Comparison of Infrared and Visible Light Absorption Properties of Water and its Application in Filtering Heat Energy from Solar Radiation

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1. Introduction

Solar radiation consists of light of wavelengths ranging from deep ultraviolet to far infrared. It is often important to be able to filter the infrared radiation out of sunlight. For example, during summer months, the ability to filter out infrared (IR) radiation from sunlight entering a room through its windows could go a long way to keeping is cooler and reducing energy used for air-conditioning. Similarly, this would also help in keeping outdoor electronic devices (e.g. solar cells) from heating up.

This project will compare the relative ability of water to absorb infrared (IR) radiation and visible light radiation. The results of this comparison will be applied to study the effectiveness of water layers for:

(a) better temperature control in buildings through improved window designs, and

(b) better temperature control in solar cells.

This is expected to lead to many other cost effective, energy conserving, and environmentally friendly applications.

Problem Statement: The problem statement consists of three parts.

(a) How much more infrared radiation does a given layer of water absorb than visible light radiation?

(b) How much less is the temperature rise of a room with a layer of IR absorbing water placed over its window than an identical room with a normal window with no IR filter?

(c) How much more electricity does a solar cell placed under a layer of IR absorbing water produce than one placed directly under sunlight?

1.1. Variables

Variables

Independent Variables:

- Thickness of water layer between radiation source and sensor
- Temperature of water
- Radiation exposure time (for room temperature rise and solar cell experiments)

Constants:

- Amount of radiation power input
- Infrared sensor type
- Air temperature (for room temperature rise and solar cell experiments)
- Room size (for room temperature experiment)

Dependent Variables:

- Infrared power transmitted through water layer
- Temperature rise of room
- Energy output of solar cell

1.2 Theory

In order to generate a hypothesis, it is useful to first study the theory behind the absorption of light passing through a medium. The Beer-Lambert Law allows the determination of exactly how much of an incoming radiation is absorbed as it passes through a given thickness of a transparent medium. The Beer-Lambert law is given as:

$$I_{out}(\lambda) = \frac{I_{in}(\lambda)}{e^{a(\lambda)x}} \tag{1}$$

where I_{in} is the intensity of incoming radiation, a is the absorption coefficient of the medium, x the thickness of the medium through which the radiation passes, and λ is the wavelength of the radiation. The absorption coefficient and radiation intensities are functions of wavelength.

Equation (1) can be used to estimate how much solar radiation will be absorbed by a given height of water. To do so the incoming solar spectrum and the absorption coefficient of water needs to be first quantified. Fig. 1 shows the solar spectrum. Fig. 2 shows the absorption coefficient of water as a function of wavelength. Since both the incoming spectrum and the absorption coefficient are functions of wavelength, they have to be subdivided into narrow bands before Beer-Lambert's law can be applied. This was done using Microsoft Excel. The resulting output spectrum for a 15 cm layer of water and a 60 cm layer of water are shown in Fig. 3.

The total energy contained in any range of wavelengths is found by calculating the area under the spectrum between the lower and upper wavelength limit. The wavelength range of visible light is known to be from 380 nm to 750 nm. By computing the area under the curve shown in Fig. 1, the incoming solar spectrum, between these wavelength limits it is found that the total energy in the visible portion of the solar spectrum is 466.16 W/m^2. A similar computation using Fig. 3, the output spectrum after sunlight passes through 15 cm of water, shows that the total energy in transmitted visible light is 442.08 W/m^2. This means that 95% of the visible spectrum is transmitted through a 15 cm layer of water.

Next, the portion of the solar spectrum above 750 nm is considered. This is mainly infrared radiation which is responsible for temperature rise of a room. By calculating the area under the spectrum shown in Fig. 1 above 750 nm the energy contained in the infrared portion sunlight is found to be about 427 W/m^2. Then, using Fig 3 as before, it was found that 113 W/m^2

of infrared radiation remained after passing through a 15 cm layer of water. This means that 38% of the heat spectrum is transmitted through a 15 cm layer of water.

