying glazing material (SHGC) and window-to-wall ratio (WWR) on cooling load in a rural tropical environment. It shows the similar result with the urban tropical. Using glazing materials with higher SHGC values and higher WWR lead to a higher cooling load.

- **SUB-TROPICAL CLIMATE: URBAN AREA (HANOI)**

Thermal Comfort Condition

The PMV graph indicates that both the 100% Passive Cooling and Hybrid scenarios enhance thermal comfort compared to the Base Case in an urban sub-tropical climate. Among these, the active design scenario also provides the most consistent thermal comfort with the least variability in Predicted Mean Vote (PMV).

The PPD graph also shows that both the 100% Passive Cooling and Hybrid scenarios improve thermal comfort compared to the Base Case in an urban sub-tropical climate. The active design scenario can achieve the lowest PPD, but it also has a wider range of values. This indicates that the PPD can be lower only when the air conditioner is operating.

Cooling Load and Cooling Energy Demand

Table III-5 shows that the implementation of passive cooling can reduce significantly cooling load dan cooling energy demand.

Figure III-21 presents the sensitivity analysis of varying glazing material (SHGC) and window-to-wall ratio (WWR) on cooling load in an urban sub-tropical environment. It shows the similar result with the tropical climate. Using glazing materials with higher SHGC values and higher WWR lead to a higher cooling load.

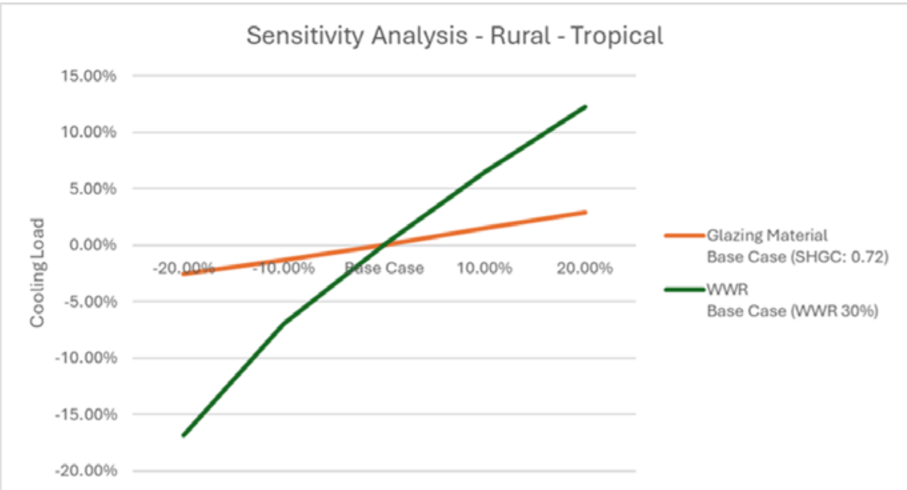

Figure III-18. Sensitivity Analysis Tropical: Rural Area (Balikpapan)

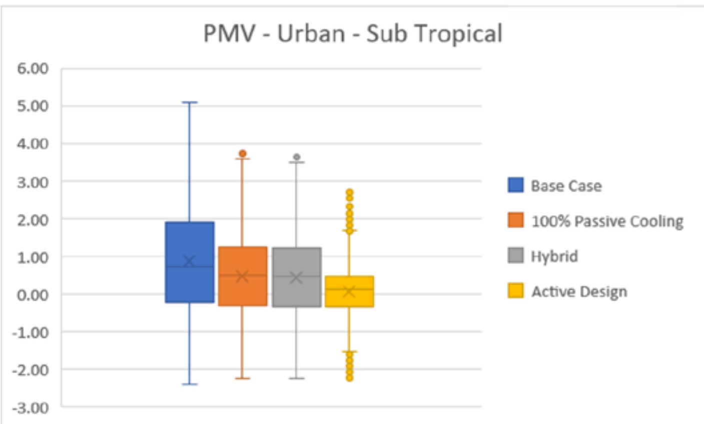

Figure III-19. PMV Results Sub-Tropical Climate: Urban Area (Hanoi)

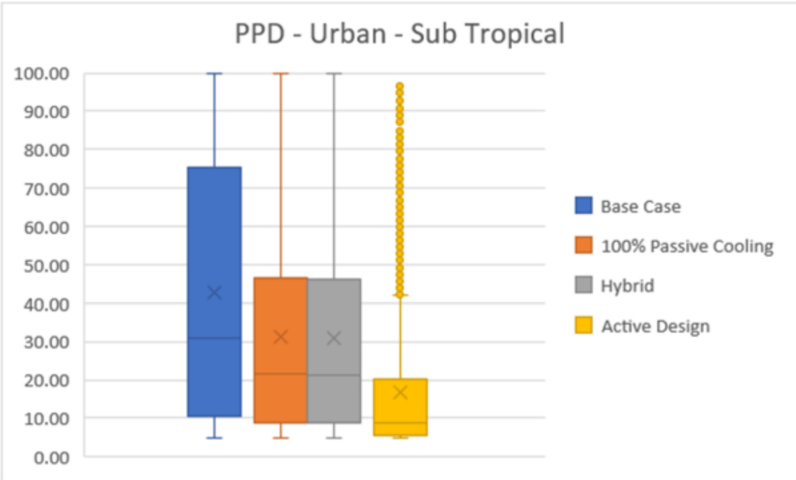

Figure III-20. PPD Results Sub-Tropical Climate – Urban Area (Hanoi)

Table III-5. Cooling Energy Demand Sub-Tropical Climate: Urban Area as the Effect of Passive Cooling

VAC Scenario	Without Passive Cooling	With Passive Cooling
Unmet Hours during Occupied	73 Hours	52 Hours
Cooling Load	7.71 kW	5.99 kW
	26,306.52 BTUh	20,437.88 BTUh
Conditioned Area	48 Sqm	48 Sqm
Cooling Load	548.05 BTUh/sqm	425.79 BTUh/sqm
Cooling Load Reduction		**22.31%**
Cooling Energy Demand	97.61 kWh/sqm	61.28 kWh/sqm
Cooling Energy Demand Reduction		**37.22%**

