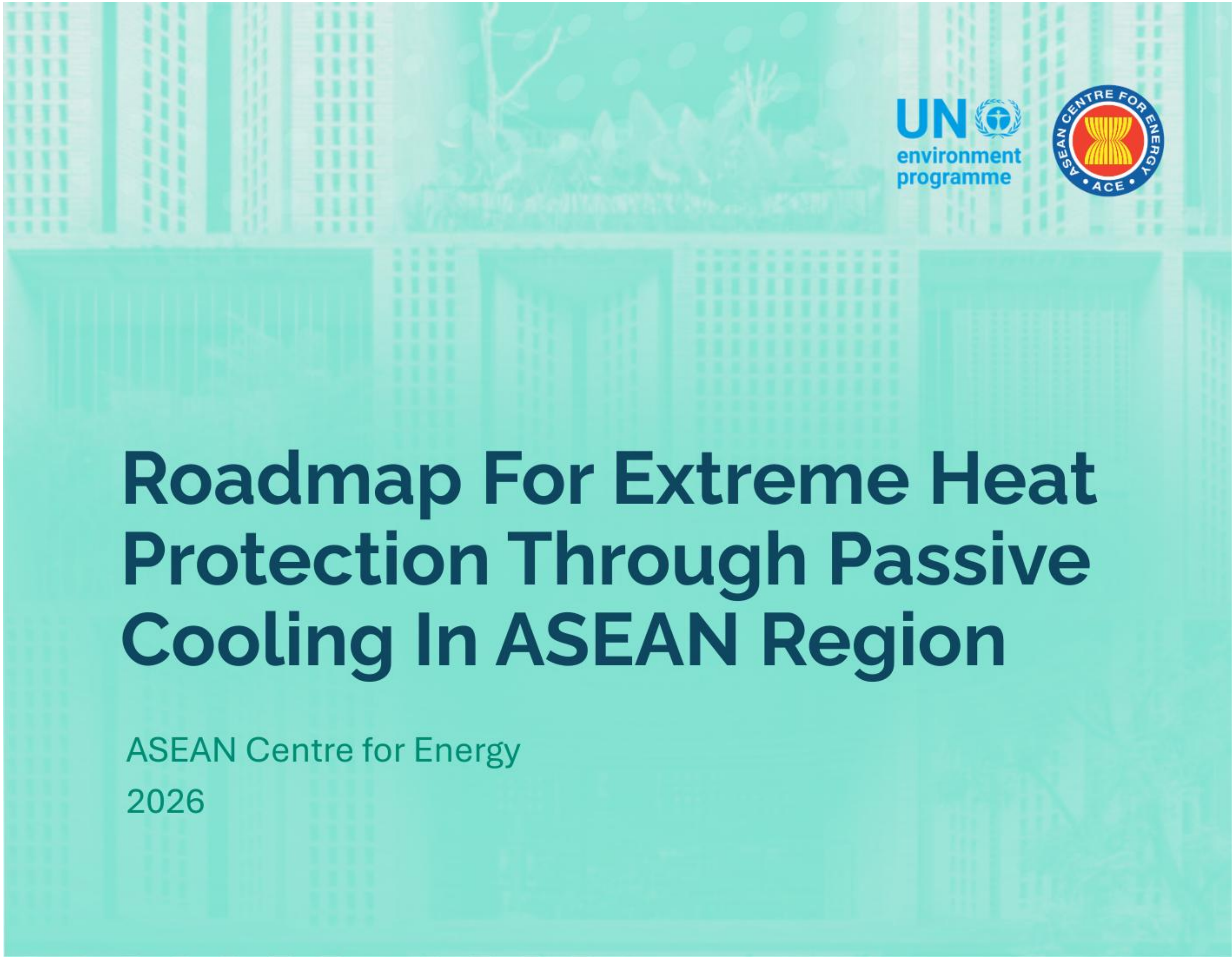


Roadmap For Extreme Heat Protection Through Passive Cooling In ASEAN Region

ASEAN Centre for Energy

2026

**ASEAN Centre
for Energy**

One Community for
Sustainable Energy

Roadmap For Extreme Heat Protection Through Passive Cooling In ASEAN Region

2026

Roadmap for Extreme Heat Protection through Passive Cooling in ASEAN Region

Published by: ASEAN Centre for Energy

Soemantri Brodjonegoro II Building, 6th fl. Directorate General of Electricity
Jl. HR. Rasuna Said Block X-2, Kav. 07-08 Jakarta 12950, Indonesia
Tel: (62-21) 527 9332
E-mail: secretariat@aseanenergy.org; www.aseanenergy.org

Disclaimer

This publication and the material featured herein are provided “as is”.

All reasonable precautions have been taken by the ASEAN Centre for Energy (ACE) to verify the reliability of the material featured in this publication. Neither ACE nor any of its officials, consultants, data or other third-party content providers or licensors provides any warranty, including as to the accuracy, completeness, or fitness for a particular purpose or use of such material or regarding the non-infringement of third-party rights. They accept no responsibility or liability with regard to the use of this publication and the materials featured therein. The ASEAN Member States (AMS) or the individuals and institutions that contributed to this report are not responsible for any opinions or judgements the report contains. The information contained herein does not necessarily represent the views, opinions or judgements of the AMS or of the individuals and institutions that contributed to this report, nor is it an endorsement of any project, product or service provider. The designations employed and the presentation of material herein do not imply the expression of any opinion on the part of ACE concerning the legal status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Report Citation

ACE (2026). *Roadmap for Extreme Heat Protection through Passive Cooling in ASEAN Region*. United Nations Environment Programme (UNEP). Nairobi. ASEAN Centre for Energy (ACE). Jakarta. Available for download from **http://aseanenergy.org/**.

For further information about this publication, please contact ACE at cee@aseanenergy.org

Acknowledgement

The successful completion of the **Roadmap for Extreme Heat Protection through Passive Cooling in ASEAN Region** is attributed to the collaborative efforts of the ASEAN Centre for Energy (ACE), United Nations Environment Programme (UNEP), and individuals. Their combined expertise, steadfast support, and dedicated contributions have significantly enhanced the quality and depth of the work.

Authors: This publication was prepared by UNEP and ACE. The lead authors are Rio Jon Piter Silitonga, Irma Ramadan, and Zahra Aninda Pradiva from ACE, including support from Satyandyka Adirajasa, Parimita Mohanty, Lily Riahi, Manjeet Singh, Gennai Kamata, Lorena de Carvalho Araujo, Leyla Prezelin and Alexandra Mutungi from UNEP. This publication is developed with invaluable contributions from Dr S. Sarpaneswaran Naesh, Director of Research and Corporate Strategy at C&G Analytica Consulting, BK Sinha, Founder and Director of Habitat Enviro, and Prof VGR Chandran Govindaraju from the University of Malaya.

Guidance and Supervision: Special recognition is extended to Martin Krause, Director of the Climate Change Division, UNEP, Hongpeng Lei, Chief of the Mitigation Branch, UNEP, Gulnara Roll, Head of the Cities Unit, UNEP, Dato' Ir. Ts. Razib Dawood, Executive Director, ACE, Naing Naing Linn, Head of Energy Efficiency and Conservation (EE&C) Department, ACE, Beni Suryadi, Senior Manager of ASEAN Plan of Action on Energy Cooperation (APAEC), ACE, and Dr Zulfikar Yurnaidi, Head of Modelling and Policy Planning (MPP) Department, ACE for their instrumental role in providing direction and supervision, ensuring the success of this publication.

Contributing ASEAN Member States: Recognition is given to the following ASEAN Energy Efficiency and Conservation Sub-Sector Network (EE&C-SSN) Working Group on Building, whose expertise and commitment played a pivotal role in shaping the content and direction of this publication: Noor Ani Amarina Adanan, Mohammad Abdul Muizz Faiz Hazwan Hj Mat Yassin, **Brunei Darussalam**; Gnan Bora, **Cambodia**; FF Hendro Gunawan, Fajar Zawa Tri Mulya, **Indonesia**; Viengsavanh Inthirath, Phonepasong Sithideth, **Lao PDR**; Syafiqah binti Hazmi, Steve Anthony Lojuntin, Khairil Anwar bin Arifin, Malaysia; Aye Kay Khaing Soe, Pyae Sone Oo, **Myanmar**; Daniel Collin G. Jornales, Vittorio Leif Ericson J. Santos, **Philippines**; James Tan, Singapore; Apiwadee Dangkong, Wisaruth Maethasith, Krisanatas Sumdangrit, **Thailand**; Dong Thi Minh Ha, **Vietnam**.

Supporting Organisations: Thanks are extended to departments in the ASEAN Centre for Energy and the United Nations Environment Programme (UNEP) for their collaborative support in facilitating the research, writing, and publication process.

Experts: Special appreciation is extended to Dr Daniel Collin G. Jornales and Dr Tetsu Kubota, as the Chair and Co-Chair of the ASEAN Passive Cooling Advisory Group, for

their invaluable insights and expertise in energy efficiency initiatives in the building sectors.

Reviewers: Appreciation is expressed to members of the ASEAN Passive Cooling Advisory Group, including , Aarti Nain, UNEP, , Benjamin Hickman, UNEP, Srinidhi Ravishankar, UNEP, Eleni Myrivili, UNEP, Andeol Cadin, UNEP, Zhuolun Chen, UNEP-CCC, Liwayway Adkins, UNEP, Athena Denise Galao, UN Women, Kimberly Roseberry, UN ESCAP, Muhammad Nur Fajri Alfata, Ministry of Public Works, Indonesia, Mom Mony, Ministry of Land Management, Urban Planning and Construction, Cambodia, Luu Linh Huong, Ministry of Construction, Vietnam, Chieko Matsubara, Japan International Cooperation Agency, Makoto Kanagawa, Japan International Cooperation Agency, Ginga Nakadai, Japan International Cooperation Agency, Philippe Brunet, Swiss Development Agency, Xiaoyi Jin, Clean Cooling Collaborative, Andhang Rakhmat Trihamdani, YKKAP R&D Center Indonesia, Chu Yen, Academy of Construction Strategy and Cadres Training, Hai Ha Pham Thi, Hanoi University of Civil Engineering, Dr Tetsu Kubota, Hiroshima University, Sumedha Basu, University of Leeds, Sheikh Ahmad Zaki bin Shaikh Salim Mjiit, Universiti Teknologi Malaysia, Takashi Asawa, Institute of Science, Tokyo for the time and effort dedicated by the reviewers from various organisations in providing constructive feedback and ensuring the quality of this publication.

Design and Layout: Acknowledgment is given to Muhammad Bayu Pradana Effendy and Fadhiel Handira Ishaq for their creative contributions to the design and layout of this publication.

Communications Team: Special recognition goes to Firdaus Fadhlullah Designerindy and Amara Zahra Djamil from ACE, in cooperation with Sofia Maria Giannouli from UNEP, for their efforts in preparing the communications strategy and final stages of preparing this publication for distribution.

Funding Support: Gratitude is expressed for the financial support provided by the United Nations Environment Programme (UNEP) that made this publication possible.

This collaborative effort reflects the dedication of a diverse group of organisations, and their valuable contributions are truly appreciated.

Executive Summary

The roadmap provides a regional framework to address the increasing risks of extreme heat caused by rapid urbanisation, climate change, and rising energy demand. It aims to promote affordable, equitable, and energy-efficient passive cooling solutions that protect people, communities, and populations in vulnerable situations, particularly women, children, older persons, low-income households, and informal workers, and persons with disabilities, whilst helping AMS achieve their energy, climate, and health goals. The roadmap is in line with the ASEAN Plan of Action for Energy Cooperation (APAEC) 20265–2030, the Sustainable Development Goals, the Paris Agreement, the Global Cooling Pledge, and the Declaration de Chaillot and applies to both urban and rural contexts in the region. The roadmap advocates a Passive First design philosophy: optimise building design, orientation, and envelope performance to eliminate or minimise the need for mechanical cooling at the outset. Passive cooling strategies, such as natural ventilation, shading, high-performance envelopes, cool roofs, and urban greenery are the primary response to extreme heat in ASEAN's built environment, not a supplement to mechanical systems. Where residual cooling loads remain after passive measures have been fully applied, mechanical cooling may be sized and deployed only to address that remaining load, thereby reducing both energy consumption and capital costs significant.

The roadmap was developed using a multi-stage methodology combining desk research, surveys, stakeholder mapping, and regional consultation workshops. This mixed-methods approach ensured the proposed recommendations are evidence-based and informed by inputs from government agencies, private sector actors, urban planners, and community representatives across the ASEAN region.

KEY FINDINGS

- Major ASEAN cities are projected to experience between 85 and 120 days a year with temperatures above 35°C by 2050, with Bangkok facing the most severe exposure, posing significant consequences for health, productivity, and energy systems.
- Passive cooling strategies, such as natural ventilation, reflective roofs, and high-performance building envelopes, offer a transformative mitigation pathway. Individual measures deliver cooling energy savings of 10–30% through natural ventilation and hybrid systems, and 35–70% through high-performance glazing and envelope improvements, with blended strategies typically achieving 20–50% depending on the climate zone and baseline building characteristics.
- The regional policy and regulatory landscape remain fragmented, with several AMS lacking mandatory building energy codes, and existing regulations are often hindered by weak enforcement and a lack of technical standards.

- Survey findings indicate a massive gap between interest and implementation. Most respondents, representing building occupants, building designers (architects, engineers, developers), and policymakers, express interest in passive cooling. Yet passive cooling remains under-adopted due to high upfront costs as the primary barrier, compounded by limited technical capacity, lack of awareness regarding green financing, and perceived low returns on investment (ROI).
- Passive cooling is a critical solution in ASEAN, particularly for urban low-income communities and vulnerable groups that have limited access to mechanical cooling.

RECOMMENDATIONS

Policy and Regulation

- Align passive cooling strategies with APAEC 2026–2030 and NDCs by developing harmonised regional standards for building envelope design, facade materials, natural ventilation, and thermal performance, ensuring consistency across AMS in support of the 2050 carbon neutrality transition
- Incorporate mandatory passive cooling requirements into national building energy codes, covering envelope design, shading, natural ventilation, and thermal comfort, with phased integration initially targeting large commercial and public buildings
- Scale up urban cooling measures, including green canopies, urban water bodies, cool roofs, and reflective pavements, integrating these into urban masterplans and city-level climate resilience strategies aligned with NDC commitments
- Ensure passive cooling policies explicitly prioritise populations facing differentiated heat exposure, including women, informal workers, elderly persons, persons with disabilities, and low-income urban households

Finance and Investment

- Introduce performance-based incentive packages including tax deductions, concessional loans, FAR bonuses, and expedited permitting, whilst directing public procurement to prioritise passive cooling in public buildings as a market signal
- Develop specialised green financing products with longer payback periods, performance-based lending criteria, and blended finance mechanisms to reduce transaction costs and mobilise private investment at scale
- Ensure financing mechanisms include targeted pathways for vulnerable communities where upfront investment barriers and limited access to formal finance constrain adoption

Capacity and Technical

- Integrate passive cooling at the earliest design stage through multidisciplinary collaboration, partnering with technology providers to ensure envelope optimisation, construction quality, and long-term performance
- Leverage green building certifications, energy performance ratings, and sustainability branding to differentiate projects and capture market value, supported by systematic post-occupancy evaluations
- Standardise regional green building certification incorporating dedicated modules on building physics, energy modelling, and climate-responsive design suited to ASEAN's climatic conditions
- Deploy monitoring and evaluation toolkits with clear performance indicators to track passive cooling outcomes and enable evidence-based knowledge exchange across AMS

Foreword – ASEAN Centre for Energy

The ASEAN region stands at a pivotal point, as rapid urbanisation, climate change, and escalating energy demand converge to create unprecedented challenges for our societies and economies. Extreme heat is no longer an occasional hazard but an urgent, persistent threat that endangers public health, undermines economic productivity, and strains vital infrastructure across AMS.

Recognising these risks, ASEAN has taken decisive steps to promote solutions that are not only effective but also equitable and sustainable. The Roadmap for Extreme Heat Protection through Passive Cooling in the ASEAN Region embodies our collective commitment to fostering climate resilience, supporting vulnerable populations, and ensuring that progress leaves no one behind. By prioritising passive cooling, we can reduce energy use and minimise greenhouse gas emissions, whilst creating a healthier and more inclusive urban environment. Developed through systematic research, broad stakeholder collaboration, and alignment with the ASEAN Plan of Action for Energy Cooperation (APAEC) as well as the Paris Agreement and the Global Cooling Pledge, this roadmap offers practical strategies, policy recommendations, financial frameworks, and capacity-building opportunities tailored for the unique climatic, social, and economic contexts of Southeast Asia. It serves as both a strategic vision and an actionable guide for our governments, private sector, communities, and regional agencies.

Through this comprehensive approach, ASEAN seeks not only to adapt to the realities of a warming world but to lead by example, demonstrating how regional cooperation, policy harmonisation, and community empowerment can yield durable progress. We encourage all stakeholders to embrace the insights and recommendations in this roadmap in order to invest in passive cooling as a catalyst for sustainable development, improved livelihoods, and greater regional solidarity.

We wish to express our gratitude to the contributors, partners, and communities across ASEAN whose insights and efforts have shaped this roadmap. We trust this roadmap will serve as a practical guide for governments, industry, and communities across ASEAN in advancing passive cooling solutions for a more resilient and energy-efficient future.

Dato’ Razib Dawood
Executive Director, ACE

Foreword - UNEP

Extreme heat is accelerating across Southeast Asia, and with a 1.5°C overshoot now is almost inevitable in the early 2030s, rapid action is essential to limit how far — and for how long — temperatures rise.

For ASEAN Member States, the stakes could not be higher. The region is warming quickly, and the urban heat island effect is intensifying the crisis. This threatens health, productivity and the stability of essential services.

Heat is foremost a development and equity challenge, alongside being an environmental issue. Access to cooling determines whether children can learn, hospitals can operate, workers can earn a living and food and supply systems can function. Yet the dominant response — air conditioning — cannot solve the crisis alone. If deployed unsustainably, it drives greenhouse gas emissions, power insecurity, grid stress and widening inequality. The challenge is therefore dual: to expand access to affordable, life-saving cooling while sharply reducing its energy and carbon footprint.

This roadmap highlights the most powerful and underused part of the solution: passive cooling, nature-based solutions and low-energy equipment. These measures can deliver nearly two-thirds of the cooling sector's potential emissions reductions by 2050. They are cost-effective, scalable and rooted in local climates, materials and ecosystems. Most importantly, they benefit those most vulnerable to rising heat.

Southeast Asia has deep traditions of climate-responsive design — including shaded structures, cross-ventilation and materials that work with, not against, the tropical climate. The region also has a unique opportunity: much of its urban growth still lies ahead. Decisions made today on building codes, planning frameworks, procurement standards and infrastructure investments will lock in either high-heat, high-emissions futures or cooler, more resilient and inclusive cities for decades.

This roadmap provides a practical pathway. It shows how governments can assess heat risks, expand urban green cover and cool roofs, embed passive design into regulations and use public procurement to shift markets toward efficient, low-global-warming-potential cooling technologies. It outlines how cities can integrate sustainable cooling into development strategies, how communities can champion nature-based solutions, and how UNEP and partners can support ASEAN Member States in accelerating this transition.

The message is clear: cooling can and should become a development priority — and passive cooling can form its foundation. Scaling these solutions now will protect lives, strengthen energy security, cut emissions and help ensure the almost inevitable overshoot is as small and short as possible.

ASEAN Member States are already showing leadership. This roadmap builds on that momentum. I hope it serves as both a guide and a call to action — because every degree, every cooler street and every resilient building matter.

Martin Krause
Director, Climate Change Division, UNEP

Table of Contents

List of Figures

List of Tables

Abbreviations

AC	Air Conditioner
ACE	ASEAN Centre for Energy
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of Southeast Asian Nations
BAS	Building Automation System
BCA	Building and Construction Authority
CFD	Computational Fluid Dynamics
CLMV	Cambodia, Lao PDR, Myanmar, Vietnam
CSPF	Cooling Seasonal Performance Factor
EE&C	Energy Efficiency and Conservation
ESCO	Energy Service Company
HVAC	Heating, Ventilation, and Air Conditioning
LEED	Leadership in Energy and Environmental Design
M&E	Monitoring and Evaluation
MEPS	Minimum Energy Performance Standards
NbS	Nature-Based Solutions
NDC	Nationally Determined Contribution
NZEB	Net Zero Energy Building
OBS	Outcome-Based Strategies
OTTV	Overall Thermal Transfer Value
PCMs	Phase Change Materials
PCS	Passive Cooling Strategies
ROI	Return on Investment
RTTV	Roof Thermal Transfer Value
SDGs	Sustainable Development Goals
SRI	Solar Reflectance Index
SSN	Sub-Sector Network
STEPS	Stated Policies Scenario
TMY	Typical Meteorological Year
TREES	Thai’s Rating of Energy and Environmental Sustainability

UHI	Urban Heat Island
UDH	Uncomfortable Degree Hours
WELL	WELL Building Standard
ZEB	Zero Energy Building

Introduction

Extreme heat is becoming a defining crisis of our era, with urban areas experiencing its most severe impacts. For the purposes of this roadmap, extreme heat refers to temperatures that significantly exceed the historically normal range for a given region, typically sustained daily maximum temperatures above 35°C, posing acute risks to human health, productivity, and energy systems. June 2024 marked the 13th consecutive month of record-breaking global temperatures, whilst dense development, heat-absorbing materials, and shrinking green spaces are turning cities into heat traps due to the Urban Heat Island (UHI) effect [1]. Vulnerable populations (including women, children, the elderly, and low-income communities) face disproportionate exposure. Women, in particular, endure prolonged indoor heat due to unpaid care work and limited control over housing improvements, whilst informal workers face heightened occupational risk. As the UN Secretary-General's Call to Action on Extreme Heat highlights, soaring temperatures strain energy grids, trigger blackouts, and drive emissions higher through surging air-conditioning demand [2].

ASEAN faces increasing heat risks driven by rapid urbanisation, climate change, and rising energy demand. The urban population is projected to grow from 348 million (51%) in 2022 to 521 million (66% of the population) by 2050. By 2080, up to 1.1 billion urban dwellers in South and Southeast Asia could experience extreme heat lasting more than 30 days annually, whilst 1.2 billion people in the global south already lack adequate cooling [3], [4]. Cities such as Bangkok, Manila, and Jakarta already suffer from dangerous heat. Air conditioners, whilst becoming the most common solution, remain unaffordable for the vulnerable groups and place significant pressure on national energy grids [5].

Passive cooling strategies (PCS) and nature-based solutions (NbS) offer the most sustainable and cost-effective path to managing cooling demand across ASEAN. By leveraging building design, natural ventilation, shading, insulation, and the thermal properties of the building envelope, passive cooling reduces indoor temperatures without depending on energy-intensive mechanical systems. In ASEAN's hot-humid climate, lightweight construction with low thermal mass is generally preferred to prevent heat accumulation, whilst reflective surfaces, cool roofs, and appropriate glazing further reduce heat gain. Passive cooling is the primary response, whereas mechanical systems are deployed only where a residual load remains after passive measures have been fully applied, ensuring active cooling is right-sized rather than over-specified. Globally, PCS and NbS can curb cooling capacity demand growth by 24% by 2050, avoiding up to USD 3 trillion in equipment costs and cutting 1.3 billion tonnes of CO_2e, whilst improving health, productivity, and thermal equity for communities that cannot afford mechanical cooling systems [5].

PCS reduce indoor temperatures by leveraging natural environmental conditions and the thermal properties of the building envelope. In ASEAN's hot-humid climate, the primary objective is to minimise heat absorption rather than store it. Lightweight construction with low thermal mass is therefore preferred, as high-mass materials such as concrete and brick risk retaining daytime heat and radiating it into occupied spaces. Where such materials are used, effective night ventilation and external insulation are essential to counteract this effect [5]. Natural ventilation, through cross ventilation or the stack effect, expels accumulated indoor heat and replaces it with cooler outdoor air. Shading devices, including overhangs, louvres, and trees, alongside cool roofs, reflective surfaces, and well-insulated envelopes, further limit solar heat gain [6].

Given the scale and urgency of ASEAN's cooling challenge, a coordinated regional response is essential. Aligning passive cooling strategies with the ASEAN Plan of Action for Energy Cooperation (APAEC), national adaptation plans, Nationally Determined Contributions (NDCs), and regional resilience frameworks will enable knowledge-sharing, policy harmonisation, and targeted financing across Southeast Asia's shared tropical context. The guiding principle is clear: passive cooling must be the first line of response in building design, eliminating cooling demand at source, with active mechanical systems deployed only where residual loads require them.

1.1 About this Roadmap

This roadmap responds to the growing energy and climate risks posed by extreme heat and rapid urbanisation across ASEAN's built environment. Buildings account for 23% of total final energy consumption and a comparable share of energy-related CO_2 emissions in the region. Space cooling is the fastest-growing driver within this sector; air conditioners alone represent approximately 15% of residential energy use, with fans contributing a further 9%, and space cooling electricity demand is projected to reach 300 TWh by 2040, roughly equivalent to the combined electricity consumption of Indonesia and Singapore [7].

Against this, the roadmap positions passive cooling as an affordable and accessible first response to rising cooling demand, offering actionable policy directions and implementation pathways adaptable at the national level. It also aligns AMS with broader commitments under APAEC 2026-2030, particularly the Energy Efficiency and Conservation (EE&C) Programme Area's push towards Zero Energy Buildings (ZEB) through passive building design, whilst reinforcing the Sustainable Development Goals, the Paris Agreement, the Global Cooling Pledge, and the Cool Coalition. In this way, the roadmap connects concrete responses to extreme heat in the built environment with ASEAN’s wider energy transition and climate commitments, ensuring that passive cooling is treated as a core policy instrument.

Figure 1. *Strategic Roadmap for Passive Cooling in ASEAN*
Source: ACE. All rights reserved.

Specifically, it provides

- **Evidence-based assessment** of the current understanding, awareness, and exposure of AMS to extreme heat risks and PCS.
- **Mapping and analysis of existing policy, regulatory, financial, and technological frameworks** that support or hinder the adoption of passive cooling at national and regional levels.
- **Opportunity for stakeholder engagement**, including with government officials, private sector, urban planners, architects, and community representatives, including women's organisations, local governments, public health actors and institutions responsible for social protection to identify entry points for inclusive cooling policies.
- **Identify socio-economic impacts and vulnerabilities**, especially among women, children, low-income groups, the elderly, and persons with disabilities, ensuring that the roadmap integrates gender-responsive and inclusive solutions.
- **A practical and implementable regional roadmap**, including:
    - **a.** Recommended PCS and design principles.
    - **b.** Short-, medium-, and long-term policy actions for AMS.
    - **c.** Financing and incentive mechanisms to accelerate uptake.
    - **d.** Capacity-building strategies and awareness campaigns

- **A monitoring and evaluation toolkit**, including indicators, templates, and guidelines to enable AMS to track implementation progress and evaluate impacts over time.

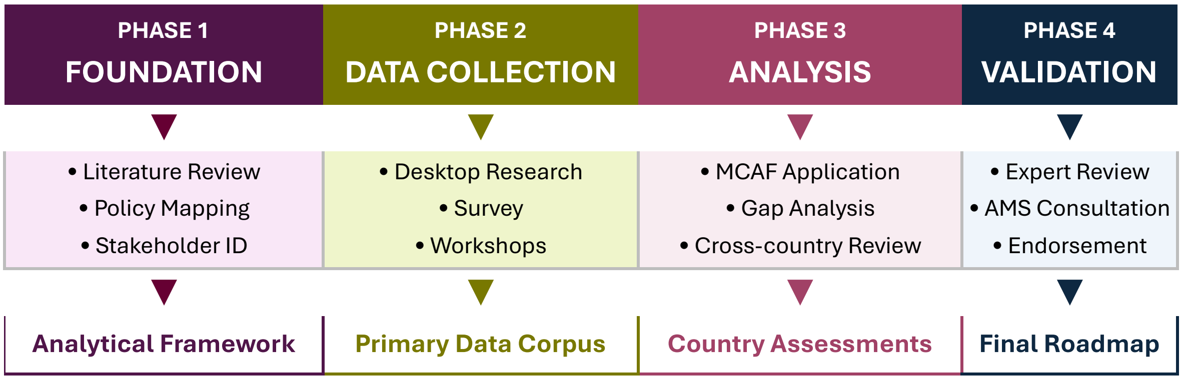
1.2 Scope and Limitations

This roadmap covers the period 2026 to 2050, with near-term priorities for 2026–2030, medium-term targets for 2031–2040, and a long-term vision through 2050. It addresses the adoption of passive and hybrid cooling solutions across all ASEAN Member States (AMS), accounting for diverse climatic, socio-economic, and urban-rural contexts. It targets vulnerable groups, including low-income households, the elderly, children, and people with disabilities, whilst engaging policymakers, building sector stakeholders, and communities. The scope encompasses heat risk assessments, policy and technology mapping, design recommendations, financing mechanisms, and capacity-building strategies, aligned with APAEC 2026-2030, the Paris Agreement, and the Global Cooling Pledge.

The scope of the roadmap study has several potential limitations that may affect its completeness and applicability in ASEAN. Data availability is inconsistent across AMS, and post-utilisation assessments remain limited, constraining the evidence base. Regulatory maturity, technical capacity, and enforcement vary significantly, particularly in CLMV countries. Access to climate finance for vulnerable groups remains constrained, supply chains for passive cooling materials are underdeveloped, and returns on investment are often unclear to building owners and developers. The diversity of building types, climates, and socio-economic conditions also means that universal recommendations are not feasible. Without sustained political commitment, targeted financing, and coordinated institutional support, these constraints risk undermining the roadmap's effectiveness.

Methodology

The development of the roadmap employed a multi-faceted methodological approach, as illustrated in Figure 2. Specifically, four primary methods were adopted: (i) desktop research; (ii) a stakeholder engagement workshop; (iii) a stakeholder and policy mapping exercise; and (iv) a questionnaire survey. The survey targeted a wide range of respondents, including building designers (e.g., architects, engineers, and building consultants), developers, building occupants, investors, financial institutions, and vulnerable groups (e.g., low-income communities, women, and the elderly). The survey also includes responses from the members of the ASEAN Passive Cooling Advisory Group, including representatives from the ASEAN EE&C-SSN Working Group on Buildings.



PHASE 1 FOUNDATION	PHASE 2 DATA COLLECTION	PHASE 3 ANALYSIS	PHASE 4 VALIDATION
• Literature Review • Policy Mapping • Stakeholder ID	• Desktop Research • Survey • Workshops	• MCAF Application • Gap Analysis • Cross-country Review	• Expert Review • AMS Consultation • Endorsement
Analytical Framework	**Primary Data Corpus**	**Country Assessments**	**Final Roadmap**

Figure 2. *Four-Phase Methodological Framework*
Source: ACE. All rights reserved.

On top of that, the roadmap assesses the level of integration of passive cooling using a multi-criteria assessment framework designed to capture the depth of national policy and market readiness. The assessment is based on three main dimensions:

1. **Policy specificity** – Assesses whether national building codes and related regulations explicitly incorporate PCS, such as natural ventilation, solar shading and building envelope optimisation.
2. **Comprehensive regulation** – Examines the extent to which standards are mandatory or voluntary, the coverage of different building types and the degree of integration with broader energy efficiency requirements
3. **Readiness for implementation** – Measures the strength of enforcement mechanisms, the degree of market acceptance, the availability of skilled labour and the existence of institutional support systems to promote compliance and acceptance.

For classification purposes, a “limited" rating was given to countries where only basic energy efficiency policies exist, with no explicit provisions for passive cooling, weak enforcement infrastructure and minimal market penetration. A "very advanced" classification, on the other hand, required comprehensive binding standards, solid enforcement, established market mechanisms and strong institutional capacity.

Situational Analysis- Climate Context and Extreme Heat Trends in ASEAN

3.1 Extreme Heat Climate and Its Impact

The ASEAN region is experiencing unprecedented warming trends that signal a future of increasingly severe extreme heat events. A study found that 6 of the 11 cities that experienced at least 30 days of climate change–driven heat between December 2024 and February 2025 were in Asia, underscoring the region's high vulnerability to prolonged heat [8].

Table 1. Temperature Projections for Major ASEAN Cities (2000-2050)

City	Baseline 2000 (°C)	Current 2025 (°C)	Change 2000-2025	Projected 2030 (°C)	Projected 2040 (°C)	Projected 2050 (°C)	Total Change 2000-2050	Days >35°C (Current)	Days >35°C (2050)
Bangkok	33.3	34.2	**+0.9°C**	35.8	36.9	38.1	**+4.8°C**	45	120
Jakarta	31.9	32.8	**+0.9°C**	34.1	35.2	36.4	**+4.5°C**	28	95
Manila	32.6	33.5	**+0.9°C**	34.9	36.0	37.2	**+4.6°C**	38	110
Ho Chi Minh City	33.0	33.9	**+0.9°C**	35.2	36.4	37.7	**+4.7°C**	42	115
Kuala Lumpur	32.2	33.1	**+0.9°C**	34.4	35.6	36.9	**+4.7°C**	35	100
Singapore	31.7	32.6	**+0.9°C**	33.8	34.9	36.1	**+4.4°C**	25	85

Note: *Baseline 2000 temperatures are calculated using observed land surface temperature trends from MODIS satellite data (2000-2022), which documented an average warming rate of 0.37°C per decade across Southeast Asian cities. Current temperatures reflect 2025 measurements. Projections based on the RCP 4.5 scenario. Higher emission scenarios (RCP 8.5) show increases of 1-2°C above these figures.*

Cities were selected based on population size, data availability, and representativeness of ASEAN's major urban climate zones. Ho Chi Minh City was selected over Hanoi as it represents the hotter southern climate zone of Viet Nam with higher cooling demand. Data for remaining AMS are incorporated in the broader regional analysis where available.

Source: [9], [10], [11], [12], [13]

Table 1 demonstrates the current climate models, projecting several concerning trends of temperature progression in the ASEAN region throughout 2050 as visualised in the map below:

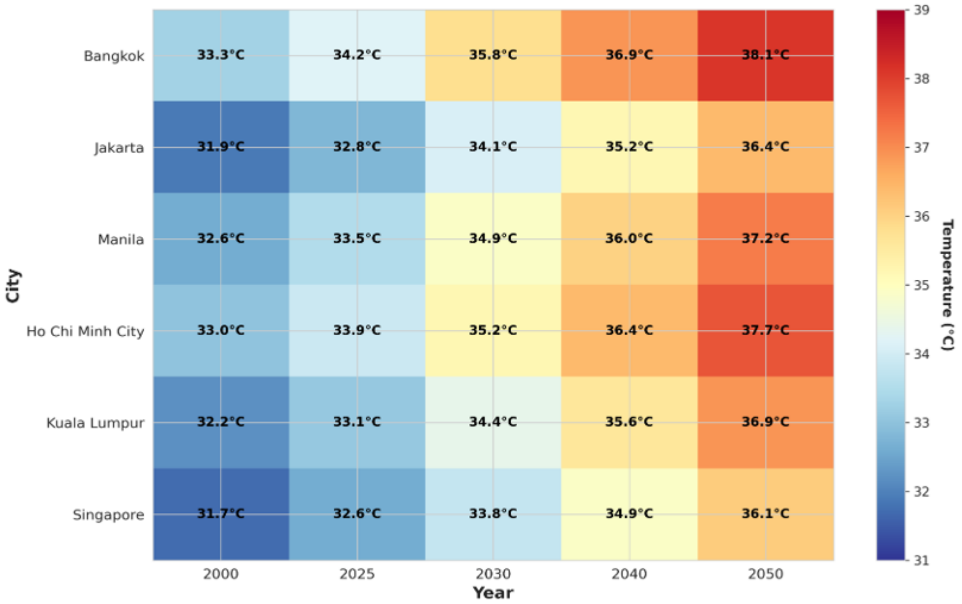


***Figure* 3.** *AMS Cities Heatmap of Temperature Evolution (2000-2050)*

This heatmap illustrates progressive warming across all cities and time periods, with the blue-to-red colour gradient enabling direct comparison of both temporal trends and inter-city differences. The analysis reveals four key climate trends affecting AMS:

Temperature Increases: Regional temperatures in major ASEAN cities are projected to rise by 4.4-4.8°C from 2000 to 2050, with warming accelerating from 0.9°C (2000-2025) to 3.6°C (2025-2050).

Seasonal Shifts: Traditional monsoon patterns are becoming less predictable, with dry seasons extending longer and wet seasons becoming more intense but shorter.

Extreme Heat Duration: Across ASEAN cities, days exceeding 35°C are projected to increase by 167-240% by 2050. Bangkok, Manila, and Ho Chi Minh City will experience between 110 - 120 extreme heat days annually, more than double current levels, with heat seasons starting earlier and lasting longer.

Humidity Effects: Rising temperatures combined with high humidity in tropical Southeast Asia are pushing wet-bulb temperatures beyond human tolerance thresholds. With the projected 85-120 extreme heat days annually by 2050 and temperatures reaching 36-38°C, PCS are essential for maintaining habitable space.

Case Study

Typical Meteorological Years (TMY) in Indonesia

Overview

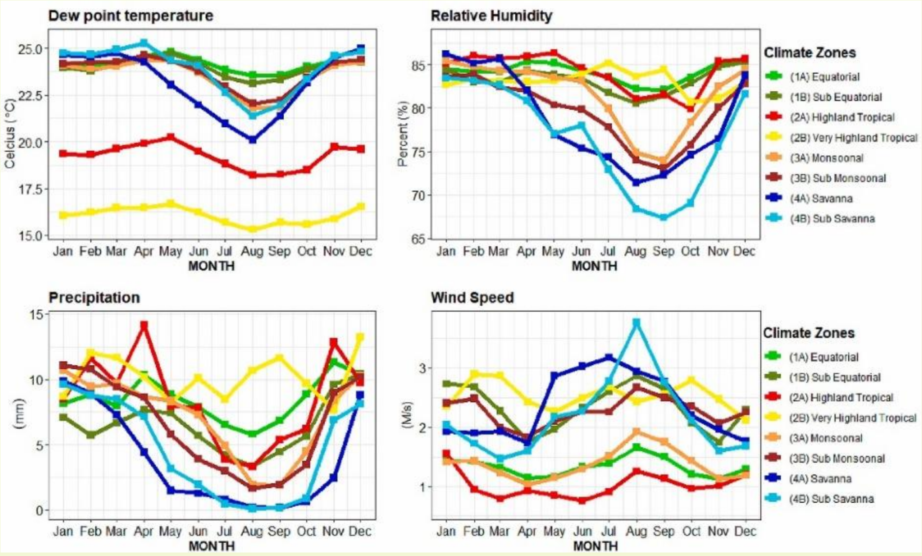
This study aims to present a methodology for developing TMYs under limited observational data conditions in Indonesia, addressing gap-filling using bias-corrected ERA5 reanalysis data, TMY generation across multiple sites, and statistical verification against long-term climatic averages.

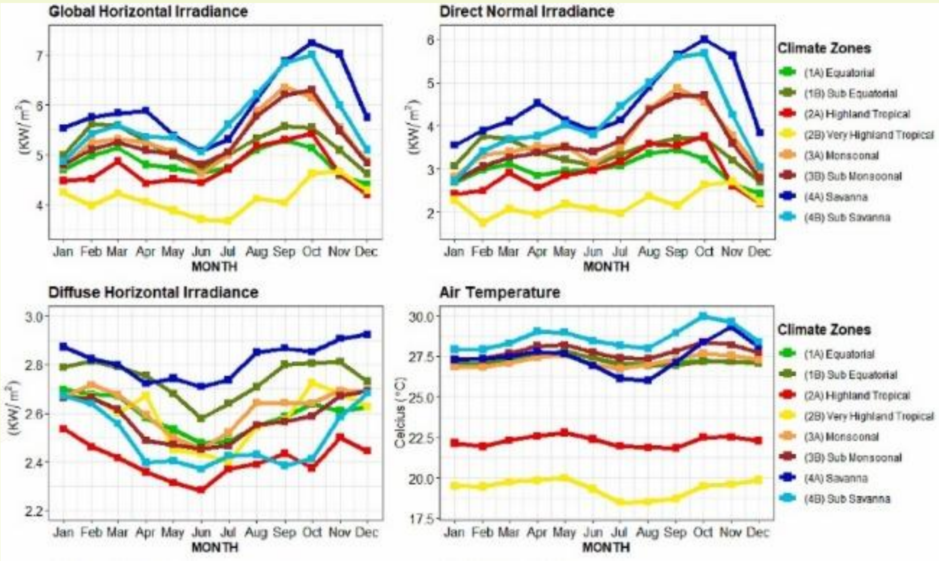
Mechanism and Challenges Addressed

TMY development requires complete long-term hourly climate records, yet data continuity remains a persistent challenge in developing countries. Solar radiation is rarely measured directly due to high instrumentation costs, necessitating the use of satellite-derived and reanalysis datasets such as ERA5. Temperature, humidity and wind speed records are further compromised by equipment failures, transmission errors and digitisation limitations, making rigorous quality control essential prior to TMY generation.

Outcomes and Impacts

This study introduced a method for developing TMYs using limited observational data. A bias correction with quantile mapping for temperature, humidity and wind speed improved ERA5 reanalysis accuracy, reducing biases from 4.5–2.7 °C to 0.014–0.005 °C, 6–10 % to 0.32–0.07%, and 4–2 m/s to 0.02–0.35 m/s. The corrected ERA5 data filled 30–50 % gaps in hourly observations from 2011 to 2020. Using the Sandia method with modified FS weighting, TMYs were generated for 106 sites across eight climate zones in Indonesia. Year selection varied by site, reflecting local climatic conditions. Statistical verification showed the TMYs captured long-term distributions well, with strong correlation (0.96 for irradiance, 0.86 for temperature) and low errors (RMSE 75 W/m^2 for irradiance, 1.3 °C for temperature).





Annual pattern of each climate elements of the TMY within various climate zones

Source: [14]

Case Study

Climate Zones for Passive Cooling Techniques in Indonesia

Overview

This study developed a climate zone classification to support passive design strategies, using Indonesia as a case study. Based on long-term hourly climate data from major cities, new zones were defined and mapped for passive cooling techniques such as night ventilation, comfort ventilation and evaporative cooling. The resulting climate zone map provides a basis for building regulations aimed at improving energy efficiency in Indonesia, and the approach can be applied to other hot and humid regions worldwide.

