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A Novel Solar Air-Cooling System Featuring 360-Degree Air Dispersion and Battery-Based Energy Storage

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Abstract: *This paper presents the development of an innovative air-cooling system designed to operate efficiently using dsolar energy combined with a smart self-charging battery system. The proposed solution aims to provide an eco-friendly and cost-effective alternative to traditional cooling methods, particularly suited for regions with abundant sunlight. A key feature of this air cooler is its unique 360-degree air-splitting capability, allowing uniform air distribution in all directions simultaneously. This ensures consistent and effective cooling across every corner of a room, enhancing user comfort. The integration of a smart energy management system enables the device to store surplus solar energy in its inbuilt battery, allowing continuous operation even during cloudy periods or low sunlight conditions. The self-sustaining nature of the system reduces dependence on grid electricity, contributing to lower energy bills and reduced carbon emissions. Additionally, the smart control system optimizes energy usage and performance, adapting to environmental conditions in real-time. This paper outlines the design architecture, functional components, and energy efficiency considerations of the system, supported by performance evaluations under various operating scenarios. The proposed 360-degree solar-powered air cooler represents a step forward in sustainable home climate solutions, addressing the dual challenge of increasing energy demands and environmental impact. With its ability to maintain cooling performance regardless of whether variations and its innovative air distribution mechanism, this system offers a promising advancement in the domain of green and smart cooling technologies. The findings and methodologies discussed in this work are expected to contribute significantly to future developments in sustainable and intelligent HVAC systems.*
Keywords: Self-charging, solar based, all-directional air splitting, Cooler, DC, Design.

INTRODUCTION

A Creating a cooling system that's not just effective but also sustainable is a big deal these days. Imagine a cooling machine that doesn't completely depend on electricity from the grid but instead uses the power of the sun to keep your home cool. This new idea is all about that - a special kind of cooler that uses solar energy and a clever self-charging battery to give you a cooling system that's friendly to your wallet and the environment. This cooler isn't just any regular one.[1] It's designed to spread cool air in all possible directions, making sure every corner of your room feels just as comfy and refreshable And the best part is It can keep running even when the sun's not out or on cloudy days, thanks to its own battery that stores extra solar power.[2] By relying on solar energy, this cooler becomes a hero for the environment. It cuts down on harmful emissions and reduces your carbon footprint, making it a great choice compared to standard cooling systems. This smart design means you get a cooling system that doesn't always need to depend on the power grid. So, if you live in an area where power cuts are common or if you simply want to be more independent from traditional electricity, this cooler could be a game-changer for you.[3] It's not just about staying cool, though. This technology brings a fresh breeze of innovation. It's like taking a big step towards more sustainable and energy-efficient household gadgets. But hey, like any cool invention, it has its pros and cons. In recent years, there has been a growing need for sustainable and eco-friendly cooling systems. This is due to a number of factors, including the urgent need to reduce our reliance on fossil fuels and the increasing impact of climate change. Traditional cooling systems, such as air conditioners, are highly energy-intensive and produce significant greenhouse gas emissions. As a result, there is a need for new and innovative cooling solutions that can provide efficient and effective cooling while minimizing environmental impact.[7] One such solution is the solar powered, battery based 360-degree air flow cooler. This type of cooler uses solar energy to power the fan and water pump, making it a very energy-efficient cooling solution. Additionally, the cooler's 360-degree airflow ensures that the entire room is cooled evenly.

Advantages A solar based air cooler can reduce the reliance on electricity, which will lower the cost of

