iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: IV Month of publication: April 2025

DOI: https://doi.org/10.22214/ijraset.2025.68602

Design and Fabrication of IoT Based Parabolic Solar Dryer with Phase Change Material for Enhanced Thermal Energy Storage

Kishore C V[1], Pavithra S[2], Mude Poorna[3], Anu Freeda M[4], Seetharam P G[5], Monika K[6]
Agricultural Engineering Jnn institute of engineering Chennai,India

Abstract:* Designing and fabrication of an indirect solar dryer that integrates phase change material (PCM) into a parabolic solar collector. The system aims to increase thermal efficiency and enable nighttime drying. Because of its high latent heat storage capacity, the PCM, which is paraffin wax, stores excess thermal energy during the hottest hours of the day and releases it at night. This cost-effective technique encourages sustainable drying solutions and reduces dependency on fossil fuels by optimising energy use. System performance can be monitored by Blynk app to track the humidity and temperature of the drying chamber in real time. The test results show how well the solar dryer uses solar energy to maximise drying, with a noticeable decrease in moisture as the temperature rises.This solar dyer is very easy to use and offers farmers in developing countries a sustainable method of lowering post-harvest losses.

Keywords: Parabolic collector, Phase change material(PCM), Paraffin wax, Blynk App.

I. INTRODUCTION

A. Why this system ?

Innovative technologies that use renewable energy have emerged in response to the growing need for sustainable and effective drying techniques in agriculture. The design and implementation of an indirect solar dryer using phase change materials (PCM) and a parabolic solar collector are the main goals of this project. Improving thermal efficiency and extending drying capabilities into the night are the goals. Faster drying times, better-quality products, reduced loss of raw materials, and increased output are all benefits of indirect solar drying. [1]

In order to maximise solar energy capture, the parabolic solar collector concentrates sunlight to create higher temperatures. The PCM is paraffin wax, which stores extra thermal energy during the day for drying at night. Accurate control and optimisation are made possible by real-time temperature and humidity monitoring. The temperature and relative humidity range from 40°C to 70°C and 30% to 60%, respectively. [2]

B. Objectives

The objectives of this project are to implement real-time monitoring using IoT-based sensors, improve overall efficiency through PCM-based thermal energy storage, increase product quality by maintaining optimal temperature and humidity levels, enable remote accessibility and monitoring, enhance safety features, and optimize performance using data analytics. Additionally, a Blynk mobile app will be integrated to allow users to remotely monitor temperature and humidity levels in real-time.

II. LITERATURE SURVEY

1) Existing Systems for Solar Dryers

Ebrahim et al. (2021) investigated The effects of incorporating phase change materials (PCMs) into flat plate solar collectors on thermal efficiency and temperature regulation were examined by Ebrahim et al. in 2021. When compared to conventional collectors, the results indicated a 10-15% increase in thermal efficiency. To ensure constant heat production, the PCM stored thermal energy during periods of high solar radiation and released it gradually. The study demonstrated how PCM reduces temperature fluctuations and has a thermal protective effect. In their investigation of different PCM types, Ebrahim et al. discovered that paraffin-based PCMs provided superior long-term stability and effective heat retention. ***[3]***

2) Phase Change Materials (PCMs) in Solar Dryers

Pramod V. Walke and Yogesh N. Nandanwar (2024) studied the impact of integrating a conical cavity receiver with phase change material (PCM) in a parabolic dish collector (PDC). Conical receivers offer superior thermal performance due to their ability to capture more solar radiation, but their efficiency with PCMs was not well understood. The study used a 1.5-meter parabolic dish, a concentration ratio of 3.51, and a two-axis tracking system. A stainless steel receiver insulated with 20 mm glass wool was used, and paraffin wax was chosen as the PCM due to its 226 kJ/kg latent heat and 58°C melting temperature. Experiments at different heat transfer fluid (HTF) flow rates (0.04, 0.05, and 0.08 kg/s) showed that the PCM-filled conical receiver significantly improved performance. It achieved output temperatures of up to 70°C, with a 42% increase in thermal efficiency and a 31% enhancement in exergy efficiency. These findings confirm that PCM integration enhances the reliability and efficiency of PDC systems for continuous solar energy applications. **[4]**

S. Bakhshipour et al. (2017) used numerical modelling to examine the impact of a PCM heat exchanger in home drying systems. By positioning the PCM heat exchanger after the heating element and before the rise valve, their study compared the drying cycle with and without PCM. The findings demonstrated that PCMs increased the efficiency of heat exchange via convection and conduction in a shell-and-tube heat exchanger (STHE). About 70% of the PCM was melted by spontaneous convection, indicating how well it stabilised the drying process. [5]

