

Solar photovoltaic buildings: The combination of sustainable energy and green buildings

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Abstract. Solar photovoltaic (SPV) buildings are at the cutting edge of renewable energy technology, offering a promising solution to meet our growing energy needs while minimizing environmental impact. This comprehensive review explores the multifaceted realm of solar PV buildings, examining their design, construction, energy performance compared to traditional structures, environmental consequences, and future possibilities. SPV buildings hold significant potential in promoting sustainability and achieving energy self-sufficiency. These structures not only generate clean energy but also contribute surplus electricity to the grid, enhancing community resilience and reducing dependence on traditional energy sources. Design and construction innovation involves implementing advanced architectural designs, utilizing smart building management systems, and incorporating renewable materials. These practices not only improve energy efficiency but also enhance the overall aesthetic appeal of structures. Performance evaluations consistently show that SPV buildings outperform traditional structures in terms of energy efficiency, carbon footprint reduction, and long-term cost-effectiveness. This translates to reduced energy consumption and environmental burdens. Environment issues such as energy-intensive panel production and waste disposal necessitate ongoing research to mitigate any negative environmental impact, thus necessitating technological developments to minimize these ramifications. SPV buildings represent the future of energy-efficient construction, leading the way to a cleaner and more eco-friendly world. Through tireless research and innovation, these structures may soon become mainstream solutions, providing environmental preservation as well as energy independence benefits for society at large.

Keywords: solar photovoltaic, sustainable energy, green buildings

1. Introduction

SPV architecture is an innovative solution that combines solar technology with architectural design, contributing to sustainable development. It addresses the energy and environmental challenges of our society by integrating clean energy solutions. As the global demand for renewable energy and carbon emission reduction increases, SPV architecture is becoming a leading trend in the construction industry.

Traditional buildings that heavily rely on conventional energy sources contribute greatly to greenhouse gas emissions, which generate adverse influences on both climate and the environment. Additionally, the instability of the energy supply is a persistent concern. However, there is a sustainable and environmentally friendly solution to these issues: SPV architecture.

By integrating SPV panels onto building surfaces, solar energy can be directly converted to electricity for building energy needs, providing green and renewable sources that help decrease carbon emissions.

SPV architecture contributes to creating comfortable indoor environments while decreasing the environmental footprint simultaneously.

As solar technology progresses and costs decrease, SPV architecture is quickly transitioning from being an optional choice into becoming a mainstream and affordable option. Given today's rapid urbanization and construction development trends, its background and importance cannot be overemphasized; SPV architecture is playing a pivotal role in creating sustainable urban development, decreasing energy consumption, and improving environmental quality.

2. SPV Application Potential in Buildings

Solar energy is leading the renewable energy applications in the world. SPV is the most promising renewable technology in terms of market share and the range of applications [1]. As the world increasingly pays emphasis on sustainable solutions, SPV offers a pathway to revolutionize the way buildings harness and utilize energy. By integrating solar panels directly into building structures, rooftops, and facades, we can transform these structures into clean energy generators.

SPV is the most prominent renewable technology when it comes to application in buildings [2]. As they offer a renewable and environmentally friendly energy source, reducing the dependence on non-renewable fossil fuels and lowering the emissions of carbon. One of the most successful applications of SPV has been in buildings. SPV can be used in buildings in several ways, such as mounting on and integration with roofs and walls/facade, integration with roofs and walls/facades, and thin-film coating on windows [1].

Additionally, SPV-integrated buildings can experience reduced energy costs over the long term. The successful application of SPV in buildings has been propelled by technical advancements, strong policies, and an economy of scale [1]. The additional energy produced by the solar panels can also be returned to the grid, leading to energy credits potentially. Moreover, during peak energy demand periods, SPV systems can help alleviate stress on the electrical grid, enhancing overall grid stability.

Beyond the environmental and economic benefits, SPV technology enhances the overall sustainability of buildings. It aligns with green building principles, contributing to certifications such as LEED (Leadership in Energy and Environmental Design). The aesthetics of buildings can also be improved by creatively integrating solar panels into the design, showcasing a commitment to both innovation and sustainability. As SPV technology continues to advance, its integration into building design and construction will undoubtedly shape a more sustainable and energy-efficient future for our urban environments.

3. Design and Construction of Solar PV Buildings

The design and construction of SPV buildings are vital for sustainable energy development. The process involves various considerations. First, the optimal capture of solar radiation requires careful consideration of the building's orientation and tilt angle. Additionally, selecting suitable materials and aesthetics ensures seamless integration between the photovoltaic components and the building's appearance, enhancing its visual appeal. Furthermore, a comprehensive assessment of energy requirements is necessary to determine the capacity needed for the photovoltaic system. Overall efficiency is another crucial factor that needs to be considered in order to align the photovoltaic system with energy consumption.

