Science Technology and Sustainability Review
Issue: STS001/25
30 June 2025

CamTech
University Press

Building Integrated Photovoltaic as a Passive Solar Design for Energy Efficiency in Residential Buildings in Cambodia

NOU Chanrachna
Department of Architecture and Interior Design, CamTech University, Phnom Penh, Cambodia

Abstract

Buildings are major energy consumers, contributing significantly to greenhouse gas emissions. Cambodia, despite having abundant sunlight, faces energy shortages and limited sustainable construction practices. With a high proportion of residential buildings in urban areas, greenhouse gas emissions are expected to increase. To mitigate this issue, the widespread adoption of Building Integrated Solar Energy (BISE), particularly Building Integrated Photovoltaics (BIPV) and Building-integrated Photovoltaic-Thermal (BiPVT) systems, is crucial as an effective passive solar design strategy for residential buildings. This paper highlights the advantages of integrating photovoltaic systems into building facades and roofs, which include reducing energy consumption, lowering greenhouse gas emissions, and enhancing building aesthetics. Despite challenges such as high initial costs and limited expertise, this article emphasizes the importance of government initiatives, education, and awareness to promote BISE adoption in Cambodia, ultimately contributing to a greener and more sustainable future.

Keywords: Building Integrated Photovoltaic, Passive Solar Design, Energy Efficiency, Residential Buildings

Introduction

A recent declaration from the United Nations (UN) news states, “The era of global warming has ended; the era of global boiling has arrived.” (UN, 2023). The burning of fossil fuels, including coal, oil, and natural gas, releases greenhouse gases into the atmosphere. These gases act like a blanket, trapping heat from the sun, causing global warming, and leading to climate change. The term becomes more terrible day by day unless people around the globe take their actions seriously. The consequences of climate change are spreading widely to increase awareness of its impacts, so that more and more focus has been placed on reducing energy consumption and moving towards more sustainable forms of energy production. According to comparison research on global energy consumption published by the International Energy Agency (IEA), solar array installations will meet about 45% of the global energy demand in 2050 (IEA, 2021b).

According to the IEA Data Service, residential buildings consumed 35% of energy demand, supply, and consumption, rather than industry, commercial, and public services in 2021 (IEA,

2021a). The huge energy consumption in the building industry not only consumes a lot of non-renewable resources but also contributes to the emission of harmful substances into the atmosphere. To solve the problems caused by environmental pollution and energy shortages, the utilization and promotion of renewable energy in residential buildings have received more attention in recent years(Yang et al., 2014).

Renewable Energy Systems are used as a passive strategy for Nearly Zero-Energy Buildings (nZEB) implementation. Passive strategies focus on utilizing natural phenomena and materials to achieve thermal comfort and reduce cooling needs in buildings,thereby minimizing energy consumption. The solutions include incorporating glazing, sun shading, sunspaces, Trombe walls, cool coatings, variable-conductivity thermoelectric materials, and phase change materials alongside nighttime ventilation for improved heat management, and vegetated and ventilated walls and roofs (Ascione, 2017; Brito-Coimbra et al., 2021). Renewable Energy Systems, for example, solar thermal panels, generate clean energy on-site and further reduce reliance on the traditional grid. These technologies offer improved thermal comfort, increased energy savings, reduced greenhouse gas emissions, and promote the development of greener cities (Brito-Coimbra et al., 2021; Prieto Hoces, 2017).

Solar energy has the highest global potential among renewable energy sources. As the most important form of renewable energy, it is an abundant and permanent resource on Earth. Compared with conventional energy, solar energy has many advantages, as follows: it is inexhaustible, clean, safe, reliable, and pollution-free. It can be captured and converted into usable energy for a variety of purposes, including power generation, heating and cooling systems of buildings, water heating systems, irrigation systems for agriculture, and powering transportation (Kabir et al., 2018). Meanwhile, Cambodia appears to be facing the challenges of population expansion, energy shortages, and a lack of access to reliable, affordable, and sustainable energy (Phoumin & Kimura, 2019). With rich solar resources in most areas of Cambodia, it is an opportunity to develop solar energy and promote energy-saving buildings, which fully reflects the concept of sustainable development and green ecological energy-saving.