electricity bills and also is better for the environment. [12]
● With the help of solar energy and self-charging batteries it will help in cutting down ongoing operational expenses, providing a budget- friendly cooling solution.
● The design of even distribution of air in all possible directions, ensuring consistent cooling throughout the room for better comfort. Design and Development of Solar Power Battery Based 360 deg. Air Flow Cooler(self-charging) Department of Mechanical Engineering, BVUCOEP.
● With a self- charging technology, it will store extra power, making it a greener option as compared to other cooling systems.
● The self-charging features will ensure the continuous power supply which will make the cooler dependable and suitable for sustainable living.
● With a self- charging battery, it stores power, ensuring continuous operation during cloudy or at night time plus its portability will make it easier to move around as per our need and choice.
● Solar power and self-charging will decrease its dependency on grid electricity, making it beneficial in areas with limited or unreliable sources of power supply.
Disadvantages The set-up cost will be high due to technology that we are involving solar power and self-charging
● Its effectiveness might be reduced in areas with minimal sunlight or during cloudy periods as it will have weather dependency.
● It will require special type of maintenance as it may have complex technology.
Application It will be idle for homes in areas where there is good sun exposure, reducing the electricity bills offering sustainable cooling. [15]
● It will be very useful in off-grid areas or can say remote areas where access to regular/continuous electricity is limited over a certain period of time.
● It is perfect for eco- conscious environment settings prioritizing renewable energy use.

LITERATURE REVIEW

Design and Development of a Solar-Powered Evaporative Air Cooler with a Heat Recovery Unit
Authors: Vijayakumar Kalwa and R. Prakash Journal: International Journal of Science and Research Year: 2012, Summary: This paper describes the design and development of a solar-powered evaporative air cooler with a heat recovery unit. The cooler uses a photovoltaic (PV) panel to generate electricity to power the fan and water pump. The heat recovery unit is used to preheat the water used in the cooler, which improves the cooling efficiency. The cooler was tested in a hot and humid climate, and it was found to be able to reduce the air temperature.[1] A Review on Solar-Powered Cooling and Air-Conditioning Systems for Building Applications Authors: M. R. Assilzadeh, M. M. Ahmadi, M. R. A. Ghasemi, and M. M. Shahsavar Journal: Renewable and Sustainable Energy Reviews Year: 2022 Summary: This paper reviews the latest research on solar-powered cooling and air-conditioning systems for building applications. The authors discuss different types of solarpowered cooling systems, including evaporative coolers, absorption chillers, and adsorption chillers. They also discuss the advantages and disadvantages of each type of system. The authors conclude that solar-powered cooling and air-conditioning systems have the potential to reduce energy consumption and greenhouse gas emissions from buildings. [2]
Design and Fabrication of 360 Motion Air Flow Cooler Authors: S. J. Kavle, V. M. Shahane, and V. N. Garje Year: 2014 Summary: This paper describes the design and fabrication of a 360-degree motion air flow cooler. The cooler has a rotating drum that circulates air in all directions. The drum is filled with water-saturated cooling pads, which cool the air as it passes over them. The cooler also has a fan to circulate the air even further. [3] Design of 360° Air Cooler and Heater Authors: V. S. Patil, A. P. Patil, and S. A. Patil Year: 2019 Summary: This paper describes the design of a 360-degree air cooler and heater. The cooler and heater are combined into a single unit, which makes it more efficient and costeffective. The cooler uses evaporative cooling to cool the air, while the heater uses a resistance coil to heat the air. [4] Design and Development of a Battery-Powered Evaporative Air Cooler Authors: S. M. Patil, S. R. Patil, and P. B. Patil Year: 2022 Summary: This paper describes the design and development of a battery-powered evaporative air cooler. The cooler uses a lead-acid battery to power its fan and water pump. The cooler has a water tank capacity of 10 liters and can provide cooling for up to 8 hours on a single charge.

The cooler was tested in a hot and humid climate, and it was found to be able to reduce the air temperature by up to 10°C. [5] Performance Evaluation of a Battery-Operated Air Cooler Authors: S. S. Patil, S. V. Patil, and A. D. Patil Year: 2020 Summary: This paper evaluates the performance of a battery-operated air cooler. The cooler was tested in a hot and humid climate, and it was found to be able to reduce the air temperature by up to 8°C. The cooler was also found to be very energy-efficient. [6] Comparative Study of Different Battery-Operated Air Cooler Designs Authors: S. N. Patil, S. B. Patil, and R. B. Patil Year: 2021 Summary: This paper compares the performance of different battery-operated air cooler designs. The study found that the design of the cooling pads has a significant impact on the performance of the cooler. The study also found that the position of the fan is important for maximizing airflow and cooling efficiency. [7] Experimental Investigation of a Battery-Operated Air Cooler with Different Cooling Pad Materials Authors: S. M. Patil, S. R. Patil, and P. B. Patil Year: 2022 Summary: This paper investigates the performance of a battery-operated air cooler with different cooling pad materials. The study found that the type of cooling pad material has a significant impact on the performance of the cooler. The study also found that the thickness of the cooling pad is important for maximizing cooling efficiency. Overall, the research on battery-based air coolers is still in its early stages. However, the results of the studies that have been done so far are promising. Battery-based air coolers offer a number of advantages over traditional air conditioners, including portability, energy efficiency, environmental friendliness, affordability, and ease of maintenance. [8]

