International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 05 May 2025
Page No: 2313- 2317
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0341

Design and Fabrication of a Solar-Powered Air Cooler with Phase Change Material Integration

Mrs. Mrinalini Chopade[1], Miss. Sakshi Sherkar [2], Miss.Payal Bahad [3], Miss. Samruddhi Munot[4], Mr. Shubham Dahiphale [5]

[1]Professor, Department of Mechanical Engineering, Vishwabharati Academy's College of Engineering, Ahilyanagar, Maharashtra, India

[2,3,4,5]Student, Department of Mechanical Engineering, Vishwabharati Academy's College of Engineering, Ahilyanagar, Maharashtra, India.

Emails: *mrinalinichopade@gmail.com[1], sakshidsherkar588@gmail.com[2], payalbahad07@gmail.com[3], munotsamruddhi8@gmail.com[4], shubhumdahiphale70@gmail.com[5]*

Abstract

With rising temperatures and energy demands, there is an urgent need for sustainable cooling solutions. This paper presents the design, fabrication, and testing of a solar-powered air cooler enhanced with phase change material (PCM) for thermal energy storage. The system operates using solar energy during the day and utilizes the PCM to continue cooling after sunset. The results show improved energy efficiency and a notable reduction in indoor temperature without using conventional electricity.

Keywords: *Solar Energy, Air Cooler, Phase Change Material, Renewable Energy, Energy Efficiency.*

1. Introduction

Global warming and urbanization have significantly increased the need for effective and sustainable cooling solutions. Traditional air conditioning systems consume a substantial amount of electricity, leading to higher carbon emissions and operational costs. Developing countries, including India, face a growing energy crisis with the rising demand for cooling in residential and commercial sectors. Solar energy presents an abundant, renewable, and eco-friendly source of energy that can be harnessed for cooling applications. Solar-powered air cooling systems offer an alternative to grid-dependent devices, reducing the load on electricity grids especially during peak hours Phase Change Materials (PCMs) are substances that absorb and release thermal energy during the process of melting and solidifying, enabling thermal energy storage. Integrating PCMs with air coolers allows for extended cooling hours, even after sunset, by utilizing stored latent heat. Combining solar power and PCM technology can create a highly efficient, off-grid cooling system suitable for both urban and rural applications. Mild steel and aluminum were chosen for the frame and body respectively to ensure structural strength, corrosion resistance, and better thermal performance. The primary aim of this project is to design, fabricate, and test a sustainable air cooler that operates predominantly on renewable energy. Performance evaluation includes measuring temperature drop, battery backup, PCM effectiveness, and overall energy savings. The project supports Sustainable Development Goals (SDGs), particularly goals related to affordable and clean energy, sustainable cities, and climate action. [1]

1.1.Background

Global warming and urbanization have significantly increased the need for effective and sustainable cooling solutions. Traditional air conditioning systems consume a substantial amount of electricity, leading to higher carbon emissions and operational costs.

1.2.Problem Statement

Developing countries, including India, face a growing energy crisis with the rising demand for cooling in residential and commercial sectors. There is a need for low-energy, eco-friendly cooling systems.

1.3. Role of Solar Energy

Solar energy presents an abundant, renewable, and eco-friendly source of energy that can be harnessed for cooling applications. Solar-powered systems reduce the dependency on conventional electricity grids.

1.4.Concept of Phase Change Materials (PCMs)

Phase Change Materials (PCMs) are substances that absorb and release thermal energy during the process of melting and solidifying, enabling thermal energy storage. They help maintain cooling even after sunset.

1.5.Integration of Solar Energy and PCMs

Combining solar power and PCM technology creates a highly efficient, off-grid cooling system suitable for both urban and rural applications. [2]

1.6.Material Selection

Mild steel and aluminum were chosen for the frame and body respectively to ensure structural strength, corrosion resistance, and better thermal performance.

1.7.Objectives of the Project

The primary aim of this project is to design, fabricate, and test a sustainable air cooler that operates predominantly on renewable energy.

1.8.Performance Evaluation

Performance evaluation includes measuring temperature drop, battery backup, PCM effectiveness, and overall energy savings achieved by the system. [3]

1.9.Environmental Impact

The use of renewable energy and PCMs significantly reduces greenhouse gas emissions and supports environmental conservation efforts.

1.10. Sustainable Development Goals

The project aligns with Sustainable Development Goals (SDGs), promoting affordable clean energy, sustainable cities, and climate action initiatives.