Mechanism and Challenges Addressed

The Koppen climate maps are widely used in research and building design, but they rely only on vegetation, temperature and rainfall. Many countries, therefore, create their own climate zones based on heating and cooling degree days, since HVAC systems dominate building energy use. However, passive design strategies require a more detailed evaluation of local conditions. Beyond degree days, a range of climatic factors must be considered, including synoptic climate, meso-climate and microclimate at the building site.

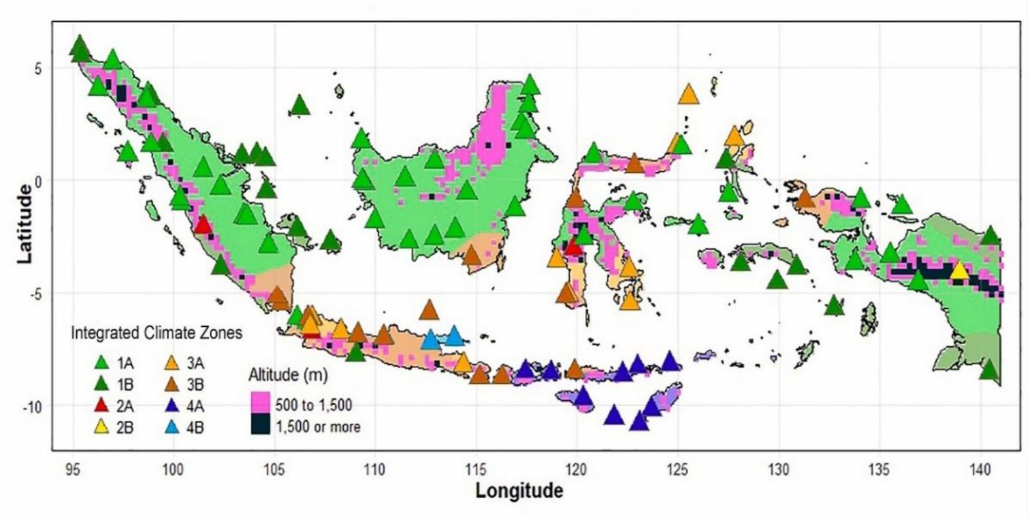
Outcomes and Impacts

A novel integrated climate zoning system was developed for Indonesia, dividing the country into eight zones: 1A equator, 1B sub-equator, 2A highland tropical, 2B very highland tropical, 3A monsoonal, 3B sub-monsoonal, 4A savanna and 4B sub-savanna. Unlike the Koppen classification, this approach incorporates topography and multiple hourly climate factors, producing more detailed spatial and temporal results. The suitability of passive cooling methods such as night ventilation,

Case Study

Climate Zones for Passive Cooling Techniques in Indonesia

evaporative cooling and comfort ventilation was assessed for each zone. At a 50% probability limit, monsoon, savanna and sub-savanna zones were suitable for comfort ventilation, whilst the sub-equatorial zone favoured a combination of night and comfort ventilation. These findings support tailored implementation plans for passive cooling across Indonesia.



Integrated climate zones in Indonesia

Scalability

Engineers, architects, and designers can refer to the information obtained in this initial research to determine the potential of passive design strategies and basic design decisions during the initial design stage, before detailed building simulation analyses are carried out in a certain climate zone.

Lesson Learned

Future research is needed to establish detailed building design guidelines based on more quantitative data that consider more factors affecting the accuracy of passive cooling methods for each zone. The detailed long-term weather observation data (hourly data) were used for the classification.

Source: [15]

Heat Waves Impacts

The ASEAN region has witnessed a dramatic escalation in both the frequency and severity of extreme heat events. Climate change made the extreme heat about 30 times more likely and 1°C hotter, demonstrating the direct attribution of current extreme events to anthropogenic climate change [16].

2000 – 2009

The region experienced an average of two to three significant heat wave events per year

2010 – 2019

Heat waves events increased, with four to six events annually that typically lasted seven to ten days

2020 – 2024

The frequency rose further to an average of 8 – 12 events per year, with some extreme cases persisting for 3 – 4 weeks

Socioeconomic and Health Impacts of Heat Waves

Heat-related mortality and morbidity increase significantly in urban areas across Asia. During heat wave periods, heat-related emergency department visits increase substantially [17].

Economic Impacts of Heat Waves

Intense heat reduces outdoor worker productivity and drives electricity demand higher through increased air-conditioning use [18], [19]. Agricultural output is also at risk, with staple crops such as rice particularly vulnerable to heat stress during critical growth stages.

3.1.1 Climate Vulnerability Assessment

The ASEAN region's vulnerability to extreme heat is unevenly distributed, with certain communities and demographic groups facing disproportionate risks. This assessment identifies key vulnerable populations across three dimensions: geographical, demographic, and socioeconomic, and examines systemic resilience gaps as follows:

Geographic Vulnerability

Across ASEAN, vulnerable populations face heightened heat exposure due to inadequate housing, limited cooling and green space in urban informal settlements, and occupational heat stress among rural agricultural workers [20].

Demographic Vulnerability

Children, older adults, pregnant women, and individuals with chronic diseases are particularly vulnerable to heat stress due to physiological and health-related factors. [21].

Socioeconomic Vulnerability

Low-income households, informal workers, and migrants face disproportionate heat exposure. Poor housing design, overcrowded space, inadequate ventilation, limited access to cooling, unsafe working environment, and weak social protection constrain their adaptive capacity and increase their health risk [22], [23].

Systemic Resilience Gaps

Inadequate public infrastructure, weak building standards, limited green space, and strained power grids compound heat vulnerability across ASEAN. Low public awareness, insufficient professional training, and a lack of locally relevant research further limit the region's capacity to respond effectively [24].

Table 2. *Climate Vulnerability Index by ASEAN Member States*

Country	Overall Vulnerability Score*	Exposure Level	Sensitivity Level	Adaptive Capacity	Priority Vulnerable Groups
Brunei Darussalam	4.8	Medium	Low	High	Elderly, outdoor workers
Cambodia	8.2	High	Very High	Low	Agricultural workers, urban poor
Indonesia	7.1	Very High	Medium	Medium	Coastal communities, informal workers
Lao PDR	7.9	High	High	Low	Rural communities, ethnic minorities
Malaysia	5.9	Medium	Medium	High	Urban poor, migrant workers
Myanmar	8.7	Very High	Very High	Very Low	Rural poor, children, elderly
Philippines	7.4	Very High	High	Medium	Island communities, urban poor
Singapore	4.2	Medium	Low	Very High	Elderly, outdoor workers
Thailand	6.2	High	Medium	Medium-High	Migrant workers, rural poor
Vietnam	6.8	High	Medium	Medium	Agricultural workers, elderly

Note: Data for Timor-Leste are not yet available and will be incorporated in a future update.

*Scale: 1-10, where 10 represents the highest vulnerability

Source: [4], [25], [26]

Table 2 summarises climate vulnerability across AMS. Myanmar, Cambodia, and Lao PDR face the highest vulnerability, driven by high exposure, sensitivity, and limited adaptive capacity. The Philippines and Indonesia follow, with coastal and informal communities most at risk. Malaysia, Brunei, and Singapore show lower overall vulnerability, though the elderly, migrants, and outdoor workers remain exposed. Significant inequities in regional climate resilience persist. This data underscores persistent inequities in regional climate resilience.

a. Resilience Gaps

Infrastructure Deficits

People in tropical and subtropical regions are exposed to high temperatures all year, whilst in cooler regions, heat exposure mainly happens in certain seasons, leading to different heat risks [27]. Poor building design, heat-trapping materials, hard surfaces, and the loss of trees, airflow, and waterways increase city temperatures and make conditions less comfortable.

Institutional Gaps

Many AMS have limited support systems to deal with extreme heat, including a lack of heatwave early warning systems, fragmented coordination for cross-border heat emergencies, and limited heat-health action plans in cities [28]. These problems are made worse by low funding for urban climate adaptation, which limits the effective rollout of heat resilience measures.

Knowledge and Awareness Deficits

Gaps in knowledge and capacity limit effective heat adaptation, including low public awareness of heat health risks, limited training for healthcare workers, and weak expertise in heat-resilient urban planning. These issues are worsened by a lack of local research on passive cooling solutions and insufficient monitoring of urban heat islands to guide targeted infrastructure improvements.

3.1.2 Impact & Mitigation of Urban Heat Island (UHI) Effect

The UHI effect describes the elevated temperatures of urban areas relative to their rural surroundings, driven by human activities, dense built materials, reduced vegetation, and altered land surfaces [32]. This thermal rise raises cooling energy demand, degrades air quality, and heightens heat-related illness [33]. Climate change amplifies UHI impacts on liveability and social equity.

Urban Heat Island Intensity Analysis

Research on major ASEAN cities has documented significant UHI effects. Surface temperatures in Jakarta exceed rural surroundings by 3-6°C, whilst nocturnal UHI in Manila reaches 2.17°C, and Bangkok records a 3°C difference between impervious surfaces and green spaces [29], [30]. Urban greening interventions can reduce air temperatures by up to 4°C, offering a practical mitigation pathway [31].

Table 3. *Urban Heat Island Intensity in Selected ASEAN Cities*

City	Population (Millions)	UHI Intensity Day (°C)	UHI Intensity Night (°C)	Urban Area (km^2)	Green Cover (%)	Priority Mitigation Areas
Bangkok	10.7	5.4	7.2	1,569	6.8	Khlong Toei, Chatuchak, commercial areas
Ho Chi	9.0	4.9	6.8	2,061	12.4	District 1, industrial zones

City	Population (Millions)	UHI Intensity Day (°C)	UHI Intensity Night (°C)	Urban Area (km^2)	Green Cover (%)	Priority Mitigation Areas
Minh City						
Jakarta	10.6	6.2	8.7	664	8.2	Central business district, industrial zones
Kuala Lumpur	1.8	4.2	5.9	243	15.6	KLCC, Chow Kit, Setapak
Manila	13.5	5.8	7.9	619	5.1	Quezon City, Makati, dense residential
Singapore	5.9	3.8	5.1	719	47.0	CBD, industrial estates

Source: [29], [30], [31]

Vulnerable Populations in UHI Zones

UHI effects fall disproportionately on vulnerable groups. Temperature monitoring in Malaysian cities has recorded dangerous indoor and outdoor heat levels, particularly affecting children, the elderly, and low-income households [32]. Informal settlements, markets, transport hubs, and care facilities across the region face compounded heat exposure requiring targeted spatial planning responses.

Spatial Distribution of Vulnerability:

Urban heat exposure is unevenly distributed. Low-income neighbourhoods are frequently located in the highest UHI intensity zones, where poor insulation and limited green space amplify thermal stress. Industrial zones expose workers to heat from both UHI and occupational sources, whilst dense residential areas with inadequate ventilation create heat-trap conditions, exacerbating thermal stress.

3.1.3 Mitigation Strategies and Implementation

Nature-Based Solutions (NbS)

NbS mitigate urban heat stress through several key strategies, such as Urban forestry targeting 30-40% tree canopy coverage, connected green corridors, vertical gardens, rooftop greenery, and restored urban waterways, collectively reducing heat stress through shading and evapotranspirative cooling.

Built Environment Interventions

Strategic planning in built environment can reduce heat exposure through cool roofing, permeable and reflective pavements, passive cooling requirements in building standards, and shading infrastructure in high-exposure areas reduce urban heat exposure through strategic built environment planning.

Policy and Planning Measures

Zoning reforms, green building codes, and public space standards form the regulatory foundation for urban heat resilience. These measures should be embedded in urban master plans, with development regulations promoting natural ventilation through appropriate street orientation, building configuration, and increased urban porosity.

3.1.4 Implementation Priorities

Based on vulnerability assessments and mitigation potential, priority interventions should focus on:

2026-2027

Immediate Actions

- Emergency cooling shelters in high-vulnerability neighbourhoods.
- Public shade structure installation in critical areas.
- Cool roofing retrofits for schools and healthcare facilities.
- Initiating City (rapid) climate mapping, enabling quick interventions on current & forecasted "Hot-Spots."

2028-2035

Medium-term Goals

- Comprehensive urban forest expansion programmes.
- Building code reforms mandating passive cooling features.
- Green infrastructure integration in all new developments.
- Integrating wind flow analysis in urban developments at neighbourhood and district levels.

2036-2050

Long-term Vision

- Transformation of cities into climate-resilient, heat-adaptive urban environments.
- Regional coordination on UHI mitigation standards and practices.
- Integration of passive cooling principles in all urban planning processes.

This comprehensive approach to understanding and addressing extreme heat trends in ASEAN provides the foundation for developing effective passive cooling solutions that can protect vulnerable populations whilst building long-term climate resilience across the region.

3.2 Building Typology and Current Practices

3.2.1 Building Typology Characteristics

1. Non-Residential Building

Non-residential buildings range from low-rise to high-rise buildings, each contributing differently to UHI and cooling demand. Commercial, office, and public buildings typically represent the region's most well-designed building stock, yet they commonly prioritise mechanical cooling over passive design strategies. Found predominantly in urban centres, these structures span modern glazed towers to adaptively reused colonial-era buildings. Public buildings, including schools, hospitals, and government offices, are frequently constructed with predominantly glazed facades that respond poorly to local climatic conditions.

Source: Fity club

Low-Rise: Typically consist of one to four storeys with smaller ground floor areas and single-building footprints, relying primarily on natural ventilation, although air-conditioning units are also commonly installed to supplement thermal comfort.

Source: Today Line

High-Rise: Characterised by extensive glazed façades, particularly in the financial districts, where limited consideration is given to solar orientation and natural ventilation in favour of sealed, air-conditioned environments. This trend is reinforced by the growth of mixed-use developments that combine retail, office, and residential functions, leading to higher cooling demand and increased urban heat accumulation.

Table 4. *Non-Residential Building Types & Characteristics*

Building Type	Typical Height	Construction Materials	Cooling Strategy	Heat Vulnerability
Office Tower	20-80+ stories	Steel, concrete, glass	Full mechanical AC	Very High
Shopping Mall	3-8 stories	Concrete, steel, glass	Central AC systems	Very High
Hotel	5-50+ stories	Concrete, steel, glass	Mechanical AC + some natural ventilation	High
School	2-4 stories	Concrete, masonry	Mixed (AC + natural ventilation)	Moderate to High
Hospital	3-15 stories	Concrete, steel	Full mechanical AC	Very High

Source: [33]

2. Residential Buildings

The residential sector in ASEAN exhibits wide diversity in building typologies, construction quality, and thermal performance, closely reflecting economic stratification across the region.

Source: afasia archzine

High-Rise: Development has expanded rapidly in major ASEAN cities due to urbanisation and land scarcity, but frequently adopts generic design patterns, including point towers and linear blocks with limited cross-ventilation, shallow balconies, and standardised layouts, resulting in poor natural ventilation and increased cooling demand.

Source: OSC Medcom

Mid-Rise: Typically, 4 to 9 storeys, are widely used for social housing often apply standardised designs across different climates. Accommodate high occupancy densities with limited maintenance, as seen in schemes such as Malaysia's People's Housing Program, Singapore's HDB flats, Thailand's National Housing Authority projects, and Indonesia's Rusunawa.

Source: Property Guru

Low-Rise: Dominate secondary cities and rural areas, often incorporating vernacular features that support natural cooling, although increasing reliance on concrete block construction and modernisation has reduced their climate responsiveness; common forms include shophouses integrating commercial and residential functions and compound housing.

***Table 5.** Occupant Vulnerability Impact by Building Types*

Residential Type	Stories	Typical Unit Size	Natural Ventilation	Passive Cooling Features	Occupant Vulnerability
Traditional House	1-2	60-150 m^2	Excellent	High ceilings, deep eaves, and courtyards	Low
Shophouse	2-3	80-200 m^2	Good	Air wells, thick walls, deep lots	Low to Moderate
Low-rise Apartment	3-5	40-80 m^2	Moderate	Limited balconies, some cross ventilation	Moderate
High-rise Condominium	10-50+	50-150 m^2	Poor	Sealed units, full AC dependence	High
Affordable Housing	10-25	30-60 m^2	Poor	Minimal passive features	Very High

Source: [34], [35], [36]

3.2.2 Existing Thermal Comfort and Current Design Limitations

Regional Variations in Thermal Comfort and Building Design Standards

Thermal comfort standards across ASEAN vary considerably. Whilst commercial buildings typically aim for indoor temperatures between 22-24°C, this results in high energy consumption. Residential buildings frequently lack formal thermal comfort targets, leaving gaps in consistent comfort and energy efficiency.

OTTV Standards
OTTV limits exist for most AMS, with values commonly ranging between 25 and 60 W/m^2, reflecting attempts to regulate building envelope heat gain. Some countries like Indonesia, Malaysia and Singapore have mandatory and well-defined OTTV requirements, whereas others lag in adopting or enforcing these standards.

Shading and Envelope Performance
Countries with more advanced codes emphasise solar shading and envelope thermal performance to reduce cooling loads, whilst others have limited or emerging guidelines.

Daylighting and Natural Ventilation
Daylighting requirements and natural ventilation design guidelines remain patchy. Singapore and Malaysia lead in mandating daylight provision and encouraging ventilation strategies, whilst others have limited or no formal mandates.

Insulation
Roof and wall insulation standards vary widely, with some countries setting minimum R-values and reflective insulation requirements, and others lacking clear policy.

A matrix based on the latest ACE's report on PCS highlights significant differences in adoption and enforcement of key thermal comfort and design indicators, including Overall Thermal Transfer Value (OTTV), shading requirements, daylighting, insulation, and natural ventilation [8].

Table 6. *ASEAN Passive Cooling-Related Provisions: Strength by Country and Theme*

	OTTV	**Shading & Envelope Performance**	**Daylighting Requirements**	**Insulation Requirements**	**Natural Ventilations**
Brunei Darussalam	**0**	**0**	**2**	**1**	**1**
Cambodia	**0**	**1**	**1**	**1**	**1**
Indonesia	**2**	**1**	**0**	**0**	**1**
Lao PDR	**0**	**0**	**0**	**0**	**0**
Malaysia	**2**	**1**	**1**	**2**	**1**
Myanmar	**0**	**0**	**0**	**0**	**0**
Philippines	**2**	**1**	**2**	**2**	**1**
Singapore	**2**	**2**	**2**	**0**	**2**
Thailand	**2**	**1**	**1**	**0**	**1**
Vietnam	**2**	**1**	**2**	**2**	**1**

Note: 0 none; 1 emerging/guidance; 2 mandatory/quantified. Data for Timor-Leste are not yet available and will be incorporated in a future update

Source: [8], [37]

Table 7. *Passive Cooling Strategies Matrix*

Country	OTTV (W/m^2)	Shading & Envelope Performance	Daylighting Requirements	Insulation Requirements	Natural Ventilation
Brunei Darussalam	Not specified	Not specified	Minimum window-to-floor ratios established	Thermal comfort targets include temperature and humidity	Some natural ventilation is prescribed for common spaces
Cambodia	No formal standards yet	No formal standards yet	No formal standards yet	No formal standards yet	No formal standards yet
Indonesia	35 (maximum)	Limited enforcement of thermal performance standards	Not specified	Insulation requirements are indicated by OTTV requirements	Not specified
Lao PDR	Not specified	No formal standards yet	No formal standards yet	No formal standards yet	No formal standards yet
Malaysia	50 (non-residential), 25 (residential)	External shading devices preferred; passive design promoted by Green Building Index	Habitable rooms min WFR 15%; daylight factor 1.5% for offices	Roof insulation with reflective materials is required	Cross and stack ventilation encouraged
Myanmar	Not specified	Not specified	Not specified	Not specified	Not specified
Philippines	45 (maximum)	Green building certification emphasise shading and envelope performance	Minimum window-to-floor-area ratios set by occupancy type	Roof insulation minimum R-8	Natural ventilation requirements vary by building type

Country	OTTV (W/m^2)	Shading & Envelope Performance	Daylighting Requirements	Insulation Requirements	Natural Ventilation
Singapore	50 (non-residential), 25 (residential)	Mandatory envelope thermal performance, effective shading for the west façade	Daylighting is mandatory in common areas	Not explicitly specified	Mandatory design for natural ventilation in common areas
Thailand	30-50 (varies by building type)	Building Energy Code (BEC) mandates OTTV/RTTV compliance for 9 building types ≥2,000 m^2 across 3 operating-hour groups; applies to both new and retrofitted buildings; effective for private buildings since March 2023	Lighting Power Density (LPD) is regulated by building type; window design is assessed through OTTV solar heat gain component	Not clearly stated; not prescriptive; insulation is an outcome-based pathway to meet OTTV/RTTV limits rather than a standalone mandatory requirement specified	No specific natural ventilation requirement in BEC; the code focuses on air-conditioned building performance
Vietnam	60 (walls), 25 (roofs)	Developing insulation and shading standards	Vent openings minimum 5% of floor area	Minimum thermal resistance for walls and roofs	Natural ventilation is encouraged in parking and spaces

Note: Data for Timor-Leste are not yet available and will be incorporated in a future update

Source: [38]

Design and Construction Practice Limitations

Commercial and Public Buildings	Residential Sector
Commercial buildings prioritise technological over passive solutions, leaving them vulnerable to energy disruptions and extreme heat. Over-reliance on mechanical cooling, poor solar shading, limited natural ventilation, and a weak understanding of tropical solar geometry collectively undermine heat resilience and drive unnecessary energy demand.	This sector is constrained by affordability barriers, regulatory gaps, and limited technical capacity. Developers prioritise floor area over passive cooling, building codes set weak thermal performance requirements, climate-appropriate materials remain inaccessible for many, and the absence of post-occupancy monitoring prevents performance accountability.

Table 8. *Heat Vulnerability Impact due to the lack of Passive Cooling Strategies*

Design Limitation	Commercial Buildings	Residential Buildings	Impact on Heat Vulnerability
Inadequate Solar Shading	High prevalence	Very high prevalence	Significant increase in cooling loads
Poor Natural Ventilation	Moderate (mixed-mode)	High (especially high-rise)	Reduced passive cooling potential
Inappropriate Material Selection	Moderate	High	Increased thermal mass effects
Lack of Thermal Zoning	Low	Very high	Inefficient space conditioning
Insufficient Insulation	Low	Very high	Higher heat transfer rates
Poor Building Orientation	Moderate	High	Suboptimal solar exposure

Source: [44], [45], [39]

Despite current limitations, the ASEAN building stock offers substantial opportunities to advance passive cooling through both new construction and retrofit interventions. Given the region’s diverse building typologies, PCS must be tailored to local climatic, social, and economic contexts to effectively reduce vulnerability to extreme heat.

Projected Growth Trajectory

ASEAN's energy demand growth continues to outpace renewable energy deployment. Electricity demand growth slowed to 3.6% in 2023, down from 4.9% in the previous year [40]. Nevertheless, demand for electricity is expected to keep rising, as Southeast Asia is projected to account for over 25% of global demand growth through 2035 [3]. Without decisive intervention, this trajectory will deepen fossil fuel dependence and undermine regional climate commitments.

***Table 9**. Growth Potential vs Income Capacity in ASEAN*

Country Cluster	Current AC Penetration	Projected 2030 Growth	Key Drivers
High-Income (Singapore, Brunei)	80-90%	15-20%	Equipment replacement, efficiency upgrades
Middle-Income (Thailand, Malaysia, Indonesia)	25-40%	200-300%	Rising incomes, urbanisation
Lower-Income (Vietnam, Philippines, Cambodia, Lao PDR, Myanmar)	5-15%	400-600%	Economic development, heat stress

Source: [41]

a. Strain on Energy Systems During Extreme Heat

Grid Stress and Peak Demand

Extreme heat places severe pressure on ASEAN's energy infrastructure. Surging cooling demand creates peak loads that strain grid stability and requires costly peaking capacity, whilst regional heterogeneity in economic development, governance, and energy market structures complicates coordinated responses.

Infrastructure Vulnerability

ASEAN's energy systems remain heavily fossil-dependent, with a 3.6% demand increase in 2024 met entirely by fossil-based generation. During extreme heat events, limited peak generation capacity, ageing grid infrastructure, and high peaking costs compound supply vulnerabilities, whilst emissions rise precisely when climate pressures are most acute.

Climate-Energy Feedback Loop

Rising temperatures and energy consumption form a reinforcing cycle, as increased cooling demand drives fossil fuel-based electricity generation that further intensifies warming. In ASEAN, achieving thermal comfort has become critical, where average daily temperatures routinely surpass 25°C and can rise to 35°C in urban areas [41].

b. Zero to Ultra-Low Energy Cooling Strategies

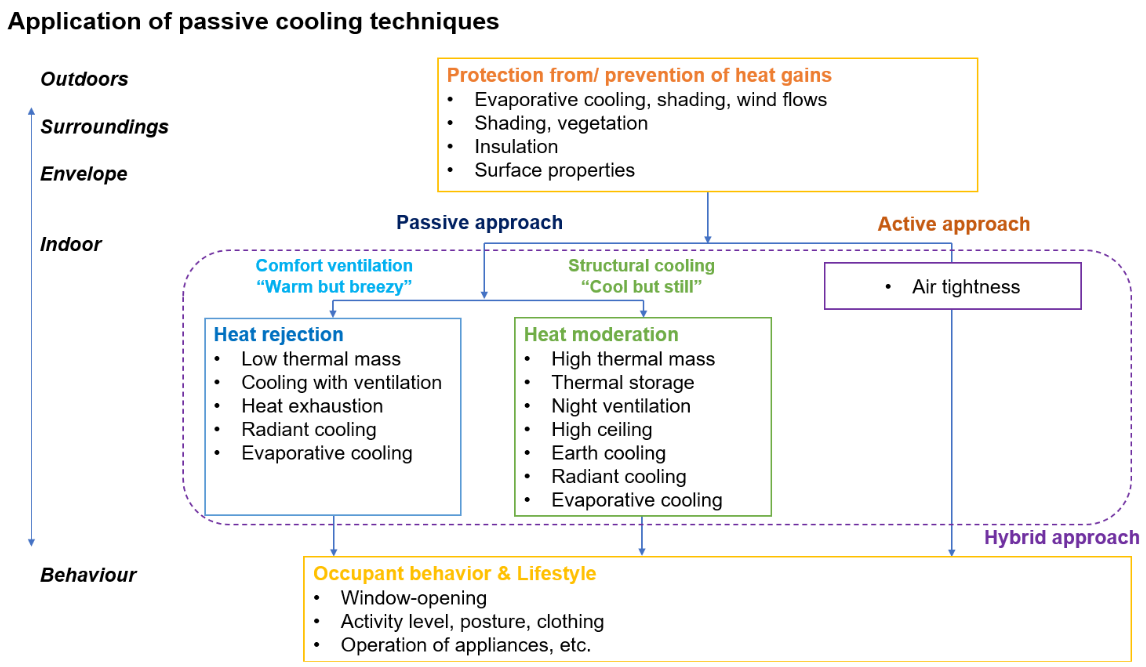


***Figure 4**. Key Passive Cooling Approaches*

Source: Adapted from Kubota, T. (Hiroshima University)

Passive Cooling Technologies

Passive cooling offers a critical pathway to reduce cooling energy demand whilst maintaining thermal comfort yet remains underutilised despite its strong potential to cut energy use and greenhouse gas emissions.

Key Passive Cooling Approaches

PCS can be implemented in its zone, such as outdoor spaces, building envelopes, indoor environments, and occupant behaviour. Indoor strategies range from fully passive to hybrid, depending on climate, materials, and design constraints. Fully passive solutions should be prioritised wherever feasible, with mechanical cooling reserved as a supplementary measure.

***Table 10.** Key Passive Cooling Approaches*

Approach	Example
Architectural Design Strategies	1. Building orientation optimisation 2. Building envelope 3. Natural ventilation optimisation (building level and neighbourhood level) 4. Thermal mass utilisation 5. Shading and solar control systems
Material-Based Solutions	1. Reflective roofing materials 2. Cool pavement technologies 3. Green roof and wall systems 4. Phase change material integration

Approach	Example
Environmental Design	1. Increase in green urban areas 2. Preservation and restoration of the surface blue network 3. Shading infrastructure (landscape/greening) 4. Integration of pervious pavements in public areas 5. Water-based cooling systems 6. Strategic landscaping prioritising the air flow in the cities, considering the main local wind directions.

Source: [8]

Performance Metrics and Standards

ASEAN is strengthening efficiency standards across both active and passive cooling. For air conditioners, the region is progressively tightening Minimum Energy Performance Standards, moving from a Cooling Seasonal Performance Factor of 3.08 W/W towards 6.09 W/W by 2025 [42]. In parallel, several AMS have simultaneously established passive cooling standards within their building regulatory frameworks.

Indonesia

Mandates energy-efficient building design, natural ventilation, shading, and envelope performance through Gov Regulation No. 16/2021 and Ministerial Regulation PUPR No. 21/2021 [43].

Malaysia

The MS 2680:2017 and MS 1525:2019 set thermal insulation, envelope performance, and natural ventilation requirements for residential and non-residential buildings, respectively [44].

Singapore

The Code for Environmental Sustainability of Buildings requires natural ventilation, shading, and efficient building orientation to reduce heat gain [45].

Philippines

The Green Building Code and Guidelines on Energy Conserving Design of Buildings encourage natural ventilation and façade shading in urban development [46].

Thailand

Building Energy Code (BEC) mandates OTTV/RTTV compliance for buildings ≥2,000 m^2, covering envelope performance and shading [47].

Vietnam

The national research and building design practices emphasise orientation, shading, thermal-efficient materials, and OTTV standards under QCVN 09:2017/BXD [48].

Table 11. *Comparison of Passive Cooling Technology and Its Costs*

Technology Category	New Building		Retrofitted Building		Cooling Energy Reduction[1]	Payback Period
	Passive Cooling Design	Est. Cost	Passive Cooling Design	Est. Cost		

Technology Category	New Building		Retrofitted Building		Cooling Energy Reduction[1]	Payback Period
Passive Ventilation	Strategic placement of windows to optimise cross ventilation.	Low	Modify façade to add windows or install new vents.	Medium–High	20–35%	6–9 years [2]
Cool Roofs	Apply reflective materials and coatings; design high roofs for an air buffer.	Low	Apply reflective roof coatings or change to reflective roof materials.	Low–Medium	10–20%	3–5 years
Building Envelope Optimisation	Design walls, roofs, windows, and insulation to reduce heat gain.	Low	Improve insulation, install energy-efficient windows, and add thermal barriers.	Medium–High	20–40%	5–10 years
Hybrid Passive–Active Systems	Combine PCS (e.g. natural ventilation and shading) with mechanical systems (e.g. ACs and fans).	Low–Medium	Retrofit building envelope for adding natural ventilation or shading. Install energy-efficient appliances (e.g. ACs or fans).	High	40–60% [3]	7–12 years

Notes:

[1] *Refers to cooling energy consumption reduction, not total building energy. Actual savings depend on building type, climate zone, baseline AC efficiency, and occupancy patterns.*

[2] *For new construction, passive ventilation is a design strategy with negligible incremental cost. The 6–9 year payback applies to retrofit scenarios requiring façade modifications (initial cost USD 25–40/m^2, per Table 19).*

[3] *Assumes full integration of multiple passive strategies with high-efficiency active systems. The lower bound (40%) is validated by ACE's DesignBuilder simulation for ASEAN (Table 14: 41.95%). The upper bound (60%) represents best-case full integration as documented in case studies (e.g. Pearl Academy, Jaipur).*

Source: [8], [49], [50], [51]

Implementation Barriers

Despite their potential, PCS face significant implementation challenges across the region. It calls for sustained collaboration among stakeholders to tackle existing challenges and promote sustainable building practices.

The implementation of PCS continues to face several hurdles, ranging from low awareness among designers and developers to regulatory environments that still favour conventional mechanical cooling. These challenges are compounded by the absence of local demonstrators where stakeholders can directly experience the benefits and review technical performance, as well as the higher upfront cost of integrated systems. Limited local expertise and supply chain capacity, together with the need for designs that respond to specific climatic contexts, further slow down wider adoption.

c. Cooling Requirements for Vulnerable Communities and PCS Thermal Comfort Provision

Vulnerability Factors

Low-income communities are particularly vulnerable to extreme heat due to inadequate housing, limited access to cooling and greater exposure to heat in domestic and occupational settings. This vulnerability is multidimensional, encompassing economic, social, and health factors that compound heat exposure risks.

Population at Risk Profile

Urban Vulnerable Communities:	**Rural Vulnerable Communities:**
Over 95 million people living in urban slums across ASEAN, alongside low-income renters, outdoor workers, children, women, the elderly, and health-compromised individuals, face the greatest heat exposure with the least capacity to adapt [52].	Agricultural workers, remote communities with limited grid access, and households in thermally poor traditional housing face compounded vulnerability through both heightened exposure and severely constrained adaptive capacity.

Health and Social Impacts

Inadequate cooling access carries severe health consequences, falling hardest on women. Beyond biological vulnerability, women face heightened maternal health risks, productivity losses in informal work, increased dehydration, and greater exposure to gender-based violence during extreme heat events, whilst structural barriers limit their access to finance for adaptation[53], [54], [55], [56]. Women also often face increased dehydration and reduced food intake [54], [55], [57]. Furthermore, women face increased risks of gender-based violence [53], [54], [55].

Passive Cooling Systems for Vulnerable Communities

PCS is particularly well-suited to vulnerable communities because it requires no reliable electricity supply and carries minimal operational costs, addressing the two constraints that make mechanical cooling inaccessible to those most at risk.

d. Effectiveness of Passive Cooling Measures

Passive cooling delivers substantial cooling energy reductions across ASEAN's climates. In tropical urban areas, high-performance building envelopes, cool roofs, low-emissivity glazing, and architectural shading achieve cooling energy reductions of 42%. Meanwhile, PCS implementation reduces 35% cooling energy demand in rural settings. This is critical for vulnerable communities in rapidly urbanising areas and remote locations with limited grid infrastructure. Sub-tropical applications show even greater potential, with a reduction of cooling demand by 37% in urban areas and 70% in rural areas due to favourable seasonal temperature variations [58].

For vulnerable communities, cool roof coatings and improved natural ventilation offer the most accessible entry points, requiring minimal upfront investment whilst delivering immediate thermal comfort benefits independent of grid electricity. This grid independence is decisive: passive cooling remains effective precisely when mechanical systems fail or become unaffordable, protecting the most at-risk populations during power outages and extreme heat events.

Table 12. *Effectiveness of Passive Measures*

Passive Cooling Intervention	Thermal Comfort Improvement	Cost Range (USD)	Impact
Solar-Control Window Films	12-28% UDH reduction	$50-200 per house	Medium – Immediate impact
Roof Insulation	11-37% UDH reduction	$200-800 per house	High – Long-term Impact
Natural Ventilation Enhancement	15-25% temperature reduction	$100-500 per house	Medium – Immediate Impact
Reflective Roof Coatings	8-15% temperature reduction	$150-400 per house	Low – Long-term Impact
Shade Structures	10-20% temperature reduction	$300-1,500 per shading unit	Medium – Immediate impact

Source: [59]

e. Implementation Strategies for Vulnerable Communities

Effective passive cooling implementation in vulnerable communities requires three mutually reinforcing approaches. Community-based delivery should centre on participatory design, local skills training, cooperative purchasing, and integration with existing development programmes. Policy and finance mechanisms must include subsidised retrofit programmes, microfinance for community-led initiatives, adaptive building codes for affordable housing, and public-private partnerships for scaled delivery. Technology adaptation should prioritise climate-specific designs, locally available materials, and modular systems enabling incremental improvement.

f. Thermal Comfort Standards and Metrics

Establishing appropriate thermal comfort standards for tropical climates is essential for evaluating PCS system effectiveness. Southeast Asia receives more than 1,500 cooling degree days annually, providing a baseline for assessing cooling needs and system performance [58].

Adaptive Comfort Models

For vulnerable communities, adaptive comfort models that account for local climate conditions, cultural practices, and economic constraints are more appropriate than international standards developed for air-conditioned environments. However, it is important to distinguish between genuine thermal adaptation and forced tolerance, where occupants accept uncomfortable or even health-threatening conditions because they lack access to alternatives. These adaptive comfort models should therefore be applied as a design tool to optimise PCS, not as a justification for lower thermal comfort standards in low-income settings. The models recognise that:

- Occupants in naturally ventilated buildings better adapt to local climate conditions.
- Thermal comfort ranges can be broader in PCS contexts.
- Cultural and behavioural adaptations affect comfort perception.
- Economic constraints influence acceptable comfort trade-offs.

The cooling demand and energy challenges facing the ASEAN region require urgent, coordinated action across multiple dimensions. Passive cooling strategies must therefore be designed to genuinely improve thermal conditions, recognising that naturally ventilated buildings allow broader comfort ranges and that behavioural adaptation, whilst real, cannot substitute for adequate thermal protection.

Assessment of Passive Cooling Strategies

4.1 Overview of Passive Cooling Principles

Passive cooling leverages natural forces, including wind, solar geometry, and material properties, to maintain thermal comfort whilst eliminating or reducing dependence on energy-intensive mechanical systems. It addresses heat gain through four mechanisms: preventing heat entry, removing excess heat, modifying heat for comfort, and utilising natural cooling sources. Critically, passive cooling must be treated as the primary design strategy, not a supplement to air conditioning. The design hierarchy follows three steps: (i) lean architecture by optimising orientation, form, and spatial layout to minimise heat gain at near-zero cost; (ii) passive design by applying envelope optimisation, ventilation, shading, cool surfaces, and insulation to reduce cooling load to the minimum achievable; and (iii) efficient active systems only for the residual load. This sequence ensures that even where mechanical cooling is required, system sizing and energy consumption are minimised.

a. Passive Cooling Urban Design Approaches

Urban design plays a crucial role in mitigating extreme heat through strategic planning that enhances natural cooling at the city and district scale. Key approaches include optimising urban morphology and layout planning to naturally reduce ambient temperatures and improve thermal comfort.

Urban Morphology and Layout Planning involve the strategic arrangement of buildings, streets, and open spaces to optimise natural ventilation and minimise UHI effects [60], [61]. Aligning streets and buildings with prevailing winds facilitates cross-ventilation, whilst carefully calibrated building heights and spacing balance airflow with shading. Traditional courtyard houses in Malaysia and Indonesia demonstrate how compact, well-ventilated layouts achieve effective passive cooling.

Urban canyon geometry, expressed through the Height-to-Width ratio, directly influences shading and outdoor thermal comfort. Research in Singapore shows that ratios of 3 or higher can reduce pedestrian thermal discomfort by up to 20°C, whilst higher aspect ratios in high-rise developments improve comfort without compromising sky view factors [62]. Another study analysing aspect ratios between 1.5 and 3.5 in Singapore’s high-rise developments found that higher ratios improve thermal comfort whilst maintaining sufficient sky view factors [63]. The Cooling Singapore initiative's guidelines emphasise that building height plays a crucial role in shading at the pedestrian level [64].

Surface material selection and albedo management significantly reduce urban heat island intensity. High-reflectance materials, cool roofing, and light-coloured pavements lower surface temperatures, whilst permeable paving enhances evaporation and reduces heat retention.

Finally, mixed-use zoning reduces transport-related emissions and fosters diverse microclimates. Integrating residential, commercial, and office uses within walkable neighbourhoods reduces dependence on air-conditioned transport and promotes active mobility, lowering both energy demand and ambient urban temperatures.

b. Natural Ventilation, Thermal Mass, Shading, and Insulation Systems

Natural ventilation drives airflow through cross-ventilation and stack effects without mechanical assistance. Window outlet areas should be 25-50% larger than inlets to optimise pressure differentials. In ASEAN's low-wind tropical conditions, solar chimneys and vertical shafts enhance buoyancy-driven ventilation.

Thermal mass effectiveness depends on the diurnal temperature range. In hot-humid equatorial climates with day-night swings below 8°C, high thermal mass is generally counterproductive as it traps and re-radiates heat. Where diurnal ranges exceed 8°C, as in parts of Indonesia, the Philippines, and Myanmar, high-mass materials coupled with night ventilation can stabilise indoor temperatures effectively [65].

Effective shading design must account for solar angles and façade orientation. East and west façades require vertical elements to address low solar angles, whilst horizontal overhangs suit north and south-facing surfaces.

Vegetation-based can be optimised through trees and green walls. These provide an adaptable, year-round shading suited to ASEAN's consistent solar exposure.

Insulation in tropical climates primarily targets heat gain reduction. Reflective roof insulation combining low emissivity with thermal resistance is essential under intense solar radiation. Ventilated roofs dissipate heat through air gaps, whilst vapour-permeable wall insulation prevents moisture accumulation. External insulation placement is generally preferred to preserve thermal mass benefits.

In conclusion, effective passive cooling integration requires a systematic design approach combining climate analysis, material selection, landscape planning, and occupant comfort considerations. Performance-based methodologies, using metrics such as indoor temperature, cooling loads, and thermal comfort indices, including Predicted Mean Vote and Adaptive Comfort Model parameters, ensure strategies are tailored to local environmental conditions and objectively evaluated [66].

c. Computational Fluid Dynamics (CFD) Simulation Applications in Passive Cooling Optimisation

CFD simulation enables designers to visualise and quantify airflow, temperature distributions, and pressure differentials beyond the reach of conventional methods [67]. Key applications include optimising window placement and sizing for natural ventilation, assessing building massing impacts on urban wind patterns, designing stack ventilation systems, predicting thermal comfort conditions, and conducting parametric optimisation of window-to-wall ratios, shading dimensions, and building orientation.

d. Passive Cooling Infrastructure

At the city scale, passive cooling infrastructure creates networks of interventions that collectively reduce urban thermal loads. Smart controls integrating sensors, weather forecasting, and automated systems, including adaptive shading, ventilation controls, and irrigation management, maximise cooling effectiveness whilst minimising resource consumption

e. Benefits of Passive Cooling over Mechanical Cooling

PCS delivers environmental, economic, social, and health benefits that extend well beyond energy savings. Well-designed passive strategies substantially reduce cooling energy requirements, lower operational costs, improve thermal comfort, and produce more sustainable outcomes than mechanical cooling alone, whilst continuing to function during power outages when vulnerable populations are most at risk.