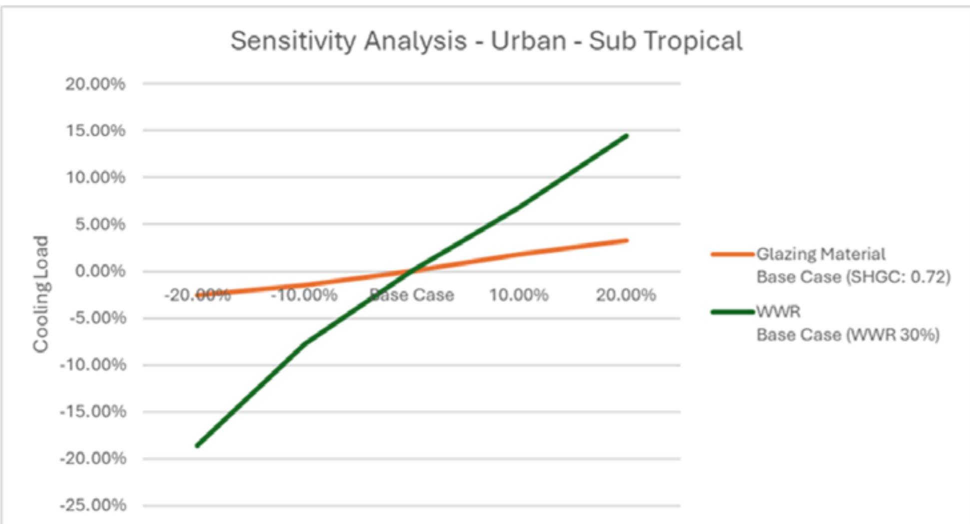

Figure III-21. Sensitivity Analysis – Subtropical Climate: Urban Area (Hanoi)

- **SUB-TROPICAL CLIMATE: RURAL AREA (SA PA)**

Thermal Comfort Condition

The subtropical climate in Sa Pa shows that the majority of temperatures in this region are below 20°C (see **Figure III-10**). Temperatures above 27°C only occur during the summer. As a result, the PMV graph shows that the passive cooling, hybrid, and active design scenarios all generate relatively similar results, as most temperatures in Sa Pa are already considered as cool (PMV less than 0.5). During the summer, the active design can maintain a maximum PMV value of around 1.

Similar with the PMV graph, the PPD graph also shows that the passive cooling, hybrid, and active design scenarios all produces relatively similar results, as most temperatures in Sa Pa are considered as cool.

Cooling Load and Cooling Energy Demand

Table III-6 shows that the implementation of passive cooling can also significantly reduce both cooling load and cooling energy demand. The reduction in cooling energy demand can be as much as 70.29% because air conditioners are only operating during the summer.

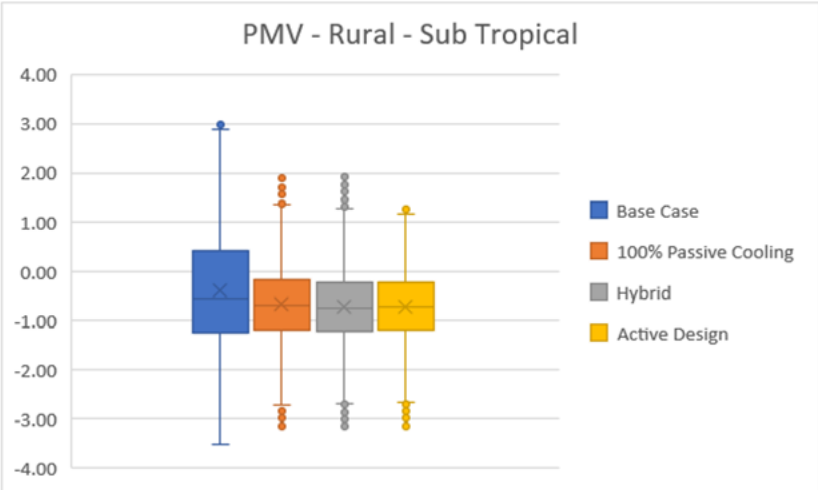

Figure III-22. **PMV Results Sub-Tropical Climate: Rural Area (Sa Pa)**

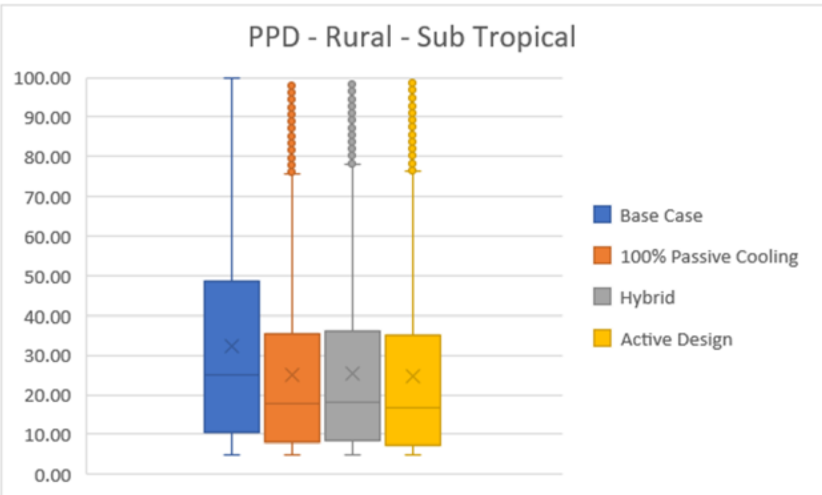

Figure III-23. **PPD Results Sub-Tropical Climate: Rural Area (Sa Pa)**

Table III-6. Cooling Energy Demand Sub-Tropical Climate: Rural Area as the Effect of Passive Cooling

VAC Scenario	Without Passive Cooling	With Passive Cooling
Unmet Hours during Occupied	2 Hours	1 Hour
Cooling Load	7.71 kW	5.99 kW
	26,306.52 BTUh	20,437.88 BTUh
Conditioned Area	48 Sqm	48 Sqm
Cooling Load	548.05 BTUh/sqm	425.79 BTUh/sqm
Cooling Load Reduction		**22.31%**
Cooling Energy Demand	28.98 kWh/sqm	8.61 kWh/sqm
Cooling Energy Demand Reduction		**70.29%**

Figure III-24 shows the sensitivity analysis of varying glazing material (SHGC) and window-to-wall ratio (WWR) on cooling load in a rural sub-tropical environment. It shows the similar result with other climate environments. Using glazing materials with higher SHGC values and higher WWR lead to a higher cooling load.

