



Solar Solution for efficient ventilation and power generation, enhancing building performance and sustainability

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Abstract: This review paper explores the potential of solar powered systems in car ventilation and photovoltaic modules, highlighting their effectiveness in reducing car cabin temperature, improving thermal comfort and reducing energy consumption. Additionally it provides an overview of ventilation in buildings, discussing solar chimney, CO₂ controlled interventions for classroom ventilation, the influence of wind or natural ventilation and the research development of natural ventilation potential analysis. The paper also presents a hierarchical air balancing control method for variable air volume system. The finding emphasize the significance of these topics in enhancing energy efficiency, indoor air quality and thermal comfort in buildings, contributing to the advancement of sustainable energy solutions.

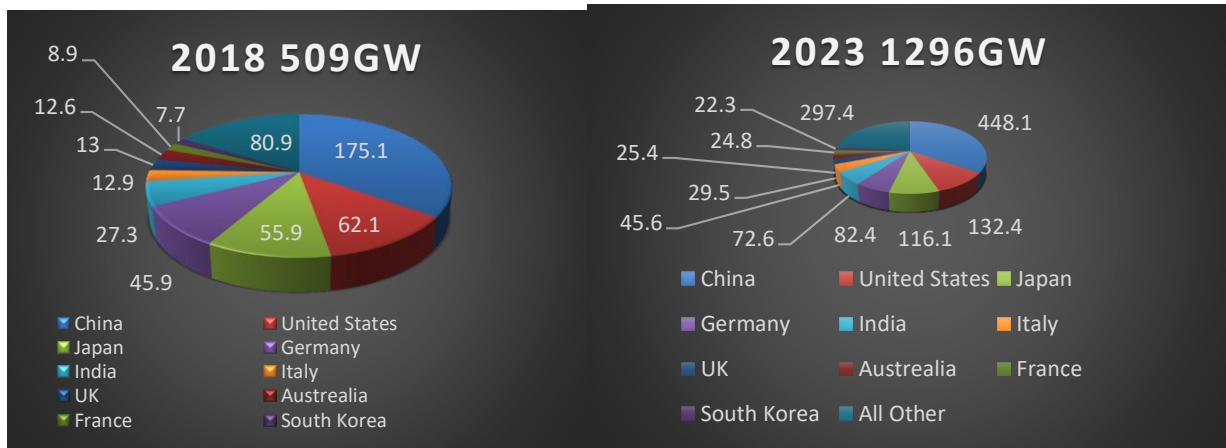
IndexTerms - air ventilation, thermal comfort, passive ventilation, temperature effect, solar power air ventilation

I. INTRODUCTION OF RENEWABLE ENERGY

Energy is really a critical factor in addressing environmental problems, particularly climate change. The use of fossil fuels, is a major contributor to greenhouse gas emissions, which drive global warming and climate change. Transitioning from fossil fuels to renewable energy sources is essential to mitigate the negative effects of climate change. Renewable energy, such as solar, wind, hydro, and geothermal power, offers numerous advantages. These clean alternatives produce little to no greenhouse gas emissions during operation, making them environmentally friendly. They also have the potential for sustainable and long-term availability, as they rely on naturally replenishing resources. Investing in renewable energy technologies has become increasingly important to achieve a more sustainable future. Not only do these technologies help reduce carbon emissions and combat climate change, but they also offer economic benefits. [1] [2] Renewable energy projects can create jobs, promote innovation, and enhance energy security by diversifying energy sources. Moreover, renewable energy technologies have seen significant advancements and cost reductions in recent years, making them increasingly competitive with fossil fuels. As these clean alternatives become more efficient and affordable, they offer a viable solution to both environmental and economic challenges. However, it's important to note that the transition to renewable energy is a complex process that requires careful planning and consideration of various factors, including infrastructure development, grid integration, and policy frameworks. Additionally, energy efficiency measures and conservation efforts should complement renewable energy deployment to maximize their benefits. Ending our dependence on fossil fuels and investing in clean, renewable energy is critical to combating climate change and protecting the environment. It provides a pathway to sustainable, efficient, affordable and reliable energy while reducing carbon emissions and mitigating the adverse effects of climate change. [3, 4]