Table 13. *Comparison of Passive Cooling Scenarios*

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%

Source: [33], [58]

Simulation evidence across ASEAN consistently demonstrates passive cooling's effectiveness in reducing energy demand and improving thermal comfort, with cooling energy demand reductions ranging from 35% in tropical rural areas to 70% in sub-tropical climates [58]. In Singapore's tropical urban climate, passive cooling reduces cooling energy demand by nearly 42%, whilst cutting unmet comfort hours and Predicted Percentage Dissatisfied (PPD) values. In tropical rural Balikpapan, reductions reach 35%, and in sub-tropical Sa Pa, Vietnam, up to 70%. Across all modelled locations and climate types, passive cooling reduces thermal discomfort, strengthens heat resilience, and lowers dependence on mechanical systems. These results confirm passive cooling's capacity to simultaneously address energy, climate, health, and social equity objectives across ASEAN's diverse conditions.

Table 14. *Benefits of Passive Cooling Compared to Active Cooling*

Benefit Category	Passive Cooling Advantages	Mechanical Cooling Limitations
Energy Performance	Zero to minimal energy consumption during operation; Peak demand reduction	High energy consumption; Peak demand contribution; Grid stress during heat waves

Environmental Impact	No direct emissions; Reduced urban heat island effect; Enhanced biodiversity	Refrigerant emissions; High carbon footprint; Heat rejection increases ambient temperatures
Economic Factors	Low operational costs; Minimal maintenance requirements; Long service life	High operational costs; Regular maintenance; Equipment replacement cycles
Resilience	Functions during power outages; No dependency on energy supply; Passive operation	Vulnerable to power failures; Supply chain dependencies; Complex system failures
Health & Comfort	Natural airflow; No noise generation; Indoor air quality benefits	Air circulation limitations; Noise generation; Potential indoor air quality issues
Social Equity	Accessible to low-income populations; No operational skill requirements	High-cost barriers; Technical operation requirements; Unequal access

Source: [59]

Passive cooling enhances energy independence by continuing to operate during power outages, providing critical thermal protection, which is particularly vital for vulnerable populations without backup power. Lifecycle costs of PCS are significantly lower than mechanical alternatives, as it requires minimal operation and maintenance. Its scalability and low technical complexity make PCS well-suited to rapid urban development without straining electrical infrastructure. Alignment with traditional architectural practices further supports community acceptance.

4.2 Neighbourhood Level Passive Cooling System Including Nature-based Solutions

Neighbourhood-scale passive cooling creates synergistic effects that exceed the sum of individual measures, requiring integrated planning across buildings, infrastructure, and natural systems.

a. Urban Forest and Tree Canopy Systems

Strategic urban forestry targeting 30-40% canopy coverage reduces ambient temperatures through shading, evapotranspiration, and wind modification, whilst delivering co-benefits for air quality, stormwater management, and biodiversity [68]. In tropical climates, fast-growing native species with dense canopies are preferred, with street trees spaced for continuous coverage and building-adjacent placement carefully managed to avoid structural damage.

b. Water-Based Cooling Systems

Blue infrastructure, including water features, is considered a nature-based solution to address urban heat problems. Water features, constructed wetlands, and permeable surfaces such as rain gardens and bioswales contribute to urban cooling through evaporation and stormwater management. However, their effectiveness is significantly reduced in ASEAN's hot-humid equatorial zones, where high ambient humidity limits evaporation rates. These systems deliver the greatest benefit in climates with pronounced dry seasons or where airflow can be directed across water surfaces to enhance evaporative potential [69].

c. Green Infrastructure Networks

Interconnected green corridors linking parks and natural areas create cooling pathways whilst supporting biodiversity and providing shaded pedestrian routes. Green roofs, walls, and community gardens integrate cooling with stormwater management, food production, and social cohesion, extending neighbourhood-scale passive cooling benefits across the urban fabric.

Table 15. *Integrated Neighbourhood Design Strategies – Benefits*

Strategy	Implementation Scale	Primary Cooling Mechanism	Co-benefits
Cool Pavements	Street and sidewalk networks	Reduced heat absorption and storage	Reduced maintenance, improved safety
Pocket Parks	Individual blocks	Evapotranspiration, shading	Recreation, social gathering, and property values
Community Shade Structures	Public spaces	Direct solar protection	Event hosting, market spaces, social interaction
Neighbourhood Wind Corridors	District planning	Enhanced natural ventilation	Air quality improvement, outdoor comfort
Integrated Water Management	Watershed scale	Evapotranspiration, thermal mass	Flood control, water quality, habitat
Transit-Oriented Cooling	Transportation nodes	Concentrated cooling investments	Reduced transportation emissions and accessibility

Source: [70]

Performance monitoring and adaptive management systems, supported by distributed sensor networks measuring temperature, humidity, and air quality, optimise cooling system effectiveness over time. Community engagement and stewardship programmes are essential for the long-term success of PCS systems, with resident education and participatory design processes ensuring sustained infrastructure upkeep.

When integrated with building-scale systems, neighbourhood cooling strategies enhance the performance of individual PCS systems. Reduced ambient temperatures and increased air movement improve natural ventilation and reduce cooling loads across the area. The success of these systems relies on comprehensive planning that considers specific climatic, urban, and social factors, ensuring that multiple strategies work together across different scales to optimise cooling effectiveness.

4.3 Existing Technologies and Materials for Passive Cooling

The ASEAN region's tropical climate, characterised by high temperatures, humidity, and intense solar radiation, necessitates effective PCS that work without mechanical energy input. This assessment examines both time-tested traditional approaches and cutting-edge innovative solutions, evaluating their relevance and adaptability to the unique climatic conditions across Southeast Asia.

a. Traditional Passive Cooling Approaches

Traditional architecture across the ASEAN region has evolved sophisticated PCS over centuries, developed in response to local climatic conditions and available materials. These solutions demonstrate remarkable effectiveness and continue to inform contemporary sustainable design practices.

Vernacular Building Design Principles

- Elevated floor structures: Traditional stilt houses in Cambodia, Indonesia, Malaysia, and Thailand elevate the ground floor to facilitate air circulation beneath the living space, capture cooling breezes, and mitigate the effects of ground heat radiation. This elevated design enhances thermal comfort and provides protection against flooding and animals.
- High ceilings and steep roofs: Found across the region to facilitate natural convection and encourage the stratification of hot air, promoting thermal comfort.
- Deep overhangs and verandas: These elements provide crucial shading, whilst also allowing for the continuous flow of natural ventilation, thereby enhancing indoor comfort.
- Cross-ventilation and building orientation: Buildings should be strategically positioned to harness prevailing winds, with openings carefully placed to optimise airflow and maximise ventilation efficiency.

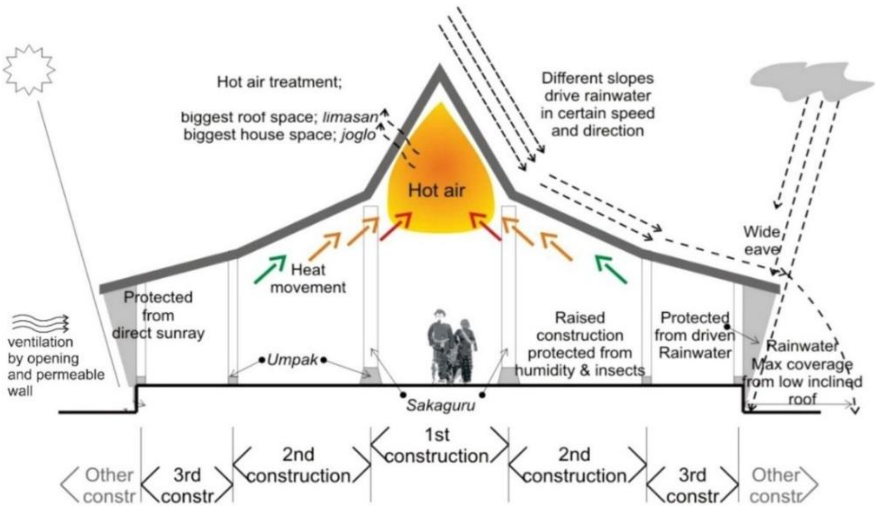


Figure 5. *Passive Cooling Design in Traditional Javanese House in Indonesia*
Source: [71], [72]

Traditional Materials and Techniques

- **Bamboo construction:** Bamboo's low thermal mass enables rapid thermal response, an advantage in hot-humid climates where passive cooling relies on continuous air movement rather than thermal inertia. Its natural permeability enhances airflow through the building envelope, improving ventilation and indoor thermal comfort. As a low-cost material, bamboo is particularly suitable for vulnerable and low-income communities [72].
- **Palm leaf thatching:** Excellent insulation properties with natural moisture regulation.
- **Clay tile roofing:** Clay tile is a commonly used roofing material in Southeast Asia, particularly for low-rise buildings. This local material is preferred for its affordability, durability, and availability. Clay tile roofs are associated with improved thermal comfort and lower indoor temperatures compared to alternative roofing systems, such as metal roofs [73], [74].
- **Timber construction:** Low thermal conductivity with natural moisture-buffering capabilities.

b. Innovative Modern Solutions

Contemporary PCS technologies build upon traditional principles whilst incorporating advanced materials science and engineering innovations. These solutions offer enhanced performance and durability for modern applications.

Cool Roof Systems:

- Reflective coatings: High solar reflectance index (SRI) materials that reflect 70-90% of solar radiation.
- Cool-coloured pigments: Infrared-reflective pigments that maintain aesthetic

appeal whilst reducing heat absorption.
- Phase change material (PCM) integration: Roof systems incorporating PCMs that absorb excess heat during peak periods and release it during cooler hours.

Case Study

BeCool Indonesia – Building Climate Resilience through Locally Produced Solar Reflective Paint

BeCool Indonesia, founded by Dr Beta Paramita after winning the Million Cool Roofs Challenge in 2022, promotes PCS through locally produced solar reflective paint and pre-coated panels developed at Indonesia University of Education (UPI) in partnership with the University of Florida, Milenium Solutions, and PT Tatalogam. The initiative addresses urban heat islands, rising cooling energy demand, and heat-related health risks across Indonesian buildings.

Technical Performance

BeCool's solar reflective paint achieves a Solar Reflectance Index (SRI) of 106, with certified solar reflectance of 0.84 and thermal emittance of 0.90 under the Cool Roof Rating Council (CRRC) standard. Applied as a two-layer system (primer and top coat), it is versatile and suitable for roller, brush, or spray application on existing roofing surfaces.

Product Innovation

Beyond roof retrofits, BeCool pioneered the RAFLESIA Cool House in collaboration with PT Tatalogam: a lightweight, earthquake-resilient steel-frame housing prototype with pre-coated solar reflective panels. These structures are cheaper and quicker to construct than conventional brick houses, demonstrating how reflective technology can simultaneously deliver thermal comfort, disaster resilience, and affordable housing.

Outcomes (2019–2024)

Approximately 300,000 m^2 of surfaces coated, benefiting over 10,000 people. Measured temperature reductions include 11–14 °C on indoor surfaces in industrial and commercial settings, 2–4 °C (metal roofing) to 5–8 °C (tile roofing) in residential buildings, and indoor-outdoor differentials of approximately 9 °C in the RAFLESIA Cool House prototypes.

Scalability and Regional Relevance

BeCool's model demonstrates that solar reflective technology can be industrialised affordably in emerging markets through local manufacturing, community awareness campaigns, and ecosystem investments, including testing capacity, international certification, and links to national housing policy. Seed funding of USD 750,000 from the Million Cool Roofs Challenge catalysed product development, production scaling, and Indonesia's first testing facility for solar reflective materials. The initiative offers a replicable pathway for scaling reflective roofing across Southeast Asia.

***Authors**: Clean Cooling Collaborative and BeCool Indonesia (Dr Beta Paramita, UPI and Xiaoyi Jin, Climateworks)*

Innovative Wall Systems:

- Double-skin facades: Ventilated cavity walls that create thermal buffers and promote stack effect ventilation.
- Green wall systems: Living walls that provide evapotranspiration cooling and improved air quality.

- Thermal mass optimisation: Strategic use of high thermal mass materials to moderate temperature fluctuations.

High-Performance Glazing Systems

Windows represent a critical element in PCS design, serving as the primary pathway for unwanted solar heat gain whilst providing natural daylighting and ventilation. PCS incorporating optimised glazing systems can reduce cooling energy demand by 35% to 70%, reflecting variations based on climate zone, urban heat island effects, and baseline building characteristics [58].

Key Performance Parameters

Glazing system effectiveness depends on four critical metrics:

- **Solar Heat Gain Coefficient (SHGC):** Measures solar radiation transmitted as heat (0-1 scale). Lower values indicate better heat rejection. Recommended: ≤0.25 for tropical climates, ≤0.30 for sub-tropical. Low-emissivity (low-e) coatings reduce SHGC to 0.20-0.30 whilst maintaining 60-70% visible light transmission.
- **Thermal Transmittance (U-value):** Rate of heat transfer (W/m^{2}K). Lower values provide better insulation. Double glazing with low-e coating (U-value 1.8-2.0 W/m^{2}K) offers excellent performance for ASEAN climates compared to single clear glass (5.8 W/m^{2}K).
- **Visible Light Transmission (VLT):** Percentage of visible light transmitted. Optimal range: 50-70% to balance heat rejection with adequate daylighting. Minimum: 40% for visual comfort.
- **Window-to-Wall Ratio (WWR):** ACE (2024) simulations show optimised design (10% WWR) achieves 20-22% cooling load reduction compared to a typical 30% WWR. Recommended maximum: 30% with proper external shading [18].

Table 16. *Recommended Specifications*

Parameter	Minimum Standard	High Performance
SHGC	≤ 0.30	≤ 0.25
U-VALUE	≤ 3.0 W/m^{2}K	≤ 2.0 W/m^{2}K
VLT	≥ 40%	≥ 60%
WWR	≤ 30%	≤ 20%

Source: [58]

Performance Impact

Comparative cooling load reductions (relative to single clear glass baseline): single low-e-glazing (12-15%), double clear glazing (15-18%), double low-e glazing (25-30%), and double low-e with argon fill (30-35%). High-performance glazing typically offers 3–7-year payback periods through reduced cooling costs and enables specification of smaller air conditioning systems.

Implementation Priorities

Successful implementation requires: (1) integration of minimum glazing performance standards into national building codes; (2) capacity building for local suppliers and installers; (3) financial mechanisms to overcome first-cost barriers; and (4) harmonisation of standards across ASEAN to facilitate regional market development. Glazing optimisation should complement external shading, building orientation, and natural ventilation strategies for maximum PCS effectiveness.

Case Study

Retrofitting a 1960s Embassy Building with Passive Cooling and Energy Innovation

Embassy of Switzerland, Bangkok, Thailand

Key Metrics

Location	Bangkok, Thailand
Building Type	1960s residential converted to office
Cooling Area	281 sq.m.
Budget	CHF 240,000
Energy Savings	51.6% reduction vs conventional cooling
Strategy	Envelope Design (insulation, airtightness, glazing)

Overview

This case study showcases the transformation of a 1960s residential building into a modern, energy-efficient workspace using PCS. Situated within the compound of the Embassy of Switzerland in Thailand, the project was completed within a constrained budget of CHF 240,000, demonstrating that sustainability and cost-efficiency can go hand in hand. Three components were prioritised to achieve the desired outcome: thermal insulation, air management, and the energy source.

Objectives

The primary goal was to retrofit an outdated building to meet modern energy efficiency standards, with a strong emphasis on PCS. The project aimed to promote PCS systems, improve indoor thermal comfort, and lower operational energy costs. Achieving near energy-neutral performance was a key target, alongside showcasing replicable methods for sustainable renovation in similar urban contexts.

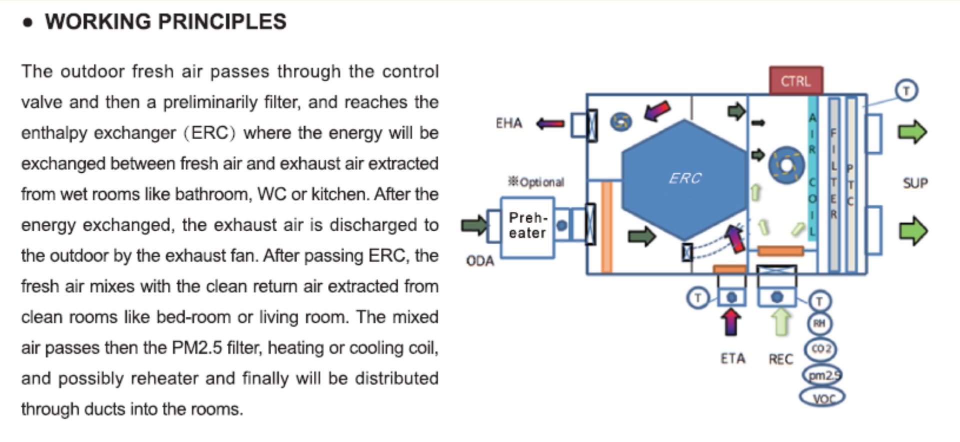
Technical and Design Features

The building envelope was comprehensively upgraded to support PCS. High-performance 10 cm Polyisocyanurate (PIR) insulation was applied to walls, façades, and ceilings, whilst airtightness was improved to reduce thermal leakage. A key innovation was the integration of Zehnder's ComfoHome advanced ventilation system, which reuses indoor air whilst continuously monitoring and adjusting oxygen levels to maintain optimal air quality. This system minimises energy loss by recovering heat and reducing the need for mechanical cooling. External insulated glazing units, including energy-saving glass (EN 356 Class P4A), and aluminium-framed windows were installed to enhance thermal resistance, security, and durability.

Case Study

Retrofitting a 1960s Embassy Building with Passive Cooling and Energy Innovation

Embassy of Switzerland, Bangkok, Thailand



- **WORKING PRINCIPLES**

The outdoor fresh air passes through the control valve and then a preliminarily filter, and reaches the enthalpy exchanger（ERC）where the energy will be exchanged between fresh air and exhaust air extracted from wet rooms like bathroom, WC or kitchen. After the energy exchanged, the exhaust air is discharged to the outdoor by the exhaust fan. After passing ERC, the fresh air mixes with the clean return air extracted from clean rooms like bed-room or living room. The mixed air passes then the PM2.5 filter, heating or cooling coil, and possibly reheater and finally will be distributed through ducts into the rooms.

Working principles of the Zehnder ComfoHome ventilation system
Source: Zehnder's Installation and Operation's Manual

Outcomes and Impacts

The renovation resulted in a substantial reduction in energy consumption and operational costs. Based on the simulation for the cooling area of 281 sq. m., the Zehnder cooling unit consumes 23,839 kWh/year compared to 49,198 kWh/year for a conventional cooling system — a 51.6% reduction. Indoor temperatures remain stable, reducing the need for mechanical cooling. The building achieved near energy-neutral status during the daytime thanks to the embassy's solar panels, with improved thermal comfort and air quality for occupants. The use of passive strategies also contributed to lower carbon emissions.

Replicability and Scalability

The strategies employed in this project are highly replicable across similar building types, especially older structures common in urban areas. The modular nature of envelope upgrades, glazing systems, and ventilation improvements allows for scalable implementation. These interventions can be adapted to various climates and regulatory contexts, making them suitable for both public and private sector renovations. The project demonstrates that PCS can be achieved within budget constraints, encouraging broader adoption.

3D building model (left) and exterior view of the retrofitted embassy building (right)
Source: Zehnder's Installation and Operation's Manual

Case Study

Retrofitting a 1960s Embassy Building with Passive Cooling and Energy Innovation

Embassy of Switzerland, Bangkok, Thailand

Challenges and Lessons Learned

Key challenges included working within budget constraints and retrofitting an ageing structure without disrupting its core functionality. Material selection and design optimisation were critical to balancing cost and performance. The project highlighted that even modest interventions can yield significant energy and comfort improvements. Future initiatives can benefit from this experience by prioritising envelope upgrades and PCS from the outset.

Drivers of Success

Success was driven by a clear sustainability vision, strong stakeholder collaboration, and strategic design choices. The use of proven technologies, such as insulated glazing and airtight construction, ensured reliable performance. Engagement with suppliers and technical experts helped optimise solutions within budget. The project's adaptability and focus on long-term benefits make it a compelling model for future renovations.

***Author**: Nadine Antenen, Swiss Embassy / SDC Regional Thematic Hub*

c. Natural Ventilation Enhancement Technologies

Wind-Driven Systems:

- **Modern wind catchers**: Contemporary interpretations of traditional Persian badgir windcatchers, adapted for tropical conditions. These architectural elements capture prevailing winds at roof level and channel airflow downward into occupied spaces, generating passive air movement without mechanical energy input. In hot-humid ASEAN climates, they are most effective when combined with exhaust openings to create continuous airflow paths.
- **Solar chimneys**: Vertical shafts with solar-absorbing surfaces that heat enclosed air, creating upward convective movement (stack effect) to draw cooler air into the building at lower levels. Performance depends on chimney height, solar exposure, and the temperature differential between inlet and outlet air.
- **Venturi effect applications**: Building forms and features designed to accelerate natural airflow by narrowing passages between structures or through building elements. As air is forced through a constriction, its velocity increases, creating localised low-pressure zones that enhance cross-ventilation in adjacent spaces.

Evaporative Cooling Systems:

- **Direct evaporative cooling**: Effective in principle but highly sensitive to ASEAN's already high humidity levels. It can still deliver meaningful cooling when designed carefully at the site level, for instance by increasing air velocity and directing airflow through materials such as charcoal or fibrous media that help strip excess moisture whilst retaining the cooling effect. The benefit depends on finding the right balance between humidity and airflow.

- **Indirect evaporative cooling**: More appropriate for dense and humid urban environments, as it reduces air temperature without adding moisture to indoor spaces. This makes it a practical option for maintaining comfort in climates where extra humidity would otherwise undermine cooling performance.
- **Transpiration cooling**: Achieved through vegetation that releases moisture and cools the surrounding environment via natural evapotranspiration, providing localised cooling whilst improving shading and micro-climate conditions.

d. Regional Relevance and Adaptability

Climate-Specific Considerations

The effectiveness of PCS varies significantly across the ASEAN region due to diverse microclimates, from the equatorial conditions of Singapore and southern Malaysia to the more variable tropical climates of northern Thailand and Myanmar.

Table 17. *Climate-Specific Passive Cooling Interventions*

Climate Zone	Key Characteristics	Priority Cooling Strategies	Adaptation Requirements
Equatorial (Singapore, parts of Indonesia, Brunei Darussalam, southern Malaysia)	High humidity (80-90%), consistent temperatures (26-32°C), minimal seasonal variation	Natural ventilation, dehumidification, lightweight/low thermal mass construction	Focus on humidity control, corrosion-resistant materials
Tropical Monsoon (Thailand, parts of Indonesia, Cambodia, southern Vietnam)	Distinct wet/dry seasons, high temperatures (28-35°C), variable humidity	Seasonal adaptability, rainwater management, thermal mass optimisation	Dual-season strategies, water management integration
Tropical Savanna (parts of Indonesia, Philippines)	Pronounced dry season, high diurnal temperature range	Night-flush cooling, thermal mass utilisation, solar protection	Enhanced thermal storage, seasonal shading systems

Source: [75]

Table 18. *Material Availability and Performance*

Material Category	Traditional Options	Modern Alternatives	ASEAN Availability	Performance Rating	Cost Effectiveness
Roofing	Clay tiles, palm thatch	Cool roof coatings, PCM-integrated tiles	High	Excellent	High
Wall Systems	Bamboo, timber	Insulated concrete forms, aerated concrete	Medium-High	Very Good	Medium
Thermal Mass	Stone, clay brick	Concrete, compressed earth blocks	High	Good	High
Insulation	Natural fibres, air gaps	Reflective insulation, bio-based foams	Medium	Excellent	Medium-Low
Shading	Natural materials, vegetation	High-performance fabrics, smart glass, shutters, louvres, awnings	Variable	Very Good	Variable

Source: [76], [77], [78]

Adaptation Strategies by Urban Context

PCS implementation must be tailored to the specific urban context, as the same city may contain areas at different stages of development. Three broad contexts shape strategy selection:

1. **High-Density Built-Up Areas** (e.g. central Singapore, Bangkok CBD, Makati): Limited space and constrained airflow are the primary constraints. Priority strategies include building envelope retrofits targeting glazing and external insulation, vertical greening, cool roof and wall technologies, coordinated cool surface programmes to mitigate urban heat island effects, and hybrid approaches combining deep overhangs and perforated screens with high-performance modern materials.

2. **Rapidly Developing Urban Areas** (e.g. peri-urban Jakarta, Ho Chi Minh City expansion zones, Clark-Subic corridor): New construction presents the opportunity to embed passive cooling from the outset. Priority strategies include mandatory passive cooling requirements in development permits, cost-effective envelope solutions suited to both formal and informal construction, integration with local supply chains, and mixed-mode designs combining natural ventilation with minimal mechanical cooling.

3. **Rural and Peri-Urban Areas:** Local materials and traditional knowledge are the foundation. Priority strategies include community-based vernacular approaches such as elevated structures, double roofing, and natural ventilation; integration

with agricultural systems, including tree shading and water features; and capacity building for local builders to apply improved insulation and shading using accessible materials.

e. Implementation Considerations

The successful deployment of PCS technologies in the ASEAN region requires careful consideration of local factors beyond pure technical performance. Cultural acceptance, construction industry capabilities, and economic constraints significantly influence the viability of different approaches.

Cultural and Social Factors*:*

- Alignment with traditional building practices and aesthetic preferences.
- Community engagement and education requirements.
- Integration with existing social spaces and lifestyle patterns.
- Consideration of privacy and security requirements in natural ventilation design.

Economic and Market Factors:

- Initial investment costs versus long-term operational savings.
- Availability of skilled labour for installation and maintenance.
- Supply chain reliability for specialised materials.
- Financing mechanisms for both individual and community-scale implementations.

Technical Infrastructure Requirements:

- Compatibility with existing building codes and standards.
- Integration with other building systems (electrical, plumbing, structural).
- Maintenance requirements and local service capabilities.
- Performance monitoring and optimisation needs.

This study reveals that the most promising PCS approaches combine traditional principles with modern material innovations, emphasising natural ventilation enhancement, strategic thermal mass application, and advanced building envelope technologies. Success depends on careful adaptation to local climate, material availability, and socio-economic contexts, with particular attention to humidity control in equatorial zones and seasonal adaptability in monsoon-affected areas.

4.4 Techno-Economic Feasibility of Scaled Adoption of Passive Cooling Systems

The transition from conventional AC systems to PCS technologies represent a critical pathway for sustainable urban development in ASEAN. This assessment covers the economic viability, environmental benefits, and technical scalability of PCS systems across diverse climatic conditions and development contexts within AMS. It is important to note that the cost-benefit comparisons presented here frame PCS against conventional AC baselines for analytical clarity. In practice, the roadmap advocates that passive strategies should be the starting design approach, with active cooling specified only for the residual demand that passive measures cannot meet.

a. Cost-Benefit Analysis of Passive Cooling vs Conventional

Cooling Economic Framework

The economic evaluation of PCS requires a comprehensive lifecycle cost analysis that considers initial capital expenditure, operational costs, maintenance requirements, and long-term energy savings. In the ASEAN context, where energy costs vary significantly between AMS and urban-rural divides persist, the economic case for PCS becomes increasingly compelling when viewed through a 20-year lifecycle perspective.

Key Economic Drivers:

- Reduced energy consumption leading to lower operational costs.
- Decreased peak load demand, reducing grid infrastructure requirements.
- Lower maintenance costs due to fewer mechanical components.
- Enhanced building durability through thermal stress reduction.
- Potential for government incentives and carbon credit monetisation.

Table 19. *Comparative Cost Analysis*

Technology Type	Initial Cost (USD/m^2)	Annual O&M (USD/m^2)	Energy Savings (%)	Payback Period (Years)	NPV (20-year, USD/m^2)	Climate Suitability	Confidence Level
Green Roofs (Extensive)	45–65	3–5	15–25	8–12	85 to 120	Hot-Humid ✓ Hot-Dry ✓	Medium-High
Cool Roofs	8–15	0.5–1	10–20	3–5	65 to 95	Hot-Humid ✓ Hot-Dry ✓	High
Natural Ventilation (Mixed-Mode)	25–40	1–2	10–30 *	6–9	75 to 140	Hot-Dry ✓ Hot-Humid Δ	Medium
Thermal Mass (with Night Ventilation)	15–30	0.5–1.5	5–18 **	7–15	-20 to 75	Hot-Dry ✓ Hot-Humid ✗	Low-Medium
Hybrid Cooling (AC + Fans)	5–15	1–2	27–32	1–3	100 to 180	Hot-Humid ✓ Hot-Dry ✓	High

Technology Type	Initial Cost (USD/m^2)	Annual O&M (USD/m^2)	Energy Savings (%)	Payback Period (Years)	NPV (20-year, USD/m^2)	Climate Suitability	Confidence Level
Standard AC (EER <3.0)	35–55	8–12	Baseline	N/A	-150 to -200	All climates	High
High-Efficiency AC (CSPF ≥6.09)	50–75	6–10	20–30% improvement	5–8	-80 to -120	All climates	High

Legend: ✓ = Well-suited Δ = Limited/conditional effectiveness ✗ = Not recommended without significant design adaptation

Confidence Levels: High = Multiple peer-reviewed sources with consistent data; Medium = Supported by literature, but ranges vary significantly; Low = Limited ASEAN-specific data or conflicting findings

Footnotes:

* **Natural Ventilation:** 10–30% savings based on WBDG/NIBS data confirming 10–30% savings in favourable climates. In hot-humid ASEAN climates, effectiveness is significantly constrained by high humidity levels. Mixed-mode (hybrid natural + mechanical) systems are required for reliable performance. Pure natural ventilation savings in tropical humid conditions are typically at the lower end (10–15%) of this range. The Singapore SinBerBEST study demonstrated 32% savings through hybrid cooling (raised AC setpoint + ceiling fans), which supports the upper range only when combined with mechanical assistance.

** **Thermal Mass:** Australian Government research (YourHome.gov.au) explicitly states high-mass construction is “generally not recommended in hot, humid climates” due to limited diurnal range and high night-time temperatures. ScienceDirect meta-analysis confirms thermal mass has “the least influence on total energy consumption” in hot-humid climates and “exhibits complex effects.” Revised range (5–18%) and NPV (-20 to 75) reflect that thermal mass can be counterproductive in hot-humid conditions without proper night ventilation and shading. The 18% upper bound applies only to hot-dry sub-climates within ASEAN (e.g., parts of Myanmar, Thailand dry season) with diurnal temperature swings exceeding 8°C.

Green Roof Cost: All available benchmarks are from the U.S. (GSA: \$15–30/ft^2 = \$161–\$323/m^2; EPA: similar range). The ASEAN figure assumes 40–60% lower labour costs, but no peer-reviewed study was found confirming this for the region. This figure should be treated as a preliminary estimate pending country-level validation. Recommend commissioning cost surveys through PEEB-ASEAN or EE&C-SSN focal points.

In addition, based on Kent et al. (2023), published in Building and Environment, Vol. 243, September 2023. The field study was conducted at Singapore’s Zero Energy Plus Building (BCA Academy) over 11 weeks by the SinBerBEST programme (UC Berkeley/NUS/NTU, funded by Singapore NRF). The study demonstrated 32% energy reduction by raising the AC setpoint from 24°C to 26.5°C and supplementing with ceiling fans. Overcooling complaints dropped from 33% to 9%. Lead researcher: Michael Kent; Senior authors: Stefano Schiavon (UC Berkeley) and Costas Spanos (CITRIS/BEARS CEO). Subsequent light retrofit demonstrations in more than 10 academic and commercial buildings in Singapore reported energy savings of 27% and a 10% increase in occupant satisfaction (UC Berkeley Research, October 2023).

Source: [79], [80], [81], [82], [83], [84]

Regional Economic Variations

The economic viability of PCS systems varies considerably across AMS due to differences in energy pricing, labour costs, and regulatory environments. Singapore and Brunei, with higher energy costs and stricter building codes, show more favourable economics for PCS adoption compared to countries like Cambodia or Lao PDR, where energy subsidies may skew the analysis.

Economic Sensitivity Factors

The feasibility and effectiveness of heat-resilient building interventions are influenced by several contextual factors, including energy pricing structures and subsidy policies, the availability of local materials and reliance on imports, the availability of skilled labour for installation and maintenance, the strength of building code requirements and enforcement, and access to financing and government incentives.

b. Emissions Reduction Potential of Passive Cooling

1. Systems Carbon Footprint Analysis

PCS offers substantial emissions reduction potential across ASEAN, where cooling demand is projected to grow by 300-400% by 2050 [49]. Benefits include reduced cooling loads, lower peak electricity demand, decreased reliance on carbon-intensive peaker plants, avoided refrigerant leakage, and lower embodied carbon through simplified mechanical systems.

As **Table 20** shows, the emissions impact is strongly shaped by the national grid carbon intensity. Indonesia and the Philippines, with coal-heavy grids, show the greatest potential, achieving savings of up to 12.3 kg CO_2/m^2 annually and over 2 tonnes/m^2 across a 20-year building lifecycle. Thailand, Malaysia, and Vietnam demonstrate moderate potential, whilst Singapore and Brunei record smaller absolute reductions despite comparable cooling energy savings, reflecting their comparatively cleaner energy grids.

Table 20. *Quantified Emissions Impact*

ASEAN Member States	Grid Carbon Intensity ($kgCO_2/kWh$)	Cooling Energy Reduction (%)	Annual CO_2 Savings (kg/m^2)	20-Year CO_2 Savings ($tonnes/m^2$)
High Potential				
Indonesia	0.82	25%	12.3	2.46
Philippines	0.69	22%	9.1	1.82
Thailand	0.4682	20%	6.9	1.38
Medium Potential				
Malaysia	0.65	18%	7.0	1.40
Vietnam	0.61	23%	8.4	1.68
Lower Potential				
Singapore	0.41	15%	3.7	0.74
Brunei	0.35	16%	3.4	0.68

Note: m^2: floor area of buildings

Source: [7], [33], [70]

2. Regional Scaling Potential

The aggregate emissions reduction potential across the ASEAN region could reach 15-25 million tonnes of CO_2 equivalent annually by 2040 if PCS systems achieve 30% market penetration in new construction and 15% retrofit adoption [85]. This represents approximately 2-3% of the region's projected building sector emissions, with the potential for carbon credit monetisation valued at USD 300-750 million annually at current carbon pricing levels [86].

a. Technical Performance and Scalability of Passive Cooling Technologies

1. Performance Metrics and Climate Adaptability

The effectiveness of PCS technologies in the ASEAN region is heavily influenced by local climatic conditions, with tropical humid climates presenting both opportunities and challenges for different PCS. The region's consistently high temperatures and humidity levels require careful technology selection and integration approaches.

Climate-Specific Performance Considerations:

- High humidity levels reduce evaporative cooling effectiveness
- Consistent solar radiation provides opportunities for thermal mass strategies
- The characteristically narrow temperature range between day and night in ASEAN's tropical climate enables year-round passive strategies
- Monsoon patterns creating opportunities for natural ventilation optimisation
- Urban heat island effects intensifying cooling requirements in dense urban areas

Table 21 evaluates the scalability of different PCS technologies by considering implementation, climate suitability, and resource needs. Cool roofs, insulation systems, cross ventilation, and concrete-based thermal mass emerge as the most scalable options, given their high suitability, low-to-medium complexity, and strong local expertise availability. Green roofs, courtyards, and indirect evaporative systems offer moderate potential but face constraints such as higher costs, maintenance, or design complexity. In contrast, phase change materials and direct evaporative cooling score lower on scalability due to high technical requirements, limited local expertise, or poor climate fit, making them less practical for ASEAN contexts.

Table 21. *Technology Scalability Assessment*

Technology Category	Scalability Rating	Implementation Complexity	Climate Suitability	Maintenance Requirements	Local Expertise Availability
1. Building Envelope					
Cool Roofs	High	Low	Excellent	Medium	High
Green Roofs	Medium	Medium	Good	Medium	Medium
Insulation Systems	High	Low	Excellent	Very Low	High
2. Natural Ventilation					
Cross Ventilation	High	Medium	Good	Low	Medium
Stack Ventilation	Medium	High	Good	Medium	Low
Courtyards	Medium	High	Excellent	Low	Medium
3. Thermal Mass					
Concrete Systems	High	Low	Good	Very Low	High
Phase Change	Low	High	Excellent	High	Very Low

Technology Category	Scalability Rating	Implementation Complexity	Climate Suitability	Maintenance Requirements	Local Expertise Availability
Materials					
4. Evaporative Systems					
Direct Evaporative	Low	Medium	Poor	Medium	Medium
Indirect Evaporative	Medium	High	Fair	High	Low
5. Shading Device					
Overhangs	High	Low	High	Low	High
Double facade	Medium	Medium	Medium	Medium	Medium
Vegetation	Low	Medium	Excellent	Medium	High

Source: [8], [85], [87]

2. Technical Integration Challenges

The successful implementation of PCS systems at scale requires addressing several technical challenges specific to the ASEAN context. These include integration with existing building practices, compatibility with local materials and construction methods, and adaptation to diverse urban morphologies across the region.

Primary Technical Barriers:

- Limited integration with existing building codes and standards
- Lack of standardised design guidelines for tropical climates
- Insufficient local testing and validation data
- Skills gaps in the design and installation workforce
- Quality control challenges in diverse regulatory environments

b. Performance Optimisation Strategies

Maximising the effectiveness of PCS systems requires a systems-thinking approach that considers the interaction between different technologies and their integration with building design. The most successful implementations combine multiple passive strategies with smart controls and hybrid systems that can adapt to varying conditions.

Key Optimisation Approaches:

- Multi-strategy integration for synergistic cooling effects.
- Adaptive controls responding to real-time weather conditions.
- Hybrid systems combining passive and low-energy active components.
- Building orientation and massing optimisation for local wind patterns.
- Integration with renewable energy systems for net-positive energy buildings.
- Strategic shading design informed by annual solar geometry, prioritising vertical

shading for low solar angles (e.g., east–west façades) and horizontal shading for higher angles (e.g., south façades).

- Optimised thermal mass and insulation placement aligned with the cooling strategy, using external insulation to activate the envelope's thermal mass and enhance night-time ventilation for reduced daytime mechanical loads, or internal insulation where continuous air conditioning diminishes the benefits of passive thermal storage.

c. Market and Policy Factors Influencing Adoption

Market Dynamics and Barriers

The adoption of PCS systems in the ASEAN region is influenced by complex market dynamics that vary significantly between AMS and market segments. Whilst the technical and economic benefits are increasingly clear, market transformation requires addressing systemic barriers related to awareness, financing, regulatory frameworks, and industry capacity.

Table 22. *Market Development Stages by Country*

Country	Market Maturity	Key Drivers	Primary Barriers	Policy Support Level
Singapore	Advanced	Green building standards, energy costs	Space constraints, existing infrastructure	High
Malaysia	Developing	Cost savings, sustainability goals	Skills gaps, financing	Medium
Thailand	Developing	Energy security, environmental concerns	Regulatory barriers, financing, and awareness	Medium
Indonesia	Emerging	Population growth, urbanisation	Financing, technical capacity	Low-Medium
Philippines	Emerging	Climate vulnerability, energy costs	Implementation capacity	Low
Vietnam	Emerging	Rapid urbanisation, energy demand	Skills, standards	Low-Medium

Source: [31], [58]

d. Policy Framework Analysis

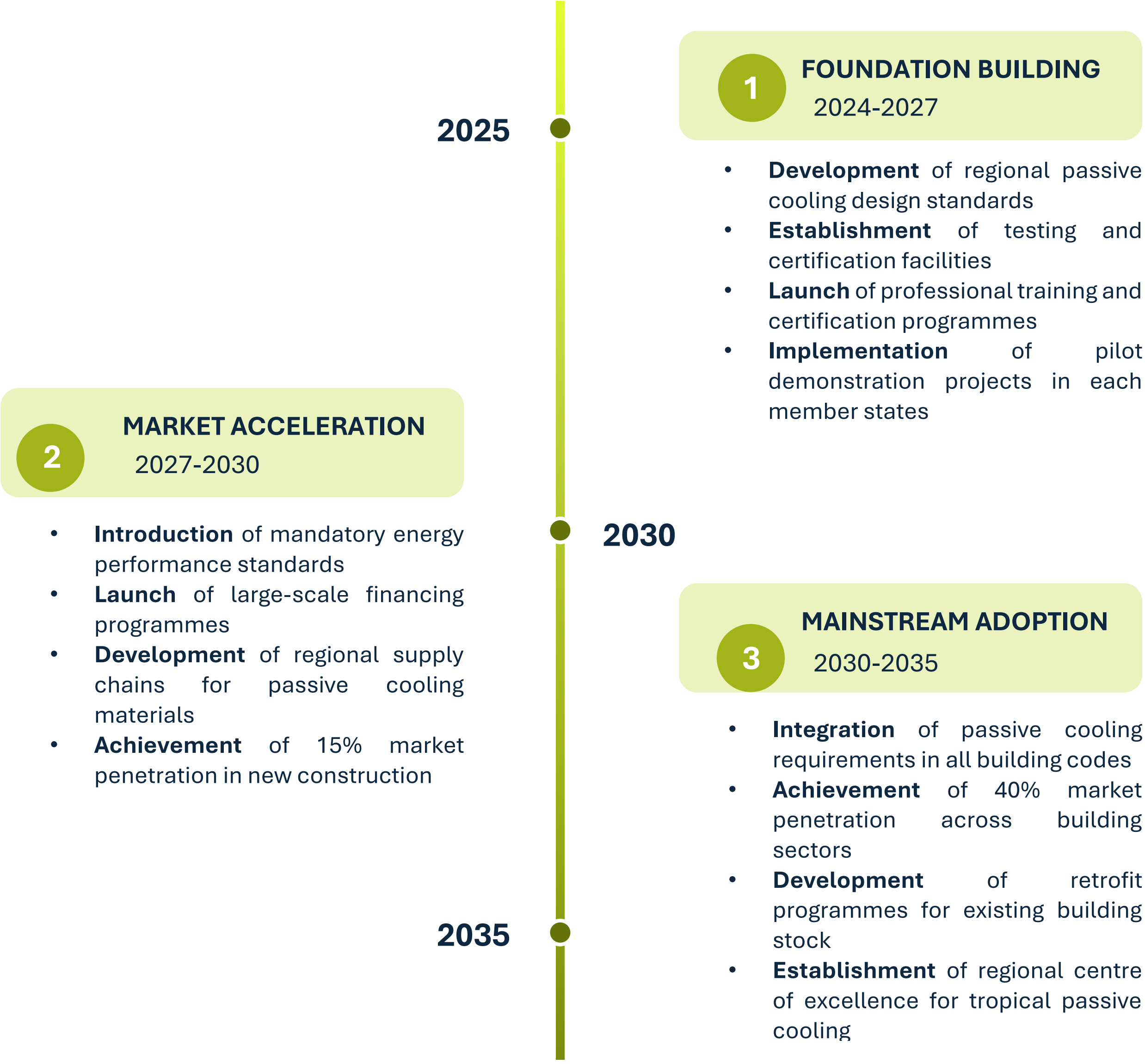
Effective policy frameworks are critical to accelerating the adoption of PCS across the ASEAN region, where policy maturity varies widely from comprehensive green building programmes to the absence of basic energy efficiency standards.

