Radiation Control of Halogen Lamps Falling on Double Pass Solar Air Heater

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Abstract. This paper studies the control of radiation on double-pass solar air heaters with porous media in the lower channel. The intensity of radiations was controlled in two ways potentiometer and mobile via the Bluetooth by designing, building, and implementing a light control system which consists of a power supply, transformer, two Arduino microcontroller (which programmed with C++ language), bridge rectifier, resistances, two optocouplers, TRAIC, Bluetooth model, toggle switch and LCD Display. The results showed the inverse relationship between the solar radiation and the resistance, the maximum solar radiation obtained from this work reached 786 W/m\(^2\) when the resistance is 1.15 k\(\Omega\), while the minimum solar radiation is 158.6 W/m\(^2\) when the resistance is 6.21 k\(\Omega\). The output power increases with increasing solar radiation, which means the maximum output power reaches 2567 W at the maximum solar radiation.

Keywords. Radiation control, Halogen lamps, Solar air heater.

1. Introduction

Solar air collector is a device that utilizes solar energy for heating air, which acts as a heat exchanger that converts solar energy into thermal energy in the transport medium [1]. Collectors are typically commonly used to dry agricultural products such as fruit, vegetables, seeds, industrial processes, and space heating. They are also used for low to moderate temperatures [2]. There are two types of working fluid flow channels in a single pass solar air collector [3] (1) Running fluid flows past the top absorber surface and (2) Running fluid flow under a flat solar collector plate. The development in the last decade of a wide range of high-intensity discharge lamp types has led to their increasing use in commercial and plant growth facilities [4]. Usually, the heat generated by a tungsten halogen lamp is considerable, particularly after prolonged use. The head of the lamp is adjustable to allow the user to direct the light as it is required [5]. There are four ways to control the change in the intensity of solar radiation such as using a device (light dimmer) that has a tuning key used in order to achieve the required solar radiation, motion sensors to turn on external lights automatically when they detect movement and switch them off after a short time. Occupancy sensors to detect internal movement within a specified region and timers [6].

Rath (2016) [7] used an advanced optical control system that can replace the old-generation lighting control system. The system works on an embedded platform, and it is equipped with a photosensitive detector (LDR) that provides the input necessary for operation. The used method to control the light is based on the sum of ambient luminous energy. Depending on the intensity of light at that instant, the lighting system is adjusted. The main embedded board contains a microcontroller chip, memory...
(Flash), and communication port used as the input module received from the peripheral devices. This machine can be used in workstations, park lights, street lighting systems, car headlights, and many more. The circuit consists mainly of a sensing element known as LDR, followed by an Arduino processing unit that takes input for the sensing element and gives the LEDs (lighting units) output. The LDR detects the light and sends the data to Arduino. Other units, such as relays and transistors, are also used to supply higher voltage. It also functions as a variable resistor with a light intensity switch.

This helps determine the amount of light intensity at that time, and thereby it accordingly helps regulate the lighting system. Vargas et al. (2017) [8] developed and implemented an innovative design of an intelligent control system using the Arduino microcontroller, photoelectric system, and ZigBee lighting described. The lighting system is connected to a generating system consisting of photovoltaic isolated cells. The lighting control system is subject to vehicle detection, which allows the light to vary intensity when moving vehicles on the highway. The light intensity difference and the lighting system regulation are managed using an Arduino microcontroller, which then wirelessly transmits information to other distributed lights along the lane (high way).

Thus, the lighting system is expected to make substantial savings in energy usage by utilizing innovative technologies. Chandramohan et al. (2017) [9] demonstrated a smart lamp and fan activity. The device is related here to temperature regulation and the power of the light. The main components for this automatic lamp and fan control are the temperature sensor (LM35) and a light-dependent resistor (LDR). There the LDR is responsible for the management of the lamp, and the LM35 is responsible for controlling fan activities. The planned home energy management systems develop and provide intelligent applications for consumers, with mobile running the proposed program. For all Android-based smartphones, Wi-Fi is the built-in support; the control system for home access will use the phone, Wi-Fi, 3G, or 4G to access the hosting site website using the Android App.

