# Real-Time Monitoring of Radiant Flux and Surface Thermal Properties via an Integrated Arduino-Thermocouple Setup

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**Abstract:** ***This study presents an innovative approach to measuring radiant flux using an Arduino-based system integrated with thermocouples. The experiment investigates the variation in surface temperature of different-coloured plates and develops a low-cost experimental setup for measuring radiant flux. The methodology involves fabricating six pairs of three-inch circular plates with drilled holes for the placement of thermocouples. The upper surfaces are painted in different colours. A 4-inch pot with a glass cover is modified to accommodate a digital thermocouple probe, with the coloured plates placed inside. A thermal light source (25W/50W UV solar basking light) is used to heat the plates, and temperature readings are recorded until stabilization. The plates are then arranged in increasing order of saturation temperatures. To enhance data accuracy and eliminate manual recording, an Arduino-based system is developed to interface with a computer, allowing real-time temperature monitoring. The system records the room temperature and the temperatures of two selected coloured plates simultaneously. This setup provides a cost-effective alternative to traditional pyranometers. Radiant flux measurement is essential for assessing the efficiency of solar energy devices. Understanding its variation across different times of the day and seasons aids in optimizing solar energy capture. This experimental setup is an educational tool and a practical solution for studying radiation flux and surface thermal properties. The results demonstrate that an Arduino-integrated thermocouple system can effectively measure solar radiation flux at a fraction of the cost of conventional instruments, making it accessible for academic research and practical applications.***

**Keywords:** Radiant Flux Measurement, Arduino-Based Data Acquisition, Thermocouple Temperature Sensing, Solar Radiation Analysis, Surface Thermal Properties

## 1. Introduction

The variation of solar radiation plays a critical role in a variety of scientific fields[1], ranging from climate studies to energy generation and agriculture [2], Understanding the fluctuations and variations of solar radiation over time is essential for predicting climate patterns, optimizing solar energy systems, and improving agricultural productivity [3]. Solar radiation is the main source of energy driving Earth's climate system [4]. Variations in solar radiation affect global temperature patterns, atmospheric circulation, and precipitation[5] . Over short timescales, such variations can influence weather, while on long timescales, they contribute to significant climate shifts. The efficiency of solar energy systems depends heavily on the amount of solar radiation received at a given location, which varies due to time of day, seasonal cycles, and local atmospheric conditions [6] . Understanding these variations is crucial for improving the performance of solar panels and for integrating solar power into the energy grid. Solar radiation is the primary source of energy for photosynthesis, which is fundamental to plant growth. Variations in solar radiation can affect crop yields and agricultural productivity, influencing food security[6].

Understanding solar radiation patterns is important for developing strategies to mitigate the effects of droughts, cloudy periods, or changing seasons. Moderate exposure to solar radiation is essential for the synthesis of vitamin D in the skin [7] . However, excessive exposure to ultraviolet radiation can lead to skin cancer and other health issues. The variation in solar radiation, especially UV radiation, influences public health, as different regions and seasons experience varying levels of UV radiation [8].

The Earth's energy balance is determined by the incoming solar radiation and the amount of heat radiated back into space. Variations in solar radiation influence atmospheric circulation patterns, ocean currents[9], and the overall heat distribution on Earth, impacting weather systems and climate stability [10]. Solar radiation, particularly during solar flares and coronal mass ejections, can disrupt communication systems, GPS satellites, and other space-based technologies[11]. Variations in solar radiation impact the Earth's magnetosphere, which can cause geomagnetic storms that affect satellite operations and communication systems[12]. Architects and engineers use solar radiation data to design buildings optimizing natural lighting, heating, and cooling. Seasonal changes in solar radiation are particularly important for passive solar heating and energy-efficient building designs. Long-term variations in solar radiation are thought to play a role in shaping Earth's climate over geological timescales [13]. These variations are tied to solar cycles, Earth's orbital variations, and changes in solar output. Radiation falling on the colour plates causes differential heating due to their colour and, therefore, a difference in their temperature[14]. By measuring this temperature difference, we get an idea of the radiation flux. This type of device (Radiometer) has to be enclosed in some enclosure with a window (if possible, hemispherical) or enclosed container to reduce both convection and reflection losses.