Regulatory measures should include building energy codes that mandate minimum PCS requirements, compulsory energy performance disclosure, urban planning regulations that promote climate-responsive design, and green building certification requirements for public buildings. These should be complemented by economic incentives such as tax credits and rebates for PCS installations, accelerated depreciation for energy-efficient technologies, green building loan programmes with preferential interest rates, and carbon pricing that rewards emissions reductions.

In parallel, capacity building initiatives are needed, including professional training for architects and engineers, public awareness campaigns on PCS benefits, dedicated research and development funding for tropical climate solutions, and technology demonstration projects to showcase best practices.

e. Market Transformation Pathway

Achieving widespread adoption of PCS systems requires coordinated market transformation efforts that address technical, economic, and institutional barriers simultaneously. The following roadmap outlines key milestones and interventions needed over the next decade.



2025

1 **FOUNDATION BUILDING**
2024-2027

- **Development** of regional passive cooling design standards
- **Establishment** of testing and certification facilities
- **Launch** of professional training and certification programmes
- **Implementation** of pilot demonstration projects in each member states

2 **MARKET ACCELERATION**
2027-2030

- **Introduction** of mandatory energy performance standards
- **Launch** of large-scale financing programmes
- **Development** of regional supply chains for passive cooling materials
- **Achievement** of 15% market penetration in new construction

2030

3 **MAINSTREAM ADOPTION**
2030-2035

- **Integration** of passive cooling requirements in all building codes
- **Achievement** of 40% market penetration across building sectors
- **Development** of retrofit programmes for existing building stock
- **Establishment** of regional centre of excellence for tropical passive cooling

2035

Figure 6. *Roadmap on Market Transformation.*
Source: ACE. All rights reserved.

f. Investment and Financing Landscape

The transition to PCS systems requires substantial investment in technology development, capacity building, and market infrastructure. Current financing mechanisms are inadequate to support the scale of transformation needed, necessitating innovative financing approaches and international cooperation.

Table 23. *Financing Requirements and Sources*

Investment Category	Capital Required (USD Billion)	Primary Funding Sources	Risk Profile	Expected Returns
Technology Development	2.5-4.0	Public R&D, Development banks	High	Long-term
Capacity Building	1.0-1.5	Multilateral organisations	Medium	Social
Market Infrastructure	3.0-5.0	Private sector, PPPs	Medium	Medium-term
Project Implementation	25-40	Private investment, green bonds	Low-Medium	Short-medium term

Source: [33], [88], [89]

g. Total Investment Requirement

The techno-economic analysis demonstrates that PCS systems offer compelling benefits for the ASEAN region, with the potential to significantly reduce energy consumption, emissions, and cooling costs whilst improving indoor comfort and building resilience.

Realising this potential requires coordinated action across multiple dimensions. Regional technical standards and certification programmes must be established to create a consistent quality baseline across AMS. These need to be supported by enabling policy frameworks, including updated building codes and financial incentives, that make passive cooling the default rather than the exception.

At the same time, innovative financing mechanisms are essential to address the upfront cost barriers that continue to limit adoption, particularly among smaller developers and lower-income communities. Sustained investment in capacity building and workforce development will ensure that the technical skills required for design, installation, and maintenance keep pace with growing market demand. Finally, targeted demonstration projects in each AMS will be critical to building market confidence, generating locally relevant performance data, and accelerating the transition from pilot to mainstream adoption.

The economic case for PCS becomes increasingly strong when viewed through a lifecycle perspective, particularly in countries with high energy costs or carbon-intensive electricity grids. With appropriate support mechanisms, PCS systems could achieve mainstream adoption within the next decade, contributing significantly to the region's climate goals whilst delivering substantial economic benefits.

4.5 Best Practices from ASEAN and Global Case Studies

1. ASEAN Regional Case Studies

a. Singapore: High-Rise Tropical Design Innovation

Singapore has emerged as a leader in tropical PCS design, particularly in high-density urban environments. The approach combines traditional tropical architecture principles with modern technologies to address extreme heat challenges.

Figure 7. *Parkroyal Collection Pickering Hotel*
Source: [90]

Parkroyal Collection Pickering Hotel represents a benchmark in tropical PCS design. The building incorporates a unique "sky garden" concept with over 15,000 square meters of sky gardens and green walls. The design features deep overhangs extending up to 4 meters, creating substantial shaded areas that reduce solar heat gain by up to 40%. The building's facade utilises a double-skin system with an outer perforated screen that creates a microclimate, reducing ambient temperatures by 2-3°C in adjacent spaces [91].

The Oasia Hotel Downtown demonstrates innovative use of living facades to create a natural cooling barrier. This bio-climatic facade reduces the building's energy consumption for cooling by approximately 25% while providing significant UHI mitigation effects [92].

b. Thailand: Traditional and Contemporary Fusion

Thailand's PCS blend centuries-old architectural wisdom with contemporary sustainability requirements, particularly relevant for the country's hot and humid climate conditions.

Figure 8. *Traditional Thai Stilt Houses*
Source: [93]

Traditional Thai Stilt Houses in rural areas continue to provide effective PCS lessons. These structures elevate living spaces 1.5-3 meters above ground, creating natural ventilation channels that can reduce indoor temperatures by 4-6°C compared to ground-level structures [94]. The raised design promotes cross-ventilation while the steep-pitched roofs with extended eaves provide comprehensive solar protection.

The Stock Exchange of Thailand Building in Bangkok showcases a modern interpretation of traditional cooling principles. The building features a unique double-roof system inspired by traditional Thai architecture, creating a thermal buffer zone that reduces heat transfer by up to 35% [95]. The design incorporates automated louvres that respond to solar angles, optimising natural ventilation while maintaining interior comfort.

Case Study

The 70th Anniversary DEDE Building, Thailand

Overview

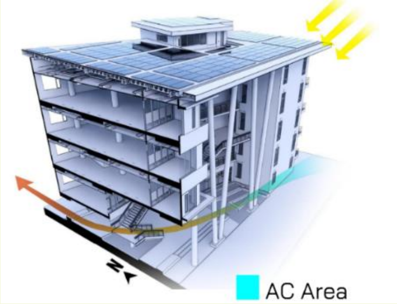
The DEDE 70th Anniversary Building is designed as a Zero Energy Building (ZEB), functioning both as an office and a demonstration site for organisations and the public. It has welcomed over 1,000 visitors and achieved Platinum certification under TREES-NC, complying with G-GOODs green building standards.

Key Design Features

The building integrates passive and active design. Passive strategies include east–west orientation to minimise heat gain, zoning that places service areas as thermal buffers, high-performance envelope (insulation, low-conductivity materials, optimised window-to-wall ratio), sun-path-based shading, and thermal-break frames. Daylighting is maximised through high-VT glazing (≥0.6), high ceilings, and open layouts. Natural ventilation is enhanced via a north–south atrium and raised corridors that capture prevailing winds for PCS. Active systems include sensor-based air conditioning and a Building Automation System (BAS) to optimise energy use.

Case Study

The 70th Anniversary DEDE Building, Thailand



Outcomes and Impacts

The building achieves up to 50% energy savings compared to conventional offices. PCS reduces indoor temperatures by 2–3°C without mechanical systems, while natural ventilation lowers HVAC demand. Daylighting reduces lighting energy use by over 30%, maintaining thermal comfort within recommended levels and demonstrating the effectiveness of integrated passive design in tropical climates.

Replicability and Scalability

The approach is replicable in tropical regions with adaptation to local conditions and regulations. Key challenges include higher upfront investment, integration of passive and active systems, and the need for strong coordination, early stakeholder engagement, and capacity building.

c. Malaysia: Tropical Modernism Excellence

Malaysia's architectural heritage in PCS stems from its diverse cultural influences and consistent tropical climate conditions, making it a valuable source of adaptable strategies for the broader ASEAN region.

Figure 9. *Menara Mesiniaga*
Source: [96]

Menara Mesiniaga in Subang Jaya represents pioneering bioclimatic architecture in Southeast Asia. The building's spiral design creates natural ventilation through the stack effect, while continuous balconies provide shading and outdoor transitional spaces. The integration of sky gardens on every third floor creates cooling microclimates that reduce mechanical cooling loads by approximately 30% [97].

Traditional Malay Houses demonstrate time-tested PCS principles that remain relevant for contemporary applications. These structures feature raised floors for ventilation, large roof overhangs for rain and heat protection, and strategically positioned windows for optimal cross-ventilation. These traditional designs can maintain indoor temperatures 3-5°C lower than conventional modern structures without mechanical cooling [98].

d. Vietnam: Adaptive Strategies for Rapid Urbanisation

Vietnam's approach to PCS reflects the challenges of rapid urban development whilst maintaining climate-responsive design principles.

Figure 10. *Saigon House*
Source: [99]

Saigon House in Ho Chi Minh City exemplifies innovative urban PCS solutions. The passive design draws strongly from traditional Saigon spatial elements to enhance comfort in a dense urban setting. The use of courtyards, narrow "alley-like" common spaces, and semi-open rooms promotes natural ventilation and airflow throughout the 3x15 m site. Layered spaces connections allow light, air, and sounds to penetrate the house, reducing reliance on mechanical cooling. Vegetation acts as a natural shading device, helping to filter sunlight and lower indoor temperatures. [99].

Traditional Vietnamese Tube Houses offer valuable lessons for dense urban environments. These narrow, deep structures utilise internal courtyards and light wells to create natural ventilation and cooling. The design principles have been successfully adapted in contemporary projects, demonstrating their continued relevance for modern urban PCS [100].

e. Indonesia: Diverse Climate Solutions

Indonesia's vast archipelago presents diverse climate conditions, from humid coastal areas to mountain regions, providing a comprehensive range of PCS applicable across different ASEAN contexts.

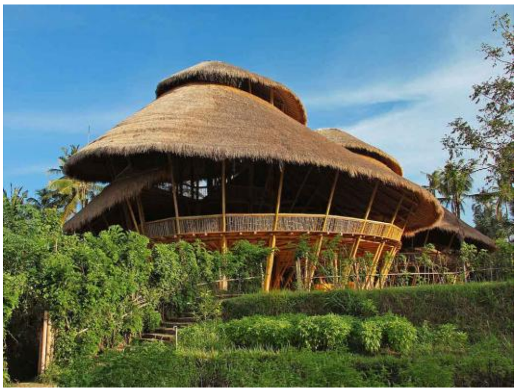


Figure 11. *Kul-Kul Farm at Green School Bali*
Source: [101]

A prime Indonesian example is the **Green School Suwung (now known as the Kul-Kul Farm at Green School Bali)**, in Badung Regency exemplifies passive cooling through vernacular design. The design philosophy was deeply rooted in using local, sustainable materials, leading to a structure primarily built with locally sourced bamboo for its primary frame and walls. The structure is built primarily from locally sourced bamboo and elevated on stilts, drawing on traditional Balinese *limasan* and *joglo* structures, which lifts the main floor to capture prevailing breezes for continuous natural ventilation.

Its most distinctive feature is a double-roof system combining high-thermal-mass Balinese clay tiles (*genteng*), over a woven bamboo inner layer, creating an insulated air cavity that traps and dissipates heat before it reaches interior spaces. Together, these strategies eliminate the need for mechanical air conditioning entirely, demonstrating how traditional techniques can be effectively adapted for modern institutional buildings [102]

Another example from Indonesia is Jakarta's traditional Betawi houses, which offer a complementary urban model, using high ceilings, strategically positioned large windows for cross-ventilation, and deep verandas to create shaded, thermally comfortable living spaces in hot-humid conditions.

2. Global Case Studies from Regions with Extreme Heat Impact

a. India: Ancient Wisdom and Modern Innovation

India's extensive experience with extreme heat conditions provides valuable insights for AMS, particularly in addressing the challenges of intense solar radiation and high temperatures. Whilst these examples originate primarily from hot-dry climates, their underlying design principles, such as solar shading, natural ventilation enhancement, and strategic building orientation remain transferable to ASEAN. However, strategies that rely on evaporative cooling or high thermal mass are less directly applicable to hot-humid conditions and require adaptation, as discussed in **Sections 4.1** and **4.2**.

Figure 12. *Hawa Mahal*
Source: [103]

Hawa Mahal, in Jaipur, represents centuries-old PCS mastery. The palace's unique facade with 953 small windows creates a sophisticated natural ventilation system using the venturi effect. The design generates continuous air movement that can reduce indoor temperatures by 8-10°C compared to outdoor conditions. This principle has been adapted in contemporary buildings across hot climates [104].

Figure 13. *Pearl Academy of Fashion*
Source: [105]

Pearl Academy of Fashion, in Jaipur, by Morphogenesis demonstrates contemporary application of traditional Indian cooling strategies. The building features a double-skin façade with cavity ventilation, internal courtyards for stack ventilation, and strategic water features for evaporative cooling. The design achieves 60% reduction in energy consumption compared to conventional buildings while maintaining optimal thermal comfort [106].

b. Middle East: Desert Climate Innovations

Middle Eastern countries offer valuable lessons for dealing with extreme heat and solar radiation, with many principles applicable to’ASEAN's drier regions and urban heat island conditions.

Figure 14. *Masdar City*
Source: [107]

Masdar City in the United Arab Emirates represents large-scale implementation of PCS in extreme heat conditions. Th' city's design incorporates traditional Arabic architectural elements including narrow streets for shade, wind towers for natural ventilation, and strategic building orientation to minimise solar exposure. The urban design can reduce ambient temperatures by 3-5°C compared to conventional developments [108].

Figure 15. *Barjeel Wind Towers*
Source: [109]

Wind Towers (*Barjeel*) of traditional Middle Eastern architecture provide proven strategies for natural ventilation in hot climates. These structures can generate significant air movement without mechanical systems, creating cooling effects equivalent to 2-3 tons of air conditioning capacity. Modern interpretations have been successfully implemented in contemporary buildings worldwide [110].

c. Australia: Hot Climate Adaptations

Australia's experience with extreme heat events and bushfire-prone conditions offers relevant strategies for AMS facing increasing climate challenges.

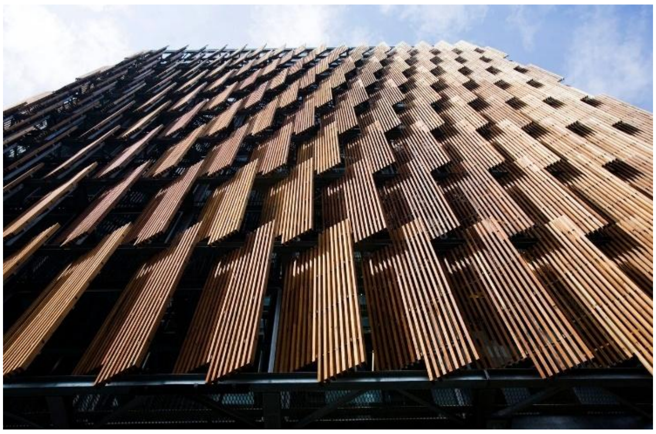


Figure 16. *Council House 2*
Source: [111]

CH2 Building in Melbourne demonstrates comprehensive PCS integration in urban environments. The building features automated exterior blinds, thermal mass optimisation, and natural ventilation systems that reduce mechanical cooling loads by 80%. The design principles are particularly relevant for ASEAN's emerging sustainable building practices [112].

Figure 17. *Australian Verandas*
Source: [113]

Traditional Australian verandas and homestead designs provide simple but effective strategies for hot climate living. Deep verandas, elevated structures, and strategic building orientation create comfortable outdoor living spaces whilst reducing indoor heat gain. These principles have been successfully adapted across tropical and subtropical regions globally.

The ASEAN and global case studies presented in the preceding section demonstrate a diverse range of passive cooling strategies in practice. Tables 24 and 25 synthesise the key performance and cost data from these examples into a structured comparative framework, allowing policymakers, designers, and investors to assess the relative merits of each strategy across climate suitability, implementation cost, and effectiveness for ASEAN conditions

Table 24. *Comparative Analysis of Passive Cooling Strategies*

Strategy Category	ASEAN Examples	Global Examples	Climate Suitability	Implementation Cost	Effectiveness Rating
Natural Ventilation	Thai stilt houses, Vietnamese tube houses	Indian courtyard houses, Middle Eastern wind towers	Hot-humid, Hot-dry	Low-Medium	High (4-8°C reduction)
Solar Shading	Deep overhangs (Singapore), Bamboo screens (Vietnam)	Masdar City canopies, Australian verandas	Universal	Low-Medium	Medium-High (30-40% heat gain reduction)
Green Infrastructure	Living facades (Singapore), Sky gardens (Malaysia)	Green roofs (Europe), Vertical gardens (Colombia)	Hot-humid	Medium-High	High (2-5°C ambient reduction)
Thermal Mass	Traditional clay construction (Indonesia)	Adobe buildings (Middle East), Rammed earth (Australia)	Hot-dry, Temperature swings	Low-Medium	Medium (2-4°C temperature moderation)
Evaporative Cooling	Water courts (Malaysia), Pond systems (Thailand)	Persian windcatchers, Indian step wells	Hot-dry, Low humidity	Medium	High (5-10°C in suitable conditions)
Elevated Structures	Stilt houses across ASEAN	Australian homesteads, African elevated granaries	Hot-humid, Flood-prone	Low	Medium-High (3-6°C improvement)

Source: [110], [114]

Table 25. *Performance Metrics and Quantitative Analysis*

Building/Project	Location	Temperature Reduction	Energy Savings	Cost Premium	Payback Period
Parkroyal Pickering	Singapore	2-3°C ambient	25% cooling energy	15%	8-10 years
Menara Mesiniaga	Malaysia	Interior comfort improved	30% total energy	12%	6-8 years
Pearl Academy	India	8-10°C peak reduction	60% total energy	20%	5-7 years
CH2 Building	Australia	Maintains comfort	80% cooling energy	25%	10-12 years
Traditional Stilt House	Thailand/Vietnam	4-6°C interior	100% cooling energy	-5% (lower cost)	Immediate

Building/Project	Location	Temperature Reduction	Energy Savings	Cost Premium	Payback Period
Gando School	Indonesia	Comfortable without AC	100% cooling energy	-10% (lower cost)	Immediate

Source: [115]

3. Lesson Learnt

a. Key Success Factors

The case studies reviewed across ASEAN and beyond reveal a consistent set of factors that distinguish successful passive cooling projects from those that underperform or fail to scale. Chief among these is **climate-responsive design**. Projects that begin with a rigorous analysis of local temperature, humidity, solar radiation, and wind patterns consistently achieve better thermal outcomes than those applying generic design solutions. This reinforces the importance of using locally calibrated climate data, including Typical Meteorological Year datasets, as the foundation of any passive cooling design process.

Equally important is the adoption of a **multi-strategy approach**. Projects combining three to five complementary passive cooling methods generate synergistic effects that exceed the sum of individual strategies. For example, integrating natural ventilation with appropriate thermal mass management and well-designed solar shading can reduce indoor temperatures by 6-10°C in tropical conditions, a performance level unachievable through any single intervention alone. This finding has significant implications for building codes and green certification schemes, which should incentivise integrated design rather than prescribing individual measures in isolation.

Cultural integration also emerges as a significant determinant of long-term success. Projects that draw on traditional architectural knowledge, whether the deep verandas of Thai stilt houses, the cross-ventilation principles of Malay kampung design, or the courtyard traditions found across the region, achieve higher occupant acceptance, stronger community ownership, and more consistent maintenance over time. This points to the value of engaging local communities and vernacular design expertise at the earliest stages of the design process, rather than treating passive cooling as a purely technical exercise.

Finally, **simplicity and maintainability** consistently prove to be decisive advantages. Systems that rely on locally available materials and skills, and that require minimal specialised maintenance, outperform technically complex alternatives across ASEAN's diverse implementation environments. This has direct implications for technology selection in lower-income AMS, where supply chains for advanced passive cooling materials remain underdeveloped and technical capacity in the building sector is still being strengthened.

b. Critical Implementation Challenges

Urban density limits natural ventilation and shading opportunities. However, successful projects demonstrate that innovative vertical solutions and facade strategies can overcome these limitations [85].

Building codes in many AMS were developed for temperate climates or default to mechanical systems, requiring extensive regulatory coordination. Successful projects often require extensive coordination with regulatory authorities and sometimes pilot project status to demonstrate compliance and performance.

Upfront cost perceptions remain a barrier despite favourable lifecycle economics, and declining traditional building skills combined with limited contemporary bioclimatic expertise constrain implementation capacity across the region. Traditional building skills that support PCS are declining, whilst contemporary expertise in bioclimatic design remains limited. Successful projects typically invest significantly in capacity building and knowledge transfer.

c. Regional Adaptation Strategies

ASEAN's hot-humid conditions favour natural ventilation, moisture management, and cross-ventilation over thermal mass strategies. As cities grow rapidly, passive cooling must address both building-level performance and neighbourhood-scale heat reduction through green infrastructure, reflective surfaces, and strategic urban planning. Low-tech solutions aligned with local skills and materials offer greater long-term sustainability, lower costs, and reduced emissions than high-tech alternatives. As climate change intensifies extreme heat events, successful strategies must also maintain effectiveness during peak conditions whilst providing residual cooling capacity.

d. Technology Integration Opportunities

Smart passive systems integrating sensors and automated controls can enhance passive cooling performance without undermining its simplicity, provided passive strategies remain primary and technology plays a supporting role. Advanced materials, including phase-change materials and high-performance reflective coatings, offer significant performance gains using locally appropriate approaches. Simple monitoring systems that track thermal performance and energy savings are increasingly essential for optimisation, accountability, and replication.

e. Scaling and Replication Guidelines

Pilot projects are the most effective starting point for scaling, establishing local performance data and stakeholder confidence under typical rather than idealised conditions. Comprehensive education programmes targeting architects, engineers, builders, and end-users simultaneously accelerate adoption. Policy alignment through building code updates, financial incentives, and climate-responsive procurement creates the enabling environment for widespread implementation. Investment in local supply chains for passive cooling components reduces import dependence and builds long-term market sustainability.

Policy and Regulatory Landscape

5.1 Overview of national and regional policy frameworks

Policy and regulation are the primary levers for mainstreaming passive cooling in the built environment, yet their development across ASEAN remains uneven. Many AMS support integrating renewable energy sources into building designs, which helps reduce reliance on fossil fuels [85]. Emerging as indispensable tools for setting baseline efficiency criteria across the residential and commercial sectors are energy codes.

Adoption of policies by ASEAN shows rather different patterns. For example, while Thailand's Building Energy Code outlines conservation criteria for nine building categories exceeding 2,000m^2, Singapore's Green Mark system prescribes thorough certification [47], [116]. Indicating changing sustainability priorities, intermediate adopters such as Malaysia, Vietnam, and Brunei use mixed regulatory approaches, including voluntary components. Less developed frameworks in Lao PDR, Myanmar, and Cambodia reflect regional differences in urbanisation speed, economic capacity, and environmental policy maturity.

The ASEAN region has shown increased interest in integrating PCS mechanisms into national policy, employing a mix of fiscal incentives and policy regulation, and essentially making PCS a part of contemporary city planning and building protocols. **Table 26** indicates that Singapore leads with comprehensive mandatory standards and advanced enforcement, whilst Malaysia and Thailand have well-established green building codes with moderate PCS integration. The remaining seven countries (Indonesia, Philippines, Vietnam, Brunei, Cambodia, Lao PDR, Myanmar) show limited to moderate policy development with significant regulatory gaps and weak enforcement mechanisms.

Table 26*. Comparative Policy Instruments across AMS*

Country	Primary Building Code/Standard	Green Building Certification	Passive Cooling Integration Level	Key Policy Instruments	Implementation Status	Regulatory Gaps
Brunei Darussalam	National Building Code	Under development	Limited	▪ Energy efficiency guidelines ▪ Basic thermal requirements	Developing	▪ Lack of specific PCS standards ▪ Limited enforcement mechanisms
Cambodia	N/A	Emerging frameworks	Basic	▪ General building standards ▪ Limited thermal requirements	Early stage	▪ No specific PCS provisions ▪ Weak enforcement infrastructure
Indonesia	Ministerial Regulation of Public Works and Housing Number 21 of 2021	Green Building Certification (Sertifikasi Bangunan Gedung Hijau)	Moderate	▪ Energy efficiency requirements ▪ Some passive design incentives	Developing	▪ Regional implementation variability ▪ Limited training programmes
Lao PDR	N/A	Under development	Limited	▪ Basic building regulations ▪ Energy efficiency guidelines	Early stage	▪ No comprehensive PCS framework ▪ Limited technical capacity
Malaysia	Uniform Building By-Laws (UBBL) MS 1525 Energy Efficiency	• Green Building Index (GBI) • GreenRE	Advanced	▪ Green Technology Master Plan ▪ Building energy intensity requirements ▪ Passive design incentives ▪ Solar heat gain coefficient standards	Well-established	▪ Regional variation in enforcement ▪ Need for mandatory implementation
Myanmar	Myanmar National Building Code	Basic frameworks	Limited	▪ General building standards ▪ Energy efficiency guidelines	Developing	▪ Lack of specific PCS provisions ▪ Limited institutional capacity
Philippines	National Building Code Energy Efficiency & Conservation Act	Building for Ecologically Responsive Design Excellence (BERDE)	Moderate	▪ Green Building Code ▪ Energy efficiency standards ▪ Solar reflectance requirements ▪ Natural ventilation provisions	Developing	▪ Limited enforcement mechanisms ▪ Need for comprehensive training

Country	Primary Building Code/Standard	Green Building Certification	Passive Cooling Integration Level	Key Policy Instruments	Implementation Status	Regulatory Gaps
Singapore	Building Code Building Control Act	Green Mark Scheme	Very Advanced	▪ Mandatory building energy efficiency ▪ Envelope Thermal Transfer Value (ETTV) ▪ Green Mark incentives ▪ Comprehensive passive design standards ▪ Building skyrise greenery incentives	Fully implemented	▪ Focus on active rather than passive solutions ▪ High compliance costs
Thailand	Building Control Act Energy Conservation Promotion Act	TREES (Thai's Rating of Energy and Environmental Sustainability)	Advanced	▪ Building Energy Code (BEC) ▪ Envelope performance standards ▪ Thai Green Building Institute standards ▪ Tax incentives for green buildings	Well-established	▪ Limited coverage of existing buildings ▪ Enforcement challenges
Vietnam	Vietnam Building Code (QCVN) Energy Efficiency Law	Leadership in Energy and Environmental Design on a Sustainable Urban System (LOTUS)	Moderate	▪ National Technical Regulation on Energy Efficiency ▪ Green building development programme ▪ Energy efficiency labelling ▪ Passive design guidelines	Developing	▪ Limited integration across building types ▪ Weak enforcement mechanisms

Note: Data for Timor-Leste are not yet available and will be incorporated in a future update.

Source: Authors' compilation from the ASEAN EE&C-SSN Working Group on Building Meeting.

5.2 Policy and Regulatory Landscape on Building, Energy Standards, and Urban Planning

5.2.1 Driving Initiatives in Key Markets

PCS is related to reducing energy consumption in buildings, especially for cooling. Across ASEAN, passive cooling is increasingly embedded in national building regulations, though depth and enforcement vary considerably.

Singapore's holistic Green Mark Scheme, run by the Building and Construction Authority (BCA), makes it a regional leader. The scheme mandates thermally responsive envelopes, optimised natural ventilation, and innovative shading, whilst its Cool Roadmap 2.0 offers gross floor area bonuses to incentivise higher sustainability performance. [116].

Thailand's TREES (Thai's Rating of Energy and Environmental Sustainability) certification and national Energy Efficiency Plan integrate passive design elements alongside urban cooling measures, including green space expansion and reflective surface [117], [118].

Malaysia's Green Building Index is a key certification tool that emphasises heavily on PCS via daylighting, thermally suitable materials, and natural ventilation maximisation. The government incentivises the adoption of certified projects through tax benefits, in addition to other efforts like subsidised cool roof installations for public housing projects [119].

Indonesia introduced Green Building Certificate under Ministerial Regulation 21/2021 mandates passive design considerations for government-funded projects, system [43]. Since its adoption, government-funded projects have been encouraged to obtain certification under this regulation. Additionally, the Greenship rating system, developed by the Green Building Council Indonesia, also integrates PCS indicators into its indoor environmental quality and energy efficiency assessments, though it remains voluntary [120].

PCS needs have been institutionalised in the **Philippines**' Building Energy Efficiency Code, which quires natural ventilation in commercial and residential buildings, backed by retrofit financing and local green infrastructure mandates. [46], [121].

Vietnam, promulgated by the Ministry of Construction, sets out National Technical Regulation on Energy Efficiency Buildings. The document provides requirements for building envelopes and mandates natural ventilation provisions as part of the building envelope considerations, supporting PCS measures [48].

5.2.2 Green Building Certification Schemes

Green building certification schemes have become powerful instruments for mainstreaming passive cooling. Regional programmes, supplemented by international standards such as Leadership in Energy and Environmental Design

(LEED) and Excellence in Design for Greater Efficiencies (EDGE), reward passive design principles, improve market competitiveness, and increasingly make passive cooling the baseline expectation in new developments rather than an optional feature. [122]. By identifying structures that apply passive design principles, these certification frameworks improve the marketability and competitive positioning of projects. PCS is now the industry standard in new developments as a result of the certification process. Through specific performance standards and incentives for passive thermal regulation techniques, these programmes methodically advance sustainable building practices.

5.2.3 Mechanisms of Integrated Policy

Promoting sustainable buildings effectively requires a multifaceted approach that includes legislative actions, educational programmes, and enforcement procedures. National and local governments' regulatory actions set the groundwork for energy-efficient building practices. These frameworks typically establish minimum requirements for energy performance, specifications for sustainable materials, mandates for the integration of renewable energy, and targets for reducing emissions. This policy approach is best demonstrated by Singapore's Green Mark Scheme, which provides certified projects with accelerated permitting and increased development density allowances, among other concrete benefits [121]. APAEC encourages AMS to incorporate PCS provisions into their national building codes, offering a unified strategy for building efficiency improvements at the regional level. To reduce reliance on mechanical cooling, these regulatory tools methodically encourage design techniques such as solar shading, optimal natural ventilation, and building envelope insulation. This policy approach is best demonstrated by Singapore's Green Mark Scheme, which provides certified projects with accelerated permitting and increased development density allowances, among other concrete benefits [123]. APAEC encourages AMS to incorporate PCS provisions into their national building codes, offering a unified strategy for building efficiency improvements at the regional level. To reduce reliance on mechanical cooling, these regulatory tools methodically encourage design techniques like solar shading, optimal natural ventilation, and building envelope insulation.

5.2.4 Capacity-Building Ecosystem

A strong network of institutions can support professional development and knowledge sharing in PCS applications. Those institutions are:

a. **Industry Organisations:** To promote sustainable building practices, green building councils throughout the region, including those in Singapore and Malaysia, run focused training courses and awareness campaigns.

b. **Academic Integration:** To guarantee that incoming professionals have the necessary knowledge of climate-responsive design, universities have integrated PCS concepts into their engineering and architecture curricula.

c. **Professional Development:** Ongoing education courses and certification programmes preserve industry expertise in developing PCS design techniques and technologies.

In Southeast Asia, a comprehensive ecosystem for sustainable building innovation should be established through the synergistic relationship between certification systems, policy instruments, and knowledge-sharing platforms.

5.2.5 Integration with Building Codes and Urban Planning

Evidence of regional commitment to climatic resilience and sustainable urban development is the AMS emerging movement toward convergence in conformity with the integration of PCS principles into their regulatory frameworks. The Philippines' Revised National Building Code, Malaysia's Uniform Building By-Laws (UBBL), Thailand's Building Control Act, Indonesia's Green Building Regulation, Singapore's Building Control (Environmental Sustainability) Regulations, and Vietnam's QCVN 09:2017 establish requirement standards for natural ventilation, solar shading, and building envelope thermal performance [43], [46], [48], [124], [125], [126]. Such harmonisation of legislation gives sustainability in building practice a common platform across ASEAN but with regionally necessary adjustments in implementation.

Urban planning frameworks in major ASEAN capitals demonstrate equally strong coordination. Three key strategies are incorporated into the land use plan of Singapore, the Comprehensive Plan of Bangkok, the Spatial Planning Regulations of Jakarta, the Green Building Ordinances of Manila, and the revised Construction Law of Ho Chi Minh City: preserving urban ventilation corridors, mandating green spaces and vegetation, and limiting the application of heat-absorbing materials in public spaces [127], [128], [129], [130], [131]. This shared approach reflects a collective understanding of urban heat challenges across diverse city morphologies [132].

Technical harmonisation is advancing at the component level. Building regulations across ASEAN capitals now generally require minimum envelope thermal performance, external shading devices with specified solar protection factors, and window-to-wall ratios of 30-40% for naturally ventilated buildings [33]. This convergence facilitates knowledge transfer and supports regional markets for passive cooling materials and technologies without compromising architectural heritage.

Regulatory mandates are reinforced by harmonised incentive mechanisms. Grant schemes, tax incentives, streamlined permitting, reduced fees, and gross floor area bonuses across multiple AMS align economic drivers with policy requirements, making passive cooling commercially viable rather than merely obligatory. The exemplary regulations include the Philippines' grant schemes, Malaysia's green building tax incentives, Thailand's streamlined permitting for sustainable developments, Indonesia's lower permit fees, and Singapore's gross floor area bonus [133]. The twin strategy has been effective in encouraging market acceptance of PCS approaches while rendering development feasible.

As policy architectures mature, the constraint is no longer ambition but consistency. Regional standards for passive cooling certification, professional training, and monitoring, reporting, and verification are now essential to translate policy convergence into credible, comparable performance outcomes across AMS. As new technologies and design philosophies become available on a regular basis, this convergence is set to become increasingly entrenched through ongoing cooperation through ASEAN working groups [7].

5.3 Financing Mechanisms and Gaps

ASEAN has established a foundation of public and private financing instruments for passive cooling, but coverage remains uneven. Low-interest loans for PCS retrofits in public and commercial buildings are the foundation of Malaysia's Green Technology Financing Scheme, Indonesia's Energy Efficiency and Conservation Clearing House, and Thailand's Energy Efficiency Revolving Fund [7]. The eligibility requirements for these programmes are similar and centred on quantifiable energy savings and thermal comfort enhancements, guaranteeing uniform investment standards internationally. Through ASEAN-wide knowledge-sharing initiatives, pilot programmes in Vietnam and the Philippines are currently replicating Singapore's Building Retrofit Energy Efficiency Financing scheme, which combines these strategies with performance-based incentives [134], [135], [136].

Major ASEAN economies' commercial banking sectors have demonstrated a growing synchronisation of green lending practices. With interest rate reductions for certified green buildings, top financial institutions in Thailand, Malaysia, and Singapore now provide favourable loan terms for projects utilising PCS design principles [137]. The ASEAN Taxonomy for Sustainable Finance, which offers uniform definitions for qualified PCS investments, has made this financial sector alignment easier [138]. Regional markets differ in how this arrangement is implemented, though, and smaller economies have a harder time developing the technical capacity of lenders to evaluate PCS proposals.

With the help of sustainability-related instruments and green bonds, capital markets are becoming a more coordinated source of funding. With proceeds going toward district-level cooling systems that incorporate passive design elements, Singapore's thriving green bond market has established regional standards for funding extensive PCS infrastructure. In order to create a standardised pipeline for institutional investment, Malaysia and Indonesia have followed suit by issuing sovereign green bonds that specifically include components for building efficiency [85]. Although secondary market liquidity is still lacking by international standards, the ASEAN Capital Markets Forum has played a significant role in fostering cross-border recognition of these instruments [133].

Through coordinated programming, ASEAN has strategically benefited from international climate finance mechanisms. Regional platforms that combine technical assistance and concessional funding have been established, such as the World Bank's Sustainable Cooling Finance Initiative [139]. These multilateral tools allow AMS to use aggregated investment strategies by adhering to standard procedures for assessing and validating the effects of PCS. Access to smaller towns and rural developments is still restricted, though, by difficult accreditation procedures and strict co-financing requirements.

Despite this progress, three critical gaps persist. Early-stage project development financing for passive cooling innovation remains scarce, with most instruments targeting implementation rather than conceptualisation [140]. Microfinance solutions for residential-scale retrofits are underdeveloped, leaving low-income households, women-led enterprises, and informal settlements without accessible options. Risk mitigation instruments such as guarantee facilities are not yet widely available, deterring commercial lenders. The ASEAN Catalytic Green Finance Facility offers a coordinated response through blended finance, but standardised project pipelines, monitoring frameworks, and lender capacity-building are prerequisites for full effectiveness.

The differences between ASEAN's financing leaders and other AMS are stark. Table 27 shows that Singapore, Malaysia, and Thailand operate mature green finance ecosystems mobilising USD 1-10 billion annually, whilst Cambodia, Lao PDR, Myanmar, and Brunei face critical gaps with nascent markets below USD 50 million annually and limited institutional capacity. Bridging this divide requires strengthened regional financial integration whilst preserving the flexibility necessary to accommodate diverse national market conditions.

Table 27. *Comprehensive Financing Mechanisms across AMS*

Country	Government Incentives	Private Financing	Green Finance Instruments	Multilateral Support	Barriers & Gaps	Market Maturity	Investment Scale (USD)
Brunei Darussalam	▪ Government sustainability fund (small scale) ▪ Public building retrofit programmes	▪ Conventional bank loans ▪ Limited ESCO presence ▪ Family office investments	▪ No dedicated green bonds ▪ Basic sustainability criteria in banking	▪ ADB project financing ▪ ASEAN Catalytic Green Finance Facility access	▪ Critical Gap: No dedicated PCS financing ▪ Limited local expertise ▪ High upfront costs vs. oil economy priorities ▪ Lack of energy efficiency mandates	Nascent	< USD 50M annually
Cambodia	▪ Basic energy efficiency rebates ▪ Import duty reductions on green tech ▪ Limited government green procurement	▪ Microfinance for small projects ▪ Commercial bank reluctance ▪ Foreign investment dependent	▪ No green bond market ▪ Basic ESG criteria emerging	▪ ADB Green Finance ▪ World Bank Climate Investment ▪ Bilateral development aid	▪ Critical Gap: No PCS specific programmes ▪ Limited access to capital ▪ Lack of technical standards ▪ Currency risk for foreign investment	Nascent	< USD 25M annually
Indonesia	▪ Tax incentives to businesses that promote EE projects with lower interest ▪ Green sukuk issuance ▪ Accelerated depreciation for green buildings	▪ PT SMI green financing ▪ ESCO market development ▪ Private equity in sustainability ▪ Real estate green premiums	▪ Green sukuk (Islamic bonds) ▪ Sustainable banking regulation ▪ Green taxonomy development ▪ Financial Service Authority (OJK) green finance guidelines	▪ ASEAN Infrastructure Fund ▪ Japan Bank for International Cooperation ▪ Asian Infrastructure Investment Bank	▪ Limited rural market access ▪ Complex bureaucracy ▪ Inconsistent regional implementation ▪ Limited technical financing expertise	Developing	USD 500M-1B annually
Lao PDR	▪ Energy efficiency fund (limited) ▪ Import tax exemptions ▪ Basic green procurement policies	▪ Limited commercial lending ▪ Development bank financing ▪ Regional bank presence	▪ No domestic green bonds ▪ Regional green finance access ▪ Basic environmental criteria	▪ ADB support ▪ Chinese development finance ▪ Mekong River Commission programmes	▪ Critical Gap: No PCS frameworks ▪ Limited domestic capital ▪ Lack of technical capacity	Nascent	< USD 20M annually

Country	Government Incentives	Private Financing	Green Finance Instruments	Multilateral Support	Barriers & Gaps	Market Maturity	Investment Scale (USD)
					▪ Regulatory uncertainty		
Malaysia	▪ Numerous public and private incentive schemes for EE ▪ Green Technology Financing Scheme (GTFS) ▪ Investment tax allowance up to 100% ▪ Green building tax incentives ▪ Energy Service Company (ESCO) support	▪ Advanced and innovative financial instruments and specialised financial models ▪ Strong ESCO market ▪ Real estate green financing ▪ Islamic green finance leadership	▪ Malaysia Green Bond Programme ▪ Green sukuk market leader ▪ Sustainable and Responsible Investment (SRI) sukuk ▪ Green financing taxonomy	▪ ASEAN+3 Multi-Currency Bond Market ▪ Islamic Development Bank ▪ Japan-Malaysia green finance cooperation	▪ SME access limitations ▪ Limited standardisation ▪ Higher costs for passive vs. active cooling ▪ Market concentration in urban areas	Mature	USD 2-3B annually
Myanmar	▪ Limited energy efficiency incentives ▪ Basic import duty reductions ▪ Government sustainability commitments (limited implementation)	▪ Limited banking sector ▪ Foreign investment restrictions ▪ Cash-based economy challenges	▪ No green finance market ▪ Basic banking ESG policies ▪ Limited capital market development	▪ Limited due to political situation ▪ Some regional development bank support ▪ Bilateral aid programmes	▪ Critical Gap: Political and economic instability ▪ No dedicated green building finance ▪ Limited institutional capacity ▪ Currency and investment risks	Nascent	< USD 10M annually
Philippines	▪ Green building tax incentives ▪ Board of Investments incentives ▪ Energy efficiency revolving fund ▪ Net metering for distributed energy	▪ ESCO market development ▪ Private green real estate financing ▪ Sustainable banking initiatives ▪ Green real estate investment trusts	▪ Green bond market development ▪ Sustainable finance roadmap ▪ BSP green finance guidelines ▪ Social impact bonds	▪ ADB Green Finance ▪ World Bank support ▪ ASEAN Infrastructure Fund access	▪ Limited PCS awareness ▪ High interest rates ▪ Limited technical expertise ▪ Disaster risk considerations	Developing	USD 300-500M annually

Country	Government Incentives	Private Financing	Green Finance Instruments	Multilateral Support	Barriers & Gaps	Market Maturity	Investment Scale (USD)
Singapore	▪ Green Finance Incentive Scheme ▪ Building skyrise greenery incentives ▪ Energy efficiency grants ▪ Green Mark certification incentives ▪ Productivity grant for green tech	▪ World-class banking sector ▪ Strong ESCO market ▪ Real estate green premiums ▪ Private wealth green investing ▪ Venture capital in climate tech	▪ Green Bond Grant Scheme ▪ World's largest green bond market ▪ Sustainable finance taxonomy ▪ Climate-related financial disclosures mandatory	▪ Regional green finance hub ▪ ASEAN green finance coordination ▪ International climate finance centre	▪ High compliance costs ▪ Focus on active over passive solutions ▪ Limited applicability to regional markets ▪ Space constraints favour active cooling	Very Mature	USD 5-10B annually
Thailand	▪ Subsidies and tax incentives, including reduced import duties and tax incentives for renewable energy ▪ Energy efficiency revolving fund ▪ Building energy efficiency incentives ▪ Numerous public and private incentive schemes for EE	▪ Advanced and innovative financial instruments and specialised financial models ▪ Strong ESCO market ▪ Green property financing ▪ Sustainable banking sector	▪ Green Bond market development ▪ LB-CONNECT green taxonomy ▪ Sustainability-linked loans ▪ Green project financing	▪ ASEAN+3 bond market initiative ▪ Japan-Thailand green finance cooperation ▪ ADB support programmes	▪ Gap: Limited rural penetration ▪ Complex approval processes ▪ Market fragmentation ▪ Limited PCS standardisation	Mature	USD 1-2B annually
Vietnam	▪ Green Credit Fund and preferential loans ▪ Energy efficiency credit programme ▪ Tax incentives for green buildings ▪ Import duty exemptions for green tech	▪ Growing ESCO market ▪ Foreign direct investment in green buildings ▪ Domestic banking green criteria ▪ Real estate sustainability financing	• Green bond development • State Bank of Vietnam green credit guidelines • Sustainable finance taxonomy development • Green lending criteria	• ADB Green Finance Programme • World Bank climate financing • Japanese green finance cooperation	• **Gap**: Limited PCS focus • Bureaucratic approval processes • Limited technical expertise • Currency risk for foreign investment	Developing	USD 400-800M annually

Source: [88], [141], [142]

5.4 Regional Prospects

ASEAN's holistic approach to sustainable cooling is realised through the combination of financial tools, such as tax incentives, subsidies, and fast-track approvals, with regulatory tools, such as building codes, certification schemes, and urban planning regulations [140]. The following analysis discusses how, despite ASEAN establishing strong policy foundations and financial mechanisms, there are still implementation gaps, especially in technical capacity, financing accessibility, and innovation ecosystems. The region's synchronised approach through ASEAN-level coordination bodies presents significant opportunities to address these challenges at scale. **Table 28** shows the summary of the existing gaps and opportunities.