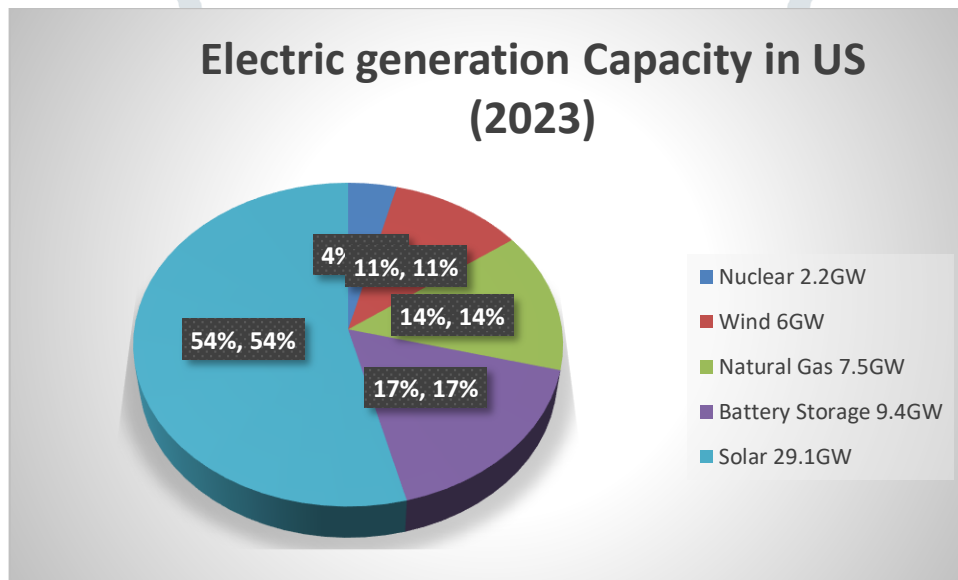
The graph shows the use of renewable energy in worldwide. In 2018, China was the global leader in renewable energy utilization, consuming 175.1 exajoules (GW) of clean energy. The United States ranked second, using 62.1 GW, followed by Japan with 55.9 GW. Significant commitments to renewables were also observed in Germany with 45.9 GW and India with 27.3 GW. Meanwhile, Italy, the UK, and Australia exhibited varying levels of adoption. Additionally, "All Other" countries collectively accounted for 80.9 GW of renewable energy consumption. These figures highlight the worldwide effort towards sustainability and the ongoing transition to cleaner energy sources.

In 2023, China remains at the forefront of renewable energy adoption, using an impressive 448.1 exajoules (GW) of clean energy. The United States follows with 132.4 GW, while Japan demonstrates significant commitment at 116.1 GW. Germany and India also contribute notably, utilizing 82.4 GW and 72.6 GW, respectively. Other countries like Italy, the UK, Australia, France, and South Korea show varying levels of progress in their renewable energy efforts. Together, "All Other" countries account for a substantial 297.4 GW of renewable energy usage. This data showcases the global emphasis on sustainability and the increasing significance of transitioning to cleaner energy sources to address environmental challenges and combat climate change.[5]



1.1 Solar Energy

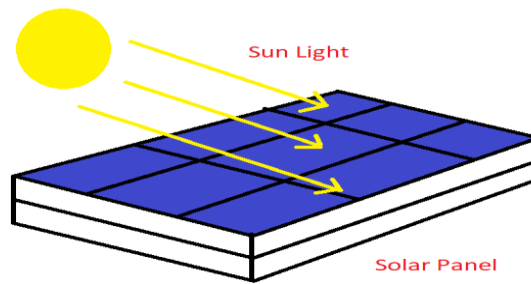
Solar energy is a literary embodiment of renewable power sourced from the sun's radiant light and heat. This bountiful and unpolluted energy serves as a wellspring that can be harnessed and transformed into practical forms of power. It encompasses the conversion of the sun's radiance into electricity or direct utilization for purposes such as heating, illumination, and diverse applications. Solar energy also symbolizes the collection of sunlight through advanced technologies like photovoltaic cells or solar thermal systems, enabling the generation of electricity or the warming of water for various societal sectors. Moreover, it epitomizes the sustainable and eco-conscious energy acquired by capturing the sun's rays and converting them into practical energy formats, thereby diminishing reliance on finite fossil fuel reserves and mitigating the release of greenhouse gases. Overall, solar energy exemplifies the radiant power emitted by the sun, which can be gathered and transformed into thermal or electrical energy through the employment of solar panels or alternative solar-driven mechanisms.[6,7]