Adoption of Building Integrated Solar Energy as Passive Solar Design in Residential Buildings

A variety of Building Integrated Solar Energy (BISE) technologies have been developed and have appeared in sustainable strategies. BISE represents a design of solar technologies approach, both functionality and aesthetics, striving to achieve optimal energy efficiency while preserving the architectural character of the structure to enhance solar energy adoption in developing countries, particularly for residential buildings (Yang et al., 2014). Particularly, Building Integrated Photovoltaics (BIPV), which serves as a foundational concept in BISE, is an

innovative approach to passive solar design strategy. BIPV is used to create a comfortable living environment by reducing a building's energy consumption (Dixit, 2020). Another cutting-edge approach of BISE is Building-integrated Photovoltaic-Thermal (BiPVT) systems that can be competitive across various system sizes with the same initial investment cost due to their ability to generate both electricity and thermal energy, making them a more versatile and potentially cost-effective solution in warmer climates (Gautam & Andresen, 2017). Ultimately, both methods utilize photovoltaics (PV) directly integrated into the building envelope and part of building components such as facades,windows and roofs, generating electricity and offering numerous advantages (Izam et al., 2022). The installation of PV on building facades differs slightly from rooftop installations, as the panels are mounted vertically on the external wall on a multi-layer facade rather than horizontally on a roof (Attoye et al., 2017). Switzerland, China, and the Netherlands have been implementing the solar façade to retrofit residential blocks with BIPV energy generation for thermal control and aesthetic appeal (Angela Clua et al., 2017; Peng et al., 2013; Valckenborg et al., 2016).

Installing PV on a building can not only create an aesthetic appeal but also a country’s geometric flexion. Nowadays, PV comes in various designs with colors and plants (Tablada et al., 2017). Some designs are even textured to blend in with the appearance of the building’s roofs and facades, enhancing the building's appearance and maximizing the absorption of daylight into the grid, as shown in *Figure 1.* SD Yoon (2021) maximized solar energy production by applying PV modules to building facades and roof installations in urban areas, as shown in *Figure 2* and *Figure 3.* The most efficient angles for energy production were found to be between 15.64°, 33.49°, and 36.33° on various southeast-, south-, and southwest-facing facades, respectively, in Seoul, Gwangju, and Busan, with a combined installation area of 1,902 square meters, resulting in an annual solar energy production of 307,734 kWh (Yoon et al., 2021). In addition, Mendis et al. (2020) found that horizontally tilted PV panels on building facades, between 15° to 45° with a depth/length ratio of four, could achieve a payback period of nine years in Colombo, Sri Lanka's tropical climate (Mendis et al., 2020).