1.11. Scope of the Project

This system can be deployed in homes, offices, rural areas, and regions with limited access to electricity. temperature drop, battery backup, PCM effectiveness, and overall energy savings

1.12. Summary

This project attempts to bridge the gap between sustainability and technological innovation by combining solar and PCM technologies for efficient air cooling.

2. Methodology

2.1.Problem Analysis

Identify the high energy consumption and environmental impact of conventional cooling systems. Recognize the need for a solar-powered, eco-friendly alternative with energy storage capacity.

2.2.System Design

Design an air cooler that integrates solar panels for energy supply and PCM for thermal storage. Use CAD tools for structural and airflow design. Calculate energy requirements, battery size, solar panel capacity, and cooling load.

2.3.Selection of Components

- **Solar Panel:** 100W monocrystalline panel
- **Battery:** 12V, 40Ah rechargeable battery
- **Phase Change Material (PCM):** Paraffin wax with a melting point around 28°C
- **Cooling Fan and Pump**: Low-power DC components
- **Frame Material:** Mild steel and aluminum sheet

2.4.Fabrication Process

Construct the frame using mild steel sections. Fit the aluminum panels, install the cooling pad, fan, water circulation system, PCM containers, and solar panel. Connect all electrical circuits safely.

Integration of Phase Change Material (PCM): Encapsulate PCM in leak-proof aluminum containers. Place them around airflow channels to maximize cooling efficiency during and after sunlight hours. [4]

2.5.System Assembly

Assemble all mechanical and electrical components. Align cooling pads, fans, pipes, and PCM containers properly. Perform leak and mechanical stability tests.

2.6.Testing Procedure

Test the cooler under various conditions. Record ambient temperature, output air temperature, battery voltage, and PCM phase change behavior. Compare system performance with and without PCM.

2.7.Performance Analysis

Analyze cooling effectiveness (temperature drop) and energy efficiency. Evaluate battery backup time, cooling duration after sunset, and overall environmental benefits.

3. Results and Discussion

3.1.Result

3.2.Observation

Without PCM, the temperature drop was 6°C, and cooling stopped shortly after sunset. With PCM, the temperature drops improved to 10°C, and the system continued cooling for 2 hours after sunset. (Table 1)

Table 1 Performance Testing Results

Parameter	Without PCM	With PCM
Ambient Temperature (°C)	**38**	**38**
Output Air Temperature (°C)	**32**	**28**
Temperature Drop (°C)	**6**	**10**
Battery Backup Time (hours)	**3**	**5**
Cooling Duration after Sunset	**0.5 hours**	**2 hours**

3.3.Discussion

3.3.1. Effectiveness of Solar Energy Integration

The solar panel effectively charged the battery during daytime. The 100W panel was sufficient to run the air cooler for continuous operation, provided clear sunlight. Energy independence was achieved, reducing reliance on conventional electricity sources.

3.3.2. Impact of Phase Change Material (PCM)

The integration of PCM significantly enhanced cooling performance:

- The PCM absorbed heat during peak sunlight and released it gradually after sunset, maintaining the output air temperature lower for a longer period.
- Backup cooling after sunset was extended from 0.5 hours to 2 hours due to the PCM storage.
- This improves comfort levels during the night without additional power consumption.

3.3.3. Energy Efficiency

The use of renewable solar energy and efficient PCM storage resulted in:

- Reduction in overall energy usage by up to 60% compared to a standard electric air cooler. [6]
- Lower operational cost and minimal carbon footprint, making the system environmentally sustainable.

3.3.4. Limitations

- Performance is highly dependent on sunlight availability; efficiency drops during cloudy/rainy days.
- Initial cost is slightly higher due to the cost of the solar panel, battery, and PCM materials.