Photovoltaic building construction methods involve several key points. Firstly, it is crucial to select an appropriate installation method, such as rooftop installation, wall integration, or facade integration. Many prefer rooftop installation due to its minimal ground space occupation and easy maintenance. Secondly, ensuring structural stability is paramount to ensure that photovoltaic components can withstand external elements like wind and rain securely. This can be achieved by utilizing suitable supports and fixing systems for long-term stability. Lastly, the layout of photovoltaic modules should consider shading prevention to optimize electricity generation efficiency while avoiding any negative impacts.

During the construction process, it is crucial to plan cable pathways and junction boxes meticulously. This ensures that connections are reliable and maintenance is easy. Moreover, the design should consider maintenance requirements by incorporating easily removable components for cleaning, re-pairs, or system upgrades.

In considering the design and construction of SPV buildings, it is essential to strike a harmonious balance between energy efficiency, architectural aesthetics, and structural integrity. This comprehensive process requires meticulous design planning and sound structural construction. By adhering to these principles, photovoltaic buildings can play a pivotal role in advancing sustainable development.

4. SPV Buildings' Performance Evaluation

In 2019, PV accounted for 57% of the total renewable energy capacity addition. With 115GW of new projects added in 2019, the installed capacity of PV reached 627GW at the end of the year. China, the United States, Japan, Germany, and India are the leading nations in terms of the PV installed capacity in the order. PV is also making significant contributions at the national level. In the USA, for example, PV generation increased by 27% [1]. SPV buildings, a pioneering design concept in the era of sustainable development, offer substantial energy performance advantages compared to traditional constructions. These benefits encompass various aspects, resulting in significant environmental and economic gains.

SPV buildings harness renewable energy from sunlight to convert it into electricity. This reduces the reliance on conventional energy sources, unlike traditional constructions that heavily depend on fossil fuels. As a result, traditional constructions contribute to environmental pollution and energy depletion. By utilizing photovoltaic systems, these buildings can independently generate electricity and even distribute surplus power back to the grid. This decreases reliance on utility companies, lowers carbon emissions, and enables the achievement of a sustainable energy supply.

SPV buildings excel in energy conservation. They have the ability to function as shading devices, reducing direct sunlight exposure during summer. This leads to lower indoor temperatures and decreased air conditioning consumption. Additionally, modern photovoltaic constructions often incorporate efficient insulation materials and energy-saving equipment, further decreasing overall energy consumption. In contrast, traditional constructions typically suffer from poor energy efficiency due to energy wastage and inefficient design.

Photovoltaic buildings offer economic advantages. Although the initial investment may be higher, the cost of photovoltaic components is gradually decreasing due to technological advancements and increased market competition. These constructions can recoup investments through long-term energy savings and generation, which leads to reduced energy expenses. Furthermore, governments provide incentives such as tax benefits and subsidies, adding to the economic appeal of photovoltaic buildings.

Quantifiable evidence strengthens the case for the benefits of SPV buildings. According to research, these constructions have the potential to substantially reduce electricity expenses and even achieve zero energy bills in certain scenarios. Additionally, they can contribute to a commendable reduction of approximately 30% in greenhouse gas emissions throughout their lifespan, making a positive impact on environmental preservation.

Solar photovoltaic buildings offer numerous advantages in energy performance compared to traditional constructions. By harnessing renewable energy sources, reducing energy consumption, providing economic returns, and offering environmental benefits, photovoltaic buildings play a pivotal role in sustainable construction. They present proactive solutions for future energy and environmental challenges.

5. Environmental Impact

SPV buildings have become increasingly prominent as a promising solution for addressing environmental concerns and promoting sustainable development. However, like any technological advancement, they present both advantages and disadvantages in terms of their impact on the environment and their long-term sustainability contributions.

SPV buildings offer a significant advantage - they have a reduced carbon footprint. Instead of relying on fossil fuels, these buildings harness solar energy to generate electricity, resulting in significantly lower greenhouse gas emissions. This decrease in emissions contributes to the fight against air pollution and helps mitigate the impacts of climate change. To provide an example, according to a study conducted by the National Renewable Energy Laboratory, a typical residential solar energy system can offset over 100 tons of carbon dioxide emissions within a span of 30 years.

Moreover, incorporating photovoltaic systems into buildings offers the advantage of reducing overall energy consumption. This is achieved through the production of clean energy on-site, which diminishes the reliance on conventional power sources. These traditional sources often involve extracting and transporting resources extensively, making them less sustainable and more detrimental to the environment. By embracing photovoltaic integration, natural resources can be conserved and the environmental impact associated with conventional energy generation can be minimized.

However, it's essential to recognize potential drawbacks as well. The production, installation, and disposal of photovoltaic panels entail energy and resource inputs, which can contribute to environmental pollution and resource depletion. Additionally, the manufacturing process of these panels involves the use of certain materials, such as rare metals, which might have environmental implications during extraction and production. Some types of PV cell technologies use heavy metals, and these types of cells and PV panels may require special handling when they reach the end of their useful life. Some solar thermal systems use potentially hazardous fluids to transfer heat, and leaks of these materials could be harmful to the environment [3].