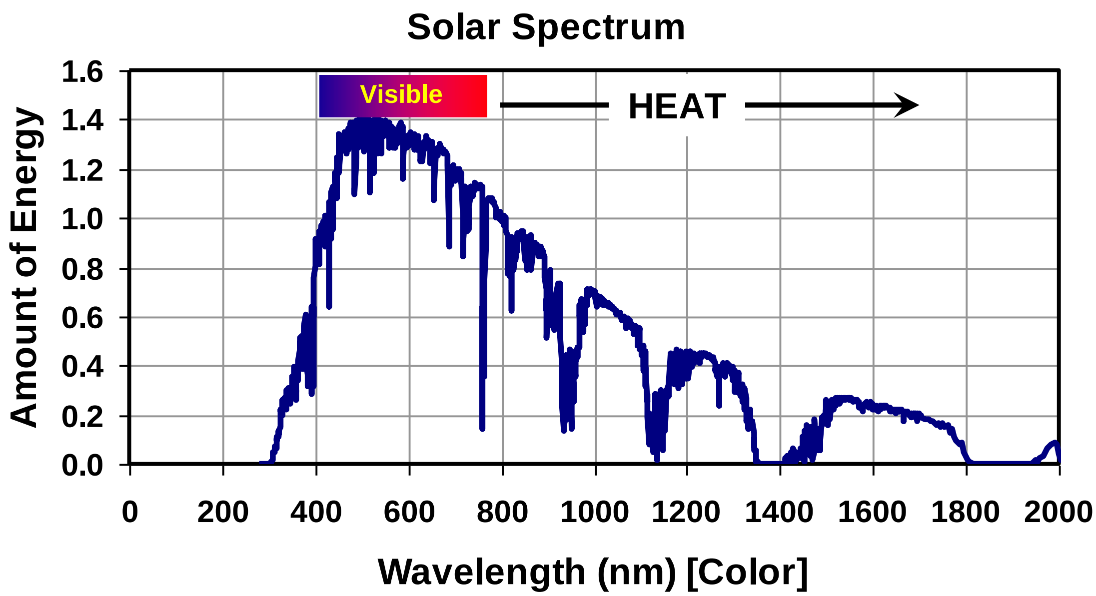


Figure 1. Solar spectrum.

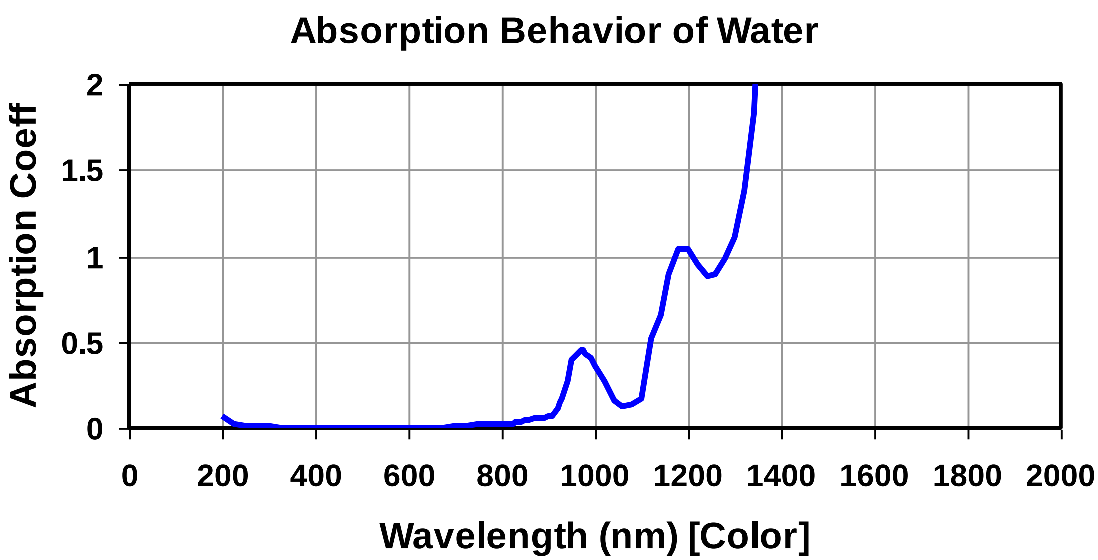


Figure 2. Absorption coefficient of water as a function of wavelength.