The data depicts a diverse energy landscape with various energy resources and their respective capacities in gigawatts (GW) and percentages. Nuclear energy contributes 2.2GW, representing 4% of the total capacity. Wind power plays a significant role, providing 6GW, or 11% of the capacity. Natural gas holds a substantial share of 7.5GW, constituting 14% of the capacity. Notably, battery storage systems show promise with a capacity of 9.4GW, making up 17% of the overall capacity. Solar energy emerges as the dominant player, supplying an impressive 29.1GW, which constitutes 54% of the total capacity. This data highlights the increasing importance of renewable energy sources like wind, solar, and battery storage worldwide, as countries strive to transition to cleaner and more sustainable alternatives to meet their energy needs. [8]

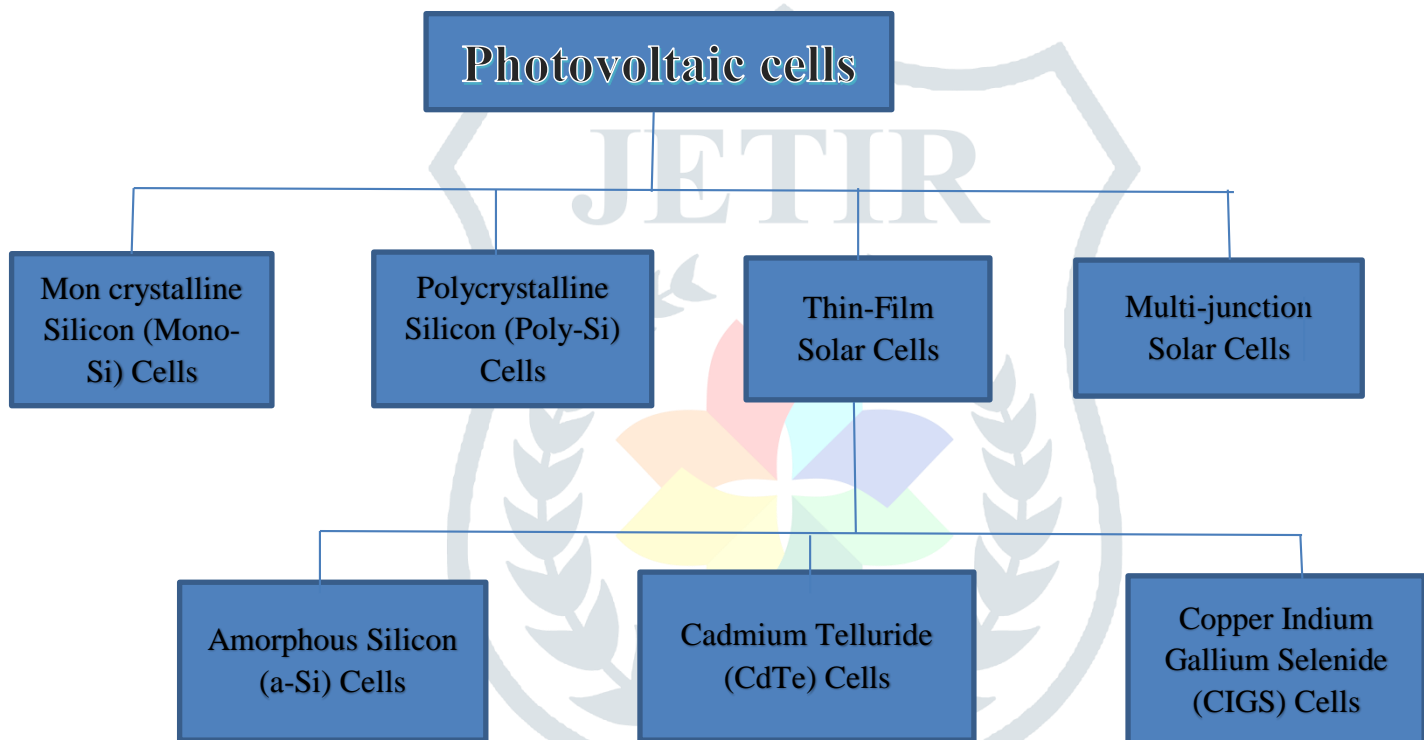
1.2 Photovoltaic Cell

A photovoltaic (PV) cell, commonly known as a solar cell, is a key component in harnessing solar energy. It is a semiconductor device that converts sunlight directly into electricity through the photovoltaic effect. The PV cell consists of layers of semiconductor material, typically made of silicon. When sunlight strikes the cell, it excites electrons in the material, generating an electric current. The basic structure of a PV cell includes a top layer that is doped with phosphorous to create an excess of electrons and a bottom layer doped with boron to create a deficit of electrons, forming a p-n junction. When photons from sunlight hit the PV cell, they transfer their energy to the electrons in the material, allowing them to break free from their atomic bonds. The electric field created by the p-n junction causes these freed electrons to flow in a particular direction, creating an electric current. Metal contacts on the top and bottom of the cell collect this current and allow it to be used externally. PV cells can be used individually or interconnected to form larger units called solar panels or modules. Multiple PV cells are wired together in series or parallel to achieve the desired voltage and current output. These panels can be installed on rooftops, in solar farms, or integrated into various devices to generate electricity for residential, commercial, or industrial applications. [9, 10]

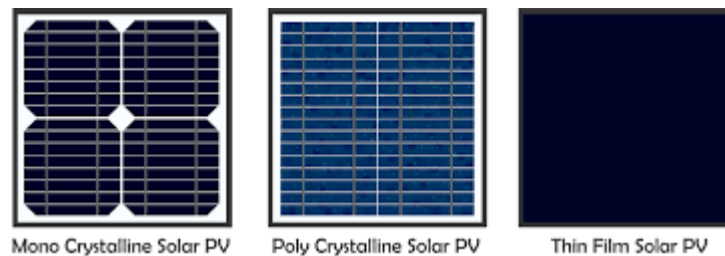