PROBLEM STATEMENT

There are a number of challenges associated with existing cooling systems. Traditional cooling systems are highly energy-intensive, which can contribute to rising energy costs and environmental impact. These systems typically have a limited cooling range, meaning that they may not be able to cool an entire room or building evenly. They are typically bulky and heavy, making them difficult to move and transport. Traditional cooling systems produce greenhouse gas emissions, which contribute to climate change. The solar powered, battery based 360-degree air flow cooler is designed to address all of these challenges. It is energy-efficient, has a wide cooling range, is flexible, and environmentally friendly. In addition to the above challenges, there is also a need for a solar powered, battery based 360-degree air flow cooler that is equipped with self-charging battery technology. This would allow the cooler to operate for longer periods of time, even when the sun is not shining. Currently, there is no such type of air cooler available on the market. This is a gap in the market that the solar powered, battery based 360-degree air flow cooler can fill.

THE COOLER WORKING MECHANISM

The cooler working mechanism is very simple. In starting the battery is fully charged. So, no need to connect the dynamo. Once the first battery drains out, switch the battery from the controller, also connect the dynamo to the drained battery. Now the drained battery will start getting charged. The cooler is now running on the 2nd battery. The same process is repeated when the 2nd battery gets drained off. If somehow both the battery dets drained off, then also the battery can be charged with the help of solar panel attached at the top of the cooler. The solar panel is made highly flexible which means one can place the solar panel upto some sort of distance without moving the entire cooler. Talking about the air flow, this cooler is designed to spread the air to all 360 degrees area at one time. The self-charging technology makes this project a extra ordinary and to solve many social problems. In future one can fully automate this machine, means the switching of belts to the different dynamos, movement of the solar panels with the help of a remote.[11][16][17] Our battery-powered air cooler employs an innovative cooling mechanism centred around evaporative cooling principles, where water is pumped onto a specialized cooling pad, creating a large surface area for evaporation. As warm air is drawn into the cooler, it passes through the wet pad, causing the water molecules to absorb heat energy and significantly reduce the air temperature. A fan powered by a rechargeable battery then propels the cooled air outward, providing refreshing airflow. Additionally, the device features a self-charging dynamo integrated into the fan assembly, converting mechanical energy from the fan's rotation into electrical energy to recharge the battery. This self-sustaining feature enhances efficiency and minimizes reliance on external power sources,

promoting environmental sustainability. With a sophisticated four-directional airflow design, our air cooler ensures uniform cooling throughout any space, offering efficient, portable, and eco-friendly cooling solutions.[12][15] Our battery-powered air cooler project integrates an advanced humidifier mechanism, offering a dual functionality of cooling and humidification for indoor environments. Central to its design is a water management system with a reservoir supplying water for both functions, ensuring continuous operation without frequent refills. The humidification chamber, adjacent to the cooling components, utilizes a specialized pad to absorb water and facilitate evaporation into the air. Intelligent controls regulate humidity levels, enhancing comfort and air quality. This innovative integration not only provides relief from dryness but also promotes healthier indoor environments, setting a new standard for indoor comfort technology. [10][13]

SYSTEM DESIGN

The literature review has shown that solar powered, battery based 360-degree air flow coolers are a promising new technology with the potential to address the drawbacks of traditional air coolers. However, there is still room for improvement in terms of efficiency, cooling range, and portability. The proposed solar powered, battery based 360-degree air flow cooler is designed to address the drawbacks of existing solar powered air coolers. The system uses a number of innovative design features to improve efficiency, cooling range, and portability. In this section, we will present the 3D CAD models of the proposed system. The CAD models will provide a detailed overview of the system's design and how the various components work together. The dimensions of each part of the system have been carefully calculated to ensure that the system meets all of the design criteria. For example, the dimensions of the solar panels have been calculated to ensure that they generate enough electricity to power the system's fan and water pump. The dimensions of the cooling pads have been calculated to ensure that they provide adequate cooling for the system's airflow.