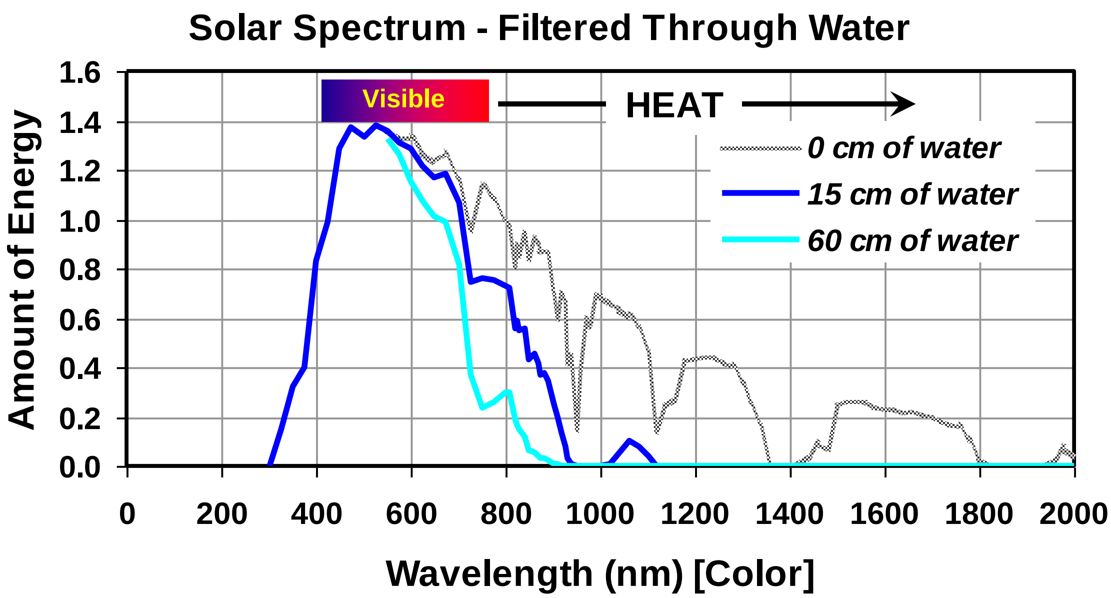


Figure 3. Solar Spectrum-Filtered Through Water.

1.3 Hypothesis

Research of previously published material (listed in Bibliography) indicates that water absorbs infrared radiation more effectively than visible light. Based on this research and theory shown in previous section it is expected that as the height of water between infrared radiation source and sensor is increased, the amount of infrared radiation sensed will decrease. On the other hand, for the same increase in water height the amount of visible light sensed will not change much.

The infrared content in solar radiation transmitted through windows is the main cause of temperature increase of a room. A layer of water placed in front of a window will absorb much of this infrared radiation. As a result, it is expected that the temperature rise of a room with a window with a layer of water placed in front of it will be less than without a water layer. In fact, as the thickness of the water layer is increased, the temperature rise of the room will decrease, assuming the exposure to sunlight remains constant. If the sunlight exposure time increases, then the temperature of the room will increase.

A solar cell works better when it is kept cool. Infrared radiation in sunlight increases the temperature of a solar cell. Due to the known effectiveness of water in absorbing infrared, it is expected that by placing a layer of water between the solar cell and the sun the amount of infrared radiation reaching the solar cell can be reduced which will keep the solar cell cooler and therefore increasing its electricity output.

2. Materials

Material Items	Amount
Cardboard or Foam board	2 sheets
30 cm tall cylindrical jar with clear bottom	1
25 cm x 25 cm x 25 cm clear plastic container	2
Cold water	Several liters (at least 10 liters)
Miscellaneous items (foam cutter, glue)	As needed
Thermometer with Celsius scale	2
Infrared LED	1
Visible light LED	1
Solar cells	2
Ammeter	1
Battery (to drive LEDs)	4
Watch/Timer/Clock	1

3. Procedure

Experiment 1

This experiment compares qualitatively the amounts of infrared radiation and visible light radiation absorbed through layers of water of increasing height.