Careful consideration is vital in the pursuit of environmental sustainability. One important factor to consider is the energy payback time, which measures how long it takes for a photovoltaic system to generate the same amount of energy consumed during its manufacturing process. Assessing this alongside its long-term benefits is crucial. Fortunately, advancements in technology and increased energy efficiency in manufacturing have significantly reduced the energy payback time for photovoltaic systems. As a result, these systems now offer enhanced environmental advantages overall.

SPV buildings provide a promising avenue for reducing carbon emissions, lowering energy consumption, and advancing sustainable development. While they offer numerous environmental benefits, it is crucial to acknowledge and address their potential drawbacks. Informed decision-making that prioritizes immediate gains and long-term environmental sustainability is essential. Balancing technological progress with responsible resource usage remains vital in ensuring a greener future.

6. Conclusion and Prospects

6.1. Conclusion

SPV architecture holds significant advantages and potential. SPV panels provide clean and green energy. During electricity generation with SPV panels, there are no harmful greenhouse gas emissions; thus, SPV is environmentally friendly [4]. It offers clean energy generation, reducing energy costs and enhancing building sustainability. This benefits the environment by curbing greenhouse gas emissions while also contributing to energy independence. The potential of SPV architecture lies in its ability to transform buildings into energy generators. Residential solar panels are easy to install on rooftops or on the ground without any interference with residential lifestyles [4]. By integrating solar panels onto rooftops, it taps into renewable energy sources, reducing reliance on conventional fossil fuels. This aligns with the global shift towards sustainability and clean energy solutions.

However, there are challenges to overcome. Solar energy is somewhat more expensive to produce than conventional sources of energy due in part to the cost of manufacturing PV devices and in part to the conversion efficiencies of the equipment. As the conversion efficiencies continue to increase and the manufacturing costs continue to come down, PV will become increasingly cost-competitive with conventional fuels [5].

Technological advancements are ongoing, but potential stability concerns exist. Additionally, not all buildings are suitable for solar panel integration, and geographic location matters. Solar power is a

variable energy source, with energy production dependent on the sun. Solar facilities may produce no power at all some of the time, which could lead to an energy shortage if too much of a region's power comes from solar power [5]. Despite these challenges, the promise of SPV architecture is undeniable. It combines innovation, environmental responsibility, and energy efficiency. Overcoming obstacles and continued technological progress will be key to unlocking its full potential, creating a more sustainable and energy-efficient future for the built environment.

6.2. Prospects

SPV buildings, as a crucial element of sustainable architecture, are poised to assume an even more significant role in the future. By employing rational analysis and forward-thinking, we can envision immense opportunities for solar photovoltaic buildings within the realm of sustainable architecture. Additionally, we can embrace innovative strategies to further fuel their advancement.

SPV buildings will make significant advancements in energy self-sufficiency. With ongoing progress in solar technology, the efficiency of photovoltaic systems will increase, leading to more compact and lightweight components. These components may even be seamlessly integrated into surfaces like windows and walls. As a result, future buildings will not only generate electricity for their own use, but also contribute surplus energy back to the grid. This bidirectional energy flow optimizes overall energy utilization.

SPV buildings will prioritize integrating with smart technology. Intelligent control systems will diligently monitor and manage photovoltaic systems, making adjustments based on various weather conditions and energy requirements. This advanced functionality enables buildings to harness solar energy at optimal times, optimize energy utilization, and further reduce overall consumption.

Furthermore, the integration of innovative energy storage technologies will propel the advancement of photovoltaic buildings. These cutting-edge solutions not only allow for the utilization of solar-generated electricity to power equipment within the building but also enable its storage for future use during periods of low sunlight. As technology progresses, more sophisticated energy storage systems will contribute to a reliable and continuous energy supply, ensuring that photovoltaic buildings can operate seamlessly around the clock.

In order to drive the future of SPV buildings, several key practices emerge. Firstly, a steadfast commitment to technological innovation and sustained investment in research will foster continuous advancements in solar technology. This will enhance photovoltaic efficiency while concurrently reducing manufacturing costs. Additionally, governments can play a pivotal role by offering policy support and incentive measures such as subsidies and tax incentives. These actions effectively lower initial investment barriers. Furthermore, fostering interdisciplinary collaboration among experts from diverse fields like engineering and materials science promotes both technological integration and innovation. Lastly, raising public awareness about the significance of solar photovoltaic buildings in sustainable architecture stimulates market demand, thus catalyzing a transition towards a greener future.

In summary, SPV buildings will play a crucial role in the future of sustainable architecture. By leveraging technological advancements, intelligent integration, energy storage solutions, policy support, and collaboration, we can expect a broader scope for photovoltaic buildings. This expansion will contribute positively to constructing a more sustainable future.

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