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Design, Construction and Testing of a Solar Bucket

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ABSTRACT

This project is about the design, construction and testing of a solar bucket. Solar bucket refers to an innovative, budget-friendly solar-powered system designed to provide essential electrical services in areas with limited access to electricity. The primary goal is to offer an affordable, portable, and sustainable solution especially in rural areas. By harnessing solar energy, they reduce dependency on conventional power sources, offer clean energy, and can enhance the quality of life in underserved communities. The incorporation of renewable energy like solar energy into relevant sectors like agriculture and businesses will see a significant reduction in the use of fossil fuel thereby combating climate related challenges. The development and widespread adoption of such low-cost systems could play a key role in advancing sustainability and particularly in scarcely electrified regions. The design was done considering many factors like transmission of heat through glass, prevention of heat loss using lagging and heat absorption by dark surfaces in mind. On testing the apparatus using 1.93 and 4.93 mm glass while maintaining 7.62 and 6.71 cm air columns within the bucket, it was shown that a temperature as high as 42.8 degree Celsius was achieved, and the computed heat transfer through the 1.93 mm glass was 2,191.75 watts, while that of 4.93 mm glass was 802.92 watts.

Keywords: Sustainable energy, Solar energy, Glass, Heat Transfer, Blackbody radiation.

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1. INTRODUCTION

The United Nations Sustainable Development Goals (SDG7), "Ensure access to affordable, reliable, sustainable, and modern energy for all" emphasizes the need for affordable energy, which is vital for the development of agriculture, business, communications, education, healthcare, and transportation worldwide. Therefore, the construction and use of renewable energy sources cannot be overemphasized. While the cost of constructing renewable energy devices is on the increase, there is need to design affordable sustainable energy devices like a solar bucket that can serve the common man. Over the years, many research have been conducted to find materials that can be used to design affordable devices that leverages renewable energy sources – this can be seen in many books. For example, in Chen and Wong's 2020 study which was published in the *Journal of Cleaner Production,* they explored the development of affordable solar bucket systems designed to improve energy access in rural areas. The research emphasizes cost-efficiency and sustainability, showcasing how these systems can provide reliable, renewable energy solutions to underserved communities. Their findings suggest significant potential for enhancing the quality of life and fostering economic development in remote regions by reducing reliance on traditional energy sources and minimizing environmental impact. Jones and Baker's 2022 study in *Solar Energy Materials and Solar Cells* presents innovative, cost-effective solar bucket designs aimed at enhancing energy accessibility in low-income regions. The research highlights the efficiency, affordability, and sustainability of these solar solutions, emphasizing their potential to significantly improve living conditions by providing reliable, clean energy in underserved areas. Solar buckets might be affordable to some people however, many people may not afford the cost of its fabrication. Therefore, this begs the question "How long will it take a sustainable energy changeover to occur as the cost of production of renewable energy technologies is very high?"

This research explores the design and construction of a solar bucket which is used to heat water, retain the hotness of the water using a transparent glass (1.93mm and 4.93mm) as the lid of the bucket, and check the heat transfer through the glass used. It also checks the rate at which water gets heated inside the bucket and the effect of humidity on the water that is being heated. The solar bucket does not only provide free hot water on an average sunny day in Nigeria but also saves approximately 30% of electricity bill and is environmentally friendly. It is easy to install and requires very little maintenance.

Additionally, this research assesses black body radiation in which a black body was fabricated with papier mâché and black paint to absorb heat. It also shades more light on the relationship between temperature of the environment (temperature out) and humidity in tables 1 to 4 and figures 10 to 13. As the temperature of the environment increases, the temperature of the water (temperature in) increases while the humidity gradually drops.

