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RESEARCH ARTICLE

DEVELOPMENT OF SOLAR EVAPORATIVE COOLING SYSTEM

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ABSTRACT

Significant challenges are presented by global warming, which is caused by rising levels of carbon dioxide (CO_2), nitrogen oxides (NOx), sulfur oxides (SOx), and other pollutants. As global temperatures rise, finding sustainable cooling solutions becomes crucial. Solar evaporative cooling systems offer a promising alternative. These systems utilize renewable solar energy, reducing dependence on fossil fuels, and consume significantly less electricity compared to traditional vapor compression refrigeration-based air conditioners (VCRC). By harnessing solar power and water evaporation, they leave a smaller carbon footprint. Unlike air conditioners, which recirculate indoor air, evaporative coolers draw in fresh outdoor air. Their simple design makes solar evaporative coolers relatively easy to construct and maintain. While solar evaporative cooling has numerous benefits, challenges such as humidity control, cooling efficiency, maintenance, and geographic suitability need to be addressed. Despite these obstacles, solar evaporative cooling provides a sustainable and environmentally friendly solution for indoor comfort. By overcoming these challenges and leveraging solar energy, efficient cooling systems can be developed that benefit both people and the environment. The research work involves designing and constructing both the internal and external units of a solar evaporative cooling system, followed by performance testing. The focus will include selecting efficient cooling pads or media, designing an effective solar collector, optimizing airflow patterns, and ensuring efficient water distribution. Additionally, the research will explore ways to enhance the overall efficiency and effectiveness of the system, taking into account various environmental and operational factors. By addressing these aspects, the research aims to develop a robust and reliable solar evaporative cooling system that can be widely adopted for sustainable indoor cooling.