Bal et al. (2020) created a solar dryer that stores extra solar energy by using paraffin wax as PCM. The system reduced the amount of energy needed to dry food and agricultural products by continuously supplying hot air between 40°C and 75°C. According to their research, choosing the right PCM and designing the system can greatly increase drying efficiency, reduce energy losses, and guarantee steady operation in a range of solar conditions. **[6]**

The efficiency and dependability of solar drying systems are increased by solar thermal energy storage using PCM. It guarantees the continuous drying of agricultural products by closing the gap between energy supply and demand, which makes solar energy more viable and sustainable.

3) Parabolic Trough Collector (PTCs) with PCM

Two crucial areas where renewable energy technologies can increase sustainability and efficiency are solar desalination and greenhouse drying. In order to improve solar desalination, Mohanraj et al. (2024) looked into integrating a Parabolic Solar Collector (PSC) and Phase Change Material (PCM) into a Double Slope Solar Distil (DSSD). To store extra thermal energy, 40 kg of paraffin wax was added to the system as a heat storage medium. A black-coated galvanised iron (GI) sheet with a 1 × 1.5 m basin was used to build the DSSD. To aid in heat transfer, a copper heat exchanger measuring 11.3 mm in diameter and 15 m in length was integrated into the PCM unit. Additionally, solar radiation was focused onto the absorber tube using a parabolic concentrator, which had dimensions of 200 cm in length, 106 cm in aperture, and 26.6 cm in focal length. The concentrator heated the saline water while it was in use by directing solar energy to the absorber tube. Even after the hottest parts of the day, the PCM helped to keep temperatures high by absorbing and storing extra heat as latent heat. In contrast to a conventional DSSD, the DSSD with PCM produced noticeably higher temperatures (59.9°C for the water and 50.9°C for the PCM surface), which enhanced the yield of freshwater. **[7]**

Similarly, Eric King'ori and Isaac N. (2024created, constructed, and tested a Parabolic Trough Solar Air Heater (PTSAH) to improve the drying efficiency of greenhouses. The PTSAH made use of an axial fan for forced air circulation, a parabolic trough lined with aluminium foil for high reflectivity, and a black-painted GI absorber tube. The system achieved an absorber tube temperature of 85.6°C and a thermal efficiency of 5.3% by increasing the air temperature by 45.6°C with an aperture area of 2.4 m². Convection and radiation accounted for 81% of the heat losses. The parabolic trough's dimensions were 2.4 m² for the total aperture area, 0.261 m for the focal length, 1.2 m for the aperture width, and 98° for the rim angle. These developments show how solar concentrators can enhance the desalination and drying processes. **[8]**

4) Angle Used for PTC

O.E. Itabiyi et al. (2024) conducted an experimental study on the impact of mass flow rate and tilt angle on a parabolic trough solar concentrator's performance. The system had a 2.1 m length, 1.2 m width, 30 cm focal length, a 10-liter storage reservoir, and adjustable rim angles (75°, 90°, 105°). Similarly, Sintali et al. (2020) analyzed the effect of tilt angles on thermal efficiency in Bauchi, Nigeria, using ten years of solar radiation data. Their findings revealed a maximum efficiency of 73% at lower tilt angles (7°–8°) and recommended optimal angles between 7° and 33° seasonally. (al. O. E., 2024)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

5) Blower Systems for Solar Dryers

Twin City Blower Companies (2000) explain that centrifugal blowers increase air or gas pressure using centrifugal force from impeller rotation. They are classified into three main types based on blade configuration: radial or straight blades, forward curve blades, and backward inclined blades. Understanding fan types, performance, and operational principles is crucial for selecting the right parameters. Computational fluid dynamics (CFD) is commonly used to analyze blower performance, requiring the application of continuity, momentum, and energy equations. Choosing the optimal turbulence model ensures accurate analysis.