- **UNMET HOURS RECAP**

Table III-7 provides a summary of unmet hours for each scenario. In a tropical climate, unmet hours occur during periods of high air temperature. In a subtropical climate, unmet hours are influenced not only by high temperatures during the summer but also by periods of excessively low temperatures.

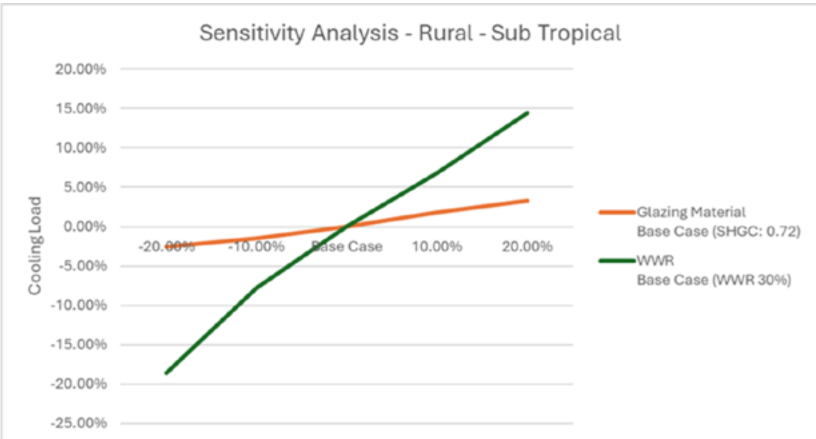

Figure III-24. Sensitivity Analysis – Subtropical Climate: Rural Area (Sa Pa)

Table III-7. Unmet Hours Recap

Climate	Location	Unmet Hours			
		Base Case	100% Passive Cooling	Active Design	Hybrid
Tropical	Urban (Singapore)	8760	8760	61	8760
	Rural (Balikpapan)	8760	8760	80	8760
Sub-Tropical	Urban (Ha Noi)	8281	8063	52	6746
	Rural (Sa Pa)	8154	8258	1	8086

IV. CURRENT STATUS OF REGULATORY INTEGRATION, ENFORCEMENT AND INCENTIVES

IV.1 Introduction of Passive Cooling Policy "Indicators"

The legal basis for implementing energy efficiency in building practices is crucial for establishing a framework that promotes sustainable construction and buildings. This framework not only sets minimum energy performance standards but also encourages the adoption of innovative technologies and practices that enhance energy efficiency. In this context, passive cooling strategies play a significant role in reducing energy consumption and improving indoor comfort without relying heavily on mechanical systems.

To effectively measure and promote the integration of passive cooling strategies, it is essential to establish clear policy indicators. These indicators serve as benchmarks for assessing the performance of buildings in terms of energy efficiency and environmental impact. They can include metrics such as the Solar Heat Gain Coefficient (SHGC), which measures a building's ability to block heat from sunlight, and the Window to Wall Ratio (WWR), which indicates the proportion of windows to wall area, influencing natural ventilation and daylighting.

By incorporating these indicators into building codes and regulations, policymakers can create a more robust framework that not only encourages the use of passive cooling techniques but also ensures compliance with energy efficiency standards. This approach aligns with global sustainability goals and fosters a culture of energy-conscious design within the construction industry. As such, the introduction of passive cooling policy indicators is a vital step towards achieving a more sustainable built environment.

• LAW/REGULATION

Regulation encompasses the policies and frameworks established by both regional and central governments to promote energy-efficient building practices. These regulations are essential for creating a structured approach to sustainability in the construction sector. They typically include the establishment of energy performance standards that dictate the minimum efficiency requirements for both residential and commercial buildings. By setting these standards, governments can ensure that new constructions and renovations contribute positively to energy conservation efforts.

In addition to energy standards, regulations often mandate sustainable construction requirements that encourage the use of environmentally friendly materials. This includes promoting materials that have lower embodied energy, are recyclable, or sourced sustainably. Furthermore, regulations may facilitate the integration of renewable energy sources, such as solar panels or wind turbines, into building designs, thereby reducing reliance on fossil fuels and decreasing overall greenhouse gas emissions.

The implementation of strong regulations not only provides a clear framework for compliance but also fosters a culture of accountability among stakeholders in the property and construction industry. By requiring adherence to these regulations, governments ensure that architects, builders, and developers prioritize sustainable practices in their projects. This collaborative approach is vital for achieving broader environmental goals and enhancing the communities' resilience against climate change.

Moreover, effective enforcement of these regulations is crucial. It ensures that all stakeholders are held accountable for their commitments to energy efficiency and sustainability. By monitoring compliance and providing incentives for exceeding standards, governments can drive innovation and encourage the adoption of advanced technologies and practices that further enhance energy efficiency in buildings.

• BUILDING CODE

Building energy codes serve as essential regulatory instruments that establish minimum energy efficiency standards for both residential and commercial building sectors. These codes are designed to ensure that new constructions and significant renovations meet specific energy performance criteria, thereby reducing overall energy consumption and promoting sustainable building practices. By outlining clear requirements for insulation, HVAC systems, lighting, and other critical components, building energy codes help to create structures that are not only more energy-efficient but also more comfortable and healthier for occupants.

A critical component of these codes is the integration of passive cooling strategies, which are essential for enhancing energy efficiency in hot and humid climates. Passive cooling techniques, such as high-performance building envelopes, natural ventilation, thermal mass, and shading, are encouraged through specific provisions in building codes. For instance, codes may specify the thermal transfer values in the building envelope thereby reducing the reliance on mechanical cooling systems.

However, window placement and orientation are site-specific and would be difficult to mandate through codes. Previous research shows the impact of window orientation on the heat gain and its correlation with OTTV. It is recommended that for ASEAN practice, windows are positioned in the short or north orientation. (Somasundaram, Thangavelu and Chong, 2020).

By incorporating passive cooling measures into building energy codes, regulators can significantly lower energy consumption associated with air conditioning, which is often one of the largest energy expenses in residential and commercial buildings. This not only leads to cost savings for building owners and occupants but also lowers demands on energy systems and contributes to broader environmental goals by reducing greenhouse gas emissions associated with energy production.