1. Set up measurement equipment as shown in Figure 4.

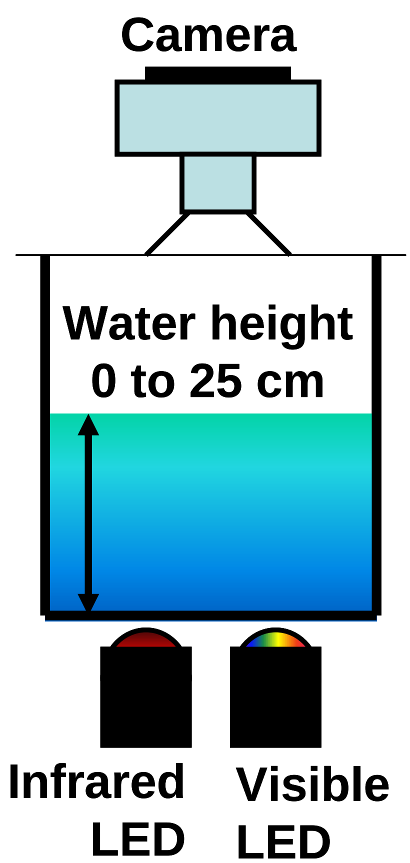


Figure 4. Setup used for Experiment 1.

2. Turn on infrared and visible light LEDs and photograph light emitted from both sources.

3. Pour 25°C water into cylindrical jar till water reaches a height of 5 cm.

4. Photograph light transmitted through water layer by both IR and visible LEDs.

5. Repeat steps 3 and 4, increasing heights of water by 5 cm each time. Proceed till water height is 25 cm.

Experiment 2

This experiment compares quantitatively the amounts of infrared radiation and visible light radiation absorbed by increasingly thicker layers of water placed between a radiation source and sensor.

6. Set up measurement equipment as shown in Figure 5.

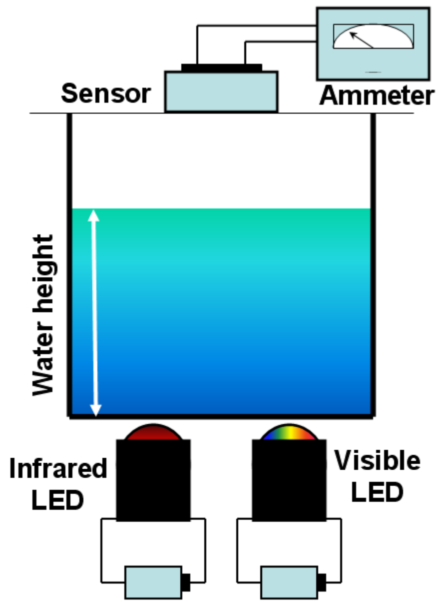


Figure 5. Setup used for Experiment 2.

7. Turn on infrared LED and record radiation sensed by ammeter.
8. Pour 25°C water into cylindrical jar till water reaches a height of 5 cm.
9. Record radiation sensed by ammeter.
10. Repeat steps 8 and 9, increasing heights of water by 5 cm each time. Proceed till water height is 25 cm.
11. Repeat steps 7 to 10 with visible light LED. Turn off IR LED for these steps.

12. Repeat all of the steps above with 5°C (cold) and 50°C (hot) water.

Experiment 3

This experiment measures the temperature rise inside a model home placed in direct sunlight with increasingly thicker layers of water placed in front of a window.

13. Build three identical houses using cardboard / foam board.
    - Make walls white to reflect radiation away from the house.
    - Put heat insulation on inside of walls to reduce heat conduction into the house.
14. Cut out opening (8 cm x 8 cm) for windows on roof of each house.
15. Place houses outside in sun; make sure they each get equal amounts of sunlight for at least two hours without having to be moved.
16. Place a 25 cm x 25 cm x 25 cm clear plastic container (window) in each of the openings on the roofs (see Figure 3).
17. Place a thermometer in each house. Details are shown in Figure 6.