In this study, an intelligent light control system for the halogen lamps is designed and built, which is implemented depending on two Arduino boards with other components and a smartphone to control radiation intensity, using two ways, potentiometer and Bluetooth in an android-based smartphone. Many radiation readings have been controlled by changing the potentiometer. Meanwhile, Rath 2016 [7], Vargas et al. 2017 [8] used only one Arduino in their work. In the former research, an advanced light control system was used, and in the latter one, an intelligent control photovoltaic system was designed, while the third one established the control system to control the halogen lamps. Chandramohan et al. 2017[9] used intelligent applications with mobile running a proposed program, similar to this work.

2. Experimental setup

Figure (1) shows the double pass solar air heater, and it is schematically presented in Figure (2). The experimental apparatus consists of the following

1) Solar collector (the main test section).
2) Tungsten halogen lamps (a solar simulator).
3) A centrifugal fan.
4) A gate.
5) Temperature sensors (thermocouples).
6) Measurement devices:

a) Temperature measurement (temperature recorder 12 channels).
b) Pressure measurement (digital manometer).
c) Radiation measurement (solar meter).
d) Hot-wire anemometer (velocity measurement).

The experimental device has been designed, constructed, and tested. The simulators use eight halogen lamps, each one with a rated power of 500 W. Dimmers are used to control the amount of solar radiation. The collector is made of aluminum, and the dimensions of double pass solar air heaters are 125 cm long, 30 cm wide, and 11 cm in height. The height consists of two passages: the first passage has a 5 cm gap; meanwhile, the second passage has a 6 cm gap. The length and width of the absorber plate are 120 cm and 30 cm, respectively, whereas the length is smaller than the length of the collector.
in order to return the airflow to the outlet. The thickness of the glass is 4 mm. The centrifugal blower is a 12 VDC electrical system for air drawing. It is connected to the outside of the lower channel to draw the air from the lower channel. A gate is mounted in a duct connected between the blower and output of the lower channel of the solar air heater. The gate is made of aluminum and used for controlling the amount of airflow rate. The airflow in the first passage and outlet from the second one, also the porous media is installed in the second channel, as shown in Figure (3). For the solar simulator, a wood frame was used to manage all the halogen lamp bulbs, which function as natural sunlight. Eight units of halogen lamps (500 Watt, 220 Volt) were connected to the solar simulator.

Figure 1. Experimental setup (a) A front view and (b) A side view.

Figure 2. Sketch of the experimental apparatus.
Figure 3. A schematic of a double-pass thermal solar collector with porous media in the second channel.

3. Solar simulators
For the solar simulator, a wood frame has been used to manage all the halogen lamp bulbs, which function as natural sunlight. Eight units of halogen lamps (500 Watt, 220 Volt) were connected to the solar simulator. The distance between halogen lamps and the solar collector is 50 cm. The distance between every two centers of the halogen lamp is about 13 cm to make the temperature distribution uniform throughout the device. Many irradiance sets of different values between 158.6 W/m² and 786 W/m² have been controlled. Figure (4) displays the configuration of the solar simulator.

4. Parts of control system
The electrical control system has been established to control halogen lamps’ radiation by designing, building, and implementing a light control system in two ways, potentiometer and mobile phone. The circuit components are:

- Power supply
- Two Arduino
- Transformer
- Bridge rectifier
- Resistances
- 4N25 Optocoupler
- TRAIC
- 2 MOC3021 Optocoupler
- LCD
- Potentiometer
- Bluetooth module
- Toggle switch

Each component is explained as follows:
**Power supply:** is an electrical system that supplies power to an electric load as shown in Figure (5).  
**Arduino:** is an efficient microcontroller used in the external control circuit, and Figure (6) shows the used Arduino board in the current study. It functions as an integrated system used for many purposes. In this study, the radiation was controlled by potentiometer using two Arduino boards instead of one; because one of them is programmed for the digital screen and the other is for halogen lights; also, in case of any fault happen in this Arduino, it is possible to continue the radiation control by the first Arduino. The second Arduino board is programmed with the C++ language. **Table (1)** displays the Arduino Uno Technical Specifications.

![Power supply](image1.png)  
**Figure 5.** Power supply.  
![Arduino Uno](image2.png)  
**Figure 6.** Arduino Uno.  