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INTRODUCTION

Evaporative cooling reduces the temperature of a substance through the cooling effect produced by water evaporation. As water evaporates, sensible heat is converted to latent heat, lowering the surrounding temperature and providing effective cooling. This method has been applied in various settings, from small-scale space cooling to large industrial systems. Numerous studies have focused on designing different types of evaporative coolers. One such development is a solar-powered evaporative cooling storage system (SPECSS), created to extend the shelf life of fruits and vegetables for smallholder farmers. However, inconsistent power supply and inadequate facilities often prevent proper storage of perishable crops, leading to postharvest losses. A recent study demonstrates how this equipment can improve human comfort, especially in hot and humid environments. People need to maintain suitable thermal conditions, which depend on factors like room temperature, humidity, and airspeed. Thermal comfort is also influenced by radiant heat from warm surfaces or heat loss from cold surfaces. "Relative humidity (RH)" refers to the amount of moisture in the air relative to its saturation point, and warmer air can hold more moisture. When air reaches 100% humidity, it's at the dew point. Building temperature is affected by factors such as atmospheric temperature, HVAC systems, and solar heat. Since room temperatures are often lower than body temperature, occupants generate heat. Solar energy offers a solution to these issues as it is abundant in nature.(Vijaykumar Kalwa & R. Prakash, 2014). Air conditioners (ACs) consume a significant amount of power, leading to high costs and electricity bills, which are often unaffordable for people in our country. This has prompted more research focused on making ACs more affordable and reducing power consumption. Although these studies aim to develop the latest technology, the cost factor is often given less priority. Today, ACs are seen as a luxury for added comfort, but as temperatures rise, many people cannot afford them during the summer. As a result, the public relies more on coolers and ceiling fans to meet their cooling needs.(Ashwani Sharma *et al.*, 2016). Spray and permeable wetted pads offer efficient cooling through evaporative air cooling, utilizing a small amount of water. As heat and mass are transferred between water and air, this process decreases the dry-bulb temperature of the air and raises humidity while keeping the wet-bulb temperature constant. There is no perceptible heat exchange when the dry-bulb temperature of completely saturated air approaches the wet-bulb temperature due to adiabatic processes (Farhan A. Khmamas, 2010). This project seeks to design and develop a solar evaporative cooling system that can provide acceptable cooling comfort, reduce environmental impact, lower energy consumption in buildings, and be simply constructed using basic, naturally available materials. Water is the working fluid in the air conditioning technique known as evaporative cooling (Fikri *et al*., 2020; MA Kattimani *et al*., 2023). In order to keep buildings cool, Egypt has been using this antiquated technology from approximately 2500 B.C. Evaporative cooling systems have developed over time from simpler to more sophisticated models (Alamdari *et al*., 2020). Evaporative cooling pads, which promote heat and mass transfer between water and air, or water spraying into the air can be used to cool an area (Tejero-González & Franco-Salas, 2021). By utilizing low-grade energy sources like solar power and eliminating ozone-depleting pollutants, these systems offer an environmentally benign substitute for vapor compression air conditioning, making them a climate-smart technology (Dhamneya *et al*., 2018). According to Dhamneya *et al.* (2018), evaporative cooling systems fall into one of three categories: direct, indirect, or a combination of the two. An ancient yet useful technique, the direct evaporative cooler (DEC) works best in hot, dry conditions (MA Kattimani *et al*., 2019; Kashyap *et al*., 2021). By comparing the wet-bulb temperature with the dry-bulb temperature of the incoming air, the effectiveness of DEC is determined (Lal Basediya *et al*., 2013). Water evaporation, which absorbs latent heat and necessitates direct air-water contact via a wet medium, is the cooling process's key component (Fouda & Melikyan, 2011). An adiabatic process transforms the sensible heat of the air into latent heat, and the rate of evaporation increases the amount of cooling (Zakari *et al*., 2016). The performance of an evaporative cooling system largely depends on the material used for the cooling pads, which can be classified by material and configuration, such as rigid media, fiber pads, and package designs (Tejero-González & Franco-Salas, 2021). To increase the effectiveness of these systems, researchers have investigated a variety of cooling media; many of these studies have concentrated on substitute materials, such as readily available vegetable fibers. PVC, sponge, cloth, cellulose, metal, coir, palm fiber, jute, and luffa are examples of materials used frequently for pads (Fouda & Melikyan, 2011; Lal Basediya *et al*., 2013; Velasco-Gómez *et al*., 2020). Environmental elements include air velocity, pad thickness, temperature, and relative humidity (Abdel-Fadeel& Attalla, 2014). significantly impact evaporative cooling performance. In extremely humid conditions, when the air is saturated with water vapor, evaporation and cooling cease (Fouda & Melikyan, 2011). In contrast, very dry air enables greater evaporation and cooling (Lal Basediya *et al*., 2013). DEC systems work more effectively as air temperature rises and humidity drops (Amer *et al*., 2015). Saturation efficiency and cooling capacity improve when the contact surface area between air and water increases (Abdel-Fadeel & Attalla, 2014; Fouda & Melikyan, 2011). The larger the wet surface, the higher the evaporation rate, leading to improved cooling efficiency (Dhamneya *et al*., 2018). Increasing the evaporative surface area and using water-absorbing materials can enhance the performance of evaporative coolers (Xuan *et al*., 2012).

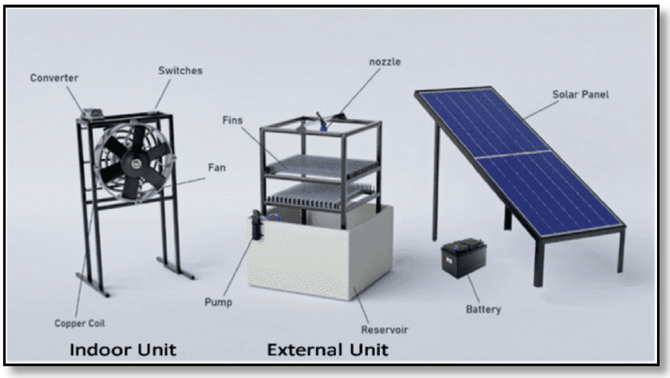

Fig.1. Internal & External Unit

METHODOLOGY

Solar energy conversion is accomplished by means of a battery, converter, and charge controller. When sunlight strikes a solar panel, the photoelectric effect transforms it into electrical energy. To hold onto this energy Chemical energy is the form that this electrical energy is kept in batteries. Thus, a charge controller is used between the solar panel and the battery to prevent overcharging (Fig. 3).