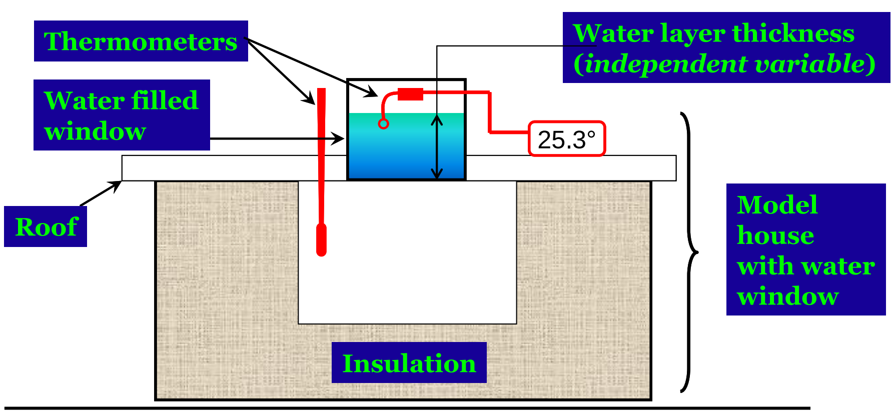


Figure 6. Setup used for Experiment 3.

18. Pour cold water in the two of containers, one till it reaches a height of 2.5 cm and the second till it reaches 5 cm. The container on the third house should have no water.

19. Place a thermometer in the water in each of the first two containers.

20. Measure temperature of each house every 10 minutes from 11am to 1 pm.

21. Measure temperature of water at same times as in step 20.

22. Measure the outside temperatures at same times as step 20.

23. Record data from steps 20, 21, and 22 in a data table.

Experiment 3

This experiment compares the electric power output from two solar cells, one placed in direct sunlight and another with a layer of water placed on top of it to absorb the infrared radiation in sunlight.

24. Set up measurements as shown in Figure 7.

25. Record voltage and current output from each solar cell.

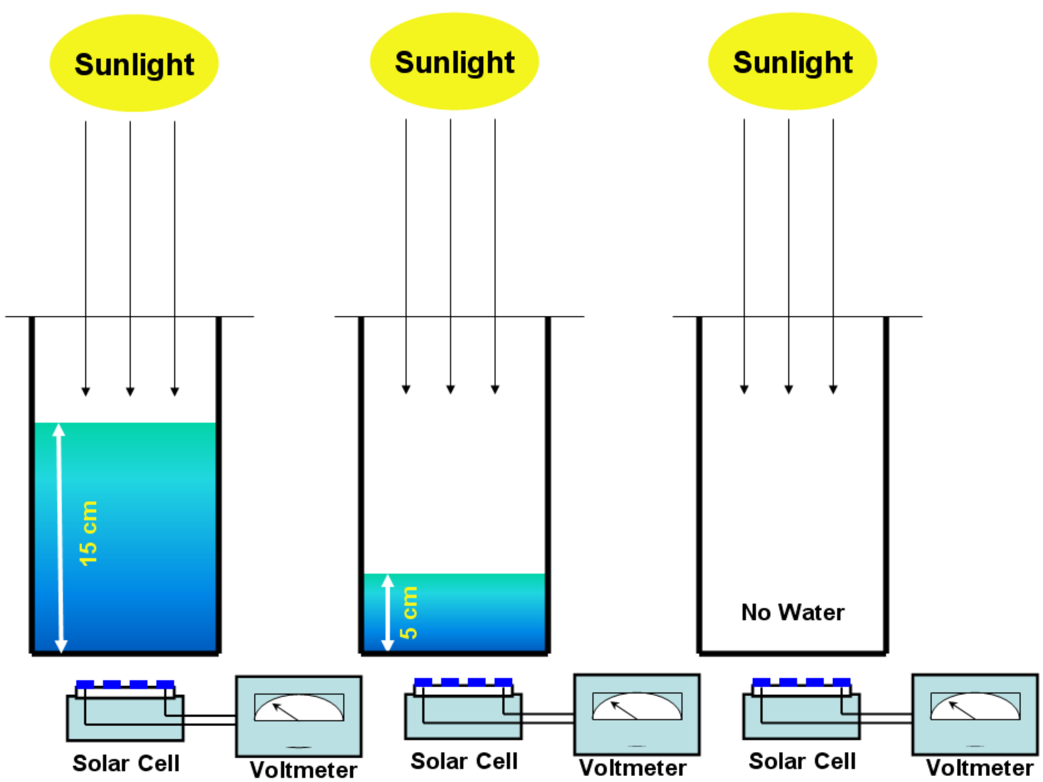


Figure 7. Setup used for Experiment 4.