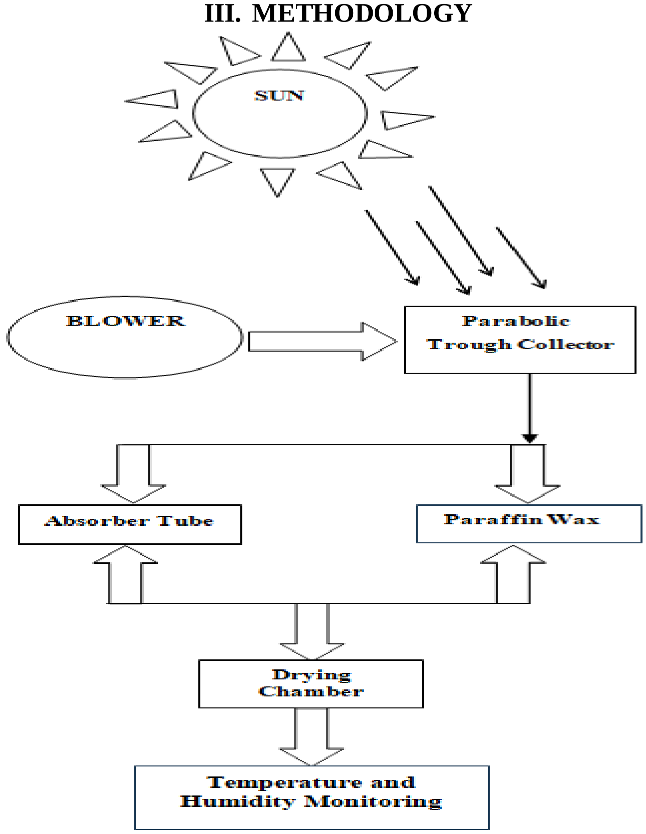
In blower design, the mobile anterotor regulates mass flow variation instead of altering motor speed. Vibration analysis is also essential, as excessive vibration can reduce bearing life. Proper measurement techniques help identify and mitigate vibrations. Preventative maintenance, such as modifying accessories like the plumber block, can prevent bearing failure, extending blower lifespan and improving long-term efficiency. This ensures reliable operation and enhances overall system performance. **[10]**

6) Temperature and Humidity Monitoring

Daisy Daimary, Khandakar Aktar Hussain, and Nicky Cruz Narzary (2021) developed an affordable and efficient real-time temperature and humidity monitoring system, improving upon traditional paper-based methods with digital logging and wireless data transfer. The system is powered by an Arduino Uno, which controls an SD card module for data storage, an RTC module (DS3231) for precise timestamps, and a DHT11 sensor for temperature and humidity measurement. An LCD display provides real-time readings, while an HC-05 Bluetooth module facilitates wireless data transfer to a mobile application.

The system was tested at the Gossaigaon Cold Storage in Kokrajhar and the Kajalgaon Cold Store in Chirang, successfully recording and presenting environmental conditions. Data was stored on an SD card and transmitted via Bluetooth, ensuring accuracy and accessibility. The results validated the system's reliability, and potential future enhancements could include cloud-based storage and remote access, further improving its usability for real-time monitoring applications. [11]

III. METHODOLOGY



A. Material

1) Polycarbonate Acrylic Sheet

Polycarbonate Acrylic are strong, stiff, hard, tough, transparent engineering thermoplastics that can maintain rigidity up to 140°C and toughness down to -20°C or special grades even lower. The material is amorphous (thereby displaying excellent mechanical properties and high dimensional stability), is thermally resistant up to 135°C and rated as slow burning. Special flame retardant grades exist which pass several severe flammability tests. **[12]**

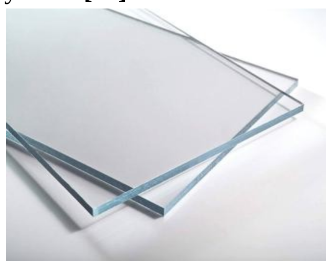


Fig 1: Polycarbonate acrylic sheet

2) Parabolic Collector

Parabolic trough collector is a type of solar thermal energy systemthat directs sunlight onto a linear receiver situated along its focal line using a curved, parabolic reflector. Usually, a heat transfer fluid in this receiver absorbs the concentrated solar energy and heats up to high temperatures.

The heated fluid can then be used for a number of purposes, such as heating water for domestic or commercial use or producing steam to power turbines that produce electricity.