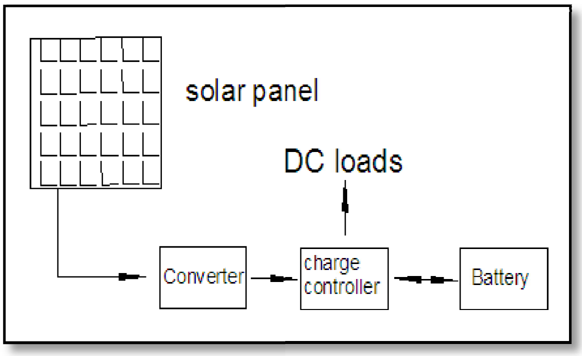

Fig. 2. Solar energy conversion process

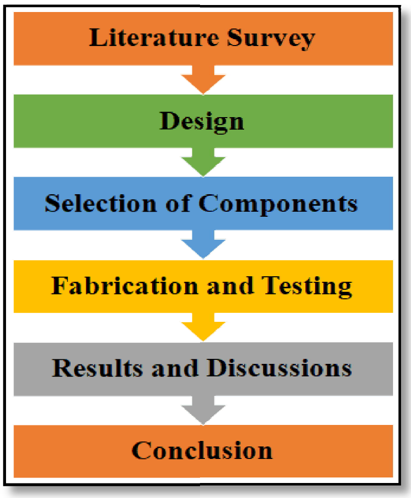

Fig. 3. Methodology

Table 1. Room Requirements for cooling

Room Length (L)	10ft
Room Width (W)	8ft
Room Height (H)	10ft
Room Volume(V)	10 x 8 x 10 or 800 Cft
Time required to cool the room(t)	20 min
Air flow required to cool the room in 20min (V / t)	800 / 20 or 40 CFM
Temperature Differenceto achieve (ΔT)	5^0C
Cooling Load (Q) 1.08 X CFM X ΔT	1.08 X 40 X 5or 216 Btu or 54.47 Kcal
Inlet water temperature of Cooling Tower (T_{cti})	28^0C
Out let water temperature of Cooling Tower (T_{cto})	23^0C
Cooling Tower Flowrate(F)	3 lit/min or 180 Lit/hr or 180Kg/hr
Specific heat of water (Cp)	1Kcal/Kg ^{0}C
Heat that can be removed by cooling tower M x Cp x (T_{cti} -T_{cto})	180 x 1 x (28 - 23) 900 Kcal/hr
Heat that can be removed by cooling tower in 20min	900 x 20/60 or 300Kcal

Heat to be removed from room in 20 min is 54.47Kcal to create 5 Deg Temperature drop and the cooling tower heat removal capacity is 300Kcal/20 min which is much higher than the required.

Table 2. Solar Panel Specifications

Power required for pump P_p	24W
Power required for FanP_f	50W
Total Power Consumption $P_t = P_p + P_f$	24 + 50 or 74W
Capacity of Solar Panel	80W

Capacity of Solar Panel is higher than the power required to run pump and fan. that means the system is self-sufficient. How ever to meet the power requirements of the system during low sun light, nights and start-up power drawls we have provided battery and AC to DC converter. That means the system can run on solar / battery as well as on grid power supply.

Table 3. Battery Specifications

Battery Current (Ib)	15Ah
Battery Voltage (Vb)	12V
Battery Power Pb= Ib x Vb	15 x 12 or 180W
Total Power Consumption P_t	74W
Battery back up time	180 /74 = 2Hrs (approx.)

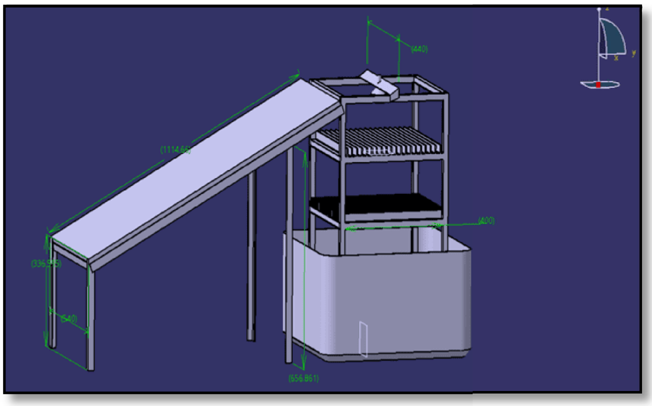

Fig. 4. Evaporative cooling system model

Fabrication and Testing: A solar based evaporative cooling system utilizes solar panels to generate electricity, powering a pump that circulates water from a reservoir over copper coil. As air is drawn through the coil by a fan, water evaporates, cooling the air which is then distributed into the desired space. This process provides efficient and sustainable cooling while not relying on fossil fuels and reducing environmental impact. Regular maintenance ensures optimal performance, making it a promising solution for combating global warming while maintaining comfortable indoor environments as shown in Fig. 5.