Furthermore, the emphasis on passive cooling within building codes reflects a growing recognition of the importance of climate-responsive design. As climate change continues to impact weather patterns and increase the frequency of extreme heat events, the need for buildings that can maintain comfortable indoor environments without excessive energy use becomes increasingly critical. Thus, building energy codes that prioritize passive cooling strategies are vital for fostering sustainable development and enhancing the resilience of communities in the face of climate challenges.

The implementation of building energy codes varies across regions, reflecting local climate conditions, energy resources, and policy priorities. As such, these codes are often updated to incorporate advancements in technology and changes in energy performance expectations. This adaptability is crucial for addressing the evolving challenges of energy efficiency and climate change. Furthermore, building codes can incentivize the use of passive cooling strategies, such as those contributing to high-performance building envelopes, by recognizing their contributions to overall energy performance.

- **STANDARDS**

Standards serve as crucial technical guidelines that provide recommended values and parameters for implementing energy-efficient building practices. These guidelines are developed through a collaborative process involving industry experts, government agencies, and re search institutions, ensuring that they reflect the latest advancements in technology and best practices in sustainability. By establishing clear benchmarks for various aspects of building design and construction—such as insulation levels, window performance, HVAC efficiency, and lighting—standards help architects, engineers, and builders create structures that minimize energy consumption while maximizing occupant comfort. The adoption of these standards is essential for achieving compliance with building energy codes and for facilitating the certification of green buildings, which can enhance market value and attract environmentally conscious investors.

Moreover, standards play a pivotal role in promoting consistency and reliability across the construction industry. They provide a framework for evaluating the performance of building materials and systems, enabling stakeholders to make informed decisions based on empirical data and proven methodologies. This is particularly important in the context of passive cooling strategies, where specific standards can guide the effective integration of natural ventilation, thermal mass, and shading techniques into building designs. By adhering to established standards, builders can ensure that their projects not only meet regulatory requirements but also contribute to broader sustainability goals, such as reducing greenhouse gas emissions and enhancing energy resilience in the face of climate change. Ultimately, the implementation of robust standards is vital for fostering a culture of energy efficiency and sustainability within the building sector.

IV.2 Mapping of Passive Cooling Integration into National Policy in ASEAN, by Country

The ASEAN region demonstrates a diverse landscape in terms of building codes and passive cooling integration policies. Singapore, Indonesia, Philippines, and Thailand have adopted more advanced approaches, implementing mandatory building codes that emphasise energy efficiency and green building practices. However, it is important to note that these building codes may not encompass all building typologies and may exclude residential buildings.

Singapore's building codes emphasise energy efficiency and green practices, supported by the well-established Green Mark certification scheme. The Philippines has made significant strides with its Philippine Green Building Code and Guidelines on Energy Conserving Design of Buildings, highlighting sustainable practices. Thailand has implemented the Building Energy Code (BEC), setting mandatory performance requirements for energy conservation in newly built buildings which has total area of 2000 m2 or more to enhance efficiency and reduce emissions, including 9 types of building: 1) Exhibition building, 2) Hotel, 3) Entertainment service, 4) Hospital, 5) School, 6) Office, 7) Department Store, 8) Condominium and 9) Theatre.

ASEAN Nations Building Codes

Overview of building codes and sustainability initiatives across ASEAN countries

Mandatory · Voluntary · Mixed · N/A

Brunei Darussalam

BUILDING CODE
Brunei's Energy Code and Standards (PBD 12: 2017) VOLUNTARY

GUIDELINES
EE&C Building Guidelines for Non-Residential Building 2015 MIXED

CERTIFICATION SCHEME
Building Energy Label Certificates (BELC), Brunei Accredited Green Unified Seal (BAGUS), Green Rating System VOLUNTARY

Cambodia

BUILDING CODE
Under development N/A

GUIDELINES
Guidelines and Certification Standards for Green Building in Cambodia (CamGCGB) VOLUNTARY

CERTIFICATION SCHEME
Cambodia Energy & Environmental Leadership (CAMEEL) VOLUNTARY

Indonesia

BUILDING CODE
Jakarta Green Building Code, Bandung Green Building Code, Semarang Green Building Code MANDATORY

GUIDELINES
Energy efficiency guidelines for building design in Indonesia VOLUNTARY

CERTIFICATION SCHEME
Greenship (voluntary), Green Building Certification (BGH) (mandatory for government building) MIXED

Lao PDR

BUILDING CODE
No specific national building code mentioned N/A

GUIDELINES
No specific guidelines mentioned N/A

CERTIFICATION SCHEME
No specific certification scheme mentioned N/A

Malaysia

BUILDING CODE
MS 1525: 2019 Energy efficiency and use of renewable energy for non-residential – Code of Practice MIXED

BUILDING CODE
MS 2680: 2017 Energy efficiency and use of renewable energy for residential building-Code of Practice VOLUNTARY

CERTIFICATION SCHEME
Green Building Index (GBI), MyCREST, GreenRE, PH JKR, GreenPASS VOLUNTARY

Myanmar

BUILDING CODE
Myanmar National Building Code (MNBC) 2020 MANDATORY

GUIDELINES
Not specifically mentioned N/A

CERTIFICATION SCHEME
JADE VOLUNTARY

The Philippines

BUILDING CODE
Philippine Green Building Code of 2015 MANDATORY

GUIDELINES
Guidelines on Energy Conserving Design of Buildings - 2020 Edition MANDATORY

CERTIFICATION SCHEME
BERDE, GREEEN, Advancing Net Zero Energy Rating Scheme VOLUNTARY

Singapore

BUILDING CODE
Building Control (Environmental Sustainability) Regulations 2008 MANDATORY

GUIDELINES
Code on Environmental Sustainability Measures for Existing Building MANDATORY

CERTIFICATION SCHEME
BCA Green Mark Certification MIXED

Thailand

BUILDING CODE
Thailand's Building Energy Code, BE 2552 (2009) MANDATORY

GUIDELINES
Not specifically mentioned N/A

CERTIFICATION SCHEME
Thailand Building Energy Efficiency Disclosure (TBEED), Thailand's Rating of Energy and Environmental Sustainability (TREES) VOLUNTARY