One of the significant advantages of PV cells is their ability to generate electricity without moving parts, making them reliable and low maintenance. They can operate silently and efficiently in a wide range of environmental conditions. With ongoing advancements in PV technology, the efficiency and affordability of solar cells have improved, making them a viable and sustainable option for renewable energy generation. Photovoltaic cells play a crucial role in the utilization of solar energy, offering a clean, renewable, and sustainable solution to meet our increasing energy demands while reducing our carbon footprint.

There are several types of photovoltaic (PV) cells, each with its own characteristics and materials. Here are some of the commonly used types of PV cells:



1. **Mono crystalline Silicon (Mono-Si) Cells:** Mono crystalline cells are made from a single crystal structure of silicon. They have a high efficiency rate, typically ranging from 15% to 22%, which makes them one of the most efficient types of PV cells. Mono crystalline cells have a uniform black appearance with rounded edges.
2. **Polycrystalline Silicon (Poly-Si) Cells:** Polycrystalline cells are made from multiple crystal structures of silicon. They have a lower efficiency rate compared to mono crystalline cells, usually ranging from 13% to 17%. Polycrystalline cells have a bluish color with a fragmented appearance due to the presence of multiple crystals.
3. **Thin-Film Solar Cells:** Thin-film cells are made by depositing one or more thin layers of photovoltaic material onto a substrate such as glass, plastic, or metal. Common types of thin batteries include:
 - a. **Amorphous Silicon (a-Si) Cells:** Amorphous silicon cells have a disordered atomic structure, which makes them less efficient than crystalline silicon cells. However, they can be flexible and are often used in applications such as solar calculators and small electronic devices.
 - b. **Cadmium Telluride (CdTe) Cells:** CdTe cells have a higher efficiency compared to amorphous silicon cells. They are cost-effective and commonly used in large-scale solar power plants.
 - c. **Copper Indium Gallium Selenide (CIGS) Cells:** CIGS cells are highly efficient and flexible. They're still in development, but they show promise for many applications.
4. **Multi-junction Solar Cells:** Multi-junction cells are made of multiple layers of different semiconductor materials, each capable of absorbing different portions of the solar spectrum. This allows them to achieve high efficiencies by capturing a broader range of wavelengths. Multi-junction cells are primarily used in concentrated photovoltaic systems and space applications where high efficiency is crucial.