In our experimental design, we have used-

1) Coloured Aluminium Circular Plates.
2) Three Digital Thermometer sensor wired as probe, height adjustable light source.
3) Source- UVB Lamp (popularly known as Turtle Bulb) with wattage 50 Watt,
4) Digital solar power meter.

From our preliminary studies, we found that the temperature varies when we change the wattage of the source, the distance of the source and the difference in sources.

## 2. Working Principle and Experimental Setup

### 2.1 Working formula

Let $T_1$ (Room Temperature), $T_2$ (Black Plate Temperature) and $T_3$ (White Plate temperature) are the sensors temperature[14], U is the radiant flux, then

$$a_2 * U = K_{d2} * (T_2 - T_1) + K_{v2} * (T_2 - T_1)^n + K_{r2} * (T_2^4 - T_1^4) \quad (1)$$

where,

$n$ = 5/4 for free convection,

$a_2$ = Absorption coefficient of Plate 2 (with final Temperature T2),

$K_{d2}$ = Coefficient related to conduction,

$K_{v2}$ = Coefficient related to convection and

$K_{r2}$ = Coefficient related to radiation for plate with temperature T2 (Generally taken as black plate)

$$a_3 * U = K_{d3} * (T_3 - T_1) + K_{v3} * (T_3 - T_1)^n + K_{r3} * (T_3^4 - T_1^4) \quad (2)$$

where, $a_3$ = Absorption coefficient of Plate 3 (with final Temperature T3),

$K_{d3}$ = Coefficient related to conduction,

$K_{v3}$ = Coefficient related to convection and

$K_{r3}$ = Coefficient related to radiation for plate with temperature T3 (Generally taken as white plate)

If we neglect, conduction and convection, then

$$a2 * U = K_{r2} * (T_2^4 - T_1^4) \quad \text{and}$$

$$a3 * U = K_{r3} * (T_3^4 - T_1^4)$$

then, $T_2^4 - T_3^4 = U * (a_2/K_{r2} - a_3/K_{r3})$ (3)

Or

U is proportional to $(T_2^4 - T_3^4)$, where $T_2$ = Black and $T_3$ = White plate

If the temperature difference is not very large between the white and black plate (say within 10ºC), then, U is proportional to $(T_2 - T_3)$

In the given experiment, we will verify this using a standard Solar power meter and our own experimental setup.

### 2.2 Working Principle

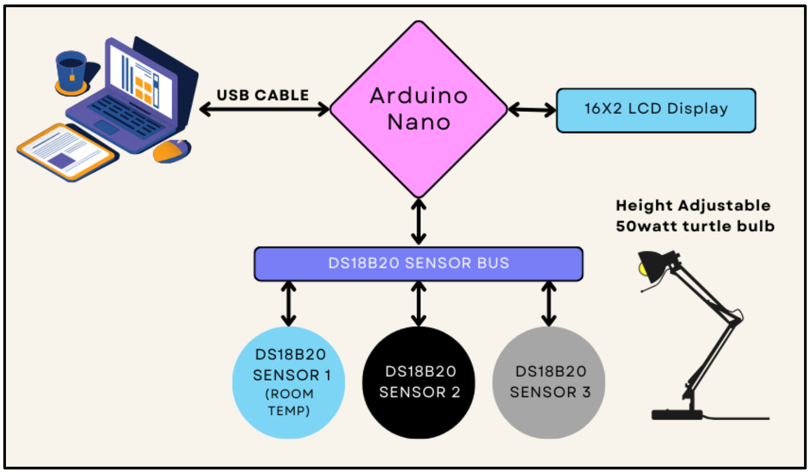


**Figure 1:** Working Principle

The Arduino Nano and DS18B20 sensor are the main components of this project. The Arduino Nano is used to collect temperature data from the DS18B20 sensors. Each DS18B20 has a 64-bit ROM that stores its unique serial code. The Arduino IDE [15] is used for programming the Arduino Nano development board. By programming the development board, we can retrieve the unique serial codes, which allow us to extract sensor data easily. This data can then be displayed on a 16x2 LCD and in the Arduino IDE's serial monitor, as shown in the schematic diagram in Figure 2.