Vietnam

BUILDING CODE
Vietnam Energy Efficiency Building Code (QCVN 09: 2013/BXD) and the National Technical Regulation on Energy Efficiency Buildings QCVN 09:2017/BXD MANDATORY

GUIDELINES
No specific guidelines mentioned N/A

CERTIFICATION SCHEME
LOTUS VOLUNTARY

Figure IV-1. ASEAN Nations Building Codes

Case study: International Collaboration and Vietnam's Energy-Efficient Building Regulations

The "Improving energy efficiency in commercial buildings and high-rise apartment buildings in Vietnam" (EECB project) is a collaboration between Vietnam, GEF, and UNDP, significantly influenced Vietnam's construction regulations, particularly the 2020 amendments to the Construction Law (Law No. 62/2020/QH14). These amendments marked a paradigm shift in Vietnam's approach to construction, elevating energy efficiency from a peripheral concern to a core principle. The law now requires energy-efficient solutions in construction planning, investment, management, and materials development, while encouraging research and application of advanced technologies for energy-efficient and environmentally friendly construction. It also expanded the Ministry of Construction's responsibilities to include setting criteria for energy-efficient buildings and ecological urban areas.

Supporting these legal changes, the project also helped develop new technical standards for energy-efficient materials and energy consumption measurement, established cost norms for energy-saving consulting services, created a roadmap for energy-efficient construction projects, and set up databases on energy-saving equipment and materials.

The impact of these regulatory changes is expected to be far-reaching, as these amendments align Vietnam's construction regulations more closely with global sustainability goals. This case study demonstrates how international collaboration can have positive impacts on national construction regulations in ASEAN. The amendments to Vietnam's Construction Law represent a significant step towards sustainable construction practices, illustrating the potential of such collaborations to drive meaningful regulatory change in the construction sector.

Additionally, countries such as Indonesia, Malaysia, Vietnam and Brunei Darussalam are positioned as progressive countries, with a mix of mandatory and voluntary measures. Their building codes incorporate some aspects of energy efficiency and passive cooling, but implementation appears less stringent compared to the advance building code. This suggests a growing awareness of sustainable building practices, but with a more flexible approach to enforcement and adoption.

On the other hand, countries like Cambodia, Myanmar, and Lao PDR show developing policies in this area. Their building codes are still under development and have limited incorporation of passive cooling strategies. This disparity highlights the varied stages of policy development and implementation across ASEAN, likely reflecting differences in economic development, urban growth rates, and environmental priorities. The situation presents both challenges and opportunities for regional cooperation, knowledge sharing, and capacity building to advance sustainable building practices across Southeast Asia.

Figure IV-2 reveals substantial differences in how passive cooling features are adopted and regulated across ASEAN countries. Singapore, Malaysia, the Philippines and Vietnam stand out for their comprehensive approach, incorporating passive cooling elements into their building regulations, both mandatory and voluntary. In contrast, Cambodia, Laos, and Myanmar lack any such features in their building codes and regulations, while Indonesia and Thailand have only limited coverage. This lack of comprehensive passive cooling regulations in many ASEAN countries poses significant challenges for realizing the benefits of passive cooling in building design and construction. Addressing this gap in regulations will be crucial for promoting passive cooling as a sustainable strategy for sustainable development and improving building energy performance across Southeast Asia.

Building Regulations in Southeast Asia

A Comparative Analysis of Regulatory Frameworks

Regulation Matrix

Country	OTTV (W/m²)	SHGC	Reflectivity/SRI	Daylighting	Insulation	Shading	WWR	Thermal Comfort	Natural Ventilation
Brunei Darussalam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mandatory	Mandatory
Cambodia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Indonesia	Mandatory	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lao PDR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Malaysia	Mandatory	N/A	Voluntary	Mandatory	Mandatory	Voluntary	Mandatory	Mandatory	Voluntary
Myanmar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Philippines	Mandatory	Voluntary	Voluntary	Mandatory	Voluntary	Voluntary	Voluntary	Mandatory	Mandatory
Singapore	Mandatory	Mandatory	N/A	Mandatory	N/A	Mandatory	Mandatory	Mandatory	Mandatory
Thailand	Mandatory	Mandatory	N/A	Voluntary	N/A	N/A	N/A	N/A	N/A
Vietnam	Mandatory	Mandatory	Voluntary	Mandatory	Mandatory	Voluntary	Voluntary	N/A	Mandatory

Regulation Distribution

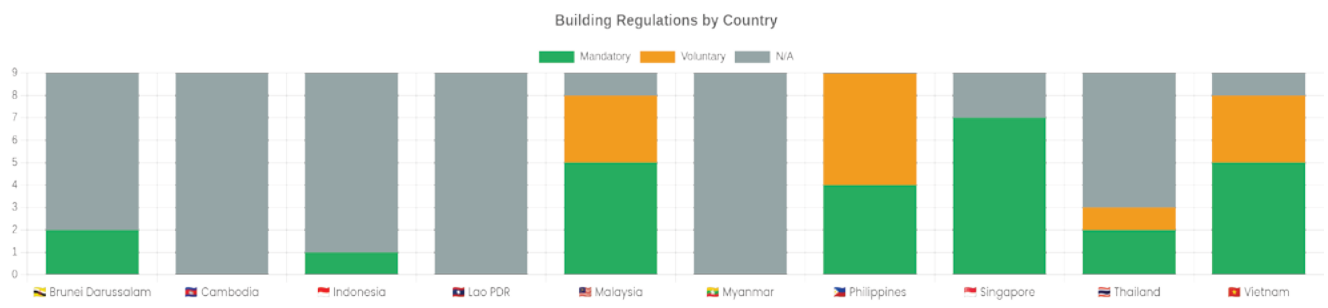

Figure IV-2. Regulations of Passive Cooling Features in ASEAN

V. INFLUENCING FACTORS ON THE UPTAKE OF PASSIVE COOLING STRATEGIES

In this chapter, the influencing factor on the uptake of passive cooling will be explained together with sample cases and common practices in ASEAN Member States

V.1 Architectural Trends and Preferences

In recent years, architectural trends in Southeast Asia have increasingly embraced passive cooling strategies. This shift is driven by several factors, including cultural influences, sustainability preferences, and the challenges posed by urban heat island effects. This analysis examines how the following aspects contribute to the adoption of passive cooling implementations in the region.