Fig. 5. Solar Evaporative cooling system

RESULTS AND DISCUSSIONS

The temperature difference within the evaporative cooling system was measured over five days, during which an equal quantity of vegetables was stored both in the system and under ambient conditions. The freshness of the veggies in the system was compared to those that were stored at room temperature for five days, and the temperature and relative humidity of the system and the surrounding environment were tracked during the experiment. The table below presents the recorded temperatures from the five-day experiment. The solar panel attached to the cooling tower is positioned at an angle to maximize sunlight for charging the battery that powers the model. Backup time can be extended by using larger batteries and solar panels. The water tank requires 15-20 liters of water at an appropriate temperature. The cooling tower is equipped with fins to aid in condensation as a natural coolant. A nozzle sprays water droplets onto polycarbonate fins, with water recirculated from the pump. The pump operates at a pressure of 6 bar and is activated by a switch on the internal unit's frame once the reservoir is filled. It draws water from the reservoir to the copper coil. A fan is turned on via a switch and can be powered either by the battery or plugged into a socket using an AC/DC converter. The copper cooling coil located behind the fan facilitates heat exchange with the cold fluid supplied by the pump. The external unit, consisting of the solar panel and cooling tower, is placed outside, while the internal unit is inside the room to cool and dehumidify it. The room should be approximately 80 sq. ft. for optimal cooling.

Table 4. List of Components

S. No.	Components	Specification
1	Solar panel	80W, 18V, 4.44A
2	Fins	25mm height and 440mm length
3	High pressure nozzle	6 bar
4	Fan	DC Motor Fan
5	Copper Tube	15OD & 12.5ID
6	AC to DC Converter	240 volts AC to 12 volts DC
7	Battery	12 volt
8	Switches	Two metal lever toggle switches
9	Water Pump	voltage range 12 to 24 volts and capable of generating high pressure up to 100 psi
10	Water storage tank	100 litres

After 20 minutes of operation, the following results were observed using an HVAC thermometer:Conventional 1-ton air conditioners consume between 1000W and 3000W to cool rooms, whereas this system uses only 74W to achieve a comfortable temperature, cooling the room to nearly 5°C below ambient temperature. Additionally, this system does not raise room humidity like conventional evaporative coolers. Temperature and Relative humidity of Day 5refered in the table 5 to table no 9. Figure 6 displays the average temperature for the environment and the cooling system, and Figure 7 displays the daily average relative humidity for the environment and the cooling system.

Table 5. Day 1's Temperature and Relative humidity

SL.NO	Time	Temperature(ºC)		Relative humidity (%)	
		Outside condition	Inside condition	Outside condition	Inside condition
1	10.30AM	28.5	24.5	45	49
2	11.30 AM	30.4	23.3	44	51
3	12.30 PM	31.5	22.7	49	52
4	1.30 PM	31.8	22.4	48	52
5	2.30 PM	32.3	21.6	44	52
6	3.30 PM	33.4	21.0	47	53
7	4.30 PM	30.6	20.2	48	53

Table 6. Day 2 Temperature and relative humidity

SL.NO	TIme	Temperature(ºC)		Relative humidity (%)	
		Outside condition	Inside condition	Outside condition	Inside condition
1	10.30AM	29.5	25.7	45	45
2	11.30 AM	30.4	24.7	43	46
3	12.30 PM	31.0	23.4	47	49
4	1.30 PM	32.5	22.5	46	50
5	2.30 PM	32.7	21.6	41	50
6	3.30 PM	33.0	21.3	44	51
7	4.30 PM	31.3	20.2	45	51

Table 7. Day 3Temperature and relative humidity

SL.NO	TIME	Temperature(°C)		RelativeHumidity (%)	
		Outside condition	Inside condition	Outside condition	Inside condition
1	10.30AM	27.5	24.3	46	48
2	11.30 AM	30.4	23.7	45	51
3	12.30 PM	32.3	22.6	48	52
4	1.30 PM	33.6	21.5	42	52
5	2.30 PM	32.7	21.2	42	53
6	3.30 PM	31.4	20.5	47	53
7	4.30 PM	30.2	20	45	54