In this project, Microsoft Excel stores the temperature data from each sensor. The Data Streamer plug-in connects directly to the Arduino Nano development board via USB. By selecting the correct port for the Arduino Nano chipset (usually CH340), data collection in Excel can be accomplished.

All three DS18B20 sensors were placed inside a 3cm radius of aluminium plates, one coloured as black and another white, among three of DS18B20 sensor; two (Black and White colour plates) were placed under the height adjustable table lamps, which 50watt UVB turtle bulb and 3rd DS18b20 put in other colours (yellow) which inside a bowl with glass top to distance from the lamp at a room temperature as figure 1.

### 2.3 Arduino Coding used

```
#include <OneWire.h>
#include <LiquidCrystal.h>
#include <DallasTemperature.h>

const int rs = 12, en = 11, d4 = 5, d5 =
4, d6 = 3, d7 = 2;
```



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```
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

#define ONE_WIRE_BUS 6

OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

// Addresses of 3 DS18B20s
uint8_t sensor1[8] = { 0x28, 0xEC, 0x79, 0x43, 0xD4, 0xE1, 0x3D, 0xC9 };
uint8_t sensor2[8] = { 0x28, 0x58, 0x80, 0x43, 0xD4, 0xE1, 0x3D, 0x47 };
uint8_t sensor3[8] = { 0x28, 0x56, 0xFA, 0x43, 0xD4, 0xE1, 0x3D, 0x84 };

void setup(void){
    lcd.begin(16, 2); //Display Setting

    Serial.begin(9600);  //Sensor setting
    sensors.begin();
}

void loop(void){
    sensors.requestTemperatures();
    lcd.clear();  lcd.setCursor(0,0);
    Serial.print("Sensor 1: ,");
lcd.print("S1:");
    printTemperature(sensor1);

    Serial.print("Sensor 2: ,");
lcd.print(" & S2:");
    printTemperature(sensor2);

    Serial.print("Sensor 3: ,");
lcd.setCursor(0,1); lcd.print("S3:");
    printTemperature(sensor3);
    Serial.println();