Source: <https://greensarawak.com/things-to-know-before-going-solar/going-solar-chapter-8-know-your-solar-pv-cells-and-panels/>

It's worth noting that the choice of PV cell type depends on various factors such as efficiency requirements, available budget, installation space, and specific application needs. Additionally, ongoing research and technological advancements continue to introduce new types of PV cells with improved efficiency and performance characteristics. [11, 12]

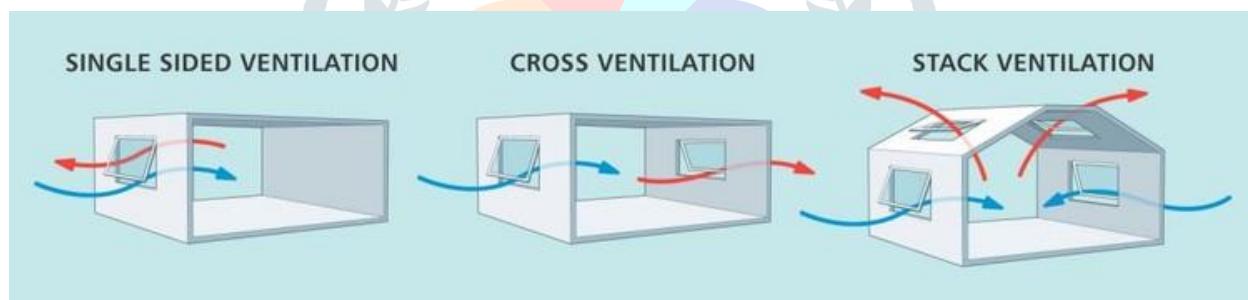
II. AIR VENTILATION

Air ventilation refers to the process of exchanging air within an enclosed space, such as a building, to maintain indoor air quality and control temperature and humidity levels. It involves the circulation of fresh air from outside, the removal of stale air, and the filtration of airborne pollutants.

Proper ventilation is essential for creating a healthy and comfortable indoor environment. It helps remove odors, moisture, and indoor pollutants like volatile organic compounds (VOCs), carbon dioxide, and allergens. Additionally, ventilation plays a crucial role in reducing the concentration of airborne pathogens and preventing the spread of diseases.

Overall, air ventilation is crucial for maintaining a healthy and pleasant indoor environment by ensuring the constant supply of fresh air, the removal of pollutants, and the control of temperature and humidity levels. It plays a vital role in residential, commercial, and industrial buildings, contributing to the well-being and productivity of occupants. [15,16]

There are different types of ventilation are used some are natural ventilation relies on openings like windows and vents to allow fresh air to enter and stale air to exit naturally through convection and wind-driven flows. Mechanical ventilation utilizes fans, ducts, and equipment to actively circulate air in the building. Mechanical ventilation systems can be categorized into exhaust ventilation, which removes stale air using exhaust fans in areas prone to moisture or pollutants, and supply ventilation, which brings in fresh air from outside using fans and ducts. Balanced ventilation systems combine both exhaust and supply ventilation to achieve a balanced exchange of indoor and outdoor air. These systems often incorporate heat recovery or energy recovery mechanisms to minimize energy loss during ventilation.



Source: <https://www.archdaily.com/963706/back-to-basics-natural-ventilation-and-its-use-in-different-contexts/60d215baf91c81a8e800009-back-to-basics-natural-ventilation-and-its-use-in-different-contexts-image>

Overall, these ventilation systems play a crucial role in maintaining indoor air quality and ensuring a comfortable and healthy environment in buildings.

Air ventilation is essential in solar panel installations to ensure optimal performance and longevity of the panels. By incorporating effective air ventilation measures into solar panel installations, it is possible to enhance their overall performance, increase energy output, and prolong their operational lifespan. It is important to consult with solar panel manufacturers and professionals in the industry to determine the appropriate ventilation strategies based on the specific installation location, climate conditions, and panel design. [17]

2.1 Application of air ventilation in solar panel

Air ventilation in the context of solar panels primarily focuses on managing the temperature of the panels to optimize their efficiency and performance. Here we are discussing some key points related to air ventilation with solar panels

Cooling Techniques: Various methods have been investigated to address the heat generated by solar panels. Passive cooling techniques involve designing panels with increased airflow, incorporating heat sinks, and using thermal insulation. Active cooling methods utilize fans or blowers to circulate air over or under the panels, dissipating heat. [18]

Ventilation Design: The design of ventilation systems for solar panels aims to balance the need for cooling with the prevention of dust and debris accumulation. Effective designs take into account factors such as panel orientation, airflow patterns, and the size and placement of ventilation openings. Well-designed ventilation systems can improve the overall performance and durability of solar panels.