Figure V-1. **Influencing Factors on The Uptake of Passive Cooling Strategies**

• CULTURAL INFLUENCE OF VERNACULAR ARCHITECTURE

Traditional architectural styles in Southeast Asia have long utilized passive cooling techniques. Elements such as large overhangs, shaded verandas, and high ceilings are intrinsic to these designs. These features are not only aesthetically pleasing but also highly functional, aiding in natural ventilation and reducing heat gain. The resurgence of these elements in modern architecture indicates a blending of cultural heritage with contemporary design practices (Toe and Kubota, 2015).

Case Study in Southeast Asia: The Joglo house, a traditional Javanese house in Indonesia, exemplifies the use of passive cooling techniques in vernacular architecture. The Joglo houses feature a distinctive high, steeply pitched roof that creates a large internal air space, promoting air circulation and reducing heat accumulation. The large overhangs and expansive verandas provide ample shade, significantly lowering direct solar heat gain and keeping the interior cool. The open floor plan and the use of natural materials such as wood and bamboo enhance ventilation and thermal comfort.

Modern interpretations of Joglo house incorporate these traditional design elements to create sustainable and energy-efficient buildings. By blending cultural heritage with contemporary practices, architects can achieve effective passive cooling, reducing reliance on mechanical cooling systems and promoting sustainability.

A traditional house of Myanmar built from a gabled thatch roof and bamboo or wooden structure are found in all houses as box-like forms. Most of the building components come from off-site fabrication and are assembled as a portable structure. The main houses are raised above the ground on a series of posts. This feature will make natural cooling underfloor possible. An open space under the main house is either underused or used for domestic animals. Houses are either one or two-storey dwellings with a backyard and are rarely multi-storey. Room spans and column spacing vary from seven to nine feet (2 meters to 3 meters). Family lifestyle patterns are usually reflected in the building size and building plan, which could serve either nuclear or extended family models (Zune, Rodrigues and Gillott, 2020).

- **PREFERENCE OF SUSTAINABLE DESIGN**

There is a growing emphasis on sustainable and energy-efficient designs in Southeast Asia's architectural landscape. This shift towards green architecture is part of a broader global trend. Architects and developers are increasingly integrating passive cooling elements into their designs to minimize environmental impact. This includes strategies such as optimizing building orientation, using insulation and materials with high thermal mass, and incorporating green roofs and walls.

The global movement towards sustainability has a significant influence on Southeast Asian architecture. As awareness of climate change and environmental degradation rises, there is a concerted effort to adopt green building practices. Passive cooling strategies align well with these efforts, providing a means to achieve thermal comfort without relying on energy-intensive air conditioning systems (Kubota, Chyee and Ahmad, 2009; Arch Daily, 2021; Ling *et al.*, 2024).

- **URBAN HEAT ISLAND (UHI) EFFECT**

The rapid urbanisation in Southeast Asia has led to the intensification of the urban heat island (UHI) effect, where dense urban areas experience significantly higher temperatures than their rural surroundings. This exacerbates the need for effective cooling solutions in cities.

Quantitatively, the UHI effect can result in urban areas being up to 7-10°C warmer than nearby rural areas. For example, studies have shown that in Jakarta, Indonesia, the temperature difference between urban and rural areas can reach up to 8°C during peak summer months.

To combat the UHI effect, passive cooling strategies are being integrated into urban planning and building design. These strategies include enhancing natural ventilation through the strategic placement of windows and vents, using shading devices to block direct sunlight, and utilising materials with high thermal mass to absorb and slowly release heat. Implementing green roofs and walls can also reduce surface temperatures by up to 20-40°C, contributing significantly to urban cooling.

Such measures are crucial in maintaining comfortable indoor temperatures while reducing reliance on mechanical cooling. By decreasing the urban-rural temperature gradient, passive cooling strategies not only improve comfort and reduce energy consumption but also mitigate the broader impacts of the UHI effect on public health and the environment (Bowler *et al.*, 2010; Hassan *et al.*, 2021; Li *et al.*, 2022).

Another strategy in order to reduce UHI is by installing roof gardens and maximizing vegetation surrounding the building. Some practices have revealed that roof gardens may reduce roof temperature by 1-2°C (EPA, 2024).

V.2 Market Awareness through Green Building Certification

The adoption of passive cooling strategies in buildings has been significantly influenced by market awareness, driven largely by the proliferation of green building certifications. These certifications serve as both motivators and validators for sustainable construction practices, including passive cooling. This analysis explores how green building certifications, government policies, and educational efforts collectively enhance the uptake of passive cooling strategies in Southeast Asia.

- **GROWTH OF GREEN BUILDING CERTIFICATIONS**

Green building certifications from Southeast Asian countries, alongside international standards like LEED and WELL, are gaining prominence in the region. These certifications are designed to encourage sustainable building practices, often incorporating requirements or incentives for passive cooling strategies.

Green building certifications play a pivotal role in raising awareness among architects, contractors, and developers. By rewarding buildings that integrate passive design, these certifications enhance market value and provide a competitive edge. Consequently, the desire to achieve certification drives the adoption of passive cooling as a standard practice in new developments. The increasing adoption of these certifications underscores the importance of market recognition in promoting sustainable building practices (Moriarty, 2014; VGBC, 2024).

• GOVERNMENT AND POLICY SUPPORT

To promote the construction and operation of sustainable, environmentally friendly, and energy-efficient buildings–specifically those that incorporate passive cooling strategies–in ASEAN, an approach that integrates policy, education, and regulatory enforcement interventions is crucial. The following provides a brief overview of the interests and interrelationships among these three components.

In this context, regulation refers to the policies and regulations implemented by both regional and central governments in Indonesia to encourage green and energy-efficient building practices. This system may include establishing energy standards, sustainable construction requirements, the use of environmentally friendly materials, integration of renewable energy sources, and the reduction of greenhouse gas emissions. Strong regulations provide a clear framework and ensure that all stakeholders in the property and construction industry adopt sustainable practices.

Government supports through incentives and regulations is critical in promoting sustainable building practices. Many Southeast Asian countries have implemented national building codes and energy performance standards that mandate or encourage energy-efficient designs, including passive cooling.