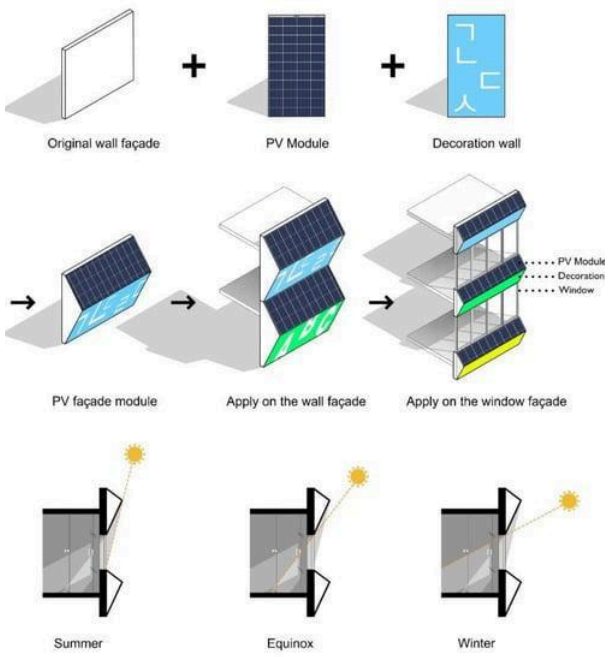

Figure 1 Diagram of the conceptual PV module design

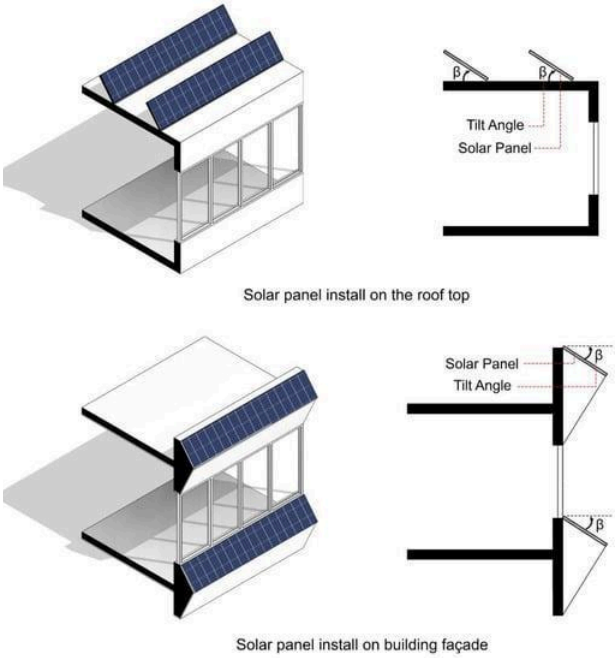

Figure 2. Tilt angle (β) of PV installed on roofs and façades.

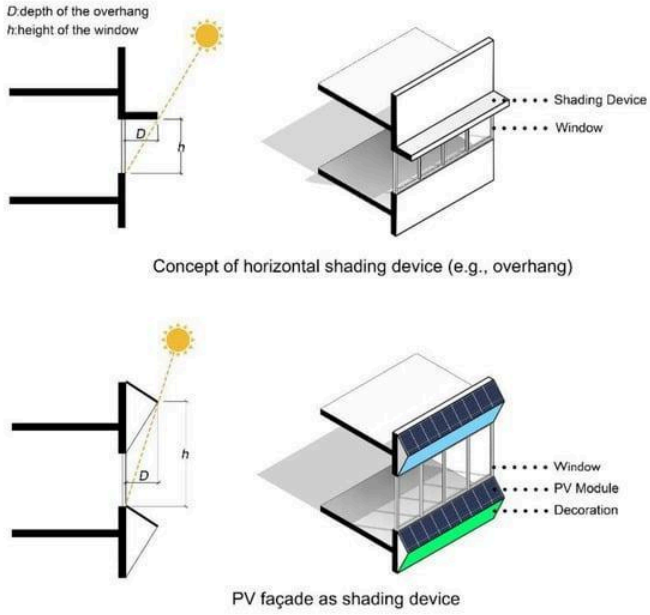

Figure 3. PV module designs.

The Potential of Building Integrated Solar Energy in Cambodia

The amount of sunlight the Earth receives varies according to geographic location, time of day, season, landscape, and weather. Cambodia is located in the Tropic of Cancer; the mean solar energy flux density is 200W per day, which might not be enough to supply energy demand in tropical regions. The limitations of using PV in Cambodia are its high initial cost, weather fluctuations, lack of technical expertise, insufficient infrastructure and maintenance, and limited awareness of its benefits (Daniel Fraile Montoro et al., 2011; UNDP, 2019; Vakulchuk et al., 2020). Therefore, the process of solar energy utilization is necessary to provide a set of collection and conversion equipment with a large area to receive enough switching power (Yang et al., 2014).

Cambodia is a developing country with a majority of low-rise and mid-rise buildings for household residents. According to the Sub-Decree 42 on the urbanization of the capital city and urban areas in Cambodia, low-rise and mid-rise buildings are up to 2 stories and 11 stories or approximately 6 meters and 30 meters tall, respectively (Government, 2015; Kram, 2019). Due to its geographical location and abundant sunlight throughout the year, the building facade and roof are heated by the sun's radiation for 8-12 hours on a clear day. On average, Cambodia receives 5.5 kWh of solar energy per square meter each day (Feng et al., 2019; Mika et al., 2021). More importantly, the panels can act as barriers against direct sunlight penetrating the interior space. This means that installing PV as a passive design feature can reduce heat and make the building more energy-efficient overall.