Table 8. Day 4 Temperature and relative humidity

SL.NO	TIME	Temperature (°C)		Relative humidity (%)	
		Outside condition	Inside condition	Outside condition	Inside condition
1	10.30AM	28.7	25.5	47	46
2	11.30 AM	30.2	24.4	45	47
3	12.30 PM	32.3	23.6	49	50
4	1.30 PM	32.7	22.3	43	51
5	2.30 PM	33.1	21.8	46	52
6	3.30 PM	32.8	20.5	47	53
7	4.30 PM	29.7	20.4	46	53

Table 9. Day 5 Temperature and relative humidity

SL.NO	TIME	Temperature(°C)		Relative humidity (%)	
		Outside condition	Inside condition	Outside condition	Inside condition
1	10.30AM	27.6	25.6	46	48
2	11.30 AM	29.4	25.4	44	47
3	12.30 PM	30.2	25.3	45	47
4	1.30 PM	31.4	24.6	45	49
5	2.30 PM	32.1	20.3	49	52
6	3.30 PM	33.5	21.2	44	52
7	4.30 PM	30.7	20.5	48	51

The temperature and relative humidity for five days are displayed in the above tables at various time intervals for both the ambient temperature and the cooling system's interior. A decrease in temperature and a rise in relative humidity are noted. The table illustrates the daily percentage reduction in both temperature and relative humidity.

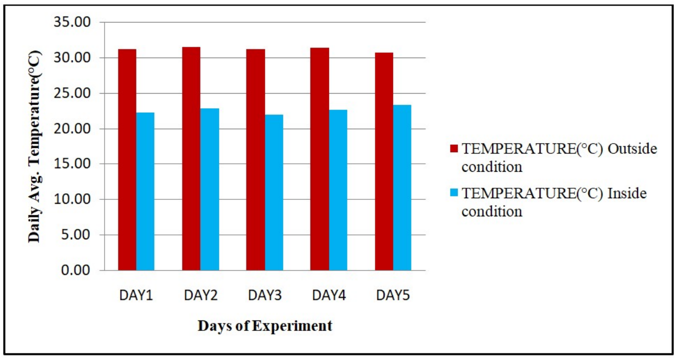

Fig. 6. The average daily temperature of the cooling system and the ambient

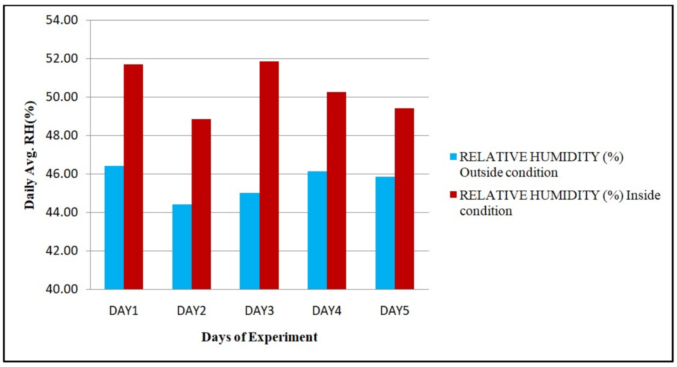

Fig. 7. The Average relative humidity per day for the cooling system and the ambient

CONCLUSION

The Solar Evaporative Cooling System is designed to provide a chemical-free, eco-friendly cooling solution. Unlike traditional air conditioners that rely on chemicals and consume a lot of electricity, this system uses solar energy stored in a battery to reduce electricity costs. It has been shown to lower the temperature of small rooms by 4 to 6 degrees Celsius. Both the external and internal units work efficiently. The external unit circulates water from a reservoir through pipes using a high-pressure positive displacement pump. These pipes are connected to a copper coil, which serves as a cooling pad. A fan draws air through the copper coil, cooling it in the process. The water is then recirculated through another pipe to a nozzle that sprays water over fins, cooling the water droplets as they are exposed to the air. This system provides an eco-friendly and efficient alternative to traditional air conditioning, significantly reducing energy consumption and greenhouse gas emissions. By utilizing renewable solar energy and the natural cooling effects of water evaporation, it offers sustainable indoor comfort and helps combat global warming. Over five days, the evaporative cooling system maintained lower temperatures and higher humidity than the surrounding environment, effectively preserving vegetable freshness. Continuous monitoring confirmed its effectiveness, demonstrating its potential as a sustainable solution for food preservation. The recorded data supports the system's consistent performance in optimal storage conditions.

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