Singapore's Green Mark Scheme, launched by the Building and Construction Authority (BCA), is a prominent example of how government policies can incentivize sustainable building practices. The Green Mark Scheme awards buildings that meet specific sustainability criteria, including energy efficiency and passive cooling strategies.

Figure V-2. Intercorrelation of Regulation – Enforcement – Education (C40, 2023)

For example, the Green Mark Incentive Scheme for Existing Buildings (GMIS-EB) provides funding support for the upgrading of building systems to improve energy efficiency. This includes grants that cover a portion of the retrofitting costs, encouraging the integration of passive cooling measures such as improved natural ventilation and shading. Additionally, Green Mark-certified projects also get regulatory incentives, such as fast-track planning approvals and higher plot ratios, allowing developers to build more floor area than typically permitted, thereby enhancing the economic viability of incorporating sustainable design features.

The ASEAN region collectively promotes sustainable building practices through initiatives such as the ASEAN Plan of Action for Energy Cooperation (APAEC). This plan includes strategies for improving energy efficiency in buildings, encouraging member states to adopt and implement green building standards that incorporate passive cooling. Additionally, the Roadmap Towards Sustainable and Energy-Efficient Space Cooling in ASEAN provides policy tools for to drive energy efficiency improvements for space cooling. It sets ambitious milestones for space cooling technologies, including air conditioners and fans, that can support achieving the energy efficiency target in Southeast Asian countries.

Governments in most Southeast Asian countries have building energy codes that require holistic approaches to reduce energy consumption. These codes encourage the integration of passive cooling strategies, such as natural ventilation, shading, and the use of materials with high thermal mass, as a means to reduce reliance on active cooling systems. By setting stringent energy performance requirements, these policies indirectly promote passive cooling as an essential component of energy-efficient building design (IEA, 2022a).

- **EDUCATIONAL AND ADVOCACY EFFORTS**

Education is another key aspect in achieving self-sufficiency in green and energy-efficient building systems. Through education, construction professionals, architects, engineers, and building owners in ASEAN can gain knowledge and understanding of sustainable practices and technologies. It is also important to raise awareness among the general public about the significance of sustainable buildings and ways to reduce the energy and environmental footprints of their own buildings. Training programs, seminars, and awareness campaigns can help strengthen the understanding and knowledge needed to apply green building practices more widely.

Non-governmental organizations, green building councils, and professional bodies are instrumental in promoting market awareness of green building certifications. Through seminars, workshops, and advocacy campaigns, these organisations educate stakeholders about the benefits of sustainable building practices, including passive cooling.

Green building councils, such as the Singapore Green Building Council and the Malaysia Green Building Confederation, play a crucial role in disseminating knowledge and best practices related to green building. They organise training programmes, certification courses, and conferences that highlight the importance of passive cooling strategies as part of broader sustainability goals.

Universities also contribute significantly by incorporating green building subjects into their curricula. Courses on sustainable architecture and building science often include modules on passive cooling techniques. By educating the next generation of architects, engineers, and urban planners, universities ensure that knowledge of passive cooling strategies is deeply embedded in professional practices.

Educational efforts highlight the advantages of green building certifications, such as reduced energy costs, improved indoor comfort, and enhanced market value. By emphasizing these benefits, NGOs, green building councils, and professional bodies drive the adoption of passive cooling strategies as an integral part of sustainable building design. These efforts ensure that the benefits of sustainable practices are widely understood and implemented, further embedding passive cooling strategies in the construction industry.

V.3 Building Material Supply Chains

The adoption of passive cooling strategies in buildings is significantly influenced by the availability and innovation of sustainable building materials. This analysis explores how the availability of local materials, advancements in material technology, and optimisation of supply chains collectively enhance the uptake of passive cooling strategies in Southeast Asia.

- **AVAILABILITY OF LOCAL MATERIALS**

In Southeast Asia, the accessibility of building materials that naturally provide insulation and reflectivity plays a crucial role in promoting passive cooling. Traditional materials such as bamboo, timber, and reflective tiles are widely available and culturally familiar, making them attractive options for sustainable construction. These materials are not only environmentally friendly but also possess inherent properties conducive to passive cooling.

The use of local materials that reflect or absorb less heat, coupled with their high-performance insulating qualities, can significantly reduce indoor temperatures. For instance, bamboo has a thermal conductivity of 0.14 W/mK, making it an excellent insulator. The reduction in indoor temperatures can lower cooling energy demand by up to 30%, depending on the specific design and materials used. This reduction decreases the reliance on mechanical cooling systems, thereby promoting energy efficiency and sustainability. The cultural acceptance and familiarity with these materials further facilitate their integration into modern building designs.

Wood, as another option of local building materials, offers substantial advantages for energy efficiency, primarily due to its inherent insulating properties. With a thermal conductivity of approximately 0.12 W/mK, wood is a far better insulator than concrete or steel. This property allows wood to effectively maintain comfortable indoor temperatures, thereby reducing the reliance on mechanical heating and cooling systems. Research found that wood's thermal performance in radiant floor heating systems can result in a 6.4% reduction in energy demand compared to high-conductivity materials like granite (Ruiz-Pardo, et al., 2022). These findings highlight wood's potential to enhance energy efficiency in buildings. Furthermore, the natural aesthetic and cultural familiarity of wood in many regions make it a preferred choice, promoting its adoption in sustainable building practices.

The reduction in energy demand contributes not only to lower operational costs but also to reduced greenhouse gas emissions, aligning with broader sustainability goals. Wood's versatility in design, from light-frame constructions to mass timber buildings, offers architects and builders flexibility in meeting both aesthetic and energy efficiency standards.

Case Study in Southeast Asia: The Green School in Bali, Indonesia, exemplifies the use of local materials for passive cooling. The school buildings are constructed primarily from bamboo, a material that is not only sustainable but also has excellent thermal properties. The design of the buildings maximizes natural ventilation and utilises the shading properties of bamboo to maintain a cool indoor environment. This approach significantly reduces the need for artificial cooling systems, highlighting the effectiveness of using local materials for passive cooling. The school reports a 20-30% reduction in energy consumption compared to conventional buildings (Atwa Eldek et al., 2024).