    delay(30000); // delay of 30 second
}
void printTemperature(DeviceAddress deviceAddress){
    float tempC = sensors.getTempC(deviceAddress);
    Serial.print(tempC);
    lcd.print(tempC);
    Serial.print(" ,");
}
```

### 2.4 Component used in this project -

1) Three aluminium circular pots with glass covers.
2) Source- UVB Lamp (popularly known as Turtle Bulb) with wattage 50 Watt.
3) Digital Lux Meter and Watt meter.
4) **Arduino Nano:** Arduino Nano development board is the main component of this project. At the heart of the board is an ATmega328 microcontroller clocked at a frequency of 16 MHz, featuring more or less the same functionalities as the Arduino® Duemilanove. The board offers 20 digital input/output pins, 8 analog pins, and a mini-USB port.
5) **DS18B20 Sensor:** Programmable Resolution 1-Wire Digital Thermometer. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus.
6) **16x2 Character LCD:** 16x2 display connected with Arduino Nano to display all the data.

### 2.5 Schematic diagram and experimental setup

The schematic diagram and circuit shown in figure 2 and 3 respectively.

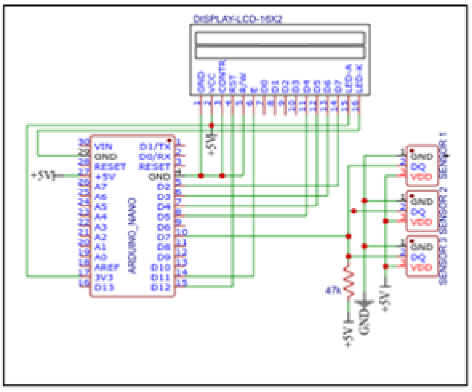


**Figure 2:** Schematic diagram

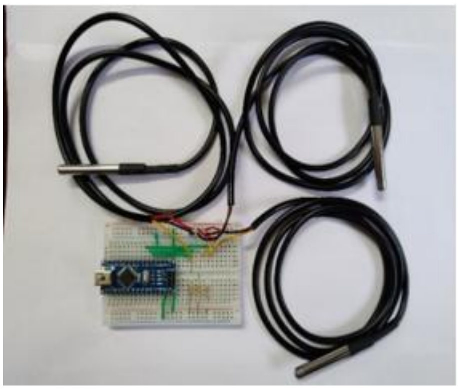

**Figure 3:** Circuit Board

The Working Setup inside lab and the colour plates used is shown in the figure 4 and 5 respectively.

**Figure 4:** Working Setup inside lab

**Figure 5:** Colour Plates

## 3. Experiment Result and Data Analysis

Our experiment has three parts –

1) We have studied the temperature response for different colour plates to test the characteristics of the plate.
2) Variation of flux/Temperature difference with Distance for Plates.
3) The variation of the Sun's Radiation Flux with Time.