Performance Impact: Studies have demonstrated that excessive heat can decrease the efficiency of solar panels. By implementing air ventilation strategies, the operating temperature of solar panels can be reduced, resulting in improved power output and enhanced

energy generation. Additionally, ventilation systems contribute to maintaining more stable temperature profiles, mitigating the negative effects of thermal stress on panel components.[20]

Dust and Debris Mitigation: Air ventilation plays a critical role in preventing the buildup of dust and debris on solar panels. The accumulation of dust can obstruct sunlight, leading to a decrease in power output. Effective ventilation systems minimize the settling of particles and facilitate their removal through natural processes such as wind or rain.[21]

Energy Savings: Some studies have explored the potential for energy savings by integrating solar panel air ventilation with building HVAC systems. By utilizing the heated air extracted from solar panels, it is possible to supplement space heating or water heating systems, resulting in energy conservation and increased overall system efficiency.

2.2 Passive air ventilation

Solar chimneys are gaining attention for their potential in reducing heat gain and improving natural cooling in buildings. They offer cost-effective and energy-efficient solutions with lower carbon emissions. By integrating with natural cooling systems and active solar technologies, solar chimneys can enhance ventilation performance. Further research is needed to optimize their design and control strategies for different climates. [22] This study aimed to improve classroom ventilation in the Netherlands using a CO₂-controlled mechanical ventilation intervention. Results from 18 classrooms showed a significant decrease in CO₂ levels by 491 ppm, enhancing indoor air quality. The study highlights the effectiveness of such interventions in reducing CO₂ levels in classrooms. [23] This paper highlights the influence of wind speed and direction on natural ventilation systems and the potential for modifying site conditions. Night ventilation cooling is effective for removing internal heat gains by circulating cooler air. Natural ventilation offers fresh air and can reduce the need for mechanical air conditioning, contributing to energy savings and improved thermal comfort.[24]. The paper discusses the research development of natural ventilation potential (NVP) analysis in buildings. It reviews existing methods from overseas studies and introduces a new evaluation system specifically designed for Chinese residential buildings. The analysis of NVP serves as a reference for building design, an energy-saving evaluation index, and aims to enhance indoor air quality while promoting the advancement of natural ventilation technology. Research [25]. This paper presents a hierarchical air balancing control method for variable air volume (VAV) ventilation systems. The method utilizes a dual loop PID control loop on a layered system structure and proposes fan-duct PID design methods for automatic design. The paper also addresses the negative open proportional characteristic of dampers and suggests a two-step action for damper PID control. Experimental results demonstrate the effectiveness and correctness of the proposed method in achieving control objectives, making it adaptable and applicable to various VAV ventilation systems for variable air volume control. [26]

2.3 Solar powered air ventilation system

This study evaluated the efficiency and performance of a solar-powered mechanical ventilation unit, considering parameters such as the maximum airflow rate of 370 m³/h and the use of photovoltaic panels, batteries, and an inverter. The results demonstrated that the system effectively met ventilation needs and power consumption without relying on the grid in Izmir. Feasibility comparisons were also made between Izmir and Romania for the same ventilation system. [27]. this research focuses on a solar-powered ventilation system for cars, using a fan to intake fresh air and expel hot air. It effectively stabilized the car's thermal conditions using solar power and a backup battery. The system reduced heat gain by 12%, providing a comfortable environment and improving energy efficiency. [28]. This study developed a solar-powered car ventilation system utilizing IoT technology for temperature control. The system effectively reduced the car cabin temperature and allowed users to monitor it via mobile devices. This research builds upon the previous literature by incorporating solar power and IoT connectivity to enhance car ventilation and provide a comfortable environment. [29]. this study implemented a solar-powered ventilation system in vehicles parked under the sun, resulting in a significant reduction in the temperature difference between the cabin and the outside environment. The proposed system improved thermal comfort, conserved energy, and contributed to a more comfortable environment inside the vehicle. This research aligns with previous literature on solar-powered solutions for addressing high temperatures in parked vehicles. [30]. this paper investigates the performance of a solar-powered cabin air ventilator in improving the thermal comfort inside parked cars. The study demonstrates that the ventilator significantly reduces the temperature inside the car cabin, enhancing occupants' comfort. Additionally, the ventilator reduces the time required for the car's air conditioning system to restore thermal comfort. The experimental study validates the effectiveness of the solar-powered cabin air ventilator, offering a sustainable solution for mitigating high cabin air temperature in parked cars. [31]. this paper examines the performance of a solar-based car ventilation system in reducing the temperature inside a sun-exposed car. The authors evaluate factors such as motor performance, solar panel power, airflow rate, tilt angle, and air duct design. The study compares a commercially available ventilator with a redesigned version and finds that the redesigned ventilator is more effective. The paper concludes by suggesting the need for further research and development in this area. [32]. this paper introduces a solar-powered ventilation system designed to effectively reduce the temperature inside parked cars, addressing the potential threat to humans and pets during hot summer days. The system utilizes solar energy to automatically initiate ventilation if the interior temperature reaches a specific threshold while parked in sunlight. By reducing fuel consumption, carbon dioxide emissions, and engine load, the proposed system aims to mitigate the problem of high temperatures and low oxygen levels inside vehicles. The paper outlines the concept, temperature reduction method, and the objective of providing a smart solution to enhance car cabin ventilation. [33]