- **INNOVATIONS IN MATERIAL TECHNOLOGY**

Innovations in material technology are pivotal in expanding the use of passive cooling techniques. Advanced facade materials that control thermal transfer and support natural ventilation can significantly reduce the need for air conditioning. High-reflectivity surfaces, breathable walls, and other material advancements are increasingly accessible in Southeast Asia, providing new opportunities for passive cooling.

The development and adoption of these advanced materials enable architects and builders to implement effective passive cooling strategies. These innovations contribute to improved thermal comfort and energy efficiency in buildings. Reflective paints, for instance, can reduce roof temperatures by up to 30%, translating into a 10-15% reduction in cooling energy needs.

Case Study in Southeast Asia: Nanyang Technological University (NTU) in Singapore has implemented several innovative materials in its campus buildings to enhance passive cooling. One notable example is the use of a specially developed reflective paint that reduces heat absorption. Additionally, NTU's School of Art, Design, and Media features a green roof covered with vegetation, which provides natural insulation and cooling through evapotranspiration. These innovative material applications significantly reduce the buildings' cooling loads and exemplify the benefits of advanced material technology in passive cooling. The green roof has been shown to lower indoor temperatures by 2-4°C, contributing to a 15-20% reduction in energy consumption for cooling (Aleksov, 2020).

• SUPPLY CHAIN OPTIMISATION

As the demand for sustainable building materials grows, supply chains in Southeast Asia are becoming more efficient. This enhanced distribution network ensures that advanced and sustainable materials are more readily available across the region, making it easier and more cost-effective to adopt passive cooling strategies.

Efficient supply chains facilitate the adoption of new materials and technologies crucial for passive cooling. Advanced thermal insulation and novel materials that improve thermal management are becoming more accessible. This supports the development of energy-efficient buildings that are better adapted to local climate conditions, achieving optimal thermal comfort while minimising environmental impact.

Furthermore, technological advancements such as utilisation of artificial intelligence (AI) in supply chain management can address the challenges in material procurement. AI can be utilised to analyse material volume, demand-forecasting models, end-to-end transparency, and supporting better decision-making process. Successfully implementing AI-enabled supply-chain management can reduce logistics costs by 15% (Alicke, et al., 2021), making sustainable construction more economically viable.

The focus on sustainable development and energy efficiency in Southeast Asia drives the adoption of innovative materials. This regional commitment ensures a continuous supply of cutting-edge materials essential for passive cooling strategies, promoting sustainable construction practices across the region.

Case Study in Southeast Asia: Eco-cities such as the Iskandar Malaysia in Johor, Malaysia, exemplify how optimised supply chains support sustainable construction. This development focuses on using sustainable building materials sourced from efficient supply chains. The incorporation of advanced insulation materials and high-reflectivity surfaces in buildings within the eco-city enhances passive cooling, reducing the need for mechanical air conditioning and demonstrating the importance of supply chain optimisation in sustainable construction. Buildings in Iskandar Malaysia have reported a 20% reduction in energy costs due to the efficient use of sustainable materials (Ho and Fong, 2011).

VI. RECOMMENDATION FOR PASSIVE COOLING IN ASEAN

VI.1 Regulatory Enforcement

- **SUPPORT FOR ENERGY EFFICIENCY AND EMISSIONS POLICY**
  - Develop and implement comprehensive national energy efficiency policies that prioritize passive cooling strategies.
  - Set specific targets for reducing cooling-related energy consumption and emissions in the building sector.
  - Integrate passive cooling requirements into national building codes and standards.

- **MEETING ROADMAP FOR ENERGY-EFFICIENT BUILDINGS AND CONSTRUCTION IN ASEAN TARGETS**
  - Align national policies with the Roadmap for Energy-Efficient Buildings and Construction in the Association of Southeast Asian Nations.
  - Establish clear milestones and timelines for implementing passive cooling strategies across the region.
  - Develop mechanisms for regular progress monitoring and reporting.

VI.2 Policy and Planning Integration

- Strengthen building regulations to mandate the inclusion of passive cooling elements in new constructions and major renovations.
- Implement robust enforcement mechanisms, including inspections, reporting and penalties for non-compliance.
- Incorporate passive cooling criteria from existing green building certification programs (such as Green Mark, LOTUS, or Greenship) or develop dedicated certification programs for passive cooling design and implementation.

VI.3 Awareness and Education

- Awareness raising and upgrading knowledge regarding the importance of the benefits of passive cooling strategies, including potential cost savings and environmental impact.
- Raise awareness of the passive cooling program for buildings among the private sector and domestic donors and other stakeholders (building's owner, developers, designers, contractors and consultant)
- Capacity development for the public at large regarding building design and construction, energy consumption, and how to properly select low energy /energy efficient appliances to lower their energy spending.

VI.4 Incentives

- **FISCAL INCENTIVES**
  - Tax Deductions: The government may provide tax deductions for buildings that implement passive cooling measures.
  - Subsidies: Direct subsidies can be provided to alleviate the fiscal burden for building owners who intend to implement passive cooling measure in order to reduce energy consumption for VAC system.
    - ✓ For new buildings, subsidies can be given to encourage owners or managers to design the building so that it can implement passive cooling principles.
    - ✓ For existing buildings, subsidies can be provided to reduce the cost of renovating building to lower cooling loads.
  - On-bill Financing: on-bill financing establishes payment based on the difference between monthly electricity bills before and after energy efficient measures are implemented. This scheme is called on-bill financing. It is primarily offered to existing buildings seeking to renovate in order to improve its energy performance. The loan amount can be determined by calculating the payback period and the potential savings in electricity bills.
- **NON-FISCAL INCENTIVES:**
  - Streamlined Building Permits: Buildings that implement passive cooling measures can enjoy a streamlined building permits process, reducing administrative requirements.
  - Density Bonus: Density bonus is typically applied in densely populated areas with high property rental prices. This incentivizes building owners to maximize the rentable area by obtaining additional floor area. Additionally, in residential buildings, this scheme can motivate unit owners to maximize their living space through implementing energy efficient building measures.
  - Recognition: Recognition can be granted through certification to buildings that successfully meet energy efficient building criteria. Furthermore, other forms of recognition can include promotion on social media or the government-owned website portal for energy efficient building information. This raises awareness among investors about buildings committed to making a positive impact on the environment.

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