In the first experiment, the testing was conducted in two parts to measure the temperature of six different coloured plates, as shown in Figure 5 (Black, Red, Green, Yellow, Blue, and White), using only three temperature sensor probes. Temperature data was collected from the first part's blue, green, and yellow plates. In the second part, data was collected from the White, Red, and Black plates, ensuring that all experimental conditions, such as experiment duration, the height of the light source, and intervals between data collection points, remained unchanged. The data from both parts were saved into two separate Excel files, which were then merged into a single file for analysis. A graph was plotted with time, as shown in Figure 6.

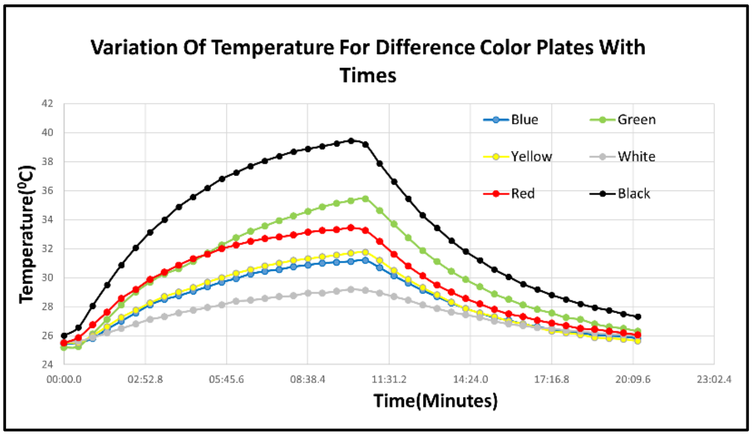


**Figure 6:** Variation of Temperature for different colour plates with time

In the second experiment, we conducted an experiment to study the variation of the flux with different distances. All the experimental test data with different distances and Black (TB), White (TW), Room (TR) in Table 1(inside the lab).

**Table 1:** Data analysis of temperature differences with distances and Lux meter data

| Distance (CM) | TR ($^0$C) | TB ($^0$C) | TW ($^0$C) | U (Watt) | TR(K) | TB(K) | TW(K) | Diff | LUX |
|---|---|---|---|---|---|---|---|---|---|
| 35 | 25.56 | 40.38 | 30.69 | 165 | 298.56 | 313.38 | 303.69 | 9.69 | 2360 |
| 40 | 25.37 | 37.25 | 29.5 | 133 | 298.37 | 310.25 | 302.5 | 7.75 | 1739 |
| 45 | 24.44 | 35 | 28.12 | 109 | 297.44 | 308 | 301.12 | 6.88 | 1410 |

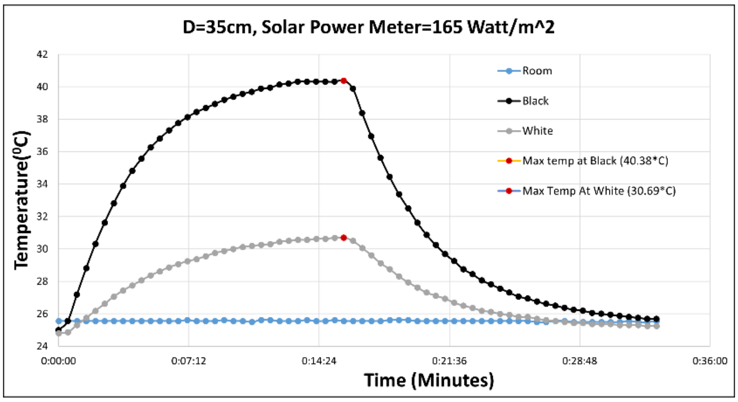


**Figure 7:** Heating and cooling for Black, White Plates for Source Distance= 35 cm

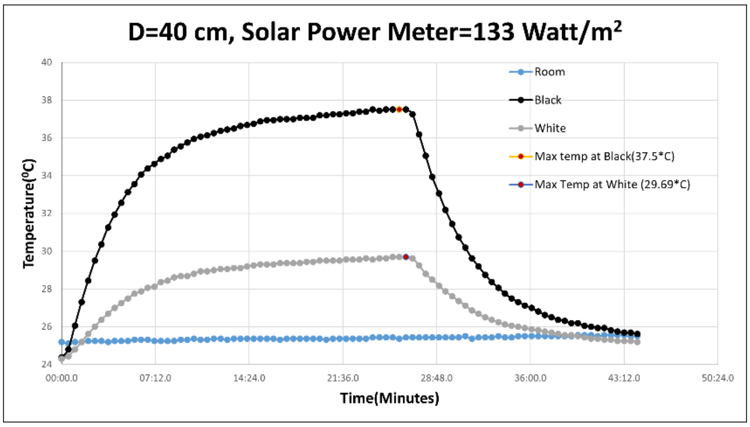


**Figure 8:** Heating and cooling for Black, White Plates for Source Distance= 40 cm

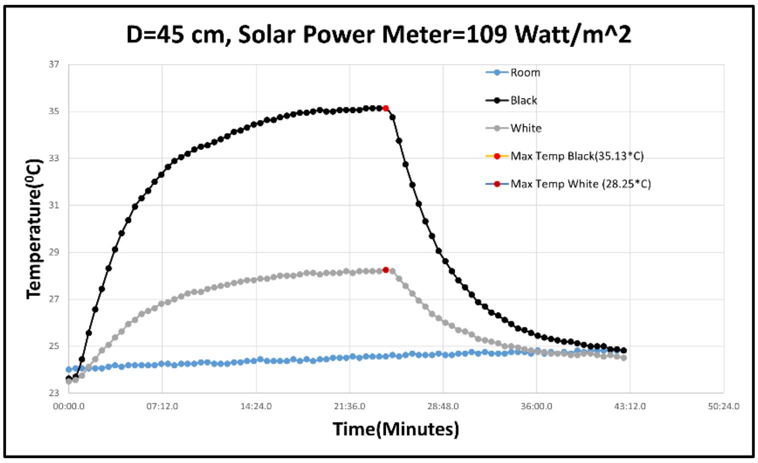


**Figure 9:** Heating and cooling for Black, White Plates for Source Distance= 45 cm

Fig 7, 8, and 9 illustrate the absorption of radiation and the heating and cooling characteristics of the white and black plates at distances of 35 cm, 40 cm, and 45 cm, respectively. The black marker line represents the characteristic curve of the black plate, the grey marker line depicts the curve for the white plate, and the blue marker line indicates the room temperature (environmental conditions).