Fig 2: Parabolic collector

3) Paraffin Wax

Paraffin wax, colourless or white, somewhat translucent, hard wax consisting of a mixture of solid straight-chain hydrocarbons ranging in melting point from about 48° to 66° C (120° to 150° F). Paraffin wax is obtained from petroleum by dewaxing light lubricating oil stocks. It is one type of PCM material

Fig 3: Paraffin wax

4) Blower

A blower is a mechanical device used to move air or gas at high velocity. It typically consists of a motor-driven fan and is used in various applications, including ventilation, cooling, and drying processes. Blowers can enhance airflow in industrial settings, improve air quality, and support combustion in heating systems

Fig 4: Blower

5) Absorber Tube

The absorber tube in a parabolic collector is a key component that captures concentrated solar energy. Located at the focal line of the parabolic reflector, it contains a heat transfer fluid, typically oil or water, which absorbs heat from the sunlight. This heated fluid is then used for power generation or heating applications, enhancing overall system efficiency. **[13]**

Fig 5: Absorber tube

6) Tray

A wire mesh tray is a versatile and durable storage solution made from a mesh of interconnected wires .It typically has a rectangular shape with raised edges to prevent contents from spilling over. The wire mesh design allows for airflow, visibility, and easy cleaning.

Fig 6: Wire mesh tray

7) Node MCU

A temperature and humidity sensor, such as the DHT11, is integrated into a Node MCU and sent to the Blynk app via Wi-Fi. Real-time temperature and humidity readings are shown by the Blynk app, which enables remote monitoring and control smartphone interface

Fig 7: Node MCU

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

8) Humidity And Temperature Sensor

Both the ambient temperature and humidity are measured by the temperature and humidity sensor. The Arduino Nano receives the data and processes it. Reliable and accurate measurements are provided by the sensor. It is an essential part of the survelliance system.

Fig 8: Temperature and Humidity sensor

9) BLYNK

The Blynk app makes it possible to monitor temperature and humidity in real time using sensors like the DHT11 and a WiFi-enabled microcontroller like the ESP32. Because it enables users to view real-time data, set alarms, analyse patterns, and remotely control IoT devices, the Blynk mobile app is ideal for smart home automation and environmental monitoring. **[14]**

Fig 9: Blynk app

B. Working Principle

The four primary parts of the indirect solar dryer's system architecture are the drying chamber, airflow and heat transfer, solar energy collecting and storage, and Internet of Things-based monitoring and control. Heat is supplied to the air moving inside a hollow copper absorber tube (50 mm outer diameter, 25 mm inner diameter) by the parabolic trough collector (PTC), which collects and concentrates solar radiation. Paraffin wax, which functions as a phase change material (PCM) to store heat and sustain drying conditions even in low sunlight, fills the space between the tube walls. Before being sent into the drying chamber, ambient air is heated in the absorber tube after being forced through it by a blower. To ensure even moisture removal, the heated air inside the chamber circulates through trays that hold the drying material, each measuring 450 x 250 mm. The humid air is subsequently expelled by an exhaust ventilation system to ensure effective drying. The system uses IoT-based temperature and humidity sensors, which are processed by an ESP8266 Nano microprocessor, to track and manage the drying process tracking in a mobile device's Blynk app. This architecture enhances drying performance and system reliability by enabling automated airflow control, remote monitoring, and efficient energy utilisation.

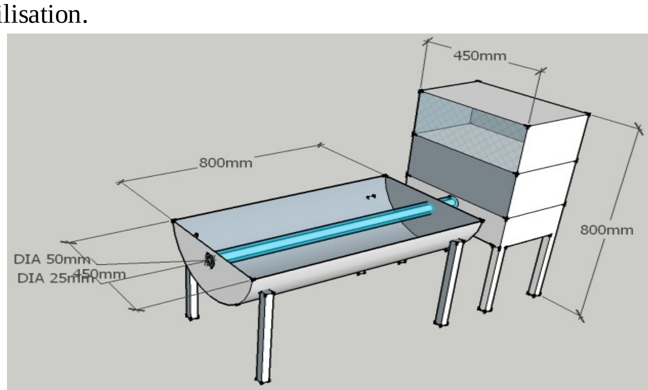


Fig 10: CAD Design

Fig 11: Fabricated PTC Solar Dryer

C. Methods

1) System Design

a) Parabolic Collector Design

- Dimensions:
  Diameter (D):450mm
  Length (L):800mm
- Reflective Material: Aluminum

b) Heat Exchanger and PCM

- Heat Exchanger Design:
  Type: cylindrical with pipes for air flow.
  Surface area (A): Calculate based on the expected heat transfer.
  A=Q/(ΔT·UQ)
  Where:
  Q = Heat transfer (W)
  ΔT = temperature difference between air and collector (°C)
  U = overall heat transfer coefficient (W/m²°C)