**Table 1.** Arduino uno technical specifications.  

| Specifications          | Value                                                |
|-------------------------|------------------------------------------------------|
| Microcontroller         | ATmega328P – 8-bit AVR family microcontroller        |
| Operating Voltage       | 5v                                                   |
| Recommended Input Voltage | 7-12v                                             |
| Input Voltage Limits    | 6-20v                                                |
| Analog Input Pins       | 6 (A0 – A5)                                         |
| Digital I/O Pins        | 14 (Out of which 6 provide PWM output)              |
| DC Current on I/O Pins  | 40 Ma                                                |
| DC Current on 3.3V Pin  | 50 Ma                                                |
| Flash Memory            | 32 KB (0.5 KB is used for Bootloader)               |
| SRAM                    | 2 KB                                                 |
| EEPROM                  | 1 KB                                                 |
| Frequency (Clock Speed) | 16 MHz                                               |

Step-down transformer renders the (secondary) output voltage to be lower than its (primary) input voltage from (220 to 6) V at a constant frequency. Figure (7) shows that the used transformer is connected to the bridge rectifier circuit, as shown in Figure (8).  
**Bridge rectifier circuit:** it consists of four diodes. Takes the input from the transformer (AC voltage) and then converts it to DC voltage to enter the next device, which is called 4N25 Optocoupler, as shown in Figure (9).
Figure 7. The used transformer.

Figure 8. Connection of bridge rectifier circuit and transformer. Figure 9. The connection between bridge rectifier and 4N25 Optocoupler.

4N25 Optocoupler: consists of a diode and a transistor. It is considered a protection circuit and has many benefits, including converting the simple circuit into a high circuit. It is characterized by being light. The current comes from the bridge rectifier and enters the diode, as shown in Figure (9), then the diode will light, and the lights fall on the base pin of a transistor. Then, the transistor converts from off to on. Figure (10) displays the 4N25 Optocoupler. Table (2) shows the specifications of the 4N25 Optocoupler.

Figure 10. 4N25 Optocoupler.
### Table 2. Specifications of 4N25 optocoupler.

| Specifications                  | Value                  |
|---------------------------------|------------------------|
| Voltage – Isolation             | 5000Vrms               |
| Input type                      | DC                     |
| Output type                     | Transistor with Base   |
| Current/ output-channel         | 50 Ma                  |
| Voltage- output                 | 70V                    |
| Vce Saturation (max)            | 500 Mv                 |
| Current Transfer Ratio (Min)    | 20% @ 10Ma             |
| Mounting type                   | Through-hole           |
| Package / Case                  | 6-DIP (0.300", 7.62mm) |
| Packing                         | Tube                   |
| Lead-Free Status                | Lead-Free              |
| RoHs status                     | RoHs Compliant         |

**TRAIC:** (triode for alternating current) is a three-terminal electronic component that conducts current in either direction when triggered. The current study used four TRAICs, every two of them is connected in parallel as shown in Figure (11) because of the high load when using four TRAICs instead of one, and each one of the parallel branches is connected to MOC3021 Optocoupler, as shown in Figure (12).

![Figure 11. TRAICs.](image1)

To control the AC voltage, the first thing that has to be done is to detect the zero crossings of the AC signal through the TRAIC, as shown in Figure (13). The frequency of the AC signal is 50 Hz, and as it is alternating in nature. Hence, every time the signal comes to zero points, the point should be detected and trigger the TRIAC as per the power requirement. To avoid this point, MOC3021 Optocoupler is used.

![Figure 12. Connection between TRAICs and Optocoupler.](image2)
For cooling, the modules or systems parts need heat sinks because the heat generated by each element or component of the electronic circuit must be dissipated to improve its reliability and prevent the component from failing prematurely. Figure (14) displays the used heat sink.

**Figure 14. Heat Sink.**

**MOC3021 Optocoupler:** it is used to maintain isolation between two electrical circuits like DC and AC signals. MOC3021 is a Non-zero Crossing Optocoupler that gives the magnitude at different levels from zero to maximum. The current study used two MOC3021 Optocouplers; when one of them stops working, the other one continues to work. Figure (15) displays the used MOC3021 in experimental work. Table (3) shows the specifications of the MOC3021 Optocoupler.