In the third experiment, a test was conducted under the Sun on 1st April, 2025 (a sunny day) with Black (T1), White (T2) and Red(T3) colour plates inside the pots and a glass cover Figure 12. Pots were used to avoid convection around the test environment, and the insulating bases to avoid conduction from the pots. Data was collected manually by interfacing the Arduino with the PC. In Table 2, selected data points are presented to match the time of manually collected data points, including Radiation Flux (Solar Power meter reading), atmosphere temperature (T4), and Humidity, Which were also recorded using another Arduino-based setup.

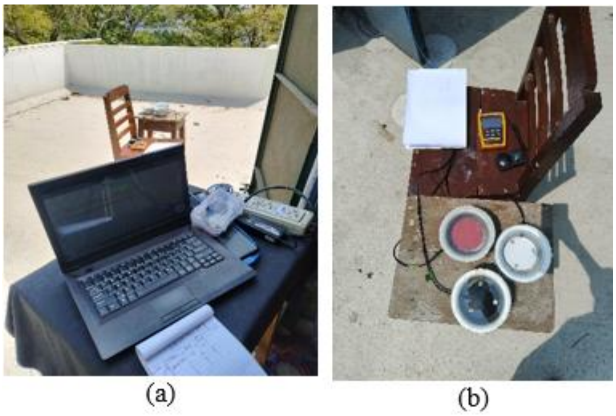


**Figure 12:** Experimental setup to measure the Radiation Flux variation under the Sun

**Table 2:** Data analysis of temperature differences with time and different colour plates of Sun radiation

| TIME INTERVAL (Minutes) | Black Plate (T1) ($^0$C) | White Plate (T2) ($^0$C) | Red Plate (T3) ($^0$C) | Envir (T4) ($^0$C) | Humidity (%) | U (Watt/m^2) |
|---|---|---|---|---|---|---|
| 00:09:09 | 71.19 | 55.31 | 65.12 | 38.5 | 19 | 788 |
| 00:21:21 | 75.94 | 59.25 | 69.31 | 39.1 | 18 | 765 |
| 00:30:30 | 76.69 | 60.19 | 69.81 | 39.5 | 18 | 775 |
| 00:40:10 | 77.25 | 60.44 | 70.44 | 39.5 | 15 | 784 |
| 00:50:20 | 78.19 | 61.31 | 71.44 | 39.5 | 14 | 768 |
| 01:00:31 | 75.56 | 59.13 | 68.5 | 40.1 | 15 | 734 |
| 01:10:10 | 75.56 | 59.25 | 69 | 39.5 | 14 | 719 |
| 01:20:20 | 75.37 | 59.56 | 68.87 | 40.6 | 14 | 711 |
| 01:30:31 | 73.94 | 58.25 | 67.37 | 40.1 | 14 | 676 |
| 01:40:10 | 72.69 | 57.5 | 66.06 | 40.1 | 14 | 646 |
| 01:50:20 | 71.06 | 56.69 | 64.69 | 40.1 | 14 | 610 |
| 02:00:30 | 68.69 | 54.81 | 62.63 | 39.5 | 15 | 560 |

## 4. Discussion

The first experiment (Figure 6) indicates that the temperature or heat absorption among the plates varies in the following order: Black, Green, Red, Yellow, Blue, and White. The coloured plates are arranged according to temperature response. We observed that the green coloured plate absorbs heat radiation more than the red one. Also, we observed that the time required to reach the Steady State or operating state was almost the same for all plates for a particular flux.