- PCM Selection: Choose PCM with a melting point around 40-60°C (e.g., paraffin wax)
  Thermal Storage Capacity: QPCM=m· Lf

Where:

i. m= mass of PCM (kg)
ii. Lf = latent heat of fusion (kJ/kg)

c) Air Heating and Distribution System:

Air Flow Rate (Q): Determine based on drying requirements.
Q=m·cp·ΔT/t
Where:
m= mass flow rate of air (kg/s)
cp = specific heat of air (approximately 1.005 kJ/ kg°C)
ΔT = temperature rise (°C)
t = drying time (s)

d) Drying Chamber Design:

Dimensions: 450mm x 250mm x 500mm
Insulation: Use materials with low thermal conductivity to minimize heat loss.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

2) Theoretical Calculations

a) Solar Radiation Calculation:

Solar Radiation (G): Assume an average solar radiation of 800 W/m².

Collector Area:

Acollector= 0.36m^2

Total Solar Energy Collected (Qs):

Qs=G·Acollector

Q=800W/m^2 *0.36m^2

Q=288W

b) Heat Transfer to Air:

Assumed Temperature Rise: From ambient (25°C) to 60°C (ΔT=35°C).

Using the heat transfer formula:

Q = m·cp·ΔT

Rearranging to find the mass flow rate :

m=Q/(cp·ΔT)

=288W/(1.005KJ/Kg°C*35°C)

=0.008Kg/s

c) PCM Heat Storage:

Assume a mass of PCM of 7kg and a latent heat of fusion of 200 kJ/ kg.

QPCM=m·Lf

=1400KJ

D. Programming Code

```
#define BLYNK_TEMPLATE_ID "TMPL3UFQCIWQ9"
#define BLYNK_TEMPLATE_NAME "Temperature monitoring"
//#defineBLYNK_AUTH_TOKEN "YMeVNH_9EWOXoMq1yN_OIRjytRJR3eHc"

#include <ESP8266WiFi.h> #include <BlynkSimpleEsp8266.h> #include <DHT.h>

#define DHTPIN D5 // GPIO2 (D4 on NodeMCU) #define DHTTYPE DHT11

char auth[] = "YMeVNH_9EWOXoMq1yN_OIRjytRJR3eHc"; char ssid[] = "Realme Narzo";
char pass[] = "123456789"; DHT
dht(DHTPIN, DHTTYPE);

void setup() {
  Serial.begin(115200); Blynk.begin(auth, ssid, pass); dht.begin();
}

void loop() { Blynk.run();
  float temperature = dht.readTemperature(); float humidity = dht.readHumidity();
  if (isnan(temperature) || isnan(humidity)) { Serial.println("Failed to read from DHT sensor!"); return;
  }
```

```
Serial.print("Temperature: ");  Serial.print(temperature); Serial.print(" °C, Humidity: ");
Serial.print(humidity); Serial.println(" %");
Blynk.virtualWrite(V1, temperature); Blynk.virtualWrite(V2, humidity);
delay(2000);  // Wait 2 seconds before the next reading}
```

Time	Avg of ambient temp	Avg of absorber temp	Avg of ambient humidity	Avg of absorber humidity
11.00-11.30	32.5	65	47.5	18
12.00-12.30	34	80	48	14
13.00-13.30	33.5	82.5	46	14
14.00-14.30	32.5	73.5	41	14

IV. RESULT AND DISCUSSION

This section outlines the final dimensions of the Parabolic solar dryer, which was fabricated based on design specification and evaluated for performance. The temperature variations under ambient and absorber conditions during daytime and night time are also analyzed. Furthermore, an IoT-based monitoring system using the Blynk app provided real- time tracking of temperature and humidity, ensuring monitoring of drying conditions and overall system performance.

A. Test of drying performance

1) Day Time

Table 4.1 Ambient result reading for Day 1

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	33	53
12.00-12.30	34	49
13.00-13.30	34	53
14.00-14.30	33	41

Table 4.2 Ambient result reading for Day 2

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	32	42
12.00-12.30	34	47
13.00-13.30	33	39
14.00-14.30	32	42

Table 4.3 Absorber result reading for Day 1

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	62	19
12.00-12.30	75	15
13.00-13.30	82	13
14.00-14.30	76	15

Table 4.4: Absorber result reading for Day 2

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	64	17
12.00-12.30	85	13
13.00-13.30	83	15
14.00-14.30	71	13

Table 4.5 Mean absorber and ambient result reading over two days

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	28	66
12.00-12.30	31	65
01.00-01.30	29	68
14.00-14.30	28	66