The Cambodian government is committed to renewable energy development. It has set a goal to improve energy efficiency to reduce high energy costs, focusing on buildings, industry, and transport by 2035. Energy-efficiency performance standards and building codes for existing and new buildings are established and implemented to reduce energy consumption by 25% in the building sector (Asian Development Bank, 2018). According to the Power Development Master Plan, the country's national power grid has the potential to accommodate up to 3,115 MW of solar power, equivalent to 29.8% of total domestic electricity energy sources in 2040 (Energy, 2023). The Australian government offers financial incentives to households installing renewable energy systems, including rebates and feed-in tariffs, which allow households to sell excess solar energy back to the grid. The average household solar installation size in Australia has seen a significant increase, contributing 25.8% of the country's total renewable energy generation in 2022, rising from 2kWp in 2011 to 8kWp in 2023 (Council, 2023). If society could achieve greater solar PV installation on homes, annual grid-based electricity consumption could be reduced by 40%, lowering greenhouse gas emissions per household annually and reducing energy bills by $2,908 per low-income household over 15 years (Dodd & Nelson, 2022).

Sustainable construction practices are not widely adopted in the Cambodian construction industry. While the adverse environmental impacts of the building and construction sector are increasingly recognized globally, understanding of green building concepts and practices in

Cambodia remains relatively low. According to the National Strategic Development Plan 2019-2023, of the 4,841 construction projects issued by the Cambodian government from 2000 to 2020, most lacked significant integration of green building concepts (Ministry of Environment et al., 2021). This presents a lack of legislative requirements, education, awareness, and knowledge, as well as reluctance to adopt new technologies, as barriers to the adoption of sustainable construction practices in Cambodia (Durdyev et al., 2018; Ministry of Environment et al., 2021). Consequently, these practices contribute to greenhouse gas emissions, air pollution, public health concerns, urban ecological challenges, and negative city environments. To promote wider adoption of building energy performance optimization, raising awareness among architects and planners, enhancing architectural education with interdisciplinary knowledge, and utilizing smart technologies to improve building performance prediction are essential (Karagianni et al., 2022; Li et al., 2020).

Conclusion

Cambodia's renewable energy industry is still in its infancy, but it is expanding quickly due to its environmental and financial benefits. PV, one of the renewable energy sources, is dominant for low-rise and mid-rise buildings in Cambodia as passive design strategies to improve interior comfort conditions, reduce energy consumption, and increase energy efficiency in buildings. Housing designers, especially sustainable architects, should not disregard PV as a passive design strategy on the roof or facade, which consumes less space, aesthetically improves facades, and provides adequate energy for residential needs with technological advancement. The most efficient angles for energy production, whether on the building’s roofs or façade, can be flexible due to the building’s orientation and geographical location. Retrofitting existing buildings to meet energy performance standards and establishing an energy efficiency building code by integrating solar technologies is critical for occupants. In addition, raising awareness among residents to use PV has many benefits such as reducing carbon footprints and saving electricity bills in the long run. Therefore, a comprehensive solar energy policy framework across the country is crucial to promote the uptake of PV, though there is still a long way to go to create a conducive environment for solar energy adoption in the country. Finally, utilizing solar PV technology is a form of protecting the environment that everyone should practice freely and wisely, contributing in the long run to a sustainable energy future for the residential sector.

Incorporating the potential and adaptation of BIPV into architectural education presents a holistic approach to a more sustainable and resilient built environment. This exemplifies how sustainability can be seamlessly integrated into design, fostering the development of adaptable and policy-compliant buildings. It means that both existing and new buildings can be retrofitted and constructed with an emphasis on energy efficiency and aesthetic appeal once future housing designers and architects are educated and encouraged in their design initiatives.