From the Second experiment, the time required to reach the Steady State or operating state changes with distance, as flux varies with distance. From Table 1 and Fig. 10, the variation of the temperature difference between a black and white plate with distance shows that the temperature difference between the black and white plates clearly decreases with increasing distance (negative slope). We observe that the variation of the flux with distance is linear as long as the temperature difference between the black and white plates is below $10^0$ °C. If the temperature between the two plates is above $10^0$ °C, it exhibits a non-linear pattern. Variation of temperature and Distance is also a linear path. The temperature differences between black and white, as well as the variation of radiation flux with distance (Figures 10 and 11), demonstrate similar linear characteristics.

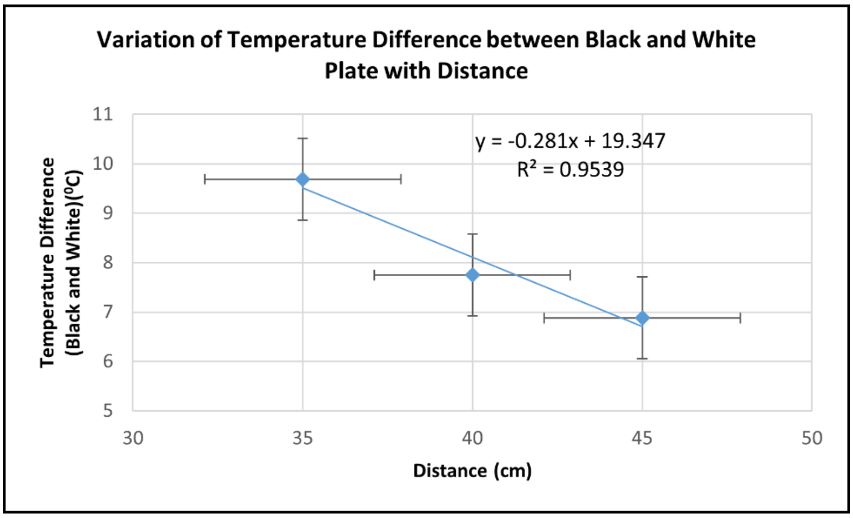


**Figure 10:** Variation of temperature differences between the black and white plates with Distance

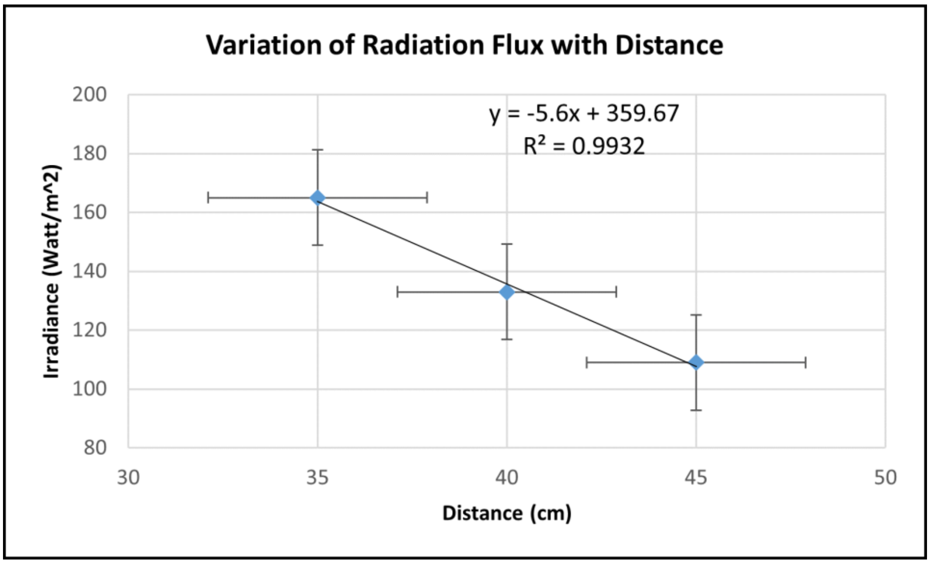


**Figure 11:** Variation of radiation flux with distance

From Figures 10 and 11, we obtained the temperature difference between the black and white-coloured plates and the irradiance (watts/m²) data, respectively. We clearly observed that as irradiance increases, the temperature difference between the two coloured plates increases, as shown in Figure 12.

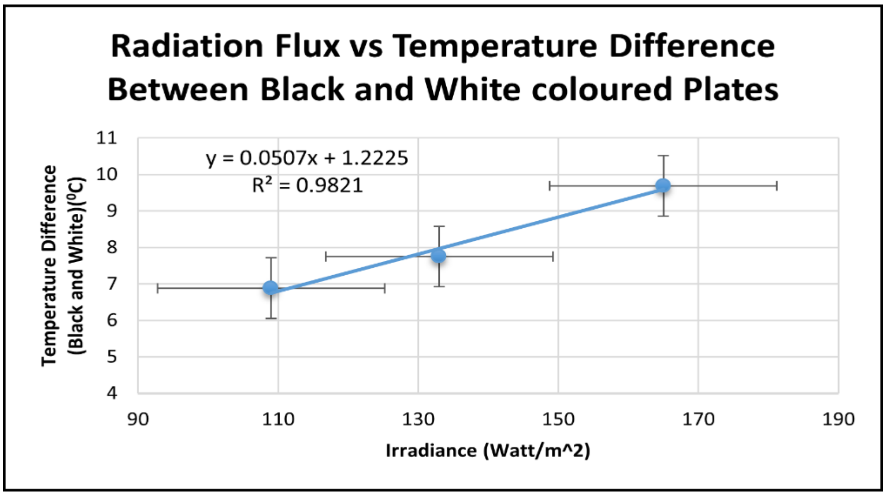


**Figure 12:** Radiation Flux vs Temperature difference between Black and White coloured plates

From the third experiment, the Sun is almost at a fixed distance from Earth, but the angle changes with time. Its flux is maximum around noon, so data were collected around that time of day to obtain a peak value around noon (12 hours). After analyzing