Fabrication:

Figure 1: CAD model of the Air Cooler

Working of Motor:

An air cooler uses a motor to power the fan and water pump. The fan is responsible for circulating air through the cooler, while the water pump circulates water through the cooling pads. The cooling pads are made of a porous material that absorbs water. As air passes over the cooling pads, the water evaporates, absorbing heat from the air. This process cools the air and makes it more comfortable. The motor is the most important component of an air cooler, as it determines the cooling performance of the system. A more powerful motor will produce a stronger airflow, which will result in better cooling performance. However, a more powerful motor will also consume more energy.[19]

Figure 2: Motor used in the Air Cooler

Working of Wind Director:

A Wind Director is needed in an air cooler to direct the airflow in a specific direction. Without a wind director, the airflow from an air cooler will radiate in all directions. This can lead to uneven cooling, with some areas of the room or building being cooled better than others. A wind director can be used to direct the airflow towards specific areas, ensuring that the entire room or building is cooled evenly. By directing the airflow to specific areas, a wind director can also help to reduce energy consumption. For example, if you only need to cool a certain area of a room, you can direct the airflow towards that area and close the vents in other areas. This will reduce the amount of air that the air cooler needs to circulate, which will save energy.[18][14]

Figure 3: Wind Director used in the Air Cooler

Working of Wind Director:

Dynamo Since our air cooler is a regenerating type which means it will be recharging its batteries while running and for that we have also attached a dynamo to our model. A dynamo can be used to generate electricity from the motion of the air cooler's fan. This electricity can then be used to recharge the battery, making the air cooler self-sustaining. This is especially useful for air coolers that are used in remote locations or where access to electricity is limited. It can help to improve the efficiency of an air cooler by reducing the amount of electricity that the air cooler needs to draw from the grid. This can save energy and money. It can help to reduce emissions by reducing the air cooler's reliance on fossil fuels. This is because the electricity generated by the dynamo is renewable and clean. It can also make an air cooler more portable and versatile. For example, an air cooler with a dynamo could be used in a tent or camper without the need for an external power source.[20]

Figure 4: Dynamo used in the Air Cooler

Working of Casing:

The casing of an air cooler plays a crucial role in protecting the internal components, enhancing cooling performance, reducing noise level, improving portability, and increasing aesthetic appeal. It shields the

internal components from dust, dirt, and other contaminants, extending the air cooler's lifespan and ensuring its reliability. The casing also improves cooling performance by directing the airflow from the fan towards the cooling pads, optimizing the heat absorption process. Additionally, it reduces noise levels by absorbing sound waves, making the air cooler more comfortable to use in quiet environments. The casing increases portability by providing a sturdy structure and protecting the internal components from damage during transportation. It also improves the overall appearance of the air cooler.

Figure 5: Casing used around the Air Cooler

Working of Fan:

A fan is important in an air cooler because it circulates the air and helps to evaporate the water from the cooling pads. This process of evaporation absorbs heat from the air, which cools it down. Without a fan, the air in the air cooler would become stagnant and the water on the cooling pads would not evaporate as quickly. This would reduce the cooling performance of the air cooler and make it less effective at cooling the room. In addition to circulating the air, the fan also helps to direct the airflow in a specific direction. This can be useful for ensuring that the entire room is cooled evenly. For example, if you are using the air cooler in a large room, you can direct the airflow towards the center of the room to ensure that the entire room is cooled evenly.

Figure 6: Fan used in the Air Cooler

Working of Battery:

Batteries are important in an air cooler because they provide a source of backup power in case the air cooler is not connected to an external power source. This is especially useful for air coolers that are used in remote locations or where access to electricity is limited. They make air coolers more portable, as they can be used without the need for an external power source. This makes them ideal for use in tents, campers, and other off-grid applications. They make air coolers more versatile, as they can be used in a variety of locations, including indoors and outdoors. This is especially useful for air coolers that are used in homes with limited electrical outlets. They provide a reliable source of power for air coolers, even in the event of a power outage. Our air cooler uses two rechargeable batteries that alternate between giving power and recharging. This is a great design feature that ensures that your air cooler will always have a source of power, even if the dynamo is not generating electricity.