Table 28. *Gaps and Opportunities for ASEAN*

Category	Existing Gaps	Emerging Opportunities
Policy Regulatory Landscape	▪ Inconsistent enforcement of building codes in developing ASEAN nations (Cambodia, Lao PDR, Myanmar) ▪ Residential buildings often excluded from mandatory PCS requirement ▪ Fragmented alignment with international climate commitments	▪ ASEAN-wide harmonisation through APAEC energy efficiency targets ▪ Model building codes for tropical climates under development ▪ Regional benchmarking of Singapore's Green Mark and Thailand's TREES schemes
Technical Integration	▪ Limited technical capacity for PCS design in CLMV countries ▪ Disparate window-to-wall ratio standards (30-40% range) ▪ Inconsistent material performance testing protocols	▪ ASEAN Cool Initiative developing regional design guidelines ▪ Shared CFD modelling standards for urban ventilation ▪ Regional material certification programmes emerging
Financing Mechanisms	▪ 80% of green financing targets commercial buildings, neglecting residential retrofits ▪ Low figure of ASEAN green bonds fund specifically for PCS ▪ Microfinance penetration below 5% for cooling solutions	▪ ASEAN Catalytic Green Finance Facility's $1.5B blended finance platform ▪ Malaysia's Green Technology Financing Scheme showing 32% YoY growth ▪ Pilot results: Indonesia's reduced permit fees increased passive design adoption by 18%
Urban Planning Synergies	▪ Only 4/10 ASEAN capitals have mapped urban ventilation corridors ▪ Heat-reflective pavement mandates cover <15% of urban areas ▪ Vertical greenery	▪ Bangkok/Jakarta/HCMC tri-city heat mitigation partnership ▪ Singapore's Cool Roadmap 2.0 demonstrating 2-4°C UHI reduction ▪ Philippines' NCAP targeting 40% PCS in new public buildings

Category	Existing Gaps	Emerging Opportunities
	requirements apply to <30% of new high-rises	
Certification Capacity	▪ Green building certifiers per capita: 1:500,000 in CLMV vs 1:50,000 in advanced states ▪ <20% of regional architecture programmes include PCS modules ▪ Post-occupancy evaluations conducted on <5% of certified projects	▪ Malaysia GBI and Singapore Green Mark mutual recognition underway
Technology Innovation	▪ Local material innovation receives <3% of clean energy RCD funding ▪ Only 8% of ASEAN construction firms use BIM for passive design optimisation ▪ Limited testing facilities for tropical building materials	▪ Thailand's TGO funding 15 material innovation projects annually ▪ Vietnam's 2025 mandate for BIM in all public buildings ▪ Regional Cool Roofs Initiative achieving 92% solar reflectance standards

Source: [8], [48], [141], [142], [143], [144]

Stakeholder Analysis

6.1 Categorise Stakeholders and Their Roles and Influence

Analysis in **Table 29** identifies key stakeholders, evaluates their influence, and provides insights on the critical roles of the stakeholders for the phased approach of roadmap implementation. The key highlights are:

- Government agencies and developers hold the highest influence due to their regulatory and financial control.
- Local authorities and architects play a crucial role in translating policies into practical designs.
- Financial institutions and tech providers act as enablers but require stronger incentives to scale investments.
- Community-based Organisations (CBOs) and academia drive awareness and innovation but need more integration into policymaking.

The stakeholder analysis emphasises crucial functions and interdependencies among various actors in advancing PCS adoption across ASEAN. Governments and developers hold the greatest influence over passive cooling adoption, setting regulatory direction and market demand. Their effectiveness depends on complementary support from financial institutions providing green financing and technology suppliers delivering scalable solutions. Local authorities and architects are critical intermediaries, translating policy into built outcomes, whilst academic institutions and NGOs remain underutilised in innovation and community engagement. Coordinated action between high-influence actors and high-interest groups is essential to overcome cost and design barriers. ASEAN's opportunity lies in establishing regionally harmonised standards through structured multi-stakeholder collaboration, whilst retaining flexibility for local climatic and socioeconomic contexts.

Table 29. *Stakeholder Roles and Influence*

Stakeholder Group	Key Entities	Primary Role	Influence	Key Interests
Government				
Government Agencies	National energy ministries, environment agencies, building authorities	Formulate policies, set regulations, enforce building codes	High	Energy security, climate commitments, public health
Local Authorities Urban Planners	City planning departments, municipal governments	Implement zoning laws, urban cooling, compliance monitoring	Medium-High	Local climate resilience, liveability, economic growth
Building Construction Sector				

Stakeholder Group	Key Entities	Primary Role	Influence	Key Interests
Developer	Building developer, Real estate firms	Execute projects, adopt passive cooling technologies	High	Profitability, regulatory compliance, market demand
Construction Companies	General contractors, specialty contractors, construction project managers, building material suppliers	Execute PCS implementation, ensure quality construction, procure appropriate materials, coordinate trades	High	Cost-effective construction, project timeline adherence, quality standards, regulatory compliance, client satisfaction
Architects, Engineers, and Other Consultants	Architecture firms, engineering consultancies, green building consultancies	Integrate PCS into building designs	High	Innovation, sustainability compliance, aesthetic-functional balance
Others				
Financial Institutions	Banks, green investment funds, insurers	Provide loans, assess risks, incentivise green buildings	Medium	ROI on green financing, risk mitigation
Academic Research Institutions	Universities, RCD centres	Conduct studies, develop materials, train professionals	Medium	Technological advancements, policy recommendations
CBOs s NGOs	Environmental groups, community advocates	Raise awareness, push for equitable cooling solutions	Low-Medium	Social equity, climate justice, public health
Private Sector Tech Providers	Cooling tech firms, material suppliers	Supply innovative materials and systems	Medium	Market expansion, commercialisation of solutions
Donors International Partners	UN agencies, World Bank, bilateral aid	Fund projects, provide technical expertise	High	Climate mitigation, SDG alignment, regional cooperation

Source: [7], [58], [145]

Critical to the implementation strategies are the involvement of the building and construction industry that encompasses the building materials, manufacturers and supplier’s segments as follows:

a. **Manufacturer Engagement** - There is a huge knowledge gap in numerous parts of Southeast Asia due to the lack of research, technology, and experts for PCS. This knowledge deficit affects material suppliers' ability to provide appropriate products and technical support for PCS applications.

b. **Material Categories and Applications** - Key building materials for PCS include thermal insulation, reflective materials, thermal mass components, and advanced glazing systems. These materials enable natural ventilation optimisation, solar heat gain control, and thermal comfort enhancement without mechanical systems. Suppliers must understand how their products contribute to overall PCS performance to effectively market solutions.

c. **Strategic Stakeholder Positioning and Supply Chain Integration** - Investment in research and development, technical training programmes, and certification processes will differentiate progressive suppliers in this growing market. Effective stakeholder engagement requires integrated supply chain approaches, connecting raw material producers, manufacturers, distributors, and end-users. Regional suppliers must adapt global technologies to local building practices, climate conditions, and economic constraints whilst maintaining quality standards essential for PCS effectiveness.

6.2 Stakeholder Mapping and Engagement Strategies

A comprehensive and extensive framework for understanding the complex ecosystem of actors involved in PCS deployment across ASEAN is critical. It is also critical to discuss how phased engagement, beginning with policy foundations, moving through market incentives, and culminating in widespread implementation, can systematically address both technical and behavioural challenges in PCS adoption. The analysis identifies key stakeholders, examines barriers and opportunities for engagement, and proposes strategies for strengthening coordination and collaboration.

6.2.1 Understanding Influence and Interest

For effective engagement, policymakers should understand the influence and interest of the various stakeholders. To prioritise engagement strategies, stakeholders are mapped based on their influence (ability to drive change) and interest (motivation to support PCS). **Figure 4** shows the influence and interest of the stakeholders.

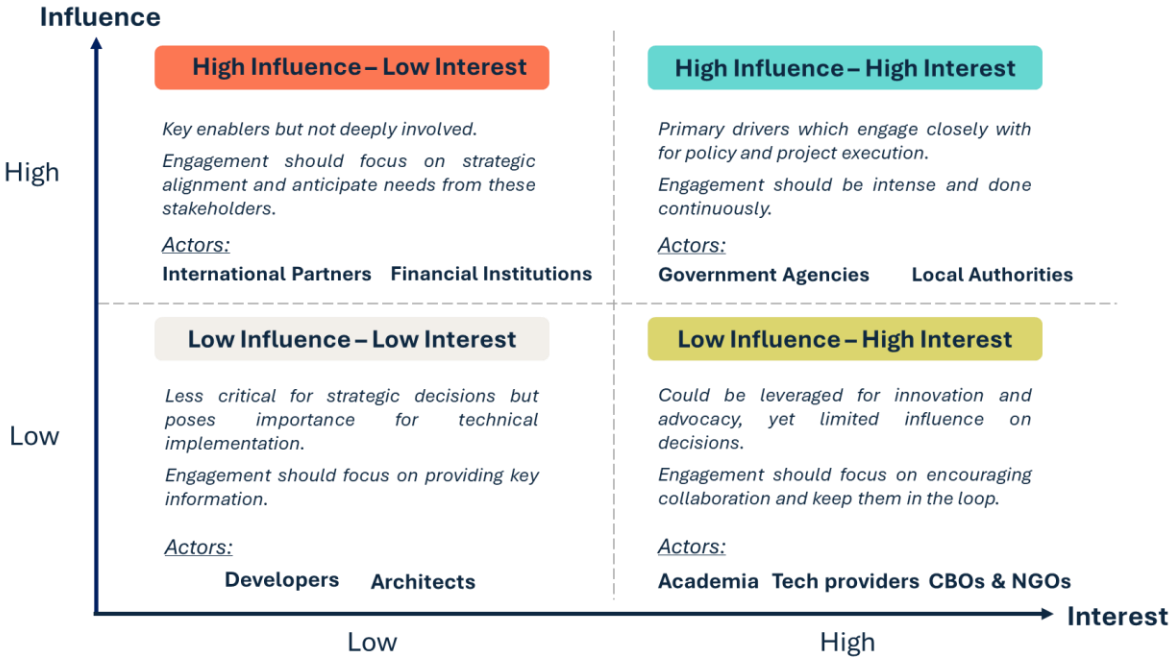


Figure 18. *Stakeholder Influence-Interest*

Source: ACE. All rights reserved.

In implementing PCS, policymakers and other stakeholders can identify the primary interest and focus areas of engagement as described in **Table 30** that consists of primary and secondary stakeholders based on influence.

Table 30. *Stakeholder Group and Primary Interest Areas*

Stakeholder Group	Key Organisations	Primary Interests Areas	Influence Level
Primary Stakeholders for Engagements			
Government Agencies	Ministry of Energy, Building Control Authorities, Urban Planning Departments	Policy implementation, energy security, climate targets	High
Construction Industry	Developers, Contractors, Architects, Engineers	Cost reduction, compliance, market competitiveness	High
Technology Providers	HVAC manufacturers, Building materials suppliers, Clean tech companies	Market expansion, product adoption, revenue growth	Medium-High
End Users	Commercial building owners, Residential developers, Industrial facilities	Operational cost savings, comfort, sustainability	Medium
Secondary Stakeholders for Engagements			

Stakeholder Group	Key Organisations	Primary Interests Areas	Influence Level
Financial Institutions	Development banks, Commercial banks, Investment funds	Risk assessment, return on investment, Environmental- Social- Governance compliance	Medium
Research Institutions	Universities, RCD centres, technical institutes	Innovation, knowledge creation, funding opportunities	Medium
International Organisations	ASEAN Centre for Energy, UN Environment, IEA	Regional cooperation, standards harmonisation, capacity building	Medium
Civil Society	Environmental NGOs, Consumer groups, Professional associations	Environmental protection, public awareness, advocacy	Low-Medium

Source: [146], [147], [148], [149]

6.3 Managing Challenges

The stakeholder analysis aims to provide a comprehensive and extensive framework for understanding current challenges to stakeholder engagements in PCS deployment across ASEAN. The analysis identifies and discusses key challenges and how they are going to impact the stakeholders involved. **Table 31** describes the technical challenges posed by various stakeholders.

***Table 31.** Technical Challenges for Stakeholders and Their Impact*

Technical Challenge	Impact Level	Affected Stakeholders	Description
Climate Adaptation	High	All stakeholders	High humidity and temperatures in the tropical ASEAN climate limit the effectiveness of some technologies
Knowledge Gaps	High	Construction industry, End users	Limited understanding of PCS design principles and implementation best practices
Technology Integration	Medium	Technology providers, Contractors	Difficulty integrating PCS with existing HVAC systems and building designs
Performance Verification	Medium	Government agencies, End users	Lack of standardised measurement and verification protocols for PCS performance
Design Constraints & Material Shortages	Medium	Architects, Planners Tech providers, Developers, Builders	Joint design workshops for compliance flexibility Regional material banks for bulk procurement

Source: [8], [148]

Likewise, institutional challenges are critical to be addressed in the efforts to implement PCS effectively. **Table 32** describes the institutional strategies that need attention from policymakers and other stakeholders.

Table 32. *Institutional Challenges and Recommended Actions*

Institutional Challenge	Impact Level	Root Causes	Recommended Actions
Fragmented Regulations	High	Varying building codes across AMS	Harmonise standards through ASEAN cooperation frameworks
Limited Policy Incentives	High	Lack of financial incentives for PCS adoption	Develop tax incentives, grants, and preferential lending
Weak Enforcement	Medium	Insufficient monitoring and compliance mechanisms	Strengthening building inspection and certification systems Digital compliance tracking (e.g., BIM-based audits)
Institutional Coordination	Medium	Poor communication between agencies	Establish inter-agency coordination committees

Source: [8], [33], [149]

Apart from technical and institutional challenges, the key for implementation is the financing gaps that limit the PCS strategy implementation. As **Table 33** describes, high upfront cost, lack of ROI, limited financing options, and market immaturity have been the key challenges.

Table 33. *Financial Challenges for Stakeholders*

Financial Barrier	Description	Impact on Stakeholders	Mitigation Strategies
High Upfront Costs	Initial investment in PCS design and materials	Developers, Building owners	Develop financing schemes, demonstrate long-term savings. Tiered subsidies (e.g., tax breaks for early adopters)
Limited Financing Options	Lack of specialised financing for PCS projects	All stakeholders	Create green bonds, concessional loans, and guarantee schemes
Uncertain ROI	Difficulty quantifying financial returns from PCS	Investors, Financial institutions	Develop standardised economic assessment tools

Financial Barrier	Description	Impact on Stakeholders	Mitigation Strategies
Market Immaturity	Limited supply chains and economies of scale	Technology providers, Contractors	Support market development through aggregated demand

Source: [8], [133], [139], [140]

6.4 Opportunities for Regional Collaboration

AMS increasingly recognise passive cooling's dual value: improved thermal comfort and reduced energy demand. Policy frameworks combining financial incentives with regulatory mandates are driving a growing market for climate-resilient building solutions. Sustained knowledge exchange and policy harmonisation across AMS remain essential to close implementation gaps and position ASEAN at the forefront of tropical climate-responsive design [140]. **Table 34** illustrates the potential areas of opportunities.

Table 34. *Potential Opportunities for Regional Collaboration*

Potential Opportunities	Key Areas
Capacity Building	▪ Develop climate-specific PCS design guidelines for tropical conditions ▪ Establish regional centres of excellence for PCS research and demonstration ▪ Create certification programmes for PCS technologies and practitioners ▪ Implement pilot projects showcasing successful PCS applications
Innovation	▪ Hybrid passive-active cooling systems optimised for ASEAN climates ▪ Smart building integration with IoT sensors for PCS optimisation ▪ Biomimetic cooling solutions inspired by regional flora and fauna ▪ Local material utilisation for thermal mass and building envelope solutions
Policy Integration	▪ Integrate PCS requirements into national building energy codes ▪ Align PCS promotion with Nationally Determined Contributions (NDCs) ▪ Include PCS in national energy efficiency action plans ▪ Develop green building rating systems that prioritise PCS
Investment	▪ Blended finance mechanisms combining public and private capital ▪ Carbon credit monetisation for PCS projects ▪ Energy service company (ESCO) models for PCS retrofits ▪ Regional development bank facilities for PCS infrastructure

Source: [8], [33]

For effective ASEAN-wide implementation of PCS, comprehensive stakeholder engagement is imperative. This requires seamless coordination across all parties through well-defined communication channels. **Table 35** presents a multi-channel communication framework designed to enhance stakeholder collaboration and information exchange.

Table 35. *Multi-Channel Communication Approach for Passive Cooling*

Channel	Target Audience	Key Messages	Frequency
Technical Workshops	Industry professionals, Government officials	Best practices, Standards, Case studies	Quarterly
Policy Dialogues	Government agencies, International Organisations	Policy frameworks, Regulatory alignment	Bi-annually
Industry Forums	Private sector, Technology providers	Market opportunities, Partnerships	Annually
Digital Platforms	All stakeholders	Information sharing, Collaboration	Ongoing

Source: [8], [147]

Survey Findings and Community Insights

The survey reached 168 respondents across ASEAN, including building occupants, architects, developers, engineers, and policymakers, with additional outreach to vulnerable groups. Their responses reveal how extreme heat is currently experienced, which cooling practices are in use, and what barriers prevent wider passive cooling adoption.

7.1 Perceptions and Awareness of Extreme Heat

Familiarity and Interest in Passive Cooling Strategies

Figure 21 highlights a consistent gap between awareness and action across all stakeholder groups. **Designers** show high familiarity but low implementation (73.1%), suggesting that knowledge alone is insufficient without enabling conditions such as incentives or reformed design processes. **Developers** present the starkest disconnect, with 66.7% reporting familiarity but no implementation, pointing to misalignment between passive cooling requirements and current development priorities. **Policymakers** show the highest implementation rate (38.1%), reflecting policy-driven engagement, though gaps remain. Among **building users**, uneven familiarity highlights the need for targeted education. The central challenge is not awareness but enabling stakeholders, particularly designers and developers, to translate knowledge into practice.

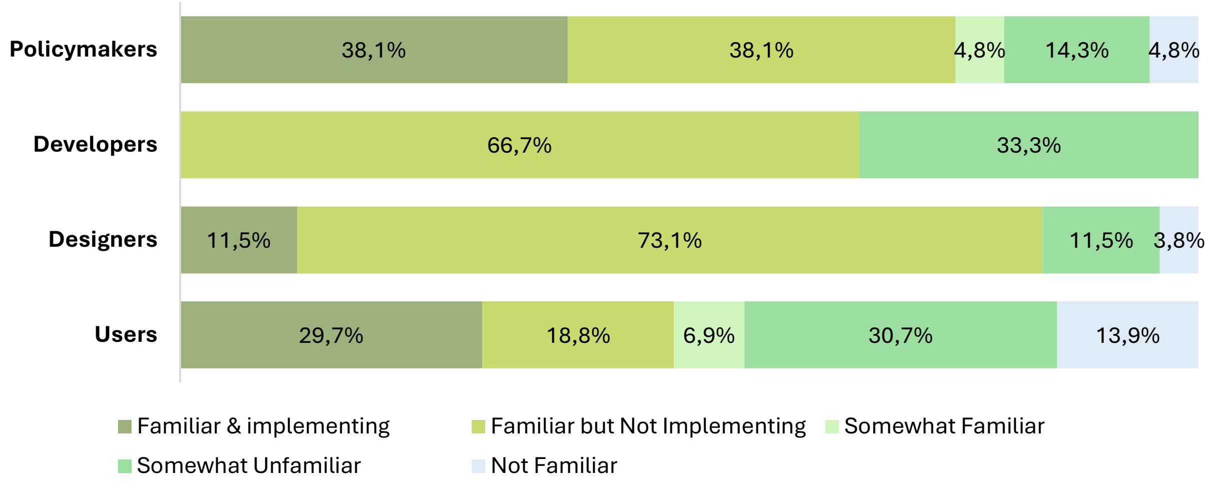


Figure 19. *Familiarity with Passive Cooling Strategies by Roles*
Source: Based on the ACE survey.
Question: Are you familiar with passive cooling strategies?

The data in **Figure 22** reveals strong interest in implementing PCS across all roles, though with varying degrees of enthusiasm. Users demonstrate broad receptiveness, suggesting that PCS is perceived as relevant and acceptable at the end-use level. Designers show particularly high enthusiasm, indicating that PCS is already well aligned with professional values and design intent. Policymakers also express a high level of interest, although the presence of neutral responses suggests that adoption may still be shaped by contextual or regulatory considerations rather than uniform commitment. Most notably, developers show unanimous interest, signalling a clear openness from the industry side. This broad interest signals a promising opportunity for wider implementation, provided that practical barriers are addressed.

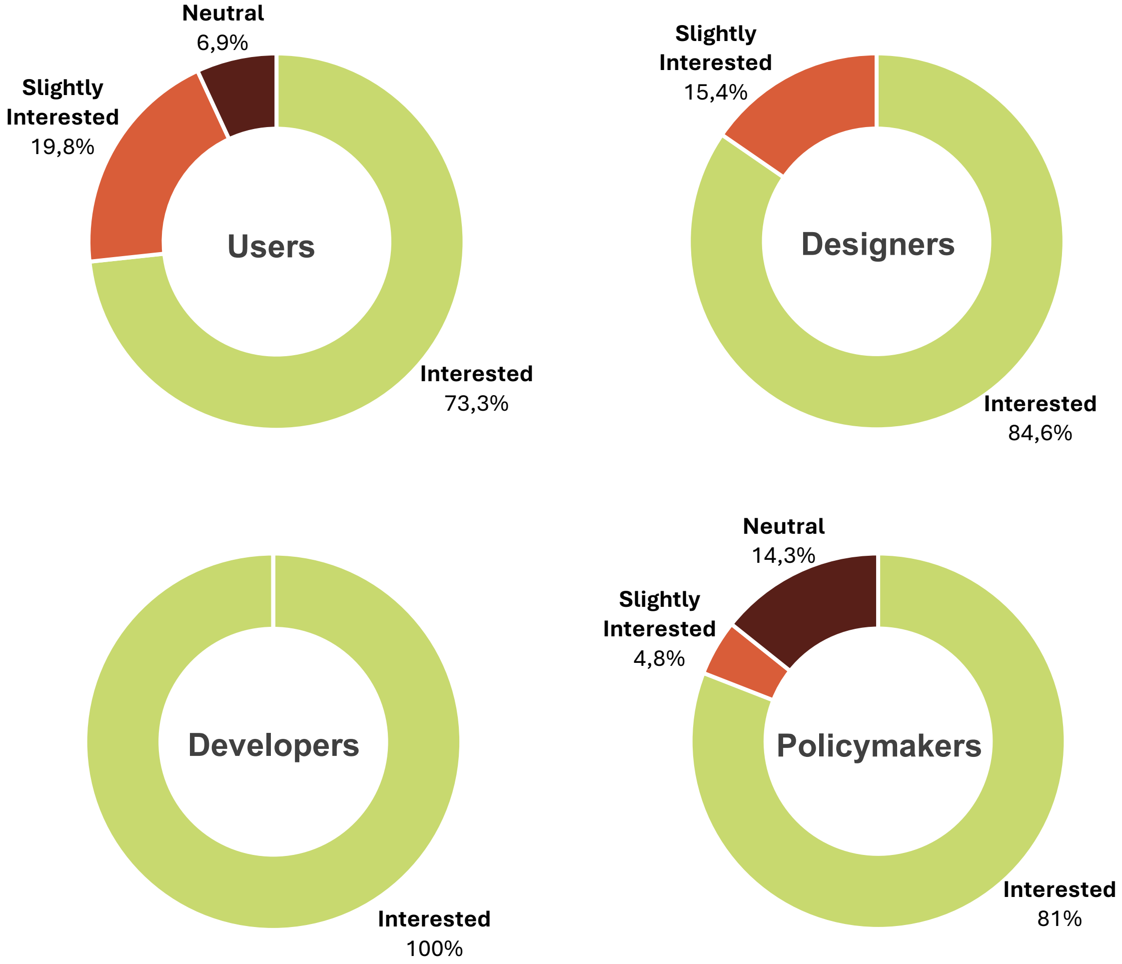


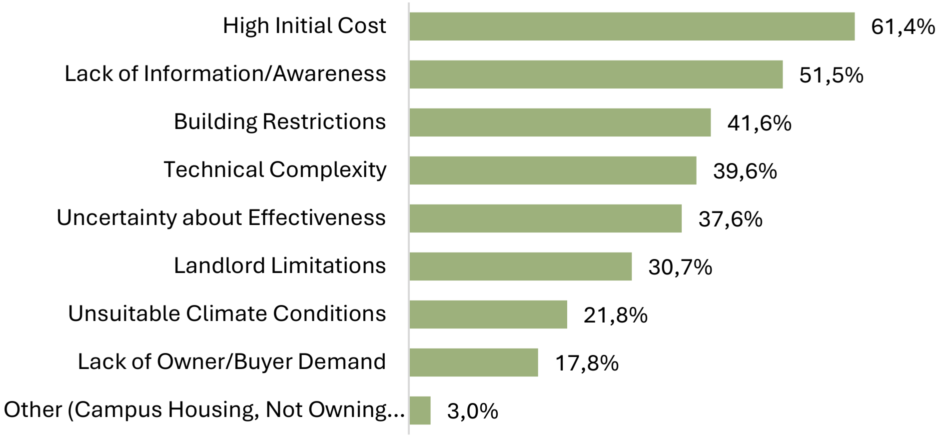
Figure 20. *Interest in Implementing Passive Cooling in the Future*

Source: Based on the ACE survey.

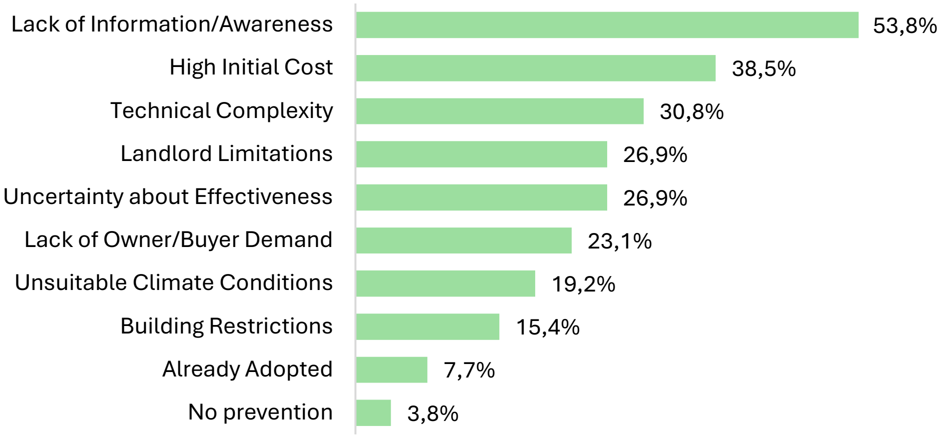
Question: Are you interested in implementing passive cooling in the future?

Figure 23 highlights the key barriers to PCS adoption across different roles, with a consistent pattern emerging across the value chain. High initial cost and lack of information or awareness are repeatedly identified as dominant constraints, suggesting that economic considerations and limited practical understanding continue to outweigh interest in adoption. For users and designers, knowledge gaps remain particularly influential, indicating that PCS is not yet sufficiently translated into accessible or actionable guidance. Developers' emphasis on cost, technical complexity, and climate suitability points to more structural and project-level challenges that affect feasibility and risk perception. Policymakers similarly recognise cost and awareness as central barriers, underscoring the need for stronger enabling frameworks.

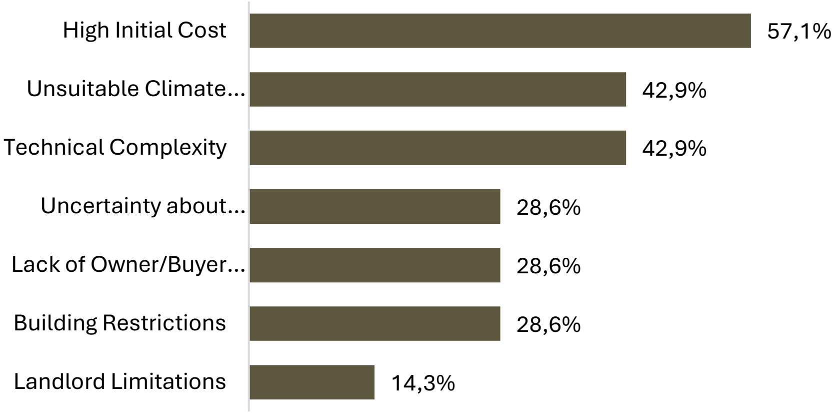
Building Users



Building Designers



Building Developers



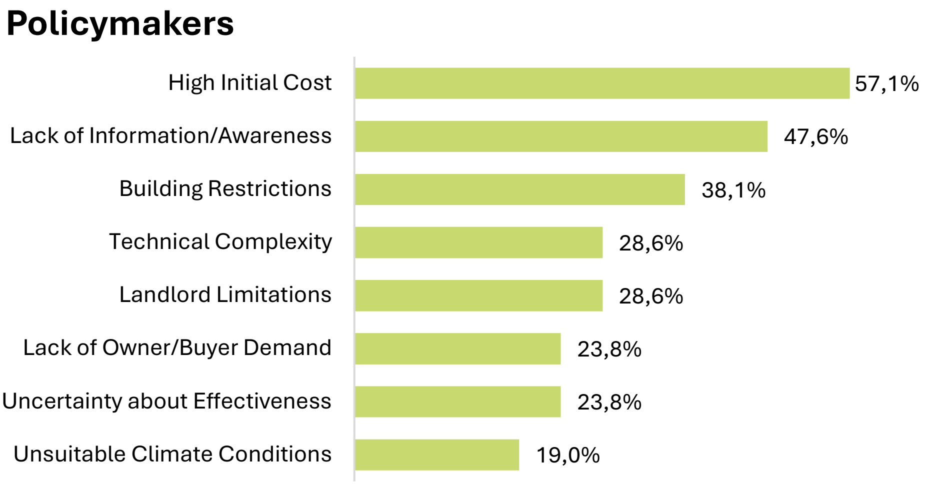


Figure 21. *Barriers to Passive Cooling Adoption by Roles*
Source: Based on the ACE survey.

7.2 Building Users' Perception (Community)

Awareness of Extreme Heat and Its Impact

A significant majority of the community has experienced extreme heat, with 86.13% reporting exposure at varying frequencies (see **Figure 24**). The frequency with which extreme heat is encountered suggests that it has become a normalised condition rather than an exceptional event. However, this widespread exposure is not matched by an equivalent level of preparedness. Despite frequent encounters with extreme heat, many respondents (54.6%) report not being prepared or only marginally prepared, pointing to a clear gap between lived experience and adaptive capacity. The sizeable neutral group further suggests uncertainty or limited understanding of what preparedness entails. These findings highlight an urgent need for public education and resources to improve heat readiness, as a large portion of the population remains vulnerable to extreme heat risks.

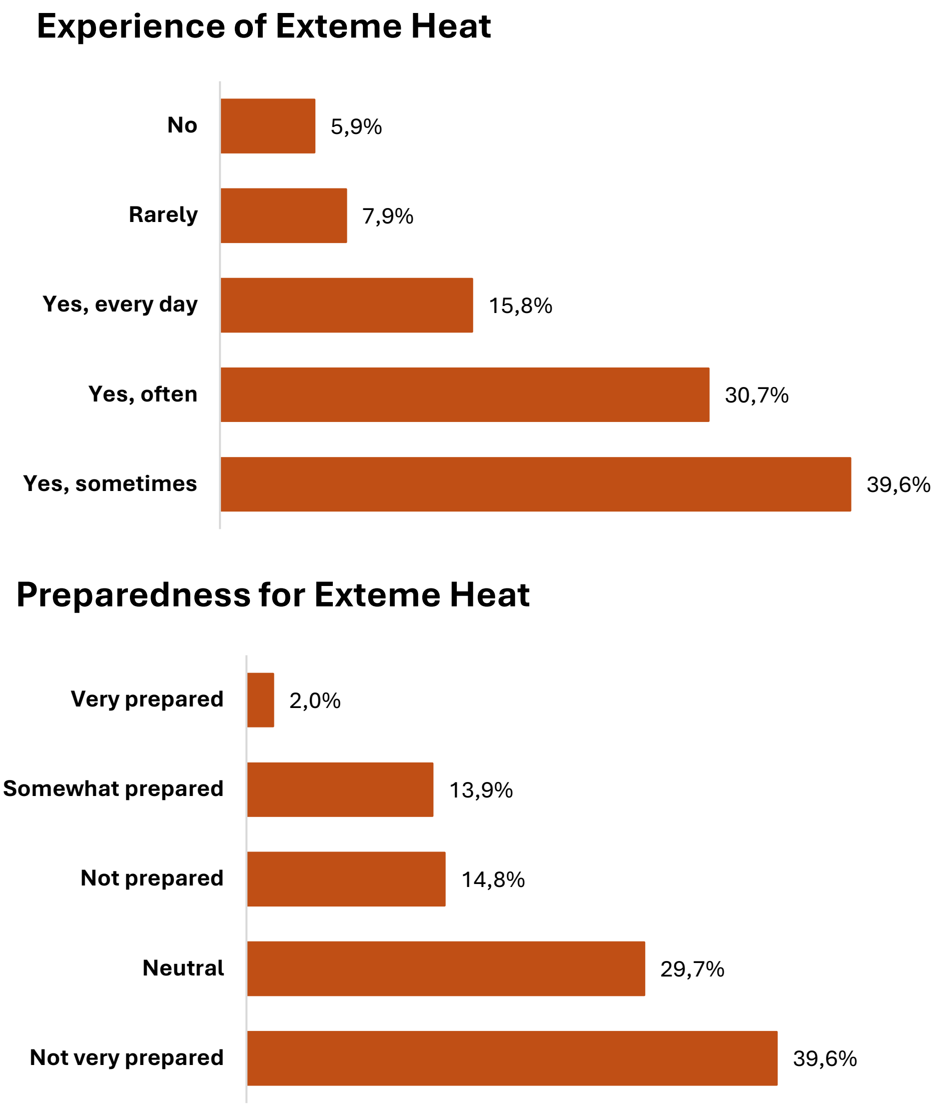


Figure 22. *Experience and Preparedness for Extreme Heat*
Source: Based on the ACE survey.

Figure 25 reveals the most common cooling methods used in homes and workplaces. Whilst homes display a more diverse mix of coping strategies, including fans, natural ventilation, and personal adjustments, workplaces appear far more standardised and constrained, relying heavily on mechanical cooling. The limited use of natural ventilation and behavioural adaptations in offices suggests institutional or comfort norms that prioritise uniform thermal conditions over flexibility. Notably, PCS features remain marginal in both environments, reinforcing the idea that cooling responses are largely reactive and technology-driven rather than design-led. The result suggests a strong preference for energy-intensive cooling solutions over passive or behavioural adaptations.

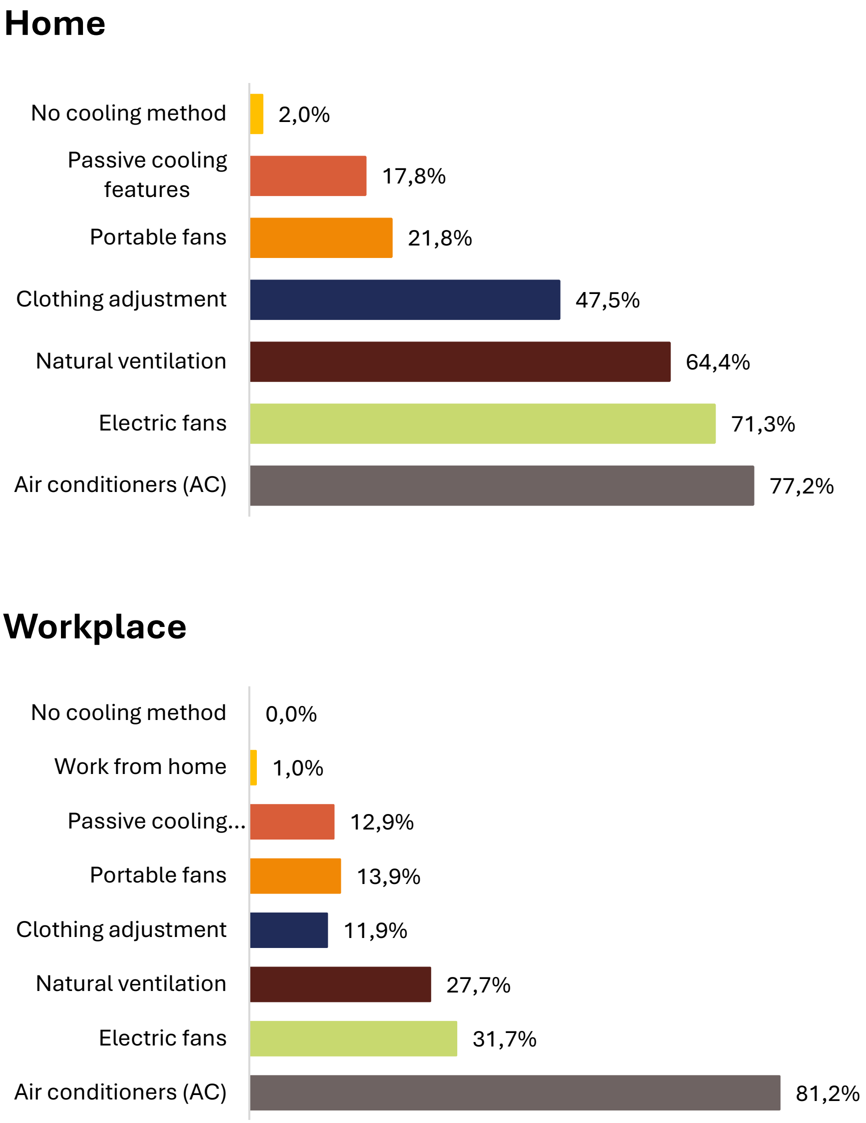


***Figure 23**. Current Cooling Methods Used*

Source: Based on the ACE survey.

It is critical to note the concerning lack of accessible cooling spaces, with 56.44% of respondents reporting no availability of community cooling centres in their area. Only 25.74% confirmed having such spaces, whilst 17.82% were unsure, suggesting limited awareness or inconsistent access (refer to **Figure 26**). With over half of the population lacking these critical resources, and nearly three-quarters either without them or uncertain, the findings underscore an urgent need to expand and promote cooling infrastructure, particularly in heat-vulnerable communities. This gap highlights a key area for intervention to enhance public resilience during extreme heat events.