the data (from table 2), we found that our setup takes 15 min time to reach operating condition under the Sun which is much faster than under room condition (Figure 7-9), the temperature differences with time of different colour plates (Fig. 13) follow the same characteristic of Radiation Flux as we noted down using Solar Power meter reading (Fig. 14).

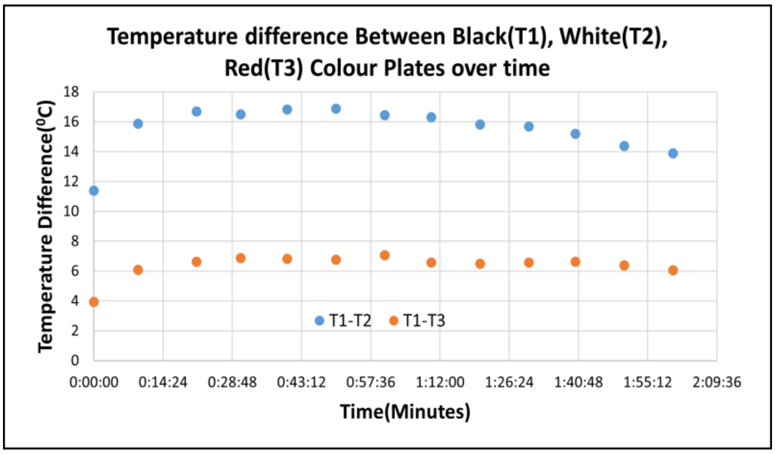


**Figure 13:** Temperature Difference Between colour plates with time under the Sun using Our Experimental setup

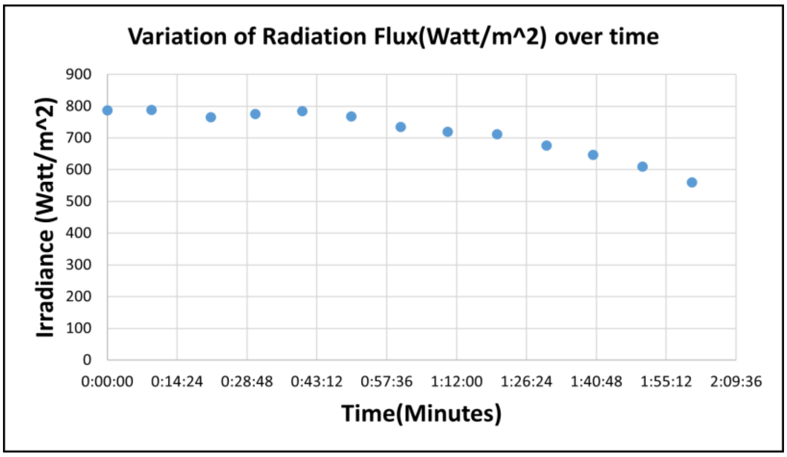


**Figure 14:** Variation of Radiation Flux over time under the Sun using Solar Power meter

## 5. Conclusion

This project enhances data accuracy and eliminates manual recording; an Arduino-based system is developed to interface with a computer, allowing real-time temperature monitoring. Many heat flux sensors are available commercially to measure the solar flux. This project aims to measure this flux with an apparatus constructed by the researcher. This project serves as an exercise in heat transfer. In future, make this instrument more durable and turn it into a wireless system.

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**Declarations**

**Author Contribution:** Hritam Sarkar: Investigation, Resources, Programming, Validation, Writing-Original draft. , Tamal Sarkar: Supervision, Project Administrator, Conceptualisation, Validation, Investigation, Resources, Writing-Original Draft, Writing Review and Editing.

**Data Availability:** The data supporting the results of this study are available on request from the corresponding author (tsarkar@nbu.ac.in).

**Conflict of Interest**: The authors do not have any conflict of interest.

**Ethical Approval**: Not Applicable.

**Code Availability**: The code has been provided in this paper.

**Consent for publication**: We affirm that the manuscript is original, has not been published elsewhere, and is not currently under consideration by another journal.

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