3.1. Data Analysis

Experiment 1

Data for experiment will consist of a series of photographs. These will be printed out.

Experiment 2

Data for experiment 2 will be taken in the table shown in Table 2.

Table 2. Data table for Experiment 2.

Date	
Water temperature	
Source	
Water height(h) cm	**Sensor Current μA**
0.0	
5.0	
10.0	
15.0	
20.0	
25.0	

After the table is made, a graph will be constructed. It is expected that the graph for the sensed current will decrease with increasing water height.

Experiment 3

Data for experiment 3 will be taken in the table shown in Table 3.

Table 3. Data table for Experiment 3.

	House Temperature (C)							
Water height (cm)	**11:00AM**	**11:15AM**	**11:30AM**	**12:00PM**	**12:15PM**	**12:30PM**	**12:45PM**	**1:00PM**
0								
5								
15								

After the table is made, a graph will be constructed. It is expected that the graph for the rooms' temperature rise will decrease with increasing water height.

Experiment 4

Data for experiment 4 will be taken in the table shown in Table 4.

Table 4. Data table for Experiment 4.

	Solar Cell Output Voltage (V)							
Water height (cm)	**11:00AM**	**11:15AM**	**11:30AM**	**12:00PM**	**12:15PM**	**12:30PM**	**12:45PM**	**1:00PM**
0								
5								
15								

After the table is made, a graph will be constructed. It is expected that the graph for the solar cell power output will increase with increasing water height.

4. Results

Results from the different experiments done in the project are described in this section.

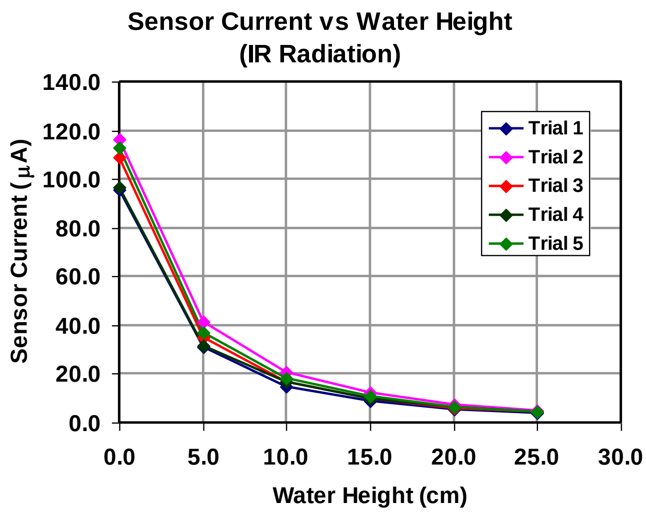
Experiment 1

Figure 8 shows a series of photographs taken of the IR and visible light LEDs with increasing water heights between the LEDs and the camera. The upper dot is the visible LED. It can be seen that as the water height increases the IR gets dimmer but the visible light does not.

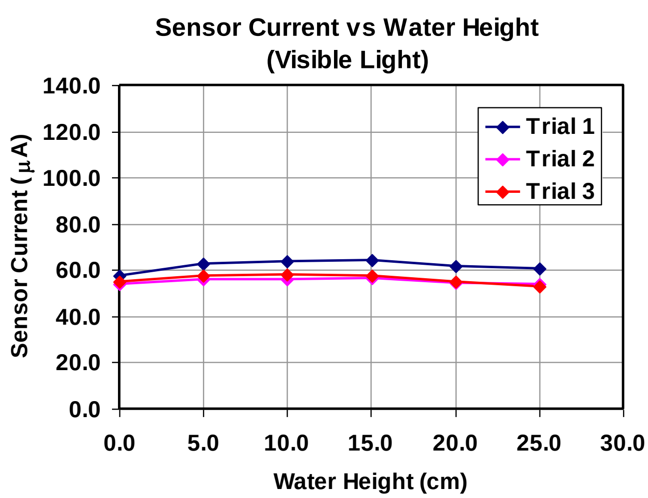
Figure 8. Results of experiment 1 showing IR radiation being absorbed by water while visible light is transmitted with no loss of brightness.