III. CONCLUSION

The reviewed literature collectively highlights the effectiveness and potential of solar powered ventilation systems in various settings, including buildings and parked cars. These systems offer energy efficient and sustainable solutions for improving indoor air quality, reducing heat gain and enhancing thermal comfort.

In the context of building, solar chimney, coupled with natural cooling systems and active solar technologies, have shown promise in reducing carbon emission, enhancing ventilation performance and minimizing the need for mechanical air conditioning. The integration of CO₂ controlled mechanical ventilation interventions in classroom results in a significant decreases in CO₂ levels, thereby

improving indoor air quality. Additionally the analysis of natural ventilation potential provides valuable insight for building design and energy saving evaluation.

For vehicles parked under the sun, solar powered ventilation systems have demonstrated their ability to mitigate high cabin temperature, enhancing occupants comfort and reducing the reliance on traditional air conditioning. These systems leverages solar energy and IOT technology to provides temperature control and monitoring capabilities, leading to energy conservation and a more comfortable environment.

Overall, the finding from these emphasize the feasibility, efficiency and effectiveness of solar powered ventilation system in reducing heat gain, improving thermal comfort and promoting sustainable practices. However further research and development are necessary to optimize system design, control strategies and performance in different climates and contexts. Continued advancements in solar and IOT technologies will contribute to the ongoing progress and adoption of these innovation solutions.