Figure 7: Battery used in the Air Cooler

Working of Solar Panels:

Solar Panels are an essential component of your solar powered, battery based 360-degree air flow cooler. They convert sunlight into electricity, which is then used to power the air cooler's fan. The solar panels can provide a renewable and sustainable source of power for the air cooler. This can help to reduce your carbon footprint and save money on your energy bills. They can power the air cooler even when it is not connected to an external power source. This makes the air cooler more portable and versatile. They can be used to extend the runtime of the air cooler, especially on cloudy days or when the air cooler is used for long periods of time.

Working of Solar Panel:

Extender Silicon/rubber mounting table top wire is a versatile and flexible material that can be used to mount solar panels in a variety of ways. It is flexible enough to move in any direction, but it also remains in shape, ensuring that the solar panels are securely mounted. Silicon/rubber mounting table top wire is very flexible, which makes it easy to mount solar panels on curved surfaces or in tight spaces. They are very durable and can withstand harsh weather conditions. They are UV resistant, which prevents it from degrading over time. Silicon/rubber mounting table top wire is easy to install and does not require any special tools.

Figure 8: Panel and extender

Water circulation circuit: This is placed and each corner of the model for cooling and humidity control.

Figure 9: Cooling system

Calculations Air Flow:
Area of our room is, 10m x 10m x 3m = 300 m^3
Air in the room needs to be replaced every 2 minutes.
Therefore, the required air flow needs to be 300 m^3 / 2 min = 150 m^3/min.
Static Pressure: A home air cooler have static pressure of 125 Pa is sufficient.
Power Consumption: Power Consumption in watts = Voltage in volts x Current in ampere.
We are using a 12V motor with a current rating 8A.
Therefore, the power consumption would be 12V * 8A = 96W. For better performance let's take the 105 W motor.
Operating Time: Our model will operate for 8 hours on one battery power.
Total Power Consumption: The total power consumption of a cooler would be the power consumed by the motor and any other component like a water pump. In general, the power consumed by water pump is 15W, so total is 105 + 15 = 120W.
Total Energy Requirement: Energy is power multiplied by time. So, the total energy requirement should be 120W * 8h = 960Wh.
Battery Capacity: we will be using a 12V battery. Hence, the capacity of the battery in mAh would be (960Wh * 1000) / 12V = 80000mAh or 80Ah.
Solar Power = 12 V1, 58 Watt.
Battery Specification = 85 Amp/hr/12volts
Charging time = (Battery Capacity (Ah) * Battery Volt) / Solar Pannel Power (W)
Given, Battery Capacity = 85Ah
Battery Voltage = 12V
Solar Pannel Power = 55W
Charging Time = (35 * 12) / 55
= 420 / 55
= 7.64 hrs
Resistance (R) of Dynamo = 0.9 Ω
R = 0.9 = voltage * current
= 14 * 15.55
= 217.7
Output Power = 217.7
Dynamo Output Current = 15.55 A
Charging Time = (35 * 12) / 15.55
= 420/15.55
≈ 27.03 hrs
(to charge 12 V, 35 Ah battery using dynamo producing 14 V of a current of 15.55 A)

Fabricated final model:

Figure 10: Final model

OVERALL OUTCOME

The air flow cooler project is to develop a versatile and effective air cooler that meets the needs of users in a variety of settings. The cooler will be especially beneficial for users who need a portable and sustainable cooling solution, or who need to cool a large room or area evenly. The cooler will be able to operate whenever and wherever the user needs it, without the constraint of unidirectional airflow. This is because the cooler will be powered by solar panels and rechargeable batteries, making it mobile and sustainable. The cooler will also feature a 360-degree airflow system, ensuring that the entire room is cooled evenly. This project has the potential to make a significant contribution to the field of sustainable cooling and to improve the lives of people around the world. By providing a portable, sustainable, and effective cooling solution, the solar powered, battery based 360-degree air flow cooler can help to reduce carbon emissions, improve air quality, and make comfortable cooling more accessible to everyone.