Experiment 2

Figure 9 (a) and (b) show the variation of the amount of IR and visible light reaching the sensor with increasing heights of water between the source and sensor. It can be seen that while the amount of IR radiation sensed decreases rapidly with increasing heights of water, there is no effect on visible light.



(a)

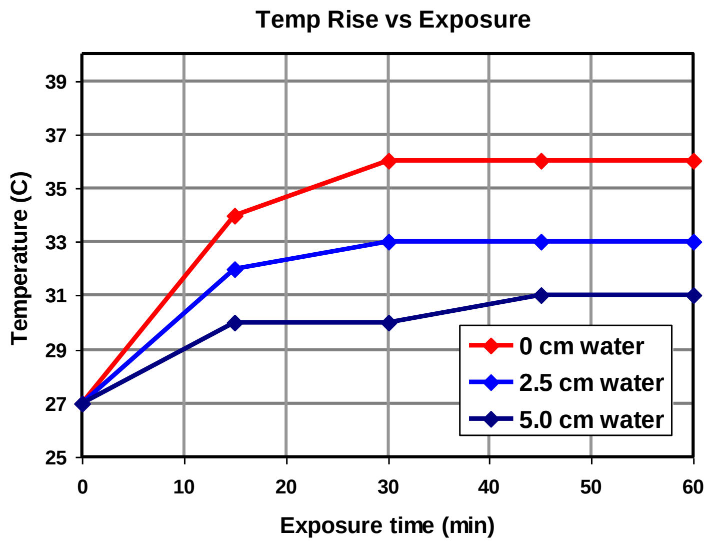


(b)

Figure 9. Results of experiment 2 showing IR radiation being absorbed by water while visible light is transmitted with no loss.

Experiment 3

Figure 10 shows the effect of placing layers of water of different thicknesses outside the window of a house exposed to sunlight on the temperature rise inside the house. It can be seen that with increasing thicknesses of water the temperature rise inside the house is reduced, i.e. it stays cooler.



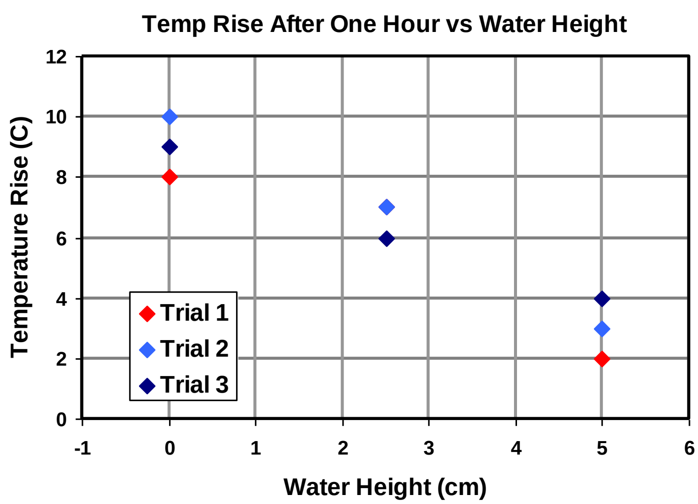
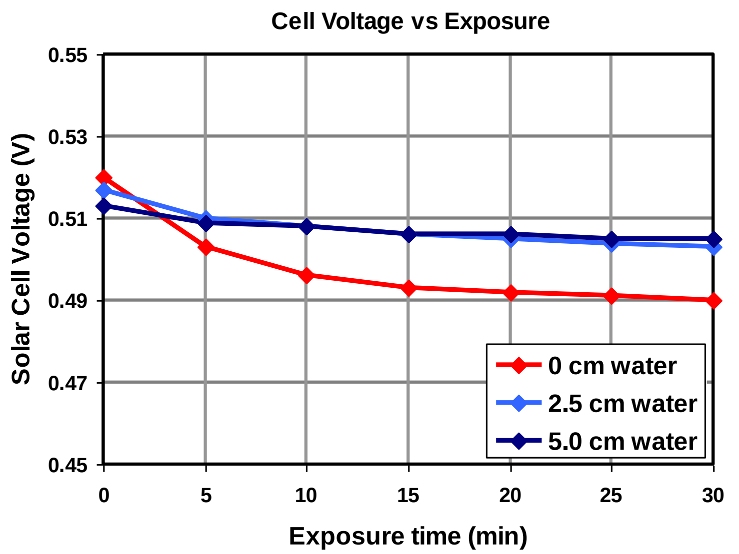