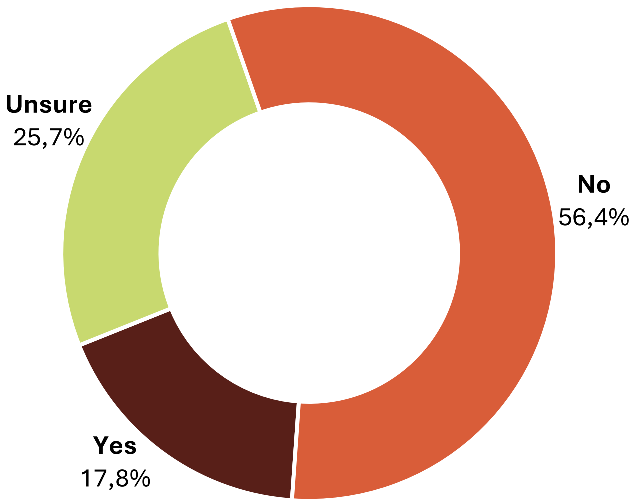


Figure *24*. Availability of Cooling Spaces/Community Centres
Source: Based on ACE survey.
Question: Are there designated cooling spaces or community centres in your area that provide relief during heatwaves (e.g. green space, park, or garden)?

Figure 27 highlights the key perceived benefits of implementing PCS is driven primarily by tangible, near-term benefits. Lower electricity bills emerge as the most significant advantage, reflecting strong economic motivation among respondents. Improved occupant comfort and reduced environmental impact further underscore that PCS is valued not only for cost savings but also for enhancing well-being and supporting sustainability objectives. The recognition of reduced cooling system maintenance and the potential to extend system lifespan suggests that respondents view PCS as contributing to better long-term building performance. These findings suggest that PCS is viewed not only as an energy-saving measure but also as a way to improve long-term building performance and occupant satisfaction.

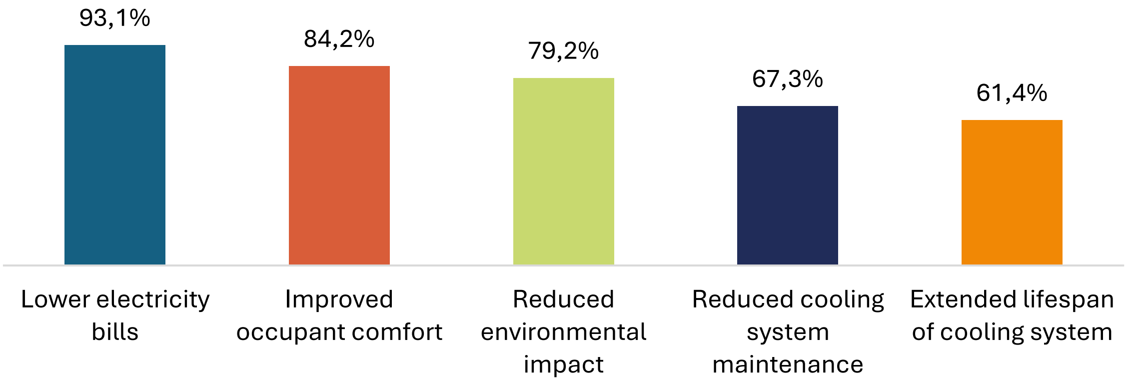


***Figure 25.** Perceived Benefits of Implementing Passive Cooling Strategies*
Source: Based on the ACE survey.

7.3 Impact

The data reveal that extreme heat leads to significant increases in electricity costs for most households (see **Figure 28**). A majority (60.4%) report a 10–25% rise in their usual bills, whilst nearly 30% face a steeper 26–50% increase. A smaller but still notable portion (7.92%) experiences a 51–75% surge, and 1.98% endure a drastic 76–100% hike. These figures highlight the financial strain of extreme heat, with 90% of respondents seeing at least a 10–50% jump in electricity expenses, emphasising the need for energy-efficient cooling solutions and financial support for vulnerable households.

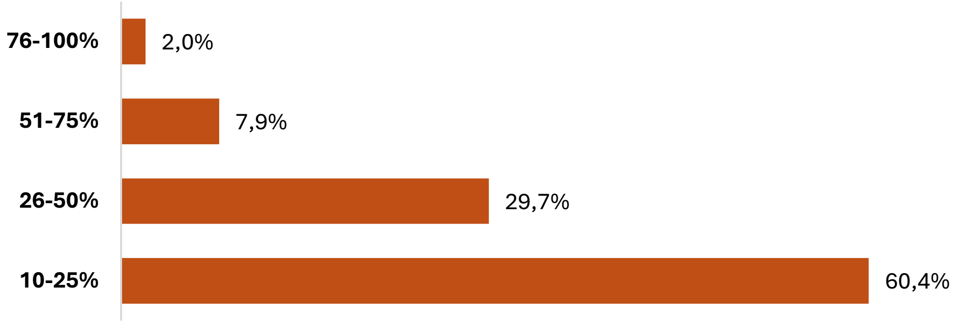


Figure 26. *Electricity Cost Increase Due to Extreme Heat*
Source: Based on the ACE survey.
Question: How many percent is the increase in your electricity costs during the heatwave compared to the average?

Figure 29 highlights the health and lifestyle impact of extreme heat, showing that its effects extend well beyond discomfort. The high incidence of sleep disruption and increased household expenses indicates that extreme heat directly affects daily functioning and financial stability. Reduced productivity at work or school suggests broader economic and social implications, whilst the presence of reported health issues points to tangible risks rather than perceived inconvenience. The very small share of respondents reporting no impact reinforces that these challenges are widely shared across the community.

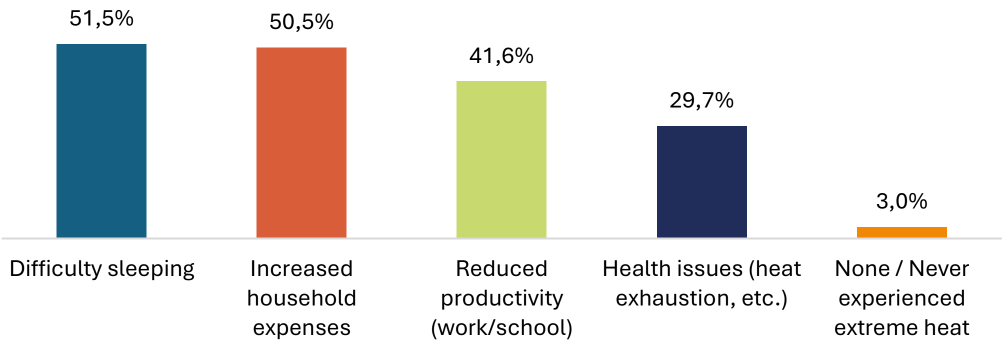


Figure 27. *Impact on Health*
Source: Based on the ACE survey.

7.4 Financial Awareness and Preparedness to Implement Passive Cooling Strategies

The survey data on financial awareness (financial options) among building users reveals that a majority (55.4%) are not aware of the availability of financial options on PCS (refer to **Figure 30**). Only a small portion of the users have awareness (17.9%), with the larger portion of the building users recording not sure (26.7%). Strengthening the availability of financial options for PCS installations is critical to help bridge the gap, ensuring more informed decision-making and higher adoption rates for PCS installations.

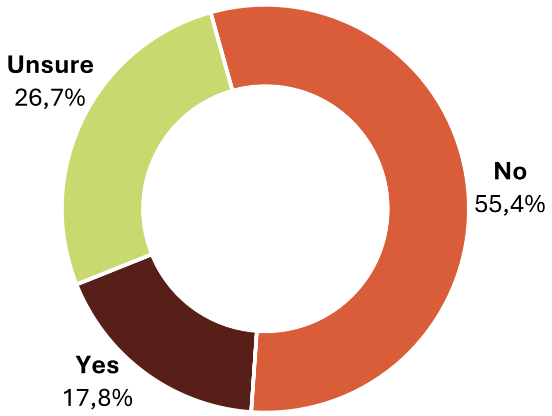


Figure 28. *Financial Awareness Among Building Users*

Source: Based on a survey.

Question: Are you aware of any financing options for passive cooling installations?

The survey results indicate strong interest in participating in future passive cooling research or pilot programs, with 68.32% of respondents answering "Yes" and 31.68% responding "No" (see **Figure 31**). This clear majority willingness suggests a high level of engagement and openness to exploring PCS solutions. The significant interest (nearly 70%) presents a valuable opportunity for researchers and policymakers to leverage this enthusiasm when designing and implementing future initiatives. The nearly 2:1 ratio in favour of participation demonstrates a solid foundation of public support that could help accelerate the adoption and testing of PCS technologies. For the nearly one-third who declined, further investigation into their reasons (e.g., lack of time, scepticism, or insufficient information) could help identify potential barriers to broader participation. Overall, these findings are encouraging for the advancement of PCS.

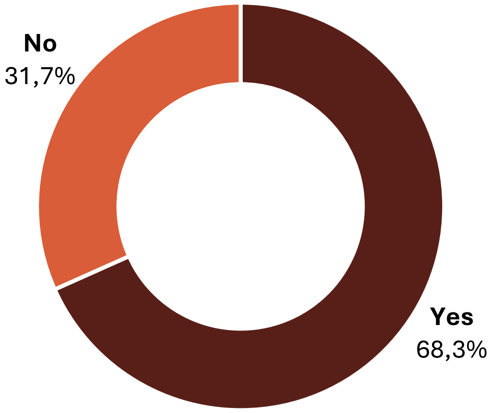


Figure 29. *Interest in Participating in Future Passive Cooling Programmes*
Source: Based on ACE Survey.
Question: Would you be interested in participating in future research or pilot programmes on passive cooling?

Figure 32 shows respondents' expectations and tolerance regarding budget increases for adopting PCS. The concentration of responses in the lower increase ranges suggests that most households are only willing to accept modest budget increases, indicating a relatively low threshold for upfront or additional expenditure. The drop in acceptance beyond the mid-range implies that willingness declines quickly as costs rise, even if long-term benefits are recognised. Whilst a small share is prepared to accommodate higher increases, the overall pattern suggests that cost sensitivity remains high. These findings indicate that affordability expectations could significantly shape adoption, underscoring the importance of cost-effective designs, phased implementation, or financial incentives to align PCS solutions with household willingness to pay.

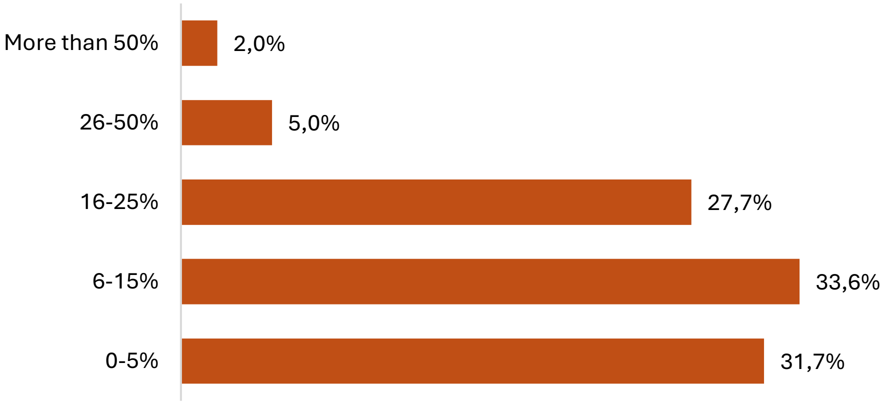


Figure 30. *Budget Increase Due to Passive Cooling Strategies*
Source: Based on ACE Survey
Question: What would be your maximum percentage of budget increase for passive cooling in your residential property?

Strong interest in PCS is seen if financial barriers are addressed. A majority (57.43%) say they would definitely adopt these strategies if funding were available, whilst another 40.59% remain open to the idea, depending on cost (refer to **Figure 33**). Only 1.98% prefer sticking to their current cooling methods. This suggests that 98% of respondents are at least somewhat willing to transition to PCS with proper financial support, highlighting a significant opportunity for policies or incentives to make these energy-efficient solutions more accessible.

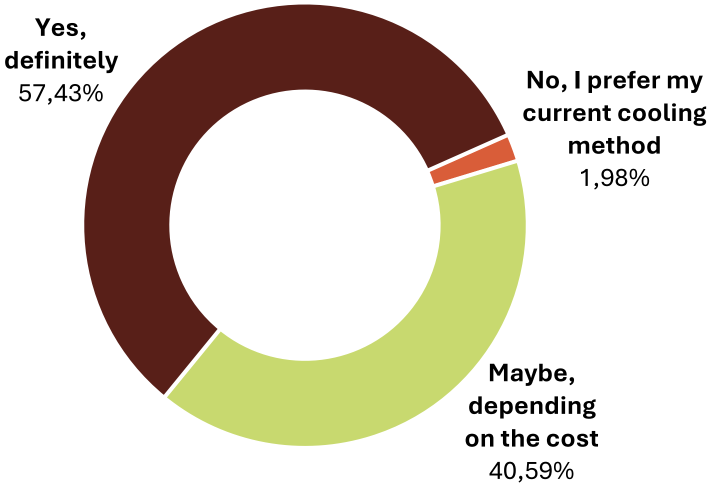


Figure 31. *Readiness to Implement Passive Cooling if Finance is Available*

Source: Based on ACE Survey.

Question: Would you consider utilising passive cooling strategies to retrofit your building, if financial assistance were available?

Figure 34 indicates that interest in PCS is strongly conditioned by the availability of financial support rather than by resistance to change. The large share of respondents who would definitely adopt PCS if funding were available shows that cost is a decisive factor in moving from interest to action. The additional group that remains open but cost-dependent further reinforces that adoption is largely an economic decision. The very small proportion preferring to retain existing cooling methods suggests minimal behavioural inertia. Overall, the findings imply that demand for PCS already exists, and that targeted financing mechanisms or incentives could rapidly unlock uptake by addressing the primary financial barrier.

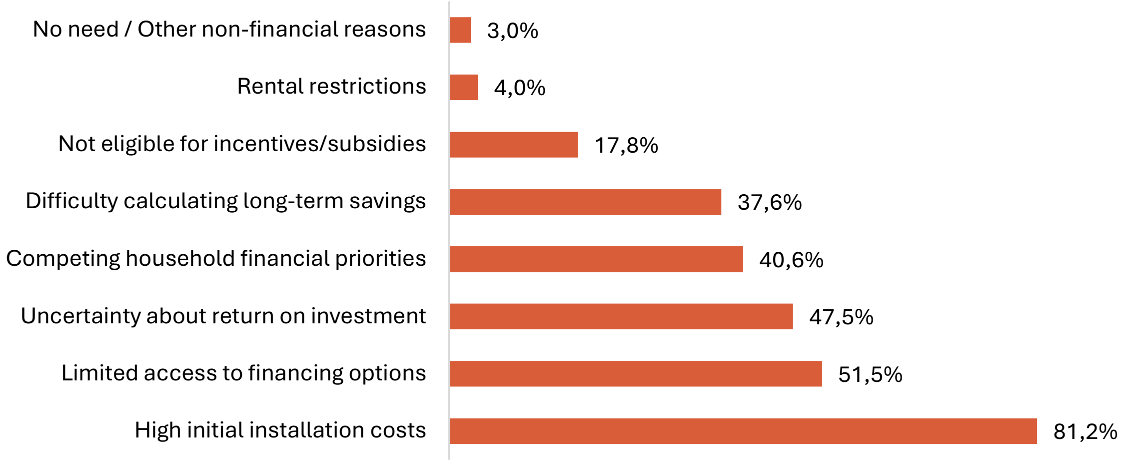
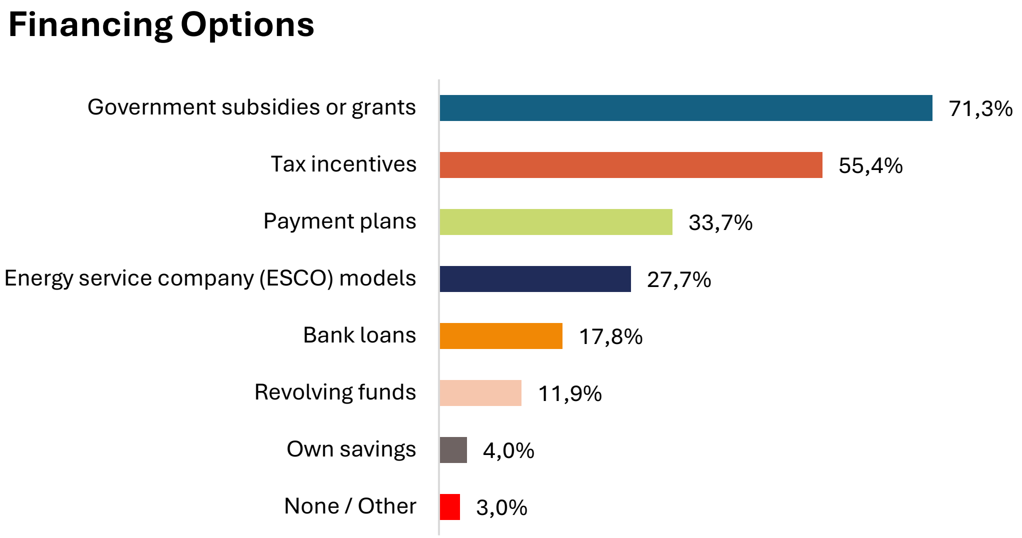


Figure 32. *Financial Barriers to Adopting Passive Cooling*
Source: Based on ACE Survey.

Figure 35 highlights that passive cooling adoption requires both financial and non-financial support. Subsidies and tax incentives are the most preferred instruments, indicating that upfront cost remains the primary barrier, whilst interest in payment plans and ESCO models reflects openness to alternative financing. Equally, the strong demand for clear guidelines, energy audits, and technical assistance signals that regulatory clarity and practical support are just as critical as financial incentives to drive adoption.



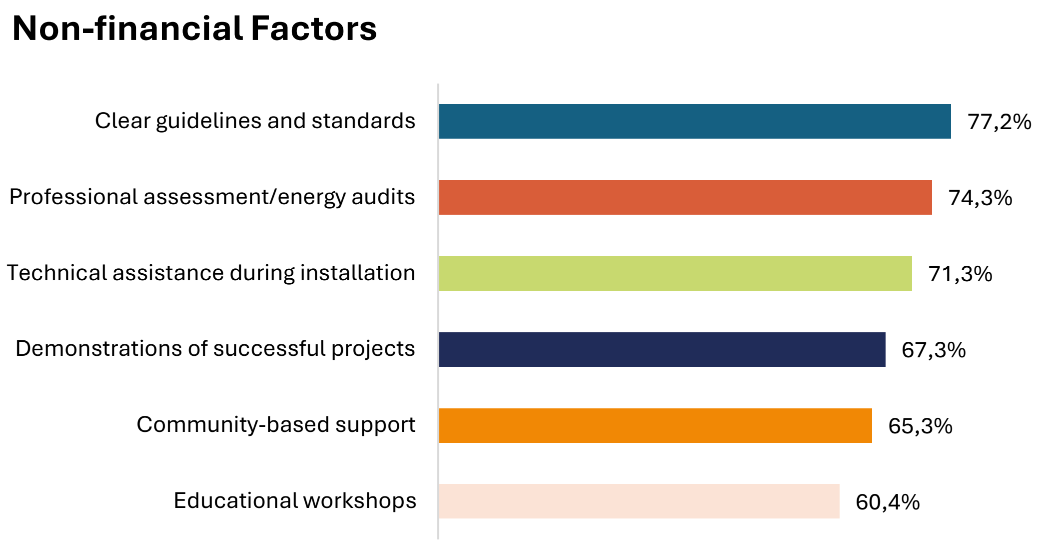


Figure 33. *Preferred Financing and Non-Financial Options for Passive Cooling Adoption*

Source: Based on ACE Survey.

7.5 Building Designers

Building designers face varying levels of accessibility for different sustainable building materials (see **Figure 36**). Bamboo-based materials and timber are the most readily available, with 38.46% and 34.62% of respondents reporting easy access, respectively. However, their availability is inconsistent, as an additional 26.92% to 38.46% note that they are only sometimes or rarely accessible. In contrast, traditional roofing materials such as wood shingles and thatched roofs are reported as rarely available or not available at all by a majority, pointing to declining market presence or limited commercial supply.

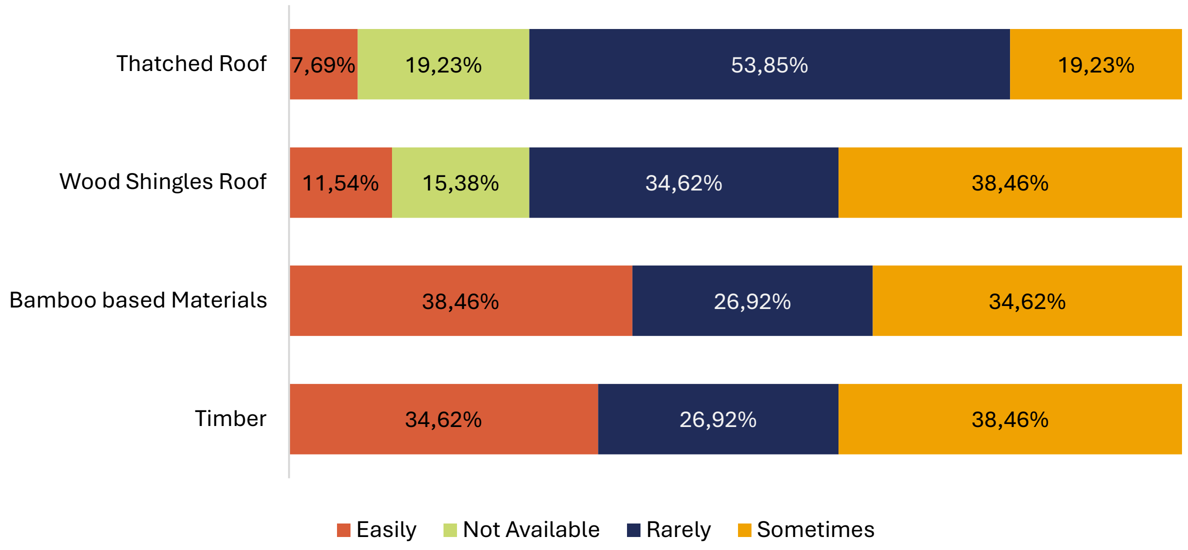


Figure 34. *Sustainable Material Availability*

Source: Based on ACE Survey.

In recent building projects, PCS have been implemented across multiple design layers to enhance thermal comfort sustainably (refer to **Table 36**). Building orientation, high ceilings, and green open spaces optimise natural airflow and shading. Facade design combines insulated walls, Low-E glass, architectural shading, and vertical gardens to minimise heat gain, whilst roofs employ insulation, reflective coatings, and green roofs to dissipate heat. Natural ventilation, radiant cooling, and enthalpy recovery reduce mechanical system reliance. Together, these layered measures create a low-energy cooling approach adaptable to diverse climates.

***Table* 36.** *Passive Cooling Design Strategies*

Overall Design Strategy	HVAC Strategy	Building Facade Strategy	Roof Strategy
▪ Landscaping or green open space ▪ Building orientation to north-south ▪ High floor-to-ceiling ratio ▪ Air sealing (for buildings that are air conditioned)	▪ Natural ventilation ▪ Radiant cooling ▪ Evaporative cooling ▪ Integrated enthalpy recovery and cooling with high efficiency Specific Electric Power Rate	▪ Wall insulation ▪ Low-emissivity (Low-E) glass ▪ Architectural shading ▪ Reducing WWR ▪ Light-coloured or reflective wall surfaces ▪ Mass composition, secondary skin, vertical garden ▪ Underground insulation (where applicable), air tightness, thermal bridge reduction	▪ Roof insulation ▪ Green roof ▪ Reflective roof ▪ Ventilated roof

Source: Based on ACE Survey.

Question: What are passive cooling strategies that you have applied in your recent building projects?

The primary obstacles to implementing PCS stem from client resistance (53.8%) and budget constraints (46.2%), reflecting scepticism or financial prioritisation of conventional systems (see **Figure 37**). Knowledge gaps and material availability further constrain uptake, pointing to limitations in both professional capacity and supporting supply chains. Technical limitations and perceived market demand appear as secondary barriers, indicating that PCS is still not considered a standard expectation in projects. Only 3.8% report no challenges, underscoring the widespread need for advocacy, cost-effective solutions, and skill-building to mainstream PCS in design practice.

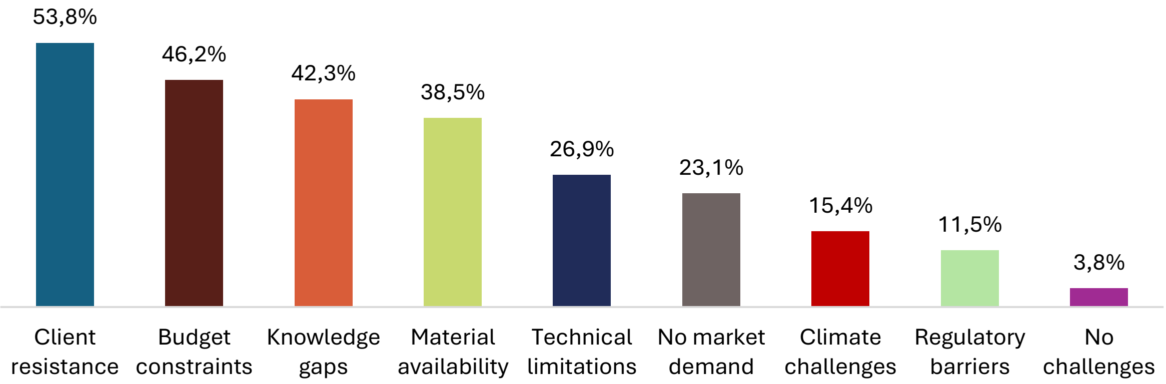


Figure 35. *Challenges in Designing with Passive Cooling Strategies*
Source: Based on ACE Survey.

Energy modelling software (73.1%) is the most widely used tool for assessing PCS savings, highlighting its importance in predictive design (refer to **Figure 38**). However, reliance on third-party consultants (53.8%) suggests that many practitioners still depend on external expertise. Whilst post-occupancy evaluations (42.3%) are moderately adopted, their lower frequency compared to modelling indicates a potential gap in real-world performance verification. The use of rule-of-thumb estimates (42.3%) and manual calculations (38.5%) reflects a pragmatic mix of quick approximations and manual assessment. Notably, 7.7% do not evaluate savings at all, signalling a need for broader adoption of performance tracking.

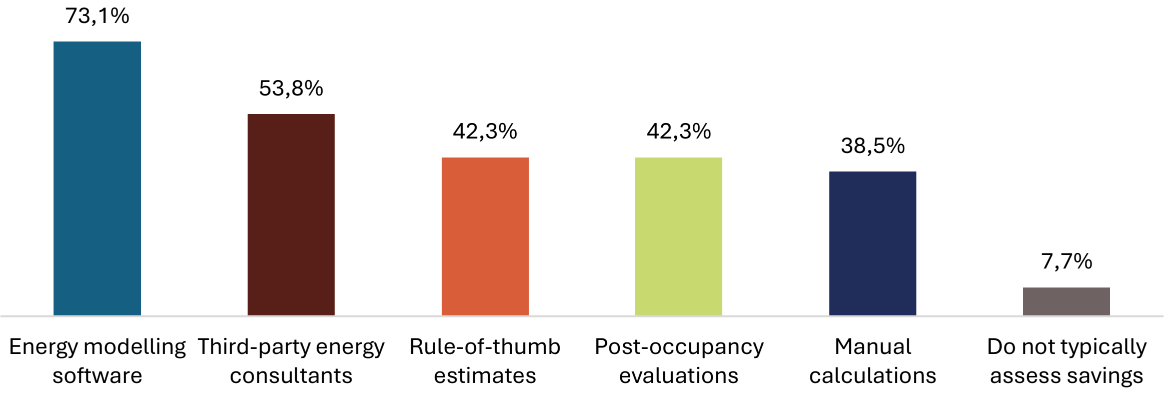


Figure 36. *Methods in Assessing Energy Savings from Passive Cooling Designs*
Source: Based on ACE Survey.

The survey reveals strong demand for information on PCS, financing options, and energy efficiency programmes, highlighting a clear focus on both design knowledge and financial feasibility (see **Figure 39**). The additional interest in energy savings and installation services suggests a focus on practical implementation. The very limited attention to more specialised topics, such as thermal comfort analysis, implies that respondents prioritise actionable guidance over technical depth. The frequent combination of PCS information with financing and efficiency programmes further suggests that adoption is viewed as a bundled decision, where technical knowledge and economic feasibility must be addressed together.

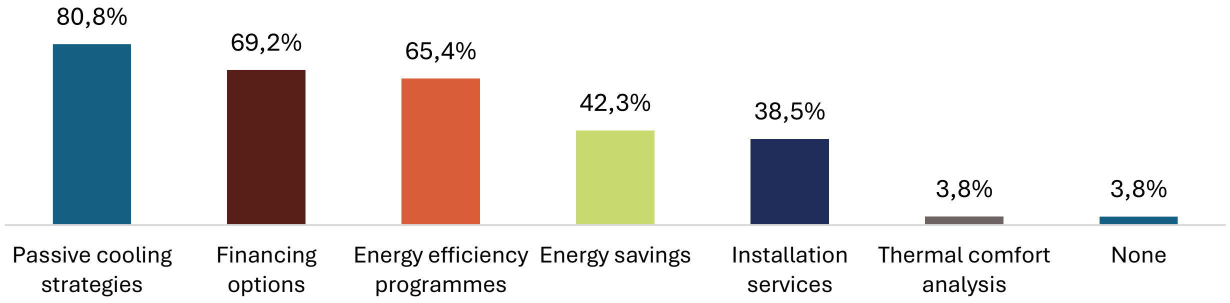


Figure 37. *Information Needed*
Source: Based on ACE Survey.

7.6 Building Developers

The data reveals that improving indoor comfort (83.3%) is the primary driver for investing in PCS, reflecting a strong focus on occupant wellbeing (refer to **Figure 40**). Environmental considerations also play a strong role, reflecting growing awareness of sustainability in building decisions, whilst reduced electricity bills remain an important but secondary factor. The more limited emphasis on health benefits and building longevity suggests that these co-benefits are recognised but not yet central to decision-making. The low influence of property value increase indicates that PCS is not currently perceived as a market differentiator.

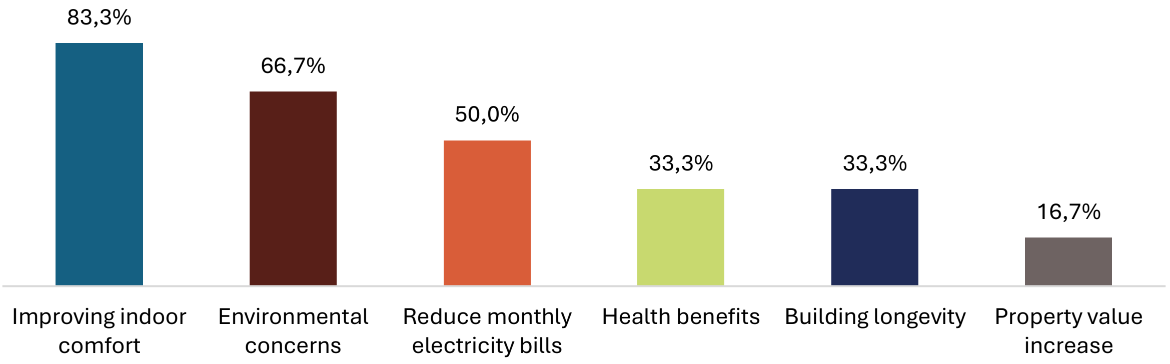


Figure 38. *Key Factors Influencing Investment in Passive Cooling Strategies*
Source: Based on ACE Survey.

Survey among building developers show a cautious yet pragmatic approach to budgeting for PCS (see **Figure 41**). The willingness of most respondents to accommodate a modest budget increase suggests openness to investment when costs are predictable and contained. At the same time, the sizeable group is only comfortable with minimal increases, which underscores strong cost sensitivity and risk aversion within development decisions. The limited readiness to accept higher cost increases indicates that larger investments are likely to be confined to selective or flagship projects rather than mainstream practice.

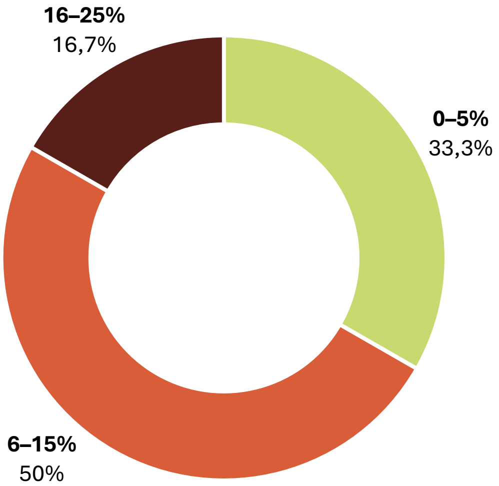


Figure 39. *Maximum Budget Increase for Passive Cooling Implementation*
Source: Based on ACE Survey.

Figure 42 below indicates that passive design and green building features are increasingly prominent in marketing strategies, with 66.7% of respondents promoting them prominently, reflecting their growing value as competitive differentiators. However, 16.7% still relegate these features to secondary status, whilst another 16.7% do not highlight them at all, suggesting lingering hesitancy in some market segments. This split underscores a transitional phase where sustainability is becoming mainstream but has yet to be universally prioritised. To accelerate adoption, clearer evidence of return on investment and consumer demand could help persuade lagging stakeholders to elevate green features in their marketing.

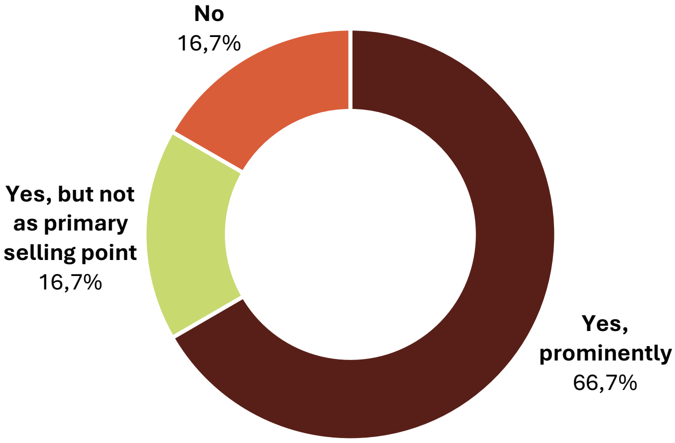


Figure 40. *Promotion of Passive Design/Green Building Features in Marketing Materials*
Source: Based on ACE Survey.

The survey reveals a unanimous demand (100%) for cost-benefit analyses, underscoring the critical need for clear financial justification when investing in PCS solutions. Additionally, technical details and case studies (both 83.3%) are highly sought after, demonstrating a reliance on both empirical evidence and practical precedents to inform decision-making (refer to **Figure 43**). A significant majority also require implementation guidelines and financing options (66.7% each), highlighting the importance of accessible support for project execution and funding. These findings suggest that to drive adoption, stakeholders must provide transparent ROI projections, region-specific technical resources, and step-by-step guidance bridging the gap between theory and real-world application.

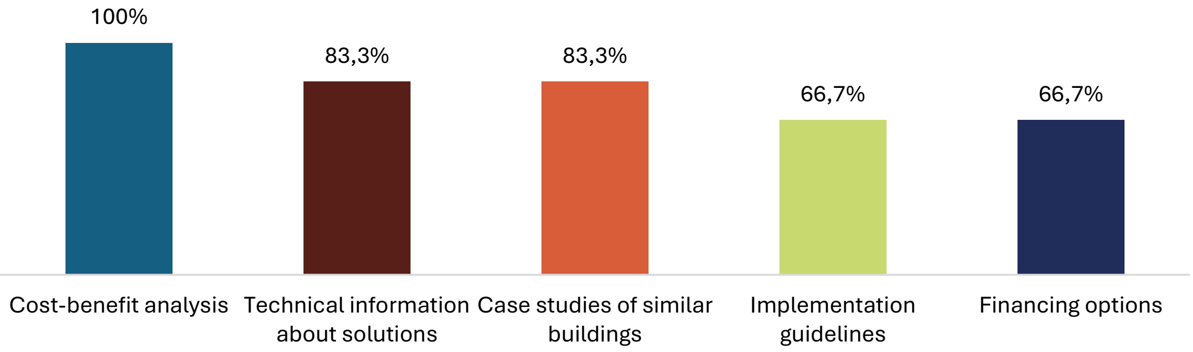


Figure 41. *Critical Information Needs for Passive Cooling Investments*
Source: Based on ACE Survey.

An overwhelming 83.3% of building developers would definitely adopt PCS if financial incentives were available, signalling strong market readiness for policy intervention (see **Figure 44**). However, awareness gaps persist, with 66.7% remaining unaware of existing financing options, revealing a critical disconnect between demand and accessibility (see **Figure 45**).

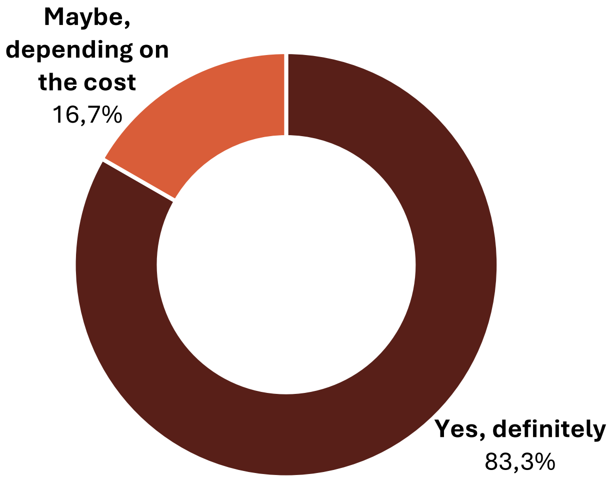


Figure 42. *Willingness to Adopt Passive Cooling with Financial Incentives*
Source: Based on ACE Survey.

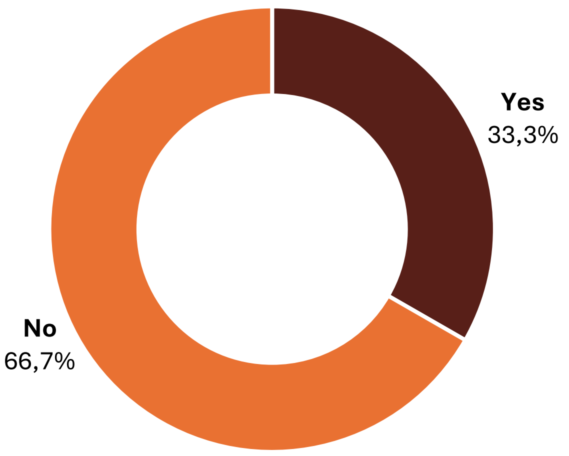


Figure 43. *Awareness of Financing Options for Passive Cooling*
Source: Based on ACE Survey.

The survey highlights a clear consensus on addressing extreme heat through education and financial incentives, reflecting a preference for practical, near-term measures to support PCS uptake (see **Figure 46**). The emphasis on public awareness and targeted funding suggests recognition that behavioural change and affordability are central to heat resilience. At the same time, the call for stricter urban planning policies and passive design guidelines points to the need for more structural, long-term solutions to embed resilience into the built environment. The smaller share favouring community-led adaptation indicates interest in localised approaches, though these are seen as complementary rather than standalone.

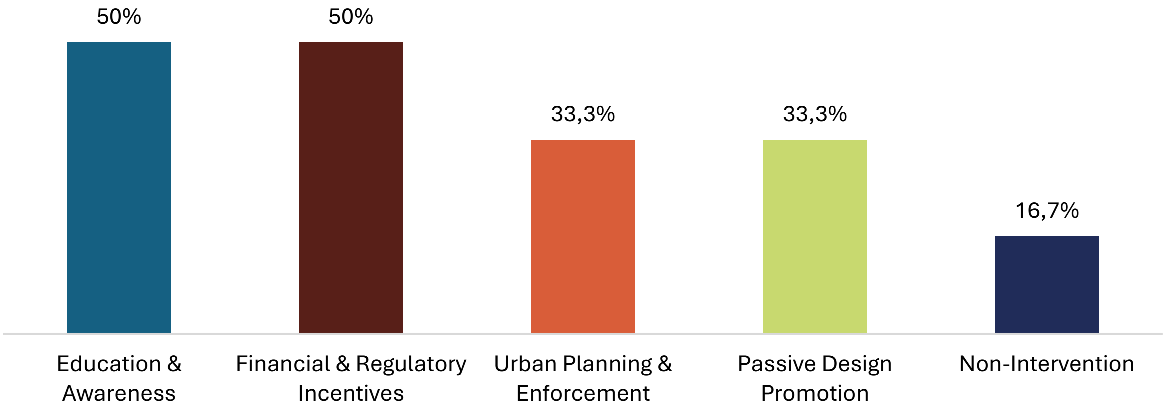


Figure 44. *Policy Recommendations for Extreme Heat Preparedness*
Source: Based on ACE Survey.

Financial support mechanisms and practical implementation guidance are equally critical for mainstreaming PCS (see **Figure 47**). The universal demand for government subsidies and the strong preference for tax incentives highlight expectations of firm public-sector leadership in reducing upfront cost barriers. At the same time, the emphasis on project demonstrations and technical or educational support indicates that stakeholders need visible proof and hands-on guidance to build confidence and capability. The interest in ESCO models and simplified permitting further suggests that private-sector engagement and regulatory efficiency can play a supporting role.