**Figure 15. MOC3021 Optocoupler.**
Table 3. Specifications of MOC3021 optocoupler.

| Specifications                  | Value                  |
|--------------------------------|------------------------|
| Product Category               | Triac & SCR Output Optocouplers |
| Output Device                  | Photo Triac            |
| Isolation Voltage              | 5000 Vrms              |
| Peak Output Voltage (Vdrm)     | 400 V                  |
| Maximum Input Voltage          | 1.5 V                  |
| Maximum Output Voltage         | 280 VAC                |
| Minimum Trigger Current        | 8 mA                   |
| Maximum Input Current          | 50mA                   |
| Maximum Reverse Diode Voltage  | 3V                     |
| Zero-Crossing Circuit          | No                     |
| Output Type                    | AC                     |

**LCD:** (A liquid-crystal display) is a flat panel display technology (4×20 cm), widely seen in TVs and computer monitors. It is also found in handheld devices such as notebooks, ipads, and cell phones. By which the type of control method is chosen. It was programmed by Arduino, and when it starts up at the start screen, the project name (Double pass solar air heater with porous media) will be displayed in an animation and a few seconds later show up (Eng. Shrooq jomaa ali) and control type (potentiometer or Bluetooth) and lighting ratio as shown in Figure (16). The internal shape of the screen is illustrated in Figure (17).

![Figure 16. LCD Display.](image)

![Figure 17. Inside of LCD Display.](image)
**Potentiometer:** 10 KΩ variable resistor potentiometer contains three sides. It is the first method for controlling the radiation manually using the potentiometer to control the solar intensity amount. Figure (18) shows the used potentiometer.

![Potentiometer (a) Outside (b) Inside.](image1)

**Figure 18.** Potentiometer (a) Outside (b) Inside.

**Bluetooth Module (HC-05):** Another method for controlling the radiation is using HC-05, which is a Bluetooth unit connected to the serial port of the microcomputer; it allows the microcomputer to communicate with other devices via a Bluetooth connection. Figure (19) displays the used Bluetooth module. In this study, Bluetooth is used to control solar radiation’s intensity by using Huawei Mobile through an application called (Light dimmer), as shown in Figure (20). Table (4) shows the HC-05 technical specifications.

![Bluetooth Module.](image2)

**Figure 19.** Bluetooth Module.

![Huawei mobile (b) Light dimmer program.](image3)

**Figure 20.** (a) Huawei mobile (b) Light dimmer program.
Table 4. HC-05 Technical Specifications.

| Specifications            | Value                                      |
|---------------------------|--------------------------------------------|
| Serial Bluetooth module   | Arduino and other microcontrollers         |
| Operating Voltage         | 4V to 6V (Typically +5V)                   |
| Operating Current         | 30mA                                       |
| Range                     | <100m                                      |
| Frequency                 | Hopping Spread Spectrum (FHSS)             |
| work conditions           | Master, Slave, or Master/Slave mode       |
| Interaction               | easily interfaced with Laptop or Mobile phones with Bluetooth |

**Toggle switch**: is a form of electrical switch defined by a handle or lever presence. The switch is also an electrical part capable of disconnecting or linking a conduction route in an electrical circuit, interrupting or diverting electrical current from one conductor to another. In this study, the Toggle switch is used to select the control method, whether it is a potentiometer or Bluetooth control; Figure (21) shows the used Toggle switch.

![Figure 21. Toggle switch (a) Outside (b) Inside.](image)

**Measurement Devices:**

**Ohmmeter**: This is an electrical device that calculates electrical resistance (an obstacle to the electrical current movement provided by a substance). It is used to measure the value of the potentiometer at each scale.

**Square LED digital dual display voltmeter ammeter**
It is an optical voltage tester signal detector, an LED monitor with high visibility, and a cylindrical mainframe. Electricity may be calculated using the meter. It may be used in the electric power line as a signal indicator, alert signal, incident signal, and other signals. It was used in the experimental circuit where the current and voltage were measured by a voltmeter connected in parallel with the output and ammeter connected in series. Figure (22) shows a digital dual display voltmeter ammeter. Table (5) illustrates the specifications of the square LED digital dual display voltmeter ammeter.

![Figure 22. Digital dual display voltmeter ammeter (a) Voltmeter (b) Ammeter (c) LED display.](image)
Table 5. Specifications of the square LED digital dual display voltmeter ammeter.

| Specifications       | Value                                      |
|---------------------|--------------------------------------------|
| Item                | Indicator Voltmeter & Ammeter              |
| Voltage             | AC 60-500V                                 |
| Current             | 0-100A                                     |
| Material            | Electrical components                      |
| Panel size          | 31x31mm/1.22x1.22inch                      |
| Mounting aperture   | 22mm                                       |
| Display color       | Red, Blue, Green, Yellow, White            |

Solar power meter
This device is used for measuring the irradiation from tungsten lamps into the surface of the double-pass solar air heater. The instrument has a reaction time of 1 second and tests the strength of radiation within the range (0 to 2000 W/m²).