REFERENCES

- [1] <https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020>
- [2] <https://www.iea.org/reports/world-energy-investment-2022/overview-and-key-findings>
- [3] <https://www.un.org/en/climatechange/raising-ambition/renewable-energy>
- [4] <https://www.un.org/en/climatechange.what-is-renewableenergy>
- [5] <http://www.fi-powerweb.com/Renewable-Energy.html>
- [6] <https://www.remoteenergy.org/blog/what-is-solarenergy>
- [7] <https://www.britannica.com/science/solar-energy>
- [8] <http://www.weforum.org/agenda/2023/03/electricity-generation-renewables-power-iea/>
- [9] Solar PV parameter estimation Technique- a review (IJARET), Volume 11, Issue 6, June,2020,
- [10] https://energyeducation.ca/encyclopedia/Photovoltaic_cell
- [11] <https://www.renewableenergyhub.co.uk/main/solar-panels/what-are-the-different-types-of-solar-photovoltaic-cells>
- [12] <https://electricalacademia.com/renewable-energy/photovoltaic-pv-cell-types-monocrystalline-polycrystalline-thin-film-solar-panel/>
- [13] <https://sites.lafayette.edu/egrs352-sp15-pv/how-do-solar-pv-panels-work/types-of-pv-panels/>
- [14] <https://www.ncbi.nlm.nih.gov/books/NBK143277/>
- [15] Natural Ventilation Review and Plan for Design and Analysis Tools Steven J. Emmerich W. Stuart Dols James W. Axley NISTIR 6781, 2001
- [16] Concepts, Definitions, Ventilation Methods, Advantages and Disadvantages by T.kozai, C. Kubota book chapter DOI: [10.1007/1-4020-3126-2_3](https://doi.org/10.1007/1-4020-3126-2_3) December 2005
- [17] Application of air ventilation in solar panel Hairol Nizam Mohd Shah¹, Indonesian Journal of Electrical Engineering and Computer Science Vol. 12, No. 3, December 2018, pp. 1211~1221 ISSN: 2502-4752, DOI: 10.11591/ijeecs.v12.i3.pp1211-1221
- [18] A review of solar photovoltaic systems cooling technologies by J.siecker [Renewable and Sustainable Energy Reviews](https://doi.org/10.1016/j.rser.2017.05.053) 79:192-203 DOI: [10.1016/j.rser.2017.05.053](https://doi.org/10.1016/j.rser.2017.05.053) 2017
- [19] Performance Enhancement of Solar Photovoltaic Panel Using Automated Solar Panel Cleaner by Aditya Kulkarni, Kedar N Majumdar DOI: [10.24247/ijmperdjun20201161](https://doi.org/10.24247/ijmperdjun20201161) 2020
- [20] An Enhancement of the Solar Panel Efficiency: A Comprehensive Review author Ravi Parthiban, Ponnambalam Pathipooranam [Frontiers in Energy Research](https://doi.org/10.937155) 10:937155 DOI: [10.3389/fenrg.2022.937155](https://doi.org/10.3389/fenrg.2022.937155) 2022
- [21] Solar Panels Dirt Monitoring and Cleaning for Performance Improvement: A Systematic Review on Smart Systems by Benjamin Oluwamuyiwa Center for Cyber-Physical Food, Energy and Water Systems (CCP-FEWS), University of Johannesburg, P.O. Box 524, Auckland Park, Johannesburg 2006, South Africa
- [22] A review for the applications of solar chimneys in buildings by X.Q. Zhai *, Z.P. Song, R.Z. Wang (2011)
- [23] A ventilation intervention study in classrooms to improve indoor air quality: the FRESH study by Jeannette TM Rosbach^{1,2}, Machiel Vonk^{2*}, Frans Duijm², Jan T van Ginkel³, Ulrike Gehring¹ and Bert Brunekreef^{1,4} (2013)
- [24] Study of Natural Ventilation through Openings on Buildings under Saharan Climatic Conditions by M.Hamdani¹, S.M.A. Bekkouche¹, T. Benouaz², M.K. Cherier¹ (2018)
- [25] Development of Natural Ventilation Potential Analysis Zhang Guo-qiang²⁰⁰⁴
- [26] Research on a hierarchical air balancing control method of variable air volume ventilation system 2020 Hui Cai¹, Can Cui², [Xin Zhang](https://doi.org/10.1016/j.zhang)
- [27] Solar powered Mechanical Ventilation: case study by Ash Birtürk¹, Orhan Ekren^{1,*}, Sinan Aktakka², Özdem Özel, Macit Toksoy (2019)
- [28] Development and implementation of solar powered ventilation system by Hairol Nizam Mohd Shah¹, Zalina Kamis², Mohd Fairus Abdollah³, Mohd Khairi Mohd Zambri⁴, Faizil Wasbari⁵, Nursabillilah Mohd Ali⁶, Amirul Anwar Mat Shah⁷(2018)
- [29] Development of a solar powered car ventilation on system with wireless monitoring by Ahmad Haziq Afiq Ahmad Azhar, Roslina Mohamad, Saiful Izwan Suliman, Murizah Kassim, Farah Yasmin Abdul Rahman(2022)
- [30] Investigation of the effect of solar ventilation on the cabin temperature of vehicles parked under the sun by Hani Al Rawashdeh, Ahmend O Hasan, Hazem A Al shankhanbeh, Mujahed Al Dhaifallah, Mohamed R Gomaa, Hegazy Rezk(2021)
- [31] Experimental investigations on the performance of solar powered cabin air ventilator (article), Sudhir Chitrapady Vishweshwara, Jalal Marhoon Al. Dhali, (2015)
- [32] Sizing, Positioning and Air Ducting Analysis Analysis for solar based car ventilation by Rosmiwati Mohd-Mokhtar and Asirah Roslan (2015)
- [33] Solar Powered Ventilation System for Parked Car by Ibtelhal M. Mishal, Mai S. Abubaqar, Razan H. Hiasat (2018)