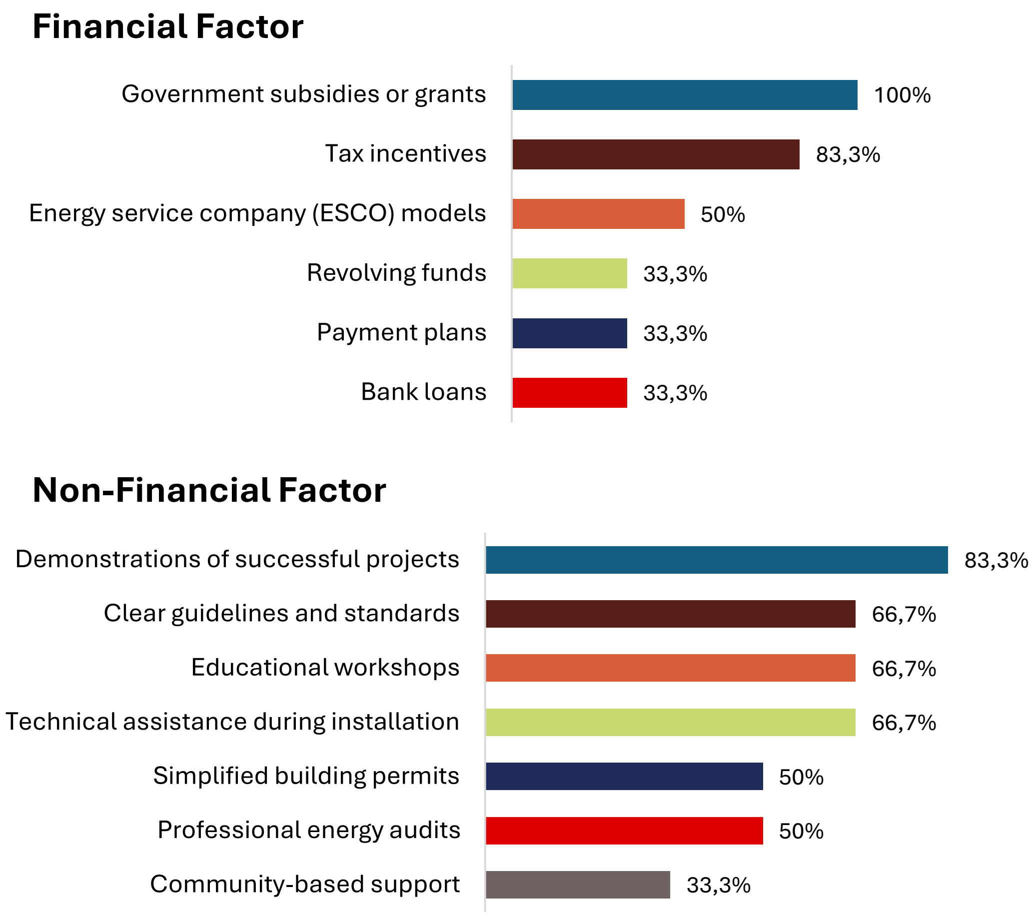


Figure 45. *Preferred Financing and Non-Financial Options for Passive Cooling Strategies*
Source: Based on ACE Survey.

7.7 Policymakers

The survey results reveal a fragmented policy landscape regarding PCS and energy-efficient building incentives. Whilst 28.57% of respondents report comprehensive policies and an equal share are actively developing them, significant gaps remain (see **Figure 48**). Jurisdictions with limited or no policies highlight uneven commitment across the region. Overall, ASEAN is in a transitional phase, and structured knowledge-sharing between advanced and developing jurisdictions could accelerate progress.

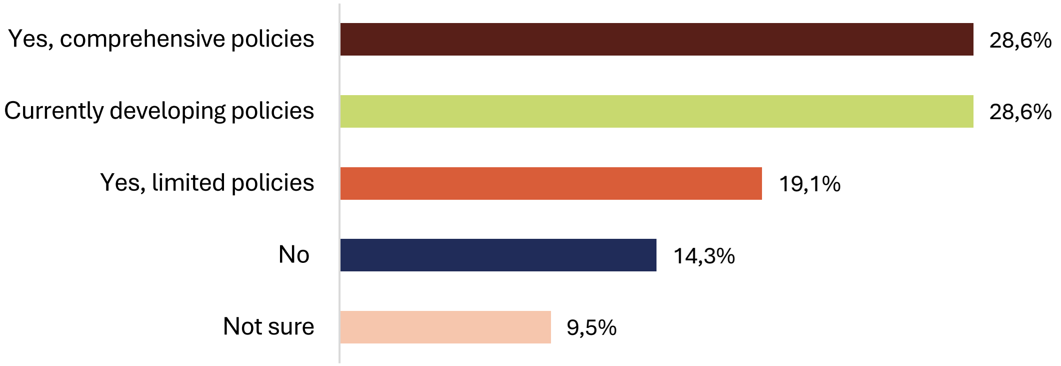


Figure 46. *Policies and Incentives for Passive Cooling*
Source: Based on ACE Survey.
Q: Does your jurisdiction have policies or incentives for passive cooling or energy-efficient buildings?

Figure 49 indicates that technical assistance is the most preferred incentive mechanism, indicating that implementation capacity rather than funding alone is the primary constraint. Subsidies, education programmes, and tax rebates rank closely behind, reflecting equal weight placed on financial relief and awareness-building. Expedited permits and low-interest loans receive moderate support, whilst award certificates and complex fiscal schemes are the least prioritised, suggesting policymakers favour practical, accessible support over symbolic recognition.

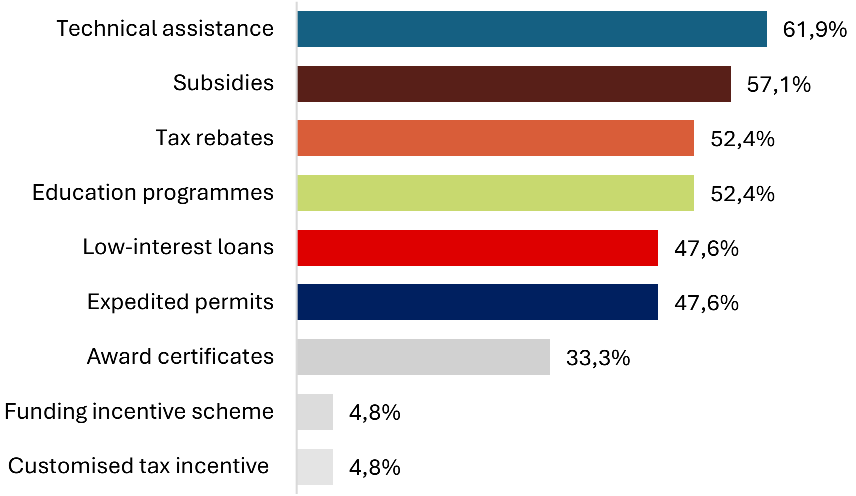


Figure 47. *Effectiveness of Incentive Mechanism*
Source: Based on ACE Survey.
Question: What types of incentives would be most effective for promoting passive cooling?

From the policymaker's perspective, only 5% of policymakers report extensively available cooling centres, whilst 45% describe limited availability and 30% report none at all. This points to a significant gap in heat relief infrastructure and underscores the urgent need for both investment in cooling facilities and improved public communication about existing resources (see **Figure 50**).

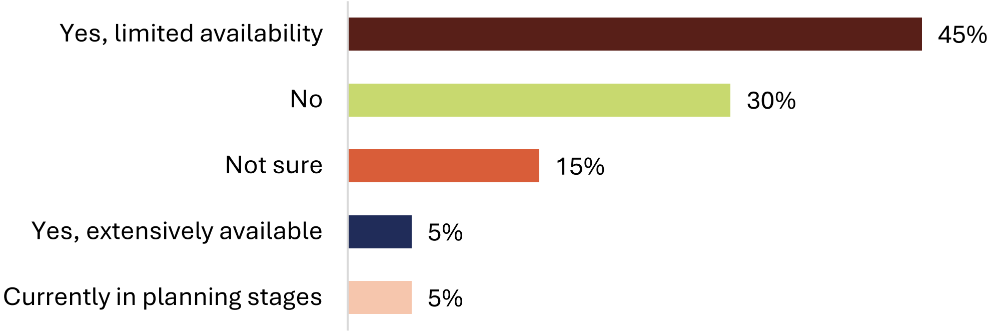


Figure 48. *Availability of Designated Cooling Spaces or Community Centres for Extreme Heat*
Source: Based on ACE Survey.

Figure 51 shows that energy consumption data is the strongest driver for developing better passive cooling policies, reflecting the need for measurable, cooling-specific metrics to ground policy decisions. Cost-benefit analysis ranks closely behind, confirming that economic justification remains central to policy approval. Technical benchmarks, regional best practices, and climate projections are also valued, indicating that policymakers seek proven, adaptable models aligned with long-term resilience planning.

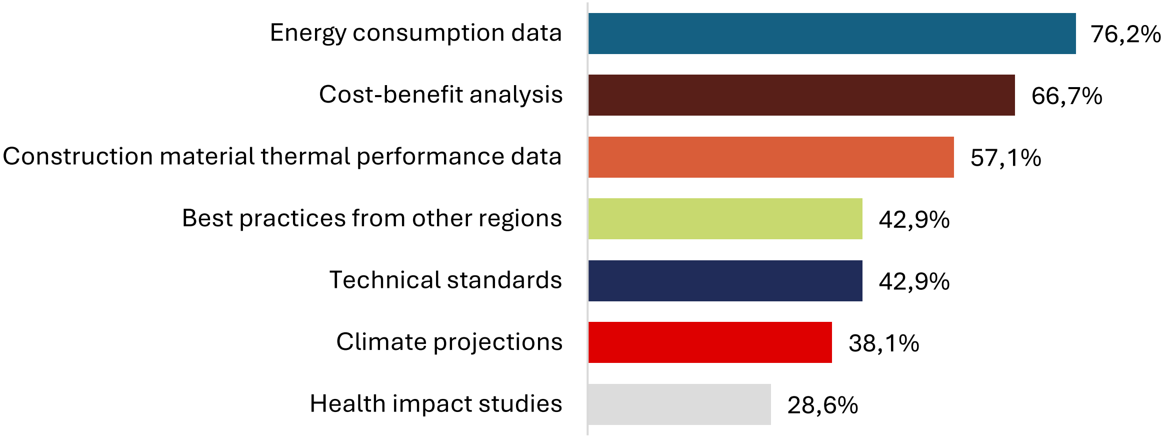


Figure 49. *Information and Data Required to Develop Effective Passive Cooling Policies*
Source: Based on ACE Survey.
Question: What kind of data would help you the most to develop better passive cooling policies?

Policymakers mostly prioritise financing options (66.67%) and passive cooling design knowledge (61.90%), with strong interest in energy efficiency programmes reflecting a preference for systemic rather than isolated interventions. Lower interest in operational details and niche technical topics suggests that strategic and financial considerations currently take precedence over implementation specifics (see **Figure 52**).

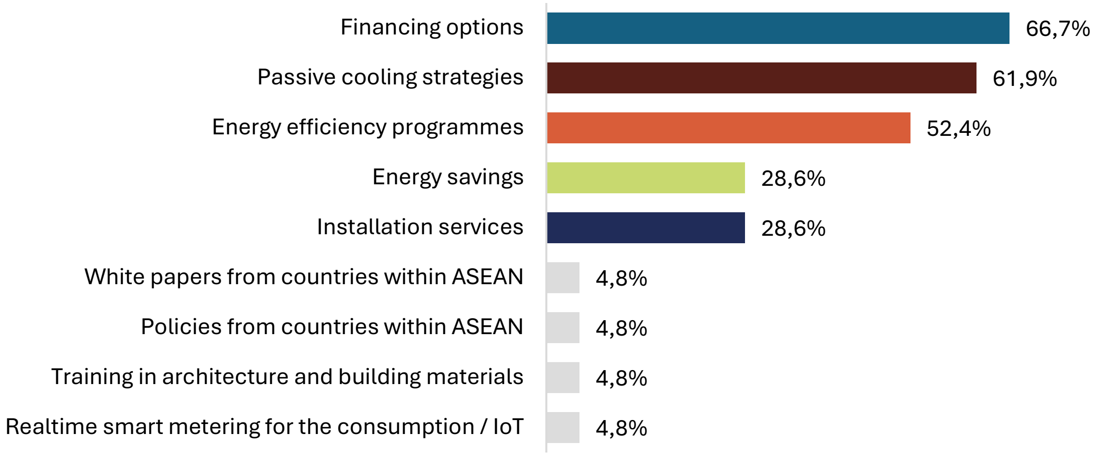


Figure 50. *Types of Information Requested by Policymakers*
Source: Based on ACE Survey.

Recommendation: Implementation Strategy and Action Pathways

This chapter translates the roadmap's analytical findings, technology assessments, and case study evidence into a structured implementation strategy for passive cooling adoption across AMS from 2026 to 2040, covering building envelope optimisation, natural ventilation, shading, cool surfaces, insulation, green infrastructure, hybrid approaches, and urban heat island mitigation. The strategy is grounded in four principles:

1. Differentiation acknowledges that AMS vary significantly in institutional capacity, regulatory maturity, and fiscal space; a single pathway cannot succeed across this spectrum.
2. Comprehensiveness reflects the evidence that passive cooling is most effective when multiple strategies are integrated, as demonstrated by the DesignBuilder simulation showing a 41.95% combined cooling demand reduction.
3. Sequencing orders interventions by feasibility and impact, building momentum progressively from low-capacity measures towards regulatory reform and market transformation.
4. Passive-first design positions passive cooling as the primary response to building thermal management, ensuring that where mechanical cooling remains necessary, systems are sized only to address residual loads, reducing both capital costs and emissions.

The strategy aligns with APAEC 2026-2030, under EE&C Programme Area, especially the Outcome-Based Strategy (OBS) on passive building design and high-performance envelopes and is designed for implementation through the existing EE&C-SSN coordination mechanism.

8.1 Regional Status Overview

Table 37. *Regional Status Overview*

AMS	Building Codes	Technical Capacity	Green Finance	Market Adoption
Brunei	Developing	Emerging	Developing	Emerging
Cambodia	Initial	Initial	Initial	Initial
Indonesia	Emerging	Developing	Emerging	Emerging
Lao PDR	Initial	Initial	Initial	Initial
Malaysia	Developing	Developing	Developing	Developing
Myanmar	Initial	Initial	Initial	Initial
Philippines	Emerging	Emerging	Emerging	Emerging
Singapore	Advanced	Advanced	Advanced	Advanced
Thailand	Developing	Developing	Developing	Developing
Vietnam	Emerging	Emerging	Emerging	Emerging

Advanced: Mature implementation
Developing: Active progress
Emerging: Early stages
Initial: Foundation building

Key Gaps Identified

- **Policy gaps:** Limited integration of PCS in national building codes; absence of mandatory requirements in most AMS
- **Technical gaps:** Insufficient TMY climate data; limited building simulation capacity; shortage of certified professionals
- **Financial gaps:** Limited green finance products; lack of standardised risk assessment frameworks; high perceived investment risks
- **Market gaps:** Low awareness among developers; fragmented supply chains; limited demonstration projects
- **Coordination gaps:** Inconsistent standards across AMS; limited technology transfer mechanisms; insufficient regional platforms

8.1.1 Opportunities for Action

- APAEC 2026-2030 explicitly includes PCS as priority action under EE&C Strategy 2.3
- Growing green building markets in Singapore, Malaysia, Thailand, and Vietnam
- Active development partner engagement (UNEP, ECCJ, GIZ, AFD, World Bank, KDB, IEA, etc)
- Rising electricity costs driving interest in energy efficiency solutions
- Corporate sustainability commitments creating demand for green buildings

8.1.2 Technology-Specific Implementation Pathways

The roadmap examines six major categories of PCS technologies, each with distinct characteristics in terms of scalability, cost, climate suitability, and implementation complexity. Rather than promoting a single technology, the strategy recognises that maximum cooling benefit comes from integrating multiple strategies, as demonstrated by the DesignBuilder simulation achieving 41.95% combined reduction. This section provides technology-specific implementation guidance calibrated to ASEAN's hot-humid climate conditions.

***Table 38.** Passive Cooling Technology Implementation Pathways for ASEAN*

Technology Category	New Construction Strategy	Retrofit Strategy	Vulnerable Communities	Key ASEAN Examples	Implementation Priority
Building Envelope Optimisation (walls, roofs, windows, insulation)	Integrated design from concept stage: OTTV compliance, high-performance glazing (SHGC ≤0.4), wall insulation (U-value per climate	Roof/ceiling insulation (most cost-effective retrofit); window film/replacement; external wall insulation where feasible. Complexity: Medium–High	Roof insulation for low-income housing (USD 200–800/house, 11–37% UDH reduction). Most accessible high-impact intervention (Table 24)	Parkroyal Hotel SGP; Stock Exchange of Thailand; Pearl Academy India (double-skin façade)	**HIGH 20–40% savings 5–10yr payback All tiers**

Technology Category	New Construction Strategy	Retrofit Strategy	Vulnerable Communities	Key ASEAN Examples	Implementation Priority
	zone), roof insulation				
Natural Ventilation (cross-ventilation, stack ventilation, courtyards, wind catchers)	Strategic window placement, building orientation, floor plan design for airflow paths, stack ventilation shafts, internal courtyards. Near-zero incremental cost at design stage.	Window modifications, addition of ventilation openings, operable façade elements. Feasibility depends on building type and urban noise/pollution context.	Natural ventilation enhancement (USD 100–500/house, 15–25% temperature reduction). Aligns with traditional practices (Table 24).	Saigon House VNM (tube house ventilation); Green School Bali IDN; Traditional Thai stilt houses	**HIGH 30–50% savings (new) Low cost (design stage) All tiers**
Shading Systems (overhangs, fins, double façades, vegetation screens, louvres)	External horizontal overhangs (N/S), vertical fins (E/W), integrated louvres, vegetation screens, double façade systems. Design for ASEAN's high solar altitude.	External shading attachment to existing façades; adjustable screens; bamboo/timber retrofit screens (culturally appropriate, low-cost).	Shade structures for community spaces (USD 300–1,500/unit, 10–20% temperature reduction). Low-tech bamboo solutions appropriate for informal settlements.	Oasia Hotel SGP (living façade mesh); Betawi Houses JKT; Masdar City UAE (urban shading)	**HIGH 30–40% solar heat gain reduction 3–7yr payback All tiers**
Cool Roofs and Cool Surfaces (reflective coatings, membranes, cool pavements)	Specify high solar reflectance (≥0.70 initial, ≥0.55 aged) and thermal emittance (≥0.75) for all roof surfaces. Cool pavement materials for surrounding areas.	Reflective coating application on existing roofs; simplest and most scalable retrofit intervention. Low complexity, minimal disruption.	Cool roof coatings for community buildings and low-income housing. Minimal upfront investment, significant thermal comfort improvement.	Wide application across ASEAN public buildings; LBNL field studies; DOE Oak Ridge data	**HIGH 10–20% cooling energy reduction 3–5yr payback All tiers**
Green Infrastructure (green roofs, living walls, vegetation corridors, urban trees)	Integrated green roof/wall systems in design; vegetation corridors between buildings; tree canopy planning; bio-climatic landscape design.	Green roof installation on structurally adequate buildings; living wall systems; strategic tree planting for façade shading.	Community tree planting programmes; vegetation-based shade structures; urban farming integrated with cooling.	Parkroyal SGP (sky gardens); Oasia Hotel (climbing plants); traditional vegetation strategies across AMS	**MEDIUM 15–25% savings 8–12yr payback UHI mitigation Tier 1–2**
Hybrid Passive-Active Systems	Design for mixed-mode operation:	Install ceiling fans + smart	Ceiling fan distribution	SinBerBEST Zero Energy Building	**HIGH 40–60% savings 7–12yr**

Technology Category	New Construction Strategy	Retrofit Strategy	Vulnerable Communities	Key ASEAN Examples	Implementation Priority
(mixed-mode, raised AC setpoints + ceiling fans, smart controls)	natural ventilation when conditions permit, efficient mechanical cooling when needed. Raised AC setpoint (26–27°C) + ceiling fans.	thermostats; BMS optimisation for mixed-mode switching; AC setpoint adjustment programmes.	programmes in public housing; community cooling centres with hybrid systems.	SGP (32% savings at 26.5°C setpoint + fans); CH2 Melbourne	**payback Most validated for ASEAN climate Tier 1–2**

Source: Synthesis of Tables 11, 14, 19, 21, and 24. Energy savings are cooling energy reductions relative to conventional baseline. Payback periods are for typical ASEAN conditions.

The combined application of these technologies, not any single intervention in isolation, delivers the transformative potential described in Chapter 5. The DesignBuilder simulation demonstrates that integrating building envelope optimisation, natural ventilation, cool surfaces, and shading achieve 41.95% cooling demand reduction, substantially exceeding any individual technology's performance. The implementation strategy therefore emphasises integrated packages calibrated to each tier's capacity.

8.1.3 Setting Strategic Vision in ASEAN

The following phased approach provides a structured pathway for implementing PCS across ASEAN, building from baseline assessment through full-scale market transformation.

The targets and timeframes presented below are grounded in the analytical findings, technology assessments, and case study evidence presented throughout this roadmap, as outlined in the implementation strategy framework at the opening of this chapter, and are consistent with the ACE-IEA Net Zero by 2050 buildings sector trajectory and the IPCC AR6 1.5°C pathway.

Table 39. *Implementation Pathways for Passive Cooling Strategies across ASEAN (2025 – 2030)*

Year	Phase	Strategic Focus
2025	**Baseline**	Current status assessment, gap analysis, stakeholder mapping
2026	**Foundation**	Roadmap publication, policy frameworks, capacity building initiation
2027	**Pilots**	Demonstration projects in 5+ AMS, knowledge platforms, regional guideline

Year	Phase	Strategic Focus
2028	**Scale-up**	Building code integration, green certification alignment, supply chain development
2029	**Acceleration**	Market transformation, financing instruments, technology transfer
2030	**Achievement**	Target verification, best practices compendium, next-phase roadmap development

8.2 Strategic Recommendations by Stakeholder

Effective PCS deployment depends on coordinated action across all stakeholders. The following recommendations provide targeted, actionable guidance for each group.

8.2.1 Policymakers

Policymakers hold the greatest leverage in driving passive cooling adoption. Through building codes, incentive structures, and public procurement, they can shape the entire building sector's trajectory. Regulatory frameworks must also be gender-responsive and inclusive, recognising that women, older persons, children, informal workers, and low-income households face disproportionate heat exposure and unequal access to cooling. Key recommendations for policymakers include:

Regulatory Measures: National building energy codes should embed minimum PCS requirements covering building envelope performance, natural ventilation, and thermal comfort standards tailored to local climates. Priority should be given to schools, health facilities, public housing, and community infrastructure serving the most heat-exposed populations. Mandatory energy audits evaluating PCS potential should be introduced to drive awareness and accountability.

Financial Incentives: Comprehensive incentive packages should include tax deductions, preferential lending through government-backed schemes, and grants for demonstration projects, all tied to clear performance criteria. Floor Area Ratio bonuses, which grant developers additional buildable floor area in exchange for certified passive cooling features, expedited permitting, and reduced import duties on PCS materials, should also be pursued. Incentive design must account for affordability barriers facing low-income and women-headed households.

Market Development Support: Government procurement policies should prioritise passive cooling in public buildings, whilst public funding supports research, technology transfer, and local supply chain development across AMS. Local governments, women-led enterprises, and community organisations should be actively engaged in passive cooling programmes and supply chains.

Local governments and communities also play an important role in PCS implementation, particularly in applying urban heat responses, community cooling solutions, public awareness and local adaptation measures.

***Table 40**. Recommended Policy Actions for Policymakers*

Action Area	Recommended Actions	Timeline	Impact
Building Codes & Standards	Incorporate PCS in national energy codes; mandate requirements for new construction; require retrofits for existing buildings.	2026-2028	**High**
Green Certification	Integrate PCS as mandatory criteria; mandate certification for public buildings; implement awareness programmes	2026-2027	**High**
Financial Incentives	Tax credits, FAR bonuses, fast-track permits, reduced import taxes for PCS materials and systems	2026-2027	**High**
Public Procurement	Government buildings as showcases; certified sustainable materials programmes; performance-based specifications	2026-2027	**Medium**
Urban Planning	Integrate PCS in city guidelines; public housing requirements; urban heat island mitigation strategies	2027-2030	**High**

8.2.2 Building Developers

Building developers drive market demand for passive cooling through their investment decisions and design choices, making their adoption critical to market transformation. Strategic recommendations for developers (**Table 40**) include:

Investment Perspective: PCS should be treated as a long-term investment that enhances asset value and reduces operational costs. Design decisions should account for the needs of diverse occupant groups, particularly women, children, older persons, and home-based workers who face prolonged indoor heat exposure.

Risk Mitigation: To address concerns about PCS performance, developers should engage experienced consultants, implement rigorous construction quality control, and secure performance guarantees from technology providers.

Market Differentiation: Green building certifications and energy performance ratings enable developers to differentiate projects, strengthen sustainability credentials, and capture value in increasingly environmentally conscious property markets.

Table 41. Strategic Actions for Building Developers to Implement Passive Cooling

Action Area	Recommended Actions	Timeline	Impact
Business Case Development	Cost-benefit analysis tools, ROI calculations, lifecycle cost assessments, operational savings documentation	2026-2027	**High**
Design Integration	Early-stage PCS consultation, integrated design processes, performance simulation	Ongoing	**High**
Supply Chain	Partnerships with technology providers, local material sourcing, quality assurance protocols	2026-2028	**Medium**
Marketing Advantage	Green certifications, sustainability branding, energy performance ratings, premium positioning	Ongoing	**High**
Risk Mitigation	Performance guarantees, experienced consultants, quality control measures, insurance products	2026-2027	**Medium**

Source: ACE. All rights reserved.

8.2.3 Financial Institutions & Investors

Financial institutions and investors have pivotal role in scaling PCS deployment by providing capital and innovative financing mechanisms. Their understanding and support of PCS technologies can unlock significant market potential across the ASEAN region. Their role is equally important in ensuring that PCS investments reach underserved groups, including women-led enterprises, low-income households and community infrastructure where conventional financing products may not be accessible. Areas of focus, as outlined in Table 39, can be implemented in:

Product Development: Specialised financing products should reflect the characteristics of passive cooling investments, including longer payback periods, performance-based lending criteria, smaller ticket sizes, and concessional windows. Carbon credit monetisation of verified energy savings offers an additional revenue stream as regional carbon markets mature.

Risk Assessment: Standardised risk assessment frameworks, encompassing technical evaluation criteria, performance benchmarks, and monitoring protocols, reduce transaction costs and improve lending decisions across diverse markets.

Partnership Strategy: Collaboration with governments, development banks, and technical experts enables commercial institutions to access concessional funding, share risks, and build market expertise, whilst supporting demonstration models that prioritise inclusive access and social impact.

***Table 42**. Priority Actions for Financial Institutions and Investors*

Action Area	Recommended Actions	Timeline	Impact
Product Development	Green building loans, energy efficiency financing, performance-based lending, longer payback terms	2026-2028	**High**
Risk Assessment	Standardised evaluation frameworks, technical criteria, performance benchmarks, monitoring protocols	2026-2027	**High**
Blended Finance	Concessional loans combined with commercial financing, technical assistance grants, capacity building	2027-2029	**High**
Green Bonds	ESG-focused investments, certified green bonds for passive cooling projects, portfolio diversification	2027-2030	**Medium**

Action Area	Recommended Actions	Timeline	Impact
Insurance Products	Performance insurance, construction risk coverage, technical due diligence, monitoring systems	2027-2028	**Medium**

Source: ACE. All rights reserved.

8.2.4 Building Designers (Architects, Engineers, Consultants)

Building designers are the technical gatekeepers who translate PCS concepts into built outcomes, making their expertise and design decisions central to roadmap success. Design decisions should also reflect differentiated occupancy and use patterns, particularly in residential, educational and community buildings. Table 40 illustrates the key areas of focus to support the PCS implementation.

Professional Excellence: Designers should maintain up-to-date knowledge of climate-responsive design, building energy modelling, and passive cooling technologies suited to ASEAN's hot-humid conditions. Completion of green building certification programmes incorporating passive cooling modules, such as Green Mark, GBI, BERDE, or LOTUS, should become standard professional practice.

Collaborative Approach: Effective passive cooling requires multidisciplinary integration from the earliest design stage. Designers should establish collaborative working methods with engineers and specialists, ensuring passive cooling considerations are embedded throughout the design process rather than addressed retrospectively.

Innovation Leadership: Designers should experiment with new materials, design approaches, and technology combinations, drawing on traditional tropical cooling knowledge where relevant. Systematic post-occupancy evaluation and knowledge-sharing within the professional community will strengthen best practice and drive continuous improvement.

***Table 43**. Recommended Actions for Building Designers on Passive Cooling Design and Integration*

Action Area	Recommended Actions	Timeline	Impact
Technical Skills	Climate analysis, building physics, CFD modelling, energy simulation, material properties expertise	Ongoing	**High**
Professional Certification	Green building certifications (Green Mark, GBI, BERDE, LOTUS) with PCS modules	2026-2028	**High**

Action Area	Recommended Actions	Timeline	Impact
Integrated Design	Multidisciplinary collaboration, early engagement, communication protocols, design optimisation	Ongoing	**High**
Innovation Leadership	New materials experimentation, traditional techniques integration, post-occupancy evaluations	Ongoing	**Medium**
Knowledge Sharing	Case study documentation, lessons learned dissemination, professional community engagement	Ongoing	**Medium**

Source: ACE. All rights reserved.

Professional Development Requirements

Architects and engineers should complete green building certification courses (Green Mark, GBI, BERDE, LOTUS) that specifically include PCS modules covering:

- Regional climate considerations for ASEAN's hot and humid conditions
- Building envelope optimisation and thermal performance simulation
- Natural ventilation principles and cross-ventilation design
- Thermal comfort standards and adaptive comfort models
- Sustainable material selection and life-cycle assessment

8.3 Carbon Neutrality Pathway Beyond 2050

Achieving carbon neutrality in the building sector requires a long-term commitment to PCS as a foundational strategy. The following pathway outlines progressive targets and actions from 2026 through 2050 and beyond.

The targets and timeframes in this table are grounded in the roadmap's own analytical findings. The near-term target of 10-20% cooling energy reduction by 2030 is supported by the technology scalability assessment (Table 21) and comparative cost analysis (Table 19), which confirm this range is achievable with currently available PCS technologies at viable payback periods across ASEAN. The medium and long-term targets through 2050 are aligned with the ACE-IEA Net Zero by 2050 buildings sector trajectory and the IPCC AR6 1.5°C pathway, both referenced in Chapter 1 as the overarching framework for this roadmap.

***Table 44**. Passive Cooling Targets and Actions Towards Carbon Neutral Buildings in ASEAN (2026–2050)*

Period	Target	Priority Actions
2026-2030	10-20% cooling energy reduction in new buildings	PCS integration in building codes, pilot demonstrations, green certification alignment
2031-2035	40% cooling energy reduction, 50% new buildings compliant	Mandatory passive design requirements, retrofit programmes, ASEAN-wide standards harmonisation
2036-2040	60% reduction, PCS mainstream practice	Deep retrofit markets, advanced materials deployment, smart passive-active integration
2041-2045	70% reduction, near-zero cooling buildings emerging	Ultra-low energy buildings, district cooling integration, urban heat island mitigation
2046-2050	Carbon neutral buildings achieved	Net-zero building stock, renewable-powered residual cooling, circular economy materials
Beyond 2050	Carbon negative-built environment	Carbon-sequestering materials, regenerative design, climate-positive urban development

8.3.1 Passive Cooling Contribution to Carbon Neutrality

PCS contributes to carbon neutrality through multiple interconnected pathways:

- Peak demand reduction: PCS reduces air conditioning electricity consumption by 20-40%, directly lowering grid stress and generation requirements during peak hours. Urban heat island mitigation: Bio-climatic design and cool surfaces reduce ambient temperatures, creating positive feedback loops for reduced cooling demand across urban areas.
- Climate adaptation: Passive strategies enhance building resilience to rising temperatures and extreme weather events, reducing long-term infrastructure investments.
- Embodied carbon reduction: Life-cycle assessment frameworks promote low-carbon construction materials, reducing upfront emissions from building construction.

- Renewable integration: Lower cooling loads make buildings more suitable for 100% renewable energy supply, accelerating the transition to carbon-free energy systems.

8.3.2 Critical Success Factors

Sustaining progress on passive cooling across ASEAN through 2050 requires enabling conditions that span political, financial, technical, and institutional dimensions. The following factors are critical to ensuring the roadmap's recommendations are implemented effectively and equitably across all AMS:

- Sustained political commitment through ASEAN Ministers on Energy Meeting (AMEM) declarations and national energy policies
- Adequate funding sources from public budgets, development finance, and private investment
- Technical capacity development through regional training centres and professional certification
- Strong coordination frameworks that encourage information exchange and cooperative action
- Regional solidarity recognising that all AMS must progress together with support for less-developed members

8.4 Regional Coordination Framework

Regional coordination is essential for accelerating PCS adoption by facilitating knowledge sharing, harmonising standards, and creating economies of scale. The following mechanisms provide the institutional architecture for collective action.

Table 45. *Regional Coordination Mechanisms for Passive Cooling Implementation in ASEAN*

Mechanism	Objectives	Approach	Success Metrics
ASEAN Passive Cooling Alliance	Regional cooperation platform, knowledge sharing, joint advocacy	Government-industry-academia partnership	11 AMS participation by 2030
Standards Harmonisation	Common technical standards, mutual recognition, quality assurance	Technical working groups, pilot implementations	Harmonised standards and guideline established in 2030
Climate Mapping Programme	TMY datasets, regional climate zones, design guidelines	Research collaboration, data sharing platforms	Complete TMY for all 11 AMS
Technology Transfer	Innovation diffusion, local adaptation, capacity building	Expert exchanges, joint R&D projects, showcases	20+ technology transfers annually

Mechanism	Objectives	Approach	Success Metrics
Investment Facilitation	Capital mobilisation, risk mitigation, market development	Blended finance, green bonds, guarantee schemes	USD 100M+ mobilised by 2030
Supply Chain Integration	Cost reduction, quality improvement, local manufacturing	Procurement coordination, investment promotion	30% cost reduction achieved

Source: ACE. All rights reserved.

The following subsections provide the operational detail for each of the six coordination mechanisms outlined in Table above.

8.4.1 ASEAN Passive Cooling Alliance

A formal alliance uniting governments, industry, academia, and civil society provides the institutional foundation for regional collaboration. The Alliance coordinates all framework mechanisms through the following key elements:

- Clear governance structure with defined roles and responsibilities for each AMS
- Sustainable funding mechanisms from member contributions and development partners
- Technical working groups for standards, capacity building, and market development
- Annual regional forums for knowledge exchange and progress review

8.4.2 Climate Mapping Programme

Comprehensive climate mapping across AMS provides the scientific foundation for climate-responsive design and standards development. Priority actions include:

1. Develop Typical Meteorological Year (TMY) datasets for current and future climate scenarios
2. Establish regional climate zones classification for PCS design guidance
3. Create evidence-based standards that reduce cooling energy demand
4. Integrate climate projections for future-proofed building design

8.4.3 Supply Chain Integration

Regionally integrated supply chains reduce costs, improve quality, and broaden market access for passive cooling technologies. This requires identifying complementary manufacturing capacities across AMS, promoting technology transfer, and developing regional procurement systems that achieve economies of scale whilst creating opportunities for marginalised communities within value chains.

8.4.4 Investment Facilitation Mechanisms

Regional investment platforms and blended finance instruments combining public and private funding reduce investment risks and mobilise resources for passive cooling projects. Cross-border investment frameworks and risk-sharing arrangements will be coordinated through the Alliance, leveraging international climate finance opportunities.

8.4.5 Framework Linkages

These mechanisms are designed to function as an integrated system. The ASEAN Passive Cooling Alliance provides governance oversight; Climate Mapping delivers the technical foundation; Standards Harmonisation ensures quality and interoperability; Technology Transfer builds local capacity; Supply Chain Integration reduces costs; and Investment Facilitation mobilises resources. Progress in each area reinforces the others, creating a virtuous cycle of regional cooperation and PCS adoption.

8.5 Stakeholder Collaboration Mechanisms

Effective passive cooling implementation requires coordinated action across stakeholders with varying capacities and mandates. The mechanisms below address coordination failures, reduce transaction costs, align incentives, and facilitate knowledge transfer across the ASEAN building sector.

Table 46. *Stakeholder Collaboration Recommended Actions*

Recommended Action	Description & Expected Output
1. Policymakers and Building Developers	
Development Incentives for Sustainable Projects	Partner with developers to create special zoning regulations or relaxed building requirements (e.g., height restrictions) for projects incorporating PCS or sustainable designs. This encourages developers to integrate PCS features by offering benefits that make such designs more feasible and attractive.
Pilot Projects and Demonstration Initiatives	Fund or support construction of pilot projects featuring state-of-the-art PCS. These buildings serve as models for future development and proof of concept, providing tangible examples that demonstrate effectiveness and viability of PCS, encouraging wider adoption.
2. Policymakers and Financial Institutions/Investors	
Risk Mitigation Measures	Set up government-backed insurance or guarantees for financial institutions to reduce risks associated with funding sustainable buildings incorporating PCS technologies. This lowers financial risks for lenders, encouraging them to provide funding for energy-efficient construction projects.
Green Investment Market Development	Develop frameworks promoting creation of a green investment market through incentives for investment in energy-efficient real estate or buildings with PCS. Work with financial institutions to facilitate

Recommended Action	Description & Expected Output
	investments through tax breaks or other incentives, driving private sector involvement in sustainable infrastructure.
3. Policymakers and Building Designers	
Design Guidelines Collaboration	Work with building designers to create specific guidelines and best practices for integrating PCS in building designs. This results in standardised approaches that developers can follow for different building types, providing clear, actionable frameworks and reducing barriers to adoption.
Workshops on Passive Cooling Strategies	Organise workshops, webinars, and training programs focused on integrating PCS covering climate-responsive design, materials selection, natural ventilation and shading. Enhances designers' technical skills whilst improving policymakers' knowledge for better policy implementation.
4. Building Developers and Financial Institutions/Investors	
Green Financing Partnerships	Establish partnerships between developers and financial institutions to create dedicated green financing products for passive cooling projects. Develop standardised assessment criteria and streamlined approval processes for sustainable building investments.
5. Building Developers and Building Designers	
Integrated Design Approach	Foster early-stage collaboration between developers and designers to incorporate PCS from project inception. Joint design charrettes and value engineering sessions can optimise PCS integration whilst maintaining project feasibility and cost-effectiveness.

Source: ACE. All rights reserved.

Monitoring & Evaluation Framework

Effective implementation requires systematic monitoring and evaluation to track progress, identify challenges, and enable adaptive management. The following framework is proposed as a guidance tool to support AMS and development partners in monitoring passive cooling progress. Adoption and adaptation of these indicators remain at the discretion of each AMS based on national capacity and priorities.

9.1 Key Performance Indicators

Table 47. *Key Performance Indicators under the M&E Framework*

KPI Area	Indicator	Baseline (2024)	Target (2030)	Assumptions & Enablers
Policy Integration	Number of AMS with PCS provisions in building codes or guidelines	2-3 AMS with partial provisions	5-6 AMS	Supports from DPs/Ios for code development; pilot countries; building on existing green building frameworks
Energy Savings	Average cooling energy reduction in buildings implementing PCS measures	Limited baseline data	15-25%	Based on demonstration building monitoring in participating AMS; verification through SAEMAS-aligned certification; accounts for tropical climate constraints and varying building typologies
Capacity Building	Certified professionals trained in PCS design and assessment, including participation of women professionals and public sector practitioners	~50-100 across region	300-400 professionals	AEMAS training programs; Improved SAEMAS certification infrastructure; national training, international partnerships
Investment Mobilisation	Cumulative green building investments incorporating PCS, including financing directed to affordable housing, public facilities or inclusive pilot models where applicable	Limited tracking	USD 50-75M	financing mechanisms; Development Bank's technical assistance loans; private sector co-financing through demonstration projects
Market Adoption	Share of new commercial/public buildings with PCS features in participating AMS	<5%	15-20%	Government procurement policies as market driver; incentive schemes in 3-4 lead AMS; developer awareness programs
Inclusive Outcomes	Number of public facilities (schools, health centres,	Limited tracking	Progressive increase	Linked to public investment and pilot demonstration

KPI Area	Indicator	Baseline (2024)	Target (2030)	Assumptions & Enablers
	community spaces) applying PCS measures in heat-vulnerable areas		across lead AMS	

Source: ACE. All rights reserved.

9.2 Reporting Mechanisms

A clear and coherent reporting mechanism is crucial to ensure transparency, accountability, and comparability of progress in AMS. Reporting should, where feasible, capture social and distributional dimensions of implementation, including the extent to which PCS measures improve conditions in public facilities, affordable housing and locations serving populations with higher heat exposure. The roadmap proposes a tiered reporting structure that works at both national and regional levels and includes provisions for public communication and feedback. **Table 47** outlines the levels of reporting, frequency, responsible entities, formats, and expected outputs.

Table 48. *Reporting Mechanisms*

Level	Frequency	Responsible Entity	Format / Tools	Outputs
National Reporting	Annual	ASEAN Member States (AMS)	Self-assessment using toolkit templates (Progress Matrix, Activity Log, Risk Tracker, Capacity Sheet)	National M&E Report submitted to ASEAN Centre for Energy
Regional Reporting	Biennial	ACE	Annual progress reports submitted to EE&C-SNN, SOME and AMEM meetings. Quarterly milestone tracking through AEDS dashboard integration	Final evaluation (2030) with lessons learned documentation and next-phase planning
Peer Review & Validation	Biennial (linked to regional reporting cycle)	ACE, AMS, technical experts, private	Regional exchange workshops	Exchange of best practices, refinement of indicators

Level	Frequency	Responsible Entity	Format / Tools	Outputs
		sector, and stakeholders		
Public Communication	Biennial (following regional report)	ACE. EE&C_SSN Focal Points	Dashboards, infographics, executive summaries	Public progress updates, case studies, awareness raising and examples of impacts on schools, health facilities and community infrastructure
Feedback & Continuous Improvement	Ongoing	ACE & AMS	Structured feedback forms, review sessions	Improved toolkit templates and alignment with global frameworks (Paris Agreement, SDGs)

Source: ACE. All rights reserved.

9.3 Monitoring and Evaluation (M&E) Toolkit for Roadmap

The M&E Toolkit supports AMS in tracking progress, identifying gaps, and ensuring accountability in roadmap implementation. It provides a harmonised framework for national and regional reporting, enabling comparability and cross-country peer learning.