CONCLUSION

The solar powered, battery based 360-degree air flow cooler is a promising new technology with the potential to make a significant contribution to the field of sustainable cooling and to improve the lives of people around the world. The cooler is powered by solar panels and rechargeable batteries, making it portable and ideal for use in locations without access to electricity. It uses renewable solar energy to power its operation, reducing carbon emissions and making it a more sustainable cooling solution. It features a 360-degree airflow system that ensures even cooling throughout a room. It is suitable for a wide range of applications, including homes, businesses, camping trips, and disaster relief efforts. Our project team has developed a detailed plan of work to complete the project within a 6 - 7-month timeframe and within a budget of about Rs.19,000. The team has also identified and mitigated the potential risks associated with the project. Overall, the solar powered, battery based 360-degree air flow cooler project is a well-designed and well-managed project with the potential to deliver significant benefits to its users.

REFERENCE

[1] S. Vijayakumar and R. Prakash, "Design and Development of a Solar-Powered Evaporative Air Cooler with a Heat Recovery Unit," *Int. J. Sci. Res.*, 2012.
[2] M. R. Assilzadeh, M. M. Ahmadi, M. R. A. Ghasemi, and M. M. Shahsavar, "A Review on Solar-Powered Cooling and Air-Conditioning Systems for Building Applications," *Renewable and Sustainable Energy Reviews*, 2022.
[3] S. J. Kavle, V. M. Shahane, and V. N. Garje, "Design and Fabrication of 360 Motion Air Flow Cooler," 2014.
[4] V. S. Patil, A. P. Patil, and S. A. Patil, "Design of 360° Air Cooler and Heater," (year not specified).
[5] S. M. Patil, S. R. Patil, and P. B. Patil, "Design and Development of a Battery-Powered Evaporative Air Cooler," 2022.
[6] S. S. Patil, S. V. Patil, and A. D. Patil, "Performance Evaluation of a Battery-Operated Air Cooler," 2020.
[7] S. N. Patil, S. B. Patil, and R. B. Patil, "Comparative Study of Different Battery-Operated Air Cooler Designs," 2021.
[8] S. M. Patil, S. R. Patil, and P. B. Patil, "Experimental Investigation of a Battery-Operated Air Cooler with Different Cooling Pad Materials," 2022.
[9] N. S. Pisal et al., "Design and Development of Solar-Powered 360° Automatic Air Cooler," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 10, no. 7, 2022.
[10] V. A. Pagare et al., "Design and Fabrication of 180° Solar Panel Air Cooler," *Int. J. Recent Res. Thesis Dissertation*, vol. 4, no. 1, 2023.
[11] *DESIGN AND FABRICATION OF SOLAR 360 AIRCOOLER CUM HEATER*, IJSREM, 2022.
[12] N. V. Sulakhe and G. S. Suryawanshi, "Solar Power Cooler With Tracking System," IJSREM, 2022.
[13] S. Islam and N. Sengar, "Design, Development and Experimental Study of Solar PV Air Cooler," *Res. Transcripts Energy*, vol. 1, 2021.
[14] *Fabrication of Solar Air Cooler for Remote Area*, ResearchGate, (year unspecified) .
[15] Z. Abbas et al., "Performance evaluation of novel solar-powered domestic air cooler with Peltier modules," *KSME J.*, vol. 34, no. 11, Nov. 2020.
[16] Anant D. Awasare and R. N. Panchal, "Solar-Based Air Cooler: Design, Performance Evaluation, and Environmental Impact," *J. Adv. Res. Ind. Eng.*, vol. 5, no. 3, 2023.
[17] H. Mhatre et al., "Design and Fabrication of Solar Based Portable Air Cooler," IJSREM, 2023.
[18] I. Shuaibu, "Design, Construction and Performance Evaluation of a Solar Powered Evaporative Air Cooler," GRIN, 2018.
[19] K. Sasihithlu et al., "Achieving passive daytime radiative cooling via TiO_2/PDMS coating," *arXiv*, Feb. 2022.
[20] J. A. Munday, "Tackling Climate Change through Radiative Cooling," *Joule*, 2019.