3.3.5. Future Scope

- Integrate solar tracking panels to increase efficiency.
- Use advanced PCMs with better heat storage capacity.
- Implement a smart controller for optimal energy management. [7]

Conclusion

In this project, a solar-powered air cooler integrated with Phase Change Material (PCM) was successfully designed, fabricated, and tested. The primary goal of developing an energy-efficient and environmentally friendly cooling system was achieved. integration of solar energy significantly reduced the dependency on conventional electricity, offering a sustainable solution for cooling needs. Additionally, the use of PCM greatly enhanced the cooling performance by storing thermal energy during peak hours and releasing it when solar input was not available. This extended the cooling effect well into the evening hours, which traditional systems cannot achieve without additional energy consumption. Testing results showed a notable temperature reduction of 10°C with PCM compared to 6°C without PCM, and an extended cooling duration after sunset by up to 2 hours. This highlights the effectiveness of thermal energy storage in enhancing system performance. Although the system's performance is weather-dependent and the initial cost is slightly higher, the long-term benefits such as reduced energy bills, lower carbon emissions, and improved environmental sustainability outweigh these drawbacks. Thus, the project successfully demonstrates the potential of combining solar energy and thermal energy storage for efficient and green cooling solutions, especially for rural and off-grid areas. With further developments like smart energy management and advanced materials, this technology could be scaled for larger commercial and residential applications in the future. [8]

Acknowledgements

We would like to express our deepest gratitude to all those who supported and guided us throughout the course of this project. First and foremost, we are sincerely thankful to our project guide, MRS.M.S. CHOPADE, for their continuous support, valuable suggestions, and encouragement during every phase of the project. Their technical expertise and constructive feedback greatly enhanced the quality of our work. are also grateful to the faculty members and staff of the Department of Mechanical Engineering, Vishwabharti Academic College Of Engineering, Ahmednagar for providing us with the necessary resources and a conducive environment to complete this project successfully. Special thanks to Lab Assistants / Technicians for their help during the fabrication and testing phases of the project. Their practical knowledge and assistance were instrumental in overcoming technical challenges We would like to acknowledge the support of our family and friends for their constant motivation and encouragement throughout the duration of the project. Finally, we thank all those who directly or indirectly contributed to making this project a success.

References

[1]. Kalaiselvam, S., and Parameshwaran, R., Thermal Energy Storage Technologies for Sustainability: Systems Design, Assessment and Applications, Academic Press, 2014.

[2]. Sharma, A., Tyagi, V. V., Chen, C. R., and Buddhi, D., “Review on Thermal Energy Storage with Phase Change Materials and Applications,” Renewable and Sustainable Energy Reviews, Vol. 13, No. 2, 2009, pp. 318-345.

[3]. Mehling, H., and Cabeza, L. F., Heat and Cold Storage with PCM: An Up to Date Introduction into Basics and Applications, Springer, 2008.

[4]. Yousef, M. S., Hassan, H., and El-Shazly, A. H., “Thermal Performance of an Air Cooler Using Phase Change Material (PCM) Under Solar Energy,” Energy Reports, Vol. 5, 2019, pp. 1295–1303.

[5]. Farid, M. M., Khudhair, A. M., Razack, S. A. K., and Al-Hallaj, S., “A Review on Phase Change Energy Storage: Materials and Applications,” Energy Conversion and Management, Vol. 45, No. 9–10, 2004, pp. 1597-1615.

[6]. International Renewable Energy Agency (IRENA), “Renewable Energy in Cooling,” 2020. [Online]. Available: www.irena.org.

[7]. Duffie, J. A., and Beckman, W. A., Solar Engineering of Thermal Processes, 4th ed., John Wiley & Sons, 2013.

[8]. Chauhan, D. S., and Srivastava, R. K., Non-Conventional Energy Resources, New Age International Publishers, 2005.

Journal Reference Style

Selecting Sources

Find and select high-quality references (books, research papers, journal articles, technical standards, online reports).

Citation in Text

- When you use information, immediately cite it inside the paragraph.
- Citation styles vary:
- Example: [1], [2] — for numerical style (common in engineering journals).

Reference List at End

- All cited sources are compiled at the end of the report in a References section.
- Number them in order of appearance.

Consistency

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 05 May 2025
Page No: 2313- 2317
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0341

- Keep the same format throughout (author names, title, journal/book, volume, pages, year).
- No missing or extra references!

Revalidation

- Cross-check each in-text citation [number] with the full citation in the reference list.
- Make sure every reference used is listed.
- Journal-Style Formatting
- Use proper reference formatting based on guidelines (e.g., IEEE, ASME, Elsevier).
- Example (IEEE Style)
- Sharma, V. V. Tyagi, C. R. Chen, and D. Buddhi, "Review on Thermal Energy Storage with Phase Change Materials and Applications," Renewable and Sustainable Energy Reviews, vol. 13, no. 2, pp. 318–345, 2009.

Final Review

Proofread and recheck — missing references can cause rejection in journals.