5. The Electrical circuit of control system
Figure (23) shows the experimental control system, and Figure (24) shows the schematic diagram of the control system designed and implemented to control the radiation amount for a halogen lamp. All the above mentioned electronic devices have been connected as explained in the previous section in order to get this practical circuit, which is supplied with electrical power in order to control the halogen lamps using two methods, the potentiometer, and Bluetooth of the mobile. Each scale of the potentiometer (fixed resistance) gives a fixed intensity of radiation. At this moment, the values of voltage and current of the output have been recorded, and the values of the resistance and the intensity of radiation. Then, this step is repeated to control many values of the radiation intensity. The potentiometer programming code is the same as the mobile, so every Bluetooth scale is the same scale as the potentiometer; therefore, it gives the same value of the controlled radiation.

Figure 23. The developed electronic control system.
6. Calculation
For evaluation, the output power can be calculated as

\[ P_o = I \times V \]  \hspace{1cm} (1)

Where, \( P_o \): is output power in (W), \( I \): is the current (A) and \( V \): is the voltage (V).

7. Results and discussion
Double and multi-pass solar air heaters with porous media offer an extended heat transfer area and decreased overall heat losses. The intensity of radiation has been controlled in two ways: potentiometer and by using mobile via Bluetooth. The potentiometer scale is the same as the mobile scale; when the potentiometer and the mobile are installed on the same scale, it gives the same radiation. Table (6) shows the readings of the potentiometer. The scale is installed at each potentiometer value to obtain the appropriate radiation for use in this work. That is, when installing the resistance 6.21 KΩ and 1.15 KΩ, radiations have been controlled at 158.6 W/m² and 786 W/m², respectively. The radiations have also been controlled at different resistors, whereas the voltage and current have been measured at each case of the measured radiation.

Table 6. The readings of potentiometer.

| Scale of potentiometer (%) | The scale of mobile (%) | Value of potentiometer (KΩ) |
|---------------------------|-------------------------|-----------------------------|
| 0                         | 0                       | 9.21                        |
| 10                        | 10                      | 8.45                        |
| 20                        | 20                      | 7.57                        |
| 30                        | 30                      | 6.66                        |
| 40                        | 40                      | 5.77                        |
| 50                        | 50                      | 4.84                        |
| 60                        | 60                      | 3.93                        |
| 70                        | 70                      | 2.93                        |
| 80                        | 80                      | 2.09                        |
| 90                        | 90                      | 1.15                        |
| 100                       | 100                     | 0.04                        |
The following figures have been obtained from the experimental work for controlling the radiation. Figure (25) shows the relationship between the potentiometer and solar radiation and displays when reducing resistance, the rate of radiation increases. Figure (26) shows the relationship between voltage and solar radiation; when the rated voltage increased, the radiation also increased. Since the voltage is directly proportional to the current, the current increase leads to an increase in the radiation, as shown in Figure (27). The power is the result of multiplying the voltage with the current. Therefore, when the power is increased, this increases the amount of radiation falling on the test section, as shown in Figure (28). The current and voltage decrease with increasing the resistance, as shown in Figure (29).

Figure 25. Relation between input and output.

Figure 26. The relationship between voltage and radiation.
Figure 27. The relationship between current and radiation.

Figure 28. The relationship between output power and solar radiation.

Figure 29. Variation of the resistance with (a) Current (b) Voltage.
8. Conclusion
The present work is for double pass solar air heater with porous media. Controlling the radiation has been experimentally investigated. Thus, many points can be concluded:

1- The radiations were controlled by two methods, namely, mobile and potentiometer, to obtain the appropriate radiation for the work.
2- The solar radiation increased by decreasing the resistance, whereas the output power increased with increasing solar radiation.
3- The maximum solar radiation obtained from this work reached 786 W/m² when the resistance is 1.15 kΩ, while the minimum solar radiation is 158.6 W/m² when the resistance is 6.21 kΩ.
4- The mobile and potentiometer are programmed as the same in order to give the same radiation at each point.

9. References
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