9.3.1 Key performance indicators (KPIs)

KPIs are central to tracking the effectiveness of the Passive Cooling Roadmap, as well as to assessing progress, identifying gaps, and ensuring alignment with regional and global commitments such as APAEC [1], the Paris Agreement [2], and the SDGs [16]. The KPIs are organised into six thematic areas:

a. **Policy Implementation**
   Percentage of recommended PCS policies adopted at national and local levels, such as building codes and regulatory frameworks. This ensures that a favourable environment is created for widespread adoption. Example KPI: Percentage of recommended policies adopted by each AMS.

b. **Capacity Building**

Tracking the development of technical knowledge and institutional capacity in governments, the private sector, and communities. Capacity development should include technical ministries, local governments, public institutions and professionals involved in social infrastructure planning. Example KPI: Number of workshops, training programmes, and awareness-raising campaigns conducted annually.

c. **Finance & Investment**

Assessment of public and private resources to support PCS initiatives, considering whether investment mechanisms can support affordable and socially relevant applications of PCS. Funding is critical for scaling up projects, supporting vulnerable groups, and demonstrating business models. Example KPI: Value of climate finance or green investments mobilised for roadmap projects.

d. **Technology & Innovation**

Capturing the demonstration, deployment, and scaling of PCS technologies in different contexts. This KPI reflects the region's ability to innovate and adapt solutions. Example KPI: Number of successfully implemented pilot projects or technology demonstrations.

e. **Impact & Outcomes**

The tangible environmental, social, and economic benefits derived from the implementation of the roadmap include energy savings, carbon emission reduction, and enhanced thermal comfort, particularly for vulnerable communities. Example KPI: Percentage reduction in greenhouse gas emissions and energy demand achieved through the adoption of PCS measures, percentage reduction in health cases related to heat stress.

f. **Regional Cooperation**

Collective action, peer learning, and harmonisation in the AMS to strengthen resilience and accelerate impact. Example KPI: Number of transnational partnerships, joint projects, or regional platforms established.

By adopting these KPIs, the AMS will be able to report on progress in a harmonised and transparent way, whilst enabling evidence-based decision-making and adaptive management of the roadmap.

9.3.2 Templates and Tracking Tools

The M&E Toolkit provides standardised templates and digital tracking tools to ensure consistent monitoring across AMS whilst allowing country-specific adaptation. Five core tools include:

a. **Progress Tracking Matrix** to track the status of roadmap action items against baselines and annual targets, capturing important details such as the implementation phase, responsible authorities and annual milestones.

b. **Activity Implementation Log** to document the planned and actual implementation of activities. The log table includes timelines, budget allocations, responsible institutions, and the status of activities. This log promotes accountability and helps tracking the effectiveness of resources use.

c. **Risk and Issue Tracker** to provide a structured way in recording risks, barriers, and challenges in implementation. Each entry includes the risk, the potential impact, mitigation measures, and the organisation responsible for resolution.

d. **Capacity and Resource Tracking Sheet to** capture information on training, including participation by women professionals, local practitioners and public institutions. It is particularly useful for measuring the results of capacity building and assessing whether technical expertise and financial resources are keeping pace with the objectives of the roadmap.

e. **Case Study Template** to provide a structured reporting format to document best practises, lessons learnt, innovative approaches, social relevance, including which user groups benefited, implementation barriers and lessons for inclusive scaling. Each case study highlights achievements, challenges, and practical recommendations that can be shared at the regional level.

Conclusion and Way Forward

10.1 Conclusion

As the region experiences rapidly rising cooling demand driven by urbanisation, economic growth, and climate change, the decisions made today on how buildings are designed, constructed, and retrofitted will shape energy consumption, carbon trajectories, and the wellbeing of hundreds of millions of people for decades. Passive cooling strategies must be the starting point of building design, not an afterthought. The fundamental question is not how to reduce air-conditioning bills, but how to eliminate the need for mechanical cooling in the first place.

The Roadmap for Extreme Heat Protection through Passive Cooling in the ASEAN Region presents a concrete pathway to reduce building energy consumption, strengthen climate resilience, and advance carbon neutrality across ASEAN. Realising this potential requires coordinated action: policymakers must create enabling frameworks, developers must embed passive design from the outset, financial institutions must provide fit-for-purpose products, and designers must deliver technical excellence.

Implementation of these recommendations necessitates strong leadership, adequate resources, and ongoing commitment. To realise the transformative potential of PCS technologies, AMS must act decisively to establish the policy foundations, build technical capacity, mobilise investment, and foster regional cooperation that will drive market transformation. The pathway to carbon neutrality by 2050 begins with immediate actions in 2026.

10.2 Way Forward

ASEAN's strategic vision for PCS should be firmly aligned with existing regional and national frameworks, including APAEC and national green building codes. Passive cooling strategies must be systematically embedded across policy, finance, and professional practice. The following recommendations are essential.

Policymakers should provide clear regulatory direction and coordinated policy support to anchor PCS within national building codes. This entails mandating envelope performance, natural ventilation, and thermal comfort standards. Performance-based incentives, including tax deductions, concessional financing, FAR bonuses, and expedited permitting, will strengthen project viability. Public procurement should lead by example, prioritising passive cooling in government buildings.

Building developers must position PCS as a long-term investment that reduces operational costs and strengthens asset resilience. Early integration of passive measures, supported by experienced consultants and rigorous quality control, mitigates performance risks. Green building certifications and energy performance ratings enable market differentiation in increasingly sustainability-driven property markets.

Financial institutions and investors should develop specialised green building products that accommodate longer payback periods and apply performance-based lending criteria. Standardised risk assessment methodologies and blended finance structures, combining concessional capital with private investment, are essential to scale adoption across AMS.

Building designers, including architects, engineers and consultants, must embed climate-responsive design principles into mainstream professional practice, strengthening expertise in building physics, energy modelling, and passive cooling suited to ASEAN's hot-humid climates. Multidisciplinary collaboration from the earliest design stage, supported by systematic post-occupancy evaluation, will drive continuous improvement and accountability.

Collectively, sustained and coordinated action across policy, finance, market actors and professional communities will be essential to mainstream PCS within ASEAN’s building sector. ASEAN holds advantages in pursuing this agenda: deep traditional knowledge of tropical building design, a rapidly growing construction sector, established regional cooperation frameworks, and active development partner engagement. By acting on the recommendations in this roadmap, ASEAN can demonstrate to the world that comfortable, resilient, and low-carbon buildings are achievable without primary dependence on mechanical cooling.

References

[1] C3S and ECMWF, “Copernicus: June 2024 marks 12th month of global temperature reaching 1.5°C above pre-industrial,” Copernicus Climate Change Service, European Centre for Medium-Range Weather Forecasts. Accessed: Nov. 20, 2025. [Online]. Available: https://climate.copernicus.eu/copernicus-june-2024-marks-12th-month-global-temperature-reaching-15degc-above-pre-industrial

[2] United Nations, “United Nations Secretary-General’s Call to Action on Extreme Heat,” United Nations. Accessed: Nov. 20, 2025. [Online]. Available: https://www.un.org/sites/un2.un.org/files/unsg_call_to_action_on_extreme_heat_for_release.pdf

[3] ACE, “8th ASEAN Energy Outlook (AEO8),” 2024.

[4] IPCC WG II, “Climate Change 2022: Impacts, Adaptation and Vulnerability.,” Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Accessed: Nov. 20, 2025. [Online]. Available: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FullReport.pdf

[5] UNEP, “Global Cooling Watch 2023,” United Nations Environment Programme. Accessed: Nov. 20, 2025. [Online]. Available: https://www.unep.org/resources/global-cooling-watch-2023

[6] P. Tuohy, L. McElroy, and C. Johnstone, “THERMAL MASS, INSULATION AND VENTILATION IN SUSTAINABLE HOUSING – AN INVESTIGATION ACROSS CLIMATE AND OCCUPANCY.” Accessed: Jan. 19, 2026. [Online]. Available: https://www.researchgate.net/publication/268273038_THERMAL_MASS_INSULATION_AND_VENTILATION_IN_SUSTAINABLE_HOUSING_-_AN_INVESTIGATION_ACROSS_CLIMATE_AND_OCCUPANCY

[7] IEA, “Roadmap Towards Sustainable and Energy-Efficient Space Cooling in ASEAN,” International Energy Agency (IEA). Accessed: Nov. 20, 2025. [Online]. Available: https://www.iea.org/events/asean-roadmaps-towards-sustainable-and-energy-efficient-buildings-and-cooling-in-southeast-asia

[8] ACE, “Passive Cooling Strategies: Current Status and Drivers of Integration into Policy and Practice within ASEAN’s Building Sector,” Jakarta, 2024. Accessed: Sep. 24, 2025. [Online]. Available: www.aseanenergy.org

[9] “IPCC WGI Interactive Atlas,” Intergovernmental Panel on Climate Change. Accessed: Feb. 19, 2026. [Online]. Available: https://interactive-atlas.ipcc.ch/regional-information#eyJ0eXBlIjoiQVRMQVMiLCJjb21tb25zIjp7ImxhdCI6OTU1MzgzOCwib

G5nIjotMTM5NzAwOCwiem9vbSI6NiwicHJvaiI6IkVQU0c6NTQwMzAiLCJtb2RlIjoiY29tcGxldGVfYXRsYXMifSwicHJpbWFyeSI6eyJzY2VuYXJpbyI6InNzcDU4NSIsInBlcmlvZCI6IjIiLCJzZWFzb24iOiJ5ZWFyIiwiZGF0YXNldCI6IkNNSVA2IiwidmFyaWFibGUiOiJ0YXMiLCJ2YWx1ZVR5cGUiOiJBTk9NQUxZIiwiaGF0Y2hpbmciOiJTSU1QTEUiLCJyZWdpb25TZXQiOiJhcjYiLCJiYXNlbGluZSI6InByZUluZHVzdHJpYWwiLCJyZWdpb25zU2VsZWN0ZWQiOlszOF19LCJwbG90Ijp7ImFjdGl2ZVRhYiI6InBsdW1lIiwic2hvd2luZyI6dHJ1ZSwibWFzayI6Im5vbmUiLCJzY2F0dGVyWU1hZyI6IkFOT01BTFkiLCJzY2F0dGVyWVZhciI6InRhcyJ9fQ==

[10] The World Bank Group and the Asian and Development Bank, “Climate Risk Country Profile: Malaysia,” Washington, DC, Aug. 2021. Accessed: Feb. 19, 2026. [Online]. Available: https://www.adb.org/publications/climate-risk-country-profile-malaysia

[11] The World Bank Group and the Asian and Development Bank, “Climate Risk Country Profile: Thailand,” Washington, DC, Aug. 2021. Accessed: Feb. 19, 2026. [Online]. Available: https://www.adb.org/publications/climate-risk-country-profile-thailand

[12] The World Bank Group and the Asian and Development Bank, “Climate Risk Country Profile: Philippines,” Washington, DC, Aug. 2021. Accessed: Feb. 19, 2026. [Online]. Available: https://www.adb.org/publications/climate-risk-country-profile-philippines

[13] The World Bank Group and the Asian and Development Bank, “Climate Risk Country Profile: Indonesia,” Washington, DC, May 2021. Accessed: Feb. 19, 2026. [Online]. Available: https://www.adb.org/publications/climate-risk-country-profile-indonesia

[14] I. D. G. A. Putra *et al.*, “Development of typical meteorological years based on quality control of datasets in Indonesia,” *Renew. Energy*, vol. 221, p. 119699, Feb. 2024, doi: 10.1016/j.renene.2023.119699.

[15] I. D. G. A. Putra *et al.*, “Development of climate zones for passive cooling techniques in the hot and humid climate of Indonesia,” *Build. Environ.*, vol. 226, p. 109698, Dec. 2022, doi: 10.1016/j.buildenv.2022.109698.

[16] World Weather Attribution, “Climate change made the deadly heatwaves that hit millions of highly vulnerable people across Asia more frequent and extreme – World Weather Attribution.” Accessed: Jan. 23, 2026. [Online]. Available: https://www.worldweatherattribution.org/climate-change-made-the-deadly-heatwaves-that-hit-millions-of-highly-vulnerable-people-across-asia-more-frequent-and-extreme/

[17] R. Basu and J. M. Samet, “Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence,” *Epidemiol. Rev.*, vol. 24, no. 2, pp. 190–202, Dec. 2002, doi: 10.1093/EPIREV/MXF007.

[18] C. Stearnbourne, “Heat stress impacts workers and the bottom line,” Harvard T.H. Chan School of Public Health. Accessed: Feb. 09, 2026. [Online]. Available: https://hsph.harvard.edu/environmental-health/news/heat-stress-impacts-workers-and-the-bottom-line/

[19] L. W. Davis and P. J. Gertler, “Contribution of air conditioning adoption to future energy use under global warming,” *Proc. Natl. Acad. Sci. U. S. A.*, vol. 112, no. 19, May 2015, doi: 10.1073/pnas.1423558112.

[20] N. Watts *et al.*, “The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises,” *The Lancet*, vol. 397, no. 10269, pp. 129–170, Jan. 2021, doi: 10.1016/S0140-6736(20)32290-X.

[21] L. Samuels *et al.*, “Physiological mechanisms of the impact of heat during pregnancy and the clinical implications: review of the evidence from an expert group meeting,” *Int. J. Biometeorol.*, vol. 66, no. 8, p. 1505, Aug. 2022, doi: 10.1007/s00484-022-02301-6.

[22] K. B. McLeod and L. Goering, “As Extreme Heat Threats Grow, Can Heat Insurance Offer Protection?,” *https://doi.org/10.3138/jccpe-2024-0044*, vol. 3, no. 2/3, pp. 215–222, May 2025, doi: 10.3138/jccpe-2024-0044.

[23] G. McGregor, lead P. editor Bessemoulin, K. Ebi, and B. Menne, “Heatwaves and Health: Guidance on Warning-System Development,” 2015.

[24] G. Luber and M. McGeehin, “Climate Change and Extreme Heat Events,” *Am. J. Prev. Med.*, vol. 35, no. 5, pp. 429–435, Nov. 2008, doi: 10.1016/j.amepre.2008.08.021.

[25] Notre Dame Global Adaptation Initiative, “Country Index.” Accessed: Feb. 09, 2026. [Online]. Available: https://gain.nd.edu/our-work/country-index/

[26] Germanwatch, “Climate Risk Index 2026.” Accessed: Feb. 09, 2026. [Online]. Available: https://www.germanwatch.org/en/cri

[27] United Nations Environment Programme, *Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate Investment and Planning on Climate Adaptation Leaves World Exposed*. United Nations Environment Programme, 2023. doi: 10.59117/20.500.11822/43796.

[28] Organisation for Economic Co-operation and Development, “Climate Finance and the USD 100 Billion Goal Climate Finance Provided and Mobilised by Developed Countries in 2013-2021 AGGREGATE TRENDS AND OPPORTUNITIES FOR SCALING UP ADAPTATION AND MOBILISED PRIVATE FINANCE,” 2023, doi: 10.1787/e20d2bc7-en.

[29] J. Liu, J.-N. Zhao, and D.-X. Sun, “Development and validation of a model for predicting air temperature in street canyons,” 2009. Accessed: Feb. 09, 2026. [Online]. Available:

https://www.researchgate.net/publication/288470353_Development_and_validation_of_a_model_for_predicting_air_temperature_in_street_canyons

[30] A. M. T. Magnaye and H. Kusaka, "Potential effect of urbanization on extreme heat events in Metro Manila Philippines using WRF-UCM," *Sustain. Cities Soc.*, vol. 110, p. 105584, Sep. 2024, doi: 10.1016/J.SCS.2024.105584.

[31] A. Aflaki *et al.*, "Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong," *Cities*, vol. 62, pp. 131–145, Feb. 2017, doi: 10.1016/j.cities.2016.09.003.

[32] S. Nitti, "Malaysia: The Urban Heat Island phenomenon and its impacts on vulnerable groups." Accessed: Feb. 09, 2026. [Online]. Available: https://www.interacademies.org/news/malaysia-urban-heat-island-phenomenon-and-its-impacts-vulnerable-groups

[33] IEA, "Roadmap for Energy-Efficient Buildings and Construction in ASEAN Timelines and actions towards net zero-carbon buildings and construction," 2022, Accessed: Feb. 10, 2026. [Online]. Available: www.iea.org/t&c/

[34] A. Sanusi Hassan and M. Ramli, "Natural Ventilation of Indoor Air Temperature: A Case Study of the Traditional Malay House in Penang," *American J. of Engineering and Applied Sciences*, vol. 3, no. 3, pp. 521–528, 2010.

[35] H. T. Dang, "Thermal Comfort in Old Traditional Shophouses in Ho Chi Minh City, Vietnam," 2022. Accessed: Feb. 09, 2026. [Online]. Available: https://www.researchgate.net/publication/361303145_Thermal_Comfort_in_Old_Traditional_Shophouses_in_Ho_Chi_Minh_City_Vietnam

[36] The ASEAN Post Team, "Affordable Housing In Southeast Asia | The ASEAN Post." Accessed: Feb. 09, 2026. [Online]. Available: https://theaseanpost.com/article/affordable-housing-southeast-asia

[37] Ministry of Environment Cambodia, Cool Coalition, United Nations Economic and Social Commission for Asia and the Pacific, and United Nations Environment Program, "Abridged Guidebook on Passive Cooling Strategies," 2024.

[38] IEA, "Staying cool without overheating the energy system," IEA. [Online]. Available: https://www.iea.org/commentaries/staying-cool-without-overheating-the-energy-system

[39] W. Wei and H. M. Skye, "Residential net-zero energy buildings: Review and perspective," *Renewable and Sustainable Energy Reviews*, vol. 142, May 2021, doi: 10.1016/j.rser.2021.110859.

[40] Energy Institute, "Statistical Review of World Energy." Accessed: Feb. 10, 2026. [Online]. Available: https://www.energyinst.org/statistical-review

[41] IEA, "Southeast Asia Energy Outlook 2022." Accessed: Feb. 10, 2026. [Online]. Available: https://www.iea.org/reports/southeast-asia-energy-outlook-2022

[42] ACE, “Recommendations for Updating the ASEAN Regional Policy Roadmap on Energy Efficient Air Conditioners.” Accessed: Feb. 10, 2026. [Online]. Available: https://aseanenergy.org/publications/recommendations-for-updating-the-asean-regional-policy-roadmap-on-energy-efficient-air-conditioners/

[43] Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, “Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 21 Tahun 2021 tentang Penilaian Kinerja Bangunan Gedung Hijau (Permen PUPR No. 21/2021),” 2021. Accessed: Feb. 09, 2026. [Online]. Available: https://peraturan.bpk.go.id/Details/217002/permen-pupr-no-21-tahun-2021

[44] Standards Malaysia, “Malaysian Standard MS2680:2017 on Energy efficiency and use of renewable energy for residential buildings - Code of practice,” 2017. Accessed: Feb. 18, 2026. [Online]. Available: http://www.sirim.my

[45] Building and Construction Authority, “Code for Environmental Sustainability of Buildings Edition 4.0,” 2021.

[46] Republic of the Philippines, “National Building Code of the Philippines (Presidential Decree No 1096),” 1977.

[47] DEDE, “Ministerial Regulation and Notification of the Ministry of Energy on Building Energy Code,” 2021.

[48] VGBC, “National Technical Regulation on Energy Efficiency Buildings - QCVN 09:2017/BXD (Unofficial Translation by Vietnam Green Building Council),” Hanoi, 2020.

[49] IEA, “The Future of Cooling in Southeast Asia,” Oct. 2019. Accessed: Nov. 20, 2025. [Online]. Available: https://iea.blob.core.windows.net/assets/dcadf8ee-c43d-400e-9112-533516662e3e/The_Future_of_Cooling_in_Southeast_Asia.pdf

[50] R. Levinson and H. Akbari, “Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants,” *Energy Effic.*, vol. 3, no. 1, pp. 53–109, Jan. 2010, doi: 10.1007/S12053-008-9038-2.

[51] Pacific Northwest National Laboratory, PECI, and U.S. Department of Energy, “Advanced Energy Retrofit Guide: Office Buildings,” 2011.

[52] M. Haj Hussein, S. Monna, R. Abdallah, A. Juaidi, and A. Albatayneh, “Improving the Thermal Performance of Building Envelopes: An Approach to Enhancing the Building Energy Efficiency Code,” *Sustainability 2022, Vol. 14, Page 16264*, vol. 14, no. 23, p. 16264, Dec. 2022, doi: 10.3390/su142316264.

[53] Asian Development Bank, “Rising Above the Heat: Strengthening Women’s Resilience to Heat Stress.” Accessed: Mar. 17, 2026. [Online]. Available: https://www.adb.org/multimedia/genderandheat/

[54] UN Women, “Gendered impacts of heat waves and drought in Asia and the Pacific: A review in the context of El Niño,” Apr. 2024.

[55] E. J. Kim, “Heat and gender: Enhancing her resilience to rising temperatures,” World Bank Blogs. Accessed: Mar. 17, 2026. [Online]. Available: https://blogs.worldbank.org/en/endpovertyinsouthasia/heat-and-gender--enhancing-her-resilience-to-rising-temperatures

[56] M. Azzi, A. Flouris, H. Graczyck, B. Nafradi, N. Scott, and eds., “Heat at work: Implications for safety and health,” International Labour Organization (ILO). Accessed: Mar. 17, 2026. [Online]. Available: https://www.ilo.org/publications/heat-work-implications-safety-and-health

[57] UN Women and ASEAN Secretariat, “ASEAN Gender Outlook 2024: Achieving the SDGs for all and leaving no woman or girl behind,” 2024. Accessed: Mar. 17, 2026. [Online]. Available: https://data.unwomen.org/publications/asean-gender-outlook-2024

[58] ACE, “Passive Cooling Strategies: Current Status and Drivers of Integration into Policy and Practice within ASEAN’s Building Sector.” Accessed: Feb. 10, 2026. [Online]. Available: https://aseanenergy.org/publications/passive-cooling-strategies-current-status-and-drivers-of-integration-into-policy-and-practice-within-aseans-building-sector

[59] J. Gamero-Salinas, A. Monge-Barrio, N. Kishnani, J. López-Fidalgo, and A. Sánchez-Ostiz, “Passive cooling design strategies as adaptation measures for lowering the indoor overheating risk in tropical climates,” *Energy Build.*, vol. 252, Dec. 2021, doi: 10.1016/J.ENBUILD.2021.111417.

[60] T. R. Oke, “Boundary Layer Climates,” 1987.

[61] B. Givoni, “Climate Considerations in Building and Urban Design.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=1868668

[62] J. A. Acero, E. J. Y. Koh, L. A. Ruefenacht, and L. K. Norford, “Modelling the influence of high-rise urban geometry on outdoor thermal comfort in Singapore,” *Urban Clim.*, vol. 36, p. 100775, Mar. 2021, doi: 10.1016/j.uclim.2021.100775.

[63] J. A. Acero, L. A. Ruefenacht, E. J. Y. Koh, Y. S. Tan, and L. K. Norford, “Measuring and comparing thermal comfort in outdoor and semi-outdoor spaces in tropical Singapore,” *Urban Clim.*, vol. 42, p. 101122, Mar. 2022, doi: 10.1016/j.uclim.2022.101122.

[64] L. A. Ruefenacht and J. A. Acero, “Strategies for Cooling Singapore: A Catalogue of 80+ Measures to Mitigate Urban Heat Island and Improve Outdoor Thermal Comfort,” Singapore, 2017. Accessed: Feb. 19, 2026. [Online]. Available: https://heathealth.info/wp-content/uploads/strategies-for-cooling-singapore.pdf

[65] F. Souayfane, F. Fardoun, and P. H. Biwole, “Phase change materials (PCM) for cooling applications in buildings: A review,” *Energy Build.*, vol. 129, pp. 396–431, Oct. 2016, doi: 10.1016/j.enbuild.2016.04.006.

[66] ASHRAE, “Standard 55 – Thermal Environmental Conditions for Human Occupancy.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

[67] E. Djunaedy, J. L. Hensen, and M. G. L. C. Loomans, “Toward external coupling of building energy and airflow modeling programs.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.researchgate.net/publication/255990057_Toward_external_coupling_of_building_energy_and_airflow_modeling_programs

[68] D. J. Nowak and E. J. Greenfield, “US urban forest statistics, values, and projections,” *J. For.*, vol. 116, no. 2, pp. 164–177, Mar. 2018, doi: 10.1093/jofore/fvx004.

[69] L. Yao, D. J. Sailor, X. Yang, G. Xu, and L. Zhao, “Are water bodies effective for urban heat mitigation? Evidence from field studies of urban lakes in two humid subtropical cities,” *Build. Environ.*, vol. 245, p. 110860, Nov. 2023, doi: 10.1016/j.buildenv.2023.110860.

[70] H. Li, Y. Zhao, C. Wang, D. Ürge-Vorsatz, J. Carmeliet, and R. Bardhan, “Cooling efficacy of trees across cities is determined by background climate, urban morphology, and tree trait,” *Communications Earth & Environment 2024 5:1*, vol. 5, no. 1, pp. 754-, Dec. 2024, doi: 10.1038/s43247-024-01908-4.

[71] N. C. Idham, “Javanese vernacular architecture and environmental synchronization based on the regional diversity of Joglo and Limasan,” *Frontiers of Architectural Research*, vol. 7, no. 3, pp. 317–333, Sep. 2018, doi: 10.1016/j.foar.2018.06.006.

[72] O. C. Dewi *et al.*, “Thermal performance of bio-based phase change material encapsulated in a bamboo wall for residential buildings: A field experiment,” *Energy and Built Environment*, vol. 147, no. 7, pp. 4451–4472, May 2025, doi: 10.1016/j.enbenv.2025.05.003.

[73] N. L. Alchapar and E. N. Correa, “Aging of roof coatings. Solar reflectance stability according to their morphological characteristics,” *Constr. Build. Mater.*, vol. 102, pp. 297–305, Jan. 2016, doi: 10.1016/j.conbuildmat.2015.11.005.

[74] S. A. Farhan *et al.*, “Effect of Roof Tile Colour on Heat Conduction Transfer, Roof-Top Surface Temperature and Cooling Load in Modern Residential Buildings under the Tropical Climate of Malaysia,” *Sustainability 2021, Vol. 13,* vol. 13, no. 9, Apr. 2021, doi: 10.3390/su13094665.

[75] M. C. Yew *et al.*, “Experimental analysis on the active and passive cool roof systems for industrial buildings in Malaysia,” *Journal of Building Engineering*, vol. 19, pp. 134–141, Sep. 2018, doi: 10.1016/j.jobe.2018.05.001.

[76] A. Budhiyanto and A. C. Tampubolon, “A Comparative Study of Cool Roof and Green Roof Performance in Tropical Area of Indonesia,” *Journal of Architectural Research and Design Studies*, vol. 9, no. 1, pp. 1–10, May 2025, doi: 10.20885/jars.vol9.iss1.art1.

[77] A. Sedaghat *et al.*, “Exploring energy-efficient building solutions in hot regions: A study on bio-phase change materials and cool roof coatings,” *Journal of Building Engineering*, vol. 76, p. 107258, Oct. 2023, doi: 10.1016/j.jobe.2023.107258.

[78] S. Chen *et al.*, “Physics-Informed Regression Modelling for Vertical Facade Surface Temperature: A Tropical Case Study on Solar-reflective Material,” Feb. 2026, Accessed: Feb. 18, 2026. [Online]. Available: http://arxiv.org/abs/2507.16174

[79] U.S. Environmental Protection Agency, “Reducing urban heat islands: Compendium of strategies,” U.S. Environmental Protection Agency. Accessed: Apr. 01, 2026. [Online]. Available: https://www.epa.gov/heatislands/guide-reducing-heat-islands

[80] H. Bai *et al.*, “Cooling potential of global urban roof greening,” *npj Urban Sustainability 2026 6:1*, vol. 6, no. 1, pp. 49-, Feb. 2026, doi: 10.1038/s42949-026-00354-9.

[81] B. Urban and K. Roth, “Guidelines for Selecting Cool Roofs,” 2010.

[82] S. Manshour and S. Lehmann, “A Systematic Review of Passive Cooling Strategies Integrating Traditional Wisdom and Modern Innovations for Sustainable Development in Arid Urban Environments,” Jul. 2025, Accessed: Apr. 01, 2026. [Online]. Available: https://arxiv.org/pdf/2507.09365

[83] M. G. Kent *et al.*, “Energy savings and thermal comfort in a zero energy office building with fans in Singapore,” *Build. Environ.*, vol. 243, p. 110674, Sep. 2023, doi: 10.1016/J.BUILDENV.2023.110674.

[84] ACE and UNEP U4E, “Recommendations for Updating the ASEAN Regional Policy Roadmap on Energy Efficient Air Conditioners,” 2021.

[85] GlobalABC, IEA, and UNEP, “GlobalABC Regional Roadmap for Buildings and Construction in Asia: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector,” Paris, 2022. [Online]. Available: www.iea.org/t&c/

[86] World Bank, “State and Trends of Carbon Pricing 2023,” *State and Trends of Carbon Pricing 2023*, May 2023, doi: 10.1596/39796.

[87] IEA, “Resilient Cooling of Buildings State of the Art Review Energy in Buildings and Communities Technology Collaboration Programme,” 2022, doi: 10.52776/COXK4763.

[88] ACE, “ASEAN Energy Investment,” 2024.

[89] ACE, “ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II: 2021-2025,” 2021.

[90] “Parkroyal Collection Pickering.” Accessed: Mar. 17, 2026. [Online]. Available: https://woha.net/project/parkroyal-on-pickering/

[91] C. Chan, “Parkroyal on Pickering Analysis Report | PDF.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.slideshare.net/slideshow/parkroyal-on-pickering-analysis-report/37315792

[92] WOHA, “WOHA Breathing Architecture.” Accessed: Feb. 18, 2026. [Online]. Available: https://woha.net/publication/woha-architektur-atmet-breathing-architecture/

[93] “Traditional Thai house.” Accessed: Mar. 17, 2026. [Online]. Available: https://maichau.ecolodge.asia/en/blog-detail/traditional-thai-house-an-unique-design-11224-5.html

[94] C. Tantasavasdi, J. Srebric, and Q. Chen, “Natural ventilation design for houses in Thailand,” *Energy Build.*, vol. 33, no. 8, pp. 815–824, Oct. 2001, doi: 10.1016/S0378-7788(01)00073-1.

[95] P. Prajongsan and S. Sharples, “Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts,” *Build. Environ.*, vol. 50, pp. 104–113, Apr. 2012, doi: 10.1016/j.buildenv.2011.10.020.

[96] “Menara Mesiniaga,” ArchNet. Accessed: Mar. 17, 2026. [Online]. Available: https://www.archnet.org/sites/957

[97] Suci Farahdilla, “MESINIAGA TOWER,” *Rumoh Journal of Architecture*, vol. 10, no. 20, pp. 85–92, Dec. 2020, doi: 10.37598/710ex405.

[98] A. Vijaya Lakshmi, “THERMAL PERFORMANCE OF TRADITIONAL AND MODERN BUILDINGS IN KERALA, SOUTH INDIA Vijaya lakshmi Akella 1 M.E (Structural engineering),” 2005.

[99] urbanNext, “Saigon House,” urbanNext. Accessed: Feb. 18, 2026. [Online]. Available: https://urbannext.net/saigon-house/

[100] V. T. Nguyen and H. L. Nguyen, “The Design of Tube Houses in Vietnam According to The Orientation of Wellness Architecture,” *International Journal of Sustainable Construction Engineering and Technology*, vol. 15, no. 3, pp. 31–39, Dec. 2024, doi: 10.30880/ijscet.2024.15.03.004.

[101] S. Ho, “Green School Bali Recognised By World Economic Forum Future Schools Report.” Accessed: Mar. 17, 2026. [Online]. Available: https://www.greenqueen.com.hk/green-school-bali-recognised-world-economic-forum-future-schools-report/

[102] Green School Bali, “Green Schools Bali.” Accessed: Feb. 18, 2026. [Online]. Available: https://bali.greenschool.org/admissions/visit-our-campus/

[103] B. Sinha, “Hawa Mahal,” Britannica. Accessed: Mar. 17, 2026. [Online]. Available: https://www.britannica.com/place/Hawa-Mahal

[104] S. Dash and M. Joshi, “Analysis of Solar Passive Architecture for Historical Structures in Hot and Dry Climate,” *International Journal of Engineering Research & Technology*, vol. 10, no. 3, Feb. 2022, doi: 10.17577/IJERTCONV10IS03037.

[105] “Pearl Academy of Fashion / Morphogenesis,” ArchDaily. Accessed: Mar. 17, 2026. [Online]. Available: https://www.archdaily.com/40716/pearl-academy-of-fashion-morphogenesis

[106] S. R, “Thesis Case Study Pearl Academy | PDF | Economic Sectors | Building.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.scribd.com/document/434638435/THESIS-CASE-STUDY-PEARL-ACADEMY-docx

[107] ARUP, “Raising the bar for sustainable city design,” ARUP. Accessed: Mar. 17, 2026. [Online]. Available: https://www.arup.com/projects/masdar-city/

[108] Masdar City, “Masdar Environmental, Social, Governance Report 2024.” Accessed: Feb. 18, 2026. [Online]. Available: https://masdarcity.ae/docs/default-source/pdf-to-download/masdar-city-esg-report-2024---en.pdf

[109] “The History of Dubai’s Traditional and Beautiful Barjeel Wind Towers.” Accessed: Mar. 17, 2026. [Online]. Available: https://matadornetwork.com/read/dubais-wind-towers-citys-traditional-beautiful-way-beat-heat/

[110] B. R. Hughes, J. K. Calautit, and S. A. Ghani, “The development of commercial wind towers for natural ventilation: A review,” *Appl. Energy*, vol. 92, pp. 606–627, 2012, doi: 10.1016/j.apenergy.2011.11.066.

[111] M. Pearce, “Council House 2,” Architectuul. Accessed: Mar. 17, 2026. [Online]. Available: https://architectuul.com/architecture/council-house-2

[112] X. Sun, “Review on CH2.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.academia.edu/17336711/Review_on_CH2

[113] J. MacMinn, “Aussie Style: Enduring Appeal of the Classic Queenslander Veranda,” Houzz. Accessed: Mar. 17, 2026. [Online]. Available: https://www.houzz.com/magazine/aussie-style-enduring-appeal-of-the-classic-queenslander-veranda-stsetivw-vs~39709619

[114] IEA, “IEA EBC Annex 80 - Resilient Cooling of Buildings,” 2019. Accessed: Nov. 20, 2025. [Online]. Available: https://annex80.iea-ebc.org/

[115] X. Sun, “Review on CH2.” Accessed: Mar. 16, 2026. [Online]. Available: https://www.academia.edu/17336711/Review_on_CH2

[116] Building and Construction Authority (BCA), “Green Mark 2021,” Building and Construction Authority. [Online]. Available: https://www1.bca.gov.sg/buildsg/sustainability/green-mark-certification-scheme/green-mark-2021?utm_source=chatgpt.com

[117] TGBI, “Thai’s Rating of Energy and Environmental Sustainability for New Construction and Major Renovation,” 2017.

[118] Ministry of Energy Thailand, “Thailand 20-Year Energy Efficiency Development Plan (2011-2030),” 2011.

[119] S. Amerudin, “The Green Building Index (GBI) Certification,” Universiti Teknologi Malaysia. [Online]. Available: https://people.utm.my/shahabuddin/?p=5856

[120] GBCI, “Certification GREENSHIP,” Green Building Council Indonesia. Accessed: Feb. 09, 2026. [Online]. Available: https://gbcindonesia.org/certification/greenship

[121] EPS Capital Corp. and ETP, “Diagnostic Review and Analysis of Energy Efficiency Development in the Philippines,” Jan. 2022. Accessed: Feb. 09, 2026. [Online]. Available: https://www.energytransitionpartnership.org/wp-content/uploads/2024/04/Diagnostic-Analyses-Report-of-Energy-Efficiency-Development-in-the-Philippines.pdf?

[122] AGC, “Green Compliance in the Region: Increasing Adoption of Green Building Rating Systems.” Accessed: Feb. 09, 2026. [Online]. Available: https://agc-glassasia.com/sustainability/sustainable-buildings/green-compliance-in-the-region/

[123] Building and Construction Authority (BCA), “The 2nd Green Building Masterplan,” Singapore, 2021.

[124] Government of Malaysia, “Uniform Building By-Laws 1984 (G.N. 5178/1984).”

[125] C. Prasert, “Thailand Building Control Act: Construction Rules & Permits 2025,” Themis Partner. Accessed: Feb. 09, 2026. [Online]. Available: https://thailand.themispartner.com/guides/thailand-building-control-act-construction-rules-permits/

[126] Building and Construction Authority (BCA), “Regulatory Requirements for Existing Buildings,” Building and Construction Authority. Accessed: Feb. 09, 2026. [Online]. Available: https://www1.bca.gov.sg/buildsg/sustainability/regulatory-requirements-for-existing-buildings?

[127] Building and Construction Authority (BCA), "Singapore Master Plan," Building and Construction Authority. Accessed: Feb. 09, 2026. [Online]. Available: https://www.ura.gov.sg/Corporate/Planning/Master-Plan

[128] Kingdom of Thailand and JICA, "The 2nd Comprehensive Review of the Progress of Implementation and Achievement ," Bangkok, 2013.

[129] Provinsi Daerah Khusus Ibukota Jakarta, "Peraturan Daerah (Perda) Provinsi Daerah Khusus Ibukota Jakarta Nomor 7 Tahun 2024 tentang Rencana Tata Ruang Wilayah," Jakarta. Accessed: Feb. 09, 2026. [Online]. Available: https://peraturan.bpk.go.id/Details/313265/perda-prov-dki-jakarta-no-7-tahun-2024

[130] City Council of Manila, "Ordinance No. 9055: An Ordinance Promoting the Creation, Use and Maintenance of Health Open Spaces in Communities, and Other Health and Environment Initiatives," Manila, 2024. Accessed: Feb. 09, 2026. [Online]. Available: https://citycouncilofmanila.com.ph/city_ordinances/ordinance-no-9055-2/

[131] National Assembly of the Socialist Republic of Vietnam, "Law on Amending and Supplementing a Number of Articles of the Construction Law (Law No. 62/2020/QH14)," Hanoi, 2020.

[132] ESMAP, "Primer for Cool Cities: Reducing Excessive Urban Heat," Washington, DC, 2020. Accessed: Feb. 09, 2026. [Online]. Available: https://www.shutterstock.com/image-

[133] Asian Development Bank, "Handbook on Energy Efficiency in Buildings," Manila, Oct. 2024.

[134] Building and Construction Authority (BCA), "Building Retrofit Energy Efficiency Financing (BREEF) Scheme," Building and Construction Authority. Accessed: Feb. 09, 2026. [Online]. Available: https://www1.bca.gov.sg/buildsg/sustainability/green-mark-incentive-schemes/building-retrofit-energy-efficiency-financing-breef-scheme

[135] Baker McKenzie, "Incentives for Green Retrofit - Vietnam," Baker McKenzie Resource Hub. Accessed: Feb. 09, 2026. [Online]. Available: https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings/asia-pacific/vietnam/topics/incentives-for-green-retrofit

[136] Baker McKenzie, "Incentives for Green Retrofit - Philippines," Baker McKenzie Resource Hub. Accessed: Feb. 09, 2026. [Online]. Available: https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings/asia-pacific/philippines/topics/incentives-for-green-retrofit

[137] IFC, "Sustainable Buildings: Finance Reference Guide," Washington, DC, 2025. Accessed: Feb. 09, 2026. [Online]. Available: www.ifc.org

[138] ASEAN Taxonomy Board, “ASEAN Taxonomy for Sustainable Finance,” 2025.

[139] World Bank, “Sustainable Cooling Initiative,” World Bank Group. Accessed: Feb. 10, 2026. [Online]. Available: https://www.worldbank.org/en/programs/sustainable-cooling-initiative/overview

[140] UNEP, “Not Passing on Passive Cooling: How Philanthropy Can Help Accelerate Passive Cooling Solutions and Their Climate Benefits,” 2021.

[141] Y. Liu and R. Noor, “Energy Efficiency in ASEAN: Trends and Financing Schemes,” Tokyo, 2020. Accessed: Feb. 10, 2026. [Online]. Available: https://www.adb.org/publications/energy-efficiency-asean-trends-financing-schemes

[142] A. Kapoor, E.-Q. Teo, D. Azhgaliyeva, and Y. Liu, “The Viability of Green Bonds as a Financing Mechanism for Green Buildings in ASEAN,” Tokyo, Sep. 2020. Accessed: Feb. 10, 2026. [Online]. Available: https://www.adb.org/publications/viability-green-bonds-financing-mechanism-green-buildings-asean

[143] Building and Construction Authority (BCA), “Code on Envelope Thermal Performance for Buildings,” Singapore.

[144] SEDA Malaysia, “Malaysian Standards: (MS) 1525: 2019 - Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings.” Accessed: Feb. 10, 2026. [Online]. Available: https://www.seda.gov.my/pdfdownload/malaysian-standards-ms-1525-2019-energy-efficiency-and-use-of-renewable-energy-for-non-residential-buildings/

[145] World Bank Group, “Unlivable: What the Urban Heat Island Effect Means for East Asia’s Cities.” Accessed: Feb. 09, 2026. [Online]. Available: https://www.worldbank.org/en/region/eap/publication/unlivable-what-the-urban-heat-island-effect-means-for-east-asia-s-cities

[146] World Bank, “Power More With Less: Scaling Up Energy Efficiency for Growth and Energy Security,” Washington, DC, 2025.

[147] D. Azhgaliyeva and D. Rahut, “Promoting Green Buildings: Barriers, Solutions, and Policies,” Tokyo, Jul. 2022. doi: 10.56506/CVYC4388.

[148] A. Tuerk *et al.*, “Integrating Plus Energy Buildings and Districts with the EU Energy Community Framework: Regulatory Opportunities, Barriers and Technological Solutions,” *Buildings 2021, Vol. 11,* vol. 11, no. 10, Oct. 2021, doi: 10.3390/buildings11100468.

[149] J. Yudelson, “Marketing green building services: Strategies for success,” *Marketing Green Building Services: Strategies for Success*, vol. 9780080942315, pp. 1–282, Jan. 2012, doi: 10.4324/9780080942315.

ASEAN Centre for Energy
One Community for Sustainable Energy

www.aseanenergy.org

@aseanenergy

ASEAN Centre for Energy

@aseanenergy

@aseanenergy