References

Angela Clua, L., Sophie, L., & Emmanuel, R. (2017, 2017). *Towards Advanced Active Façades: Analysis of façade requirements and development of an innovative construction system* https://infoscience.epfl.ch/handle/20.500.14299/138413

Ascione, F. (2017). Energy conservation and renewable technologies for buildings to face the impact of the climate change and minimize the use of cooling. *Solar Energy*, *154*, 34-100. https://doi.org/https://doi.org/10.1016/j.solener.2017.01.022

Asian Development Bank, A. (2018). *Cambodia energy sector assessment, strategy, and roadmap*. https://doi.org/http://dx.doi.org/10.22617/TCS189801

Attoye, D. E., Tabet Aoul, K. A., & Hassan, A. (2017). A Review on Building Integrated Photovoltaic Façade Customization Potentials. *Sustainability*, *9*(12), 2287. https://doi.org/10.3390/su9122287

Brito-Coimbra, S., Aelenei, D., Gloria Gomes, M., & Moret Rodrigues, A. (2021). Building façade retrofit with solar passive technologies: A literature review. *Energies*, *14*(6), 1774. https://doi.org/10.3390/en14061774

Council, C. E. (2023). *Australian rooftop solar breaks new ground in 2022: Clean energy Australia report*. https://www.cleanenergycouncil.org.au/news/australian-rooftop-solar-breaks-new-ground-in-2022-clean-energy-australia-report

Daniel Fraile Montoro, E., Pieterjan Vanbuggenhout, E., & Joanna Ciesielska, E. (2011). *Building Integrated Photovoltaics: An overview of the existing products and their fields of application*. E. P. I. Association. http://pvtrin.eu/assets/media/PDF/Publications/Other%20Publications/40.BIPV-overview_of_existing_products_PVSUNRISE.pdf

Dixit, S. (2020). Solar technologies and their implementations: A review. *Materials Today: Proceedings*, *28*, 2137-2148. https://doi.org/https://doi.org/10.1016/j.matpr.2020.04.134

Dodd, T., & Nelson, T. (2022). Australian household adoption of solar photovoltaics: A comparative study of hardship and non-hardship customers. *Energy Policy*, *160*, 112674. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112674

Durdyev, S., Zavadskas, E., Thurnell, D., Banaitis, A., & Ihtiyar, A. (2018). Sustainable construction industry in Cambodia: Awareness, drivers and barriers. *Sustainability*, *10*(2), 392. https://doi.org/10.3390/su10020392

Prakas on launching of "Principles for Permitting the Use of Rooftop Solar Power in Cambodia" (2023). https://rbh-eurochamcambodia.com/wp-content/uploads/2023-Principles-for-Permitting-the-Use-of-Rooftop-Solar-Power-in-Cambodia-EN.pdf

Feng, W., Zhang, Q., Ji, H., Wang, R., Zhou, N., Ye, Q.,…Lau, S. S. Y. (2019). A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renewable and Sustainable Energy Reviews*, *114*, 109303. https://doi.org/10.1016/j.rser.2019.109303

Gautam, K. R., & Andresen, G. B. (2017). Performance comparison of building-integrated combined photovoltaic thermal solar collectors (BiPVT) with other building-integrated solar technologies. *Solar Energy*, *155*, 93-102. https://doi.org/https://doi.org/10.1016/j.solener.2017.06.020

Government, R. (2015). *Sub Decree 42 - Urbanization of Capital City Town and Urban Area*. Retrieved from https://www.scribd.com/document/531786977/Sub-decree-42-Urbanization-of-Capital-city-Town-and-Urban-Area-2015-Eng

IEA, I. E. A. (2021a). *Sources of electricity generation*. IEA. Retrieved 04 July 2024 from https://www.iea.org/countries/cambodia/electricity

IEA, I. E. A. (2021b). *World energy outlook 2021*. https://www.iea.org/reports/world-energy-outlook-2021

Izam, N. S. M. N., Itam, Z., Sing, W. L., & Syamsir, A. (2022). Sustainable development perspectives of solar energy technologies with focus on solar photovoltaic—A review. *Energies*, *15*(8), 2790. https://doi.org/10.3390/en15082790

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K.-H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, *82*, 894-900. https://doi.org/10.1016/j.rser.2017.09.094

Karagianni, C., Schwede, D., Taing, K., & Han, V. (2022). Smart technology supporting traditional and bioclimatic building functions in reducing cooling energy demand in Cambodia. *Konrad-Adenauer-Stiftung, KAS*, *5*, 93-103.