2) *Night time (Energy from PCM)*

Table 4.6: Ambient result reading for Day1

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	30	64
12.00-12.30	29	62
01.00-01.30	31	69
14.00-14.30	30	65

Table 4.7: Ambient result reading for Day 2

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	48	28
12.00-12.30	49	25
01.00-01.30	43	29
14.00-14.30	45	26

Table 4.8: Absorber result reading for Day 1

Table 4.9: Absorber result reading for Day 2

Time	Temp(^{0}C)	Humidity(%)
11.00-11.30	47	26
12.00-12.30	45	28
01.00-01.30	42	24
14.00-14.30	44	25

Table 4.10 Mean absorber and ambient result reading over two days

Time	Avg of ambient temp	Avg of absorber temp	Avg of ambient humidity	Avg of absorber humidity
11.00-11.30	29	47.5	65.5	27
12.00-12.30	30	46	63.5	26.5
01.00-01.30	30	42.5	68.5	26.5
14.00-14.30	29	44.5	65.5	25.5

V. CONCLUSION AND FUTURE SCOPE

A Parabolic solar dryer design has been successfully developed and tested, demonstrating its ability to effectively dry agricultural products while minimizing moisture content This system is easier to replicate globally and requires less maintenance than traditional open sun drying. Its novel integration of a parabolic collector, phase change materials (PCM), and Internet of Things (IoT)-based monitoring allows for optimal drying conditions, accurate temperature and humidity control, and effective solar energy harvesting. This environmentally friendly design improves product quality, drying effectiveness, and thermal storage, making it a desirable option for agricultural applications.

REFERENCES

[1] D. Kumar et al., "Indirect solar drying with phase change materials: A review. International Journal of Energy Research, 44(2), 553-571. doi: 10.1002/er.4935," 2020.
[2] Saxena et al, "Experimental investigation of a solar dryer with phase change material Renewable Energy, 136, 1222-1232. doi: 10.1016/j.renene 2019.01.058.," 2019.
[3] Ebrahim et al., "“Effects of integrating phase change materials (PCMs) into flat plate solar collectors on temperature regulation and thermal efficiency,” Renewable Energy Research, vol. 10, no. 2, pp. 45-52,," 2021.
[4] N. Nandanwar et al, "Impact of integrating a conical cavity receiver with phase change material (PCM) in a parabolic dish collector (PDC),” International Journal of Solar Energy Applications, vol. 14, no. 1, pp. 112-125,," 2024.
[5] S. Bakhshipour et al., "Effect of a PCM heat exchanger in household drying systems: A numerical modeling approach,” Journal of Thermal Sciences, vol. 8, no. 3, pp. 233-245," 2017.
[6] Bal et. al., "Development of a solar dryer using paraffin wax as PCM for continuous drying applications,” Solar Energy Materials & Solar Cells, vol. 98, no. 4, pp. 78-89,," 2020.
[7] Mohanraj et al., "“Integration of a Parabolic Solar Collector (PSC) and Phase Change Material (PCM) in Double Slope Solar Distillation,” Desalination Research Journal, vol. 21, no. 1, pp. 101-118," 2024.
[8] E. King’ori et al., "construction, and testing of a Parabolic Trough Solar Air Heater (PTSAH) for greenhouse drying efficiency,” Journal of Sustainable Energy, vol. 15, no. 2, pp. 56-67," 2024.
[9] O.E Itabiyi. et. al., "Experimental study on mass flow rate and tilt angle effects in parabolic trough solar concentrators,” Solar Thermal Research Journal, vol. 12, no. 1, pp. 34-45," 2024.
[10] T. C. B. Companies, "Centrifugal Blowers and Their Applications, Technical Report,," 2000.
[11] D.Daimary et al, "IoT-based real-time temperature and humidity monitoring system using Arduino.".
[12] S. Kumar et al, " Design and Development of a Solar Dryer using Polycarbonate Sheet. International Journal of Advanced Research in Science, Engineering and Technology, 4(3), 2319-2326," 2017.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

[13] S. Kumar et al, "Thermal performance of a parabolic trough collector with a copper tube absorber. Journal of Solar Energy Engineering, 139(3), 031007.," 2017.
[14] S. Rao et al, ""IoT based temperature and humidity monitoring system using ESP8266 and DHT11." Journal of Advanced Research in Computer Science, vol. 8, no. 2, pp. 234-241.," 2017.