Figure 10. Results of experiment 3 showing the effect of increasing thicknesses of water layers placed outside the window of a house exposed to sunlight on the temperature inside the house.

Experiment 4

Figure 11 shows the variation in the output voltage of a solar cell exposed to sunlight with increasing heights of water placed above it. It can be seen that as the height of the water layer increases the solar cell loses less voltage.



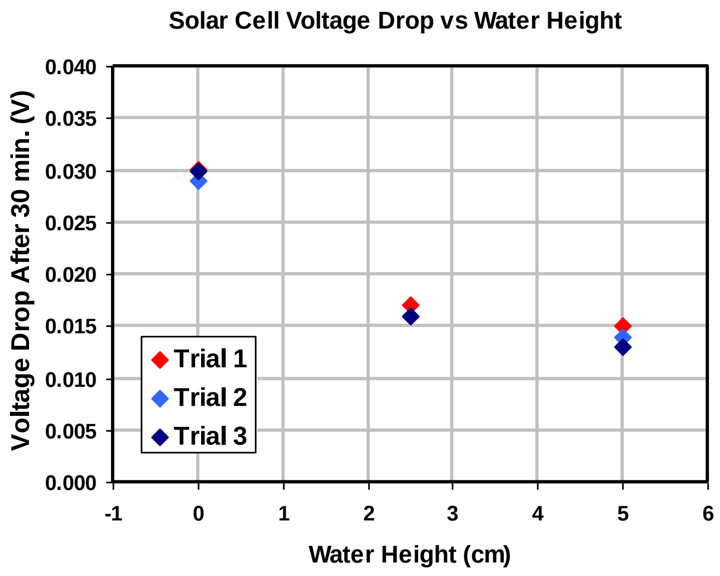


Figure 11. Results of experiment 4 showing the effect of increasing thicknesses of water layers placed above a solar cell on the output voltage of the cell.

5. Conclusions

It was found that water can be used to effectively filter infrared from visible light in solar radiation. In fact, it was observed that 5 cm of water can eliminate about 70% of IR radiation.

This finding was used in 2 practical situations.

1. It was shown that using a layer of water over the window can help lower the temperature of a house. 5 cm of water resulted in only 3°C temperature increase after an hour in sunlight as opposed to 9°C without any water.

2. It was shown that using 2.5 cm of water over a solar cell improves its output voltage by 0.015V compared to one without any filter.

6. Abstract

Solar radiation consists of light with wavelengths that range from far infrared to deep ultraviolet and beyond. In many situations it is useful to be able to separate the visible portion of the solar spectrum from the infrared (IR). In this project the absorption of infrared radiation in water has been investigated and compared to the absorption of visible light in water. Experimental results confirmed the hypothesis that water absorbs IR is much more effectively than visible light. This result was then applied to two practical situations. The first application involved the filtering of IR radiation in sunlight before it enters through the window of a house by placing a layer of water outside the window. Experiments confirmed the hypothesis that placing a layer of water outside the window of a house would lower the temperature inside compared to a window with no water layer placed outside it. This is expected to result in lower energy consumption for cooling a house and will be a topic of future research. The second application involved filtering IR from sunlight incident on a solar cell by placing a layer of water on top of the cell. It was hypothesized that such a water-based IR filter would keep a cell cooler than one without such an IR filter and therefore results in a higher output voltage. Experimental results proved this hypothesis to be correct.

7. Acknowledgements

I would like to acknowledge my father for purchasing all the materials required for the experiments described in this project and for proof-reading this report. He also helped with some of the photographs.

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