Law on construction, (2019). https://urbandatabase.khmerstudies.org/get-datas/588

Li, S., Liu, L., & Peng, C. (2020). A review of performance-oriented architectural design and optimization in the context of sustainability: Dividends and challenges. *Sustainability*, *12*(4), 1427. https://doi.org/10.3390/su12041427

Mendis, T., Huang, Z., & Xu, S. (2020). Determination of economically optimised building integrated photovoltaic systems for utilisation on facades in the tropical climate: A case study of Colombo, Sri Lanka. *Building Simulation*, *13*(1), 171-183. https://doi.org/10.1007/s12273-019-0579-4

Mika, K., Minna, M., Noora, V., Jyrki, L., Jari, K.-o., Anna, A.,…Nicholas, H. (2021). Situation analysis of energy use and consumption in Cambodia: Household access to energy. *Environment, Development and Sustainability*, *23*(12), 18631-18655. https://doi.org/10.1007/s10668-021-01443-8

Ministry of Environment, DGE technical staff, & reviewers, a. i. (2021). *Stocktaking and analytical options for green building in Cambodia*. t. K. o. C. The General Secretariat of the National Council for Sustainable Development/Ministry of Environment. https://ncsd.moe.gov.kh/sites/default/files/2022-01/Stocktaking_and_Analytical_Options_for_Green_Building_in_Cambodia_2021_En.pdf

Peng, J., Lu, L., Yang, H., & Han, J. (2013). Investigation on the annual thermal performance of a photovoltaic wall mounted on a multi-layer façade. *Applied Energy*, *112*, 646-656. https://doi.org/https://doi.org/10.1016/j.apenergy.2012.12.026

Phoumin, H., & Kimura, F. (2019). Cambodia's energy poverty and its effects on social wellbeing: Empirical evidence and policy implications. *Energy Policy, Elsevier*, *132*(C), 283-289. https://doi.org/10.1016/j.enpol.2019.05.032

Prieto Hoces, A. K., Ulrich ; Auer, Thomas et al. (2017). Solar façades: Main barriers for widespread façade integration of solar technologies. *Journal of Facade Design and Engineering*, *5*(1), 5. https://doi.org/10.7480/jfde.2017.1.1398

Tablada, A., Chaplin, I., Huang, H., Kosoric, V., Lau, S. K., Yuan, C., & Lau, S. (2017). Assessment of solar and farming systems integration on tropical building facades. 1-11. https://doi.org/10.18086/swc.2017.12.11

UN, T. U. N. (2023). *Hottest July ever signals 'era of global boiling has arrived' says UN chief* UN News. Retrieved June 26 from https://news.un.org/en/story/2023/07/1139162

UNDP, U. N. D. P. (2019). *Cambodia: Derisking renewable energy investment* New York: United Nations Development Programme).

Vakulchuk, R., Chan, H.-Y., Kresnawan, M. R., Merdekawati, M., Overland, I., Sagbakken, H. F.,…Yurnaidi, Z. (2020). *Cambodia: Five actions to improve the business climate for renewable energy investment*. http://dx.doi.org/10.13140/RG.2.2.25320.70403

Valckenborg, R. M. E., Wall, W. v. d., Folkerts, W., Hensen, J. L. M., & Vries, A. D. (2016). *Zigzag structure in facade optimizes PV yield while aesthetics are preserved*

Yang, L., He, B.-j., & Ye, M. (2014). The application of solar technologies in building energy efficiency: BISE design in solar-powered residential buildings. *Technology in Society*, *38*, 111-118. https://doi.org/https://doi.org/10.1016/j.techsoc.2014.03.002

Yoon, S. D., Vuthy, S., & Choi, H. S. (2021). Design of solar modules for building façades at educational facilities in Korea. *Energy*, *14*(9). https://doi.org/10.3390/10.3390/en14092441