2. DESIGN AND CONSTRUCTION OF A SOALR BUCKET

2.1. Design of the Solar Bucket

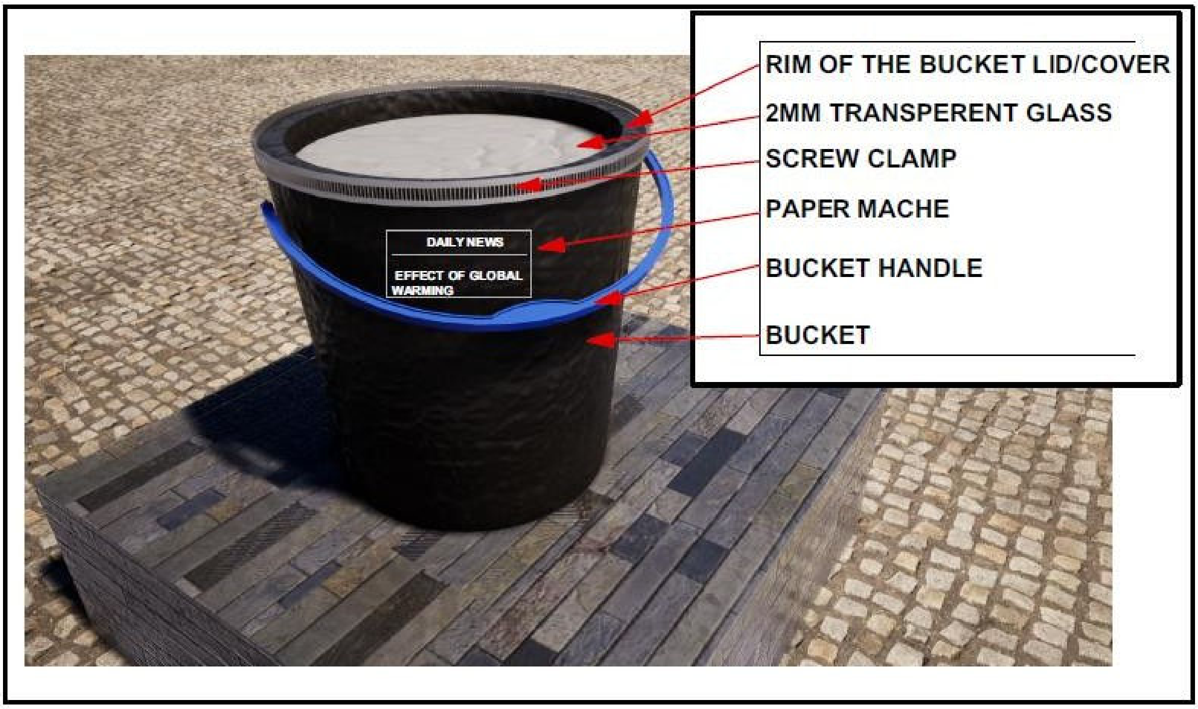

Figure 1. Solar bucket

2.2. Methods of Construction

The bucket used was a transparent bucket and the lid was removed thereby leaving the bucket open. The lid of the bucket was then cut leaving only a 1cm gap from the rim of the lid. A 1.93- millimeter and 4.93-millimeter-thick transparent glass was measured with a micrometer screw gauge and then cut out in a circular way. A thin rubber was cut out in a circular shape as well. The thin rubber that has been cut was used to cover the 1cm gap left on the rim of the bucket lid with the help of a gum to help it stick to the gap and make the bucket airtight when covered. A small hole was made in the glass.

A general adhesive (top bond) was applied 1cm round the rubber and 1cm round the transparent glass of thickness 1.93 and 4.93 millimeters. A 1 v Pu direct-glazing sealant was applied at the rim of the bucket lid to prevent water or air from coming in and allowed to dry out. A foil was then wrapped round the bucket with the shiny part facing inward and the dull part facing outward, this was done to prevent heat loss or escape and retain the heat of the water in the bucket. It acts like lagging material. A papier mâché was prepared to cover the entire bucket. A black paint was used to paint the bucket all over so that the bucket can be a heat absorber. The bucket was then covered, and a screw clamp was used to make it airtight.

2.3. Materials Used for the Construction of the Solar Bucket and Their Functions

The following are the materials used for the construction of this solar bucket.

2.3.1. 21 Litres Transparent Plastic Bucket

This is a multipurpose container for household and professional use. It has measuring increments printed on the pail in gallons and litres for easy measurement. A bucket is typically a watertight, vertical cylinder or truncated cone or square, with an open top and a flat bottom, attached to a semicircular carrying handle called the bail. A bucket is usually an open-top container.

2.3.2. 1.93-Millimeter and 4.93-Millimeter-Thick Glass

This non-crystalline amorphous solid (glass) is used in the manufacture of lenses, windows, car windshield etc. It can refract, reflect, and transmit light, which is the appropriate material to have been used for this study. Glass is an immensely versatile material, it is used every day in numerous applications, many that most of us are not even aware of. For instance, glass components are used in medical diagnostic equipment, electronics, building insulation, and as a reinforcement material in things like surfboards, wind turbines, and orthopedic casts. The glass material used was transparent, not tinted.

2.3.3. Super Glue

Cyanoacrylate adhesives are also known as super glue, bond very fast, and bond to an array of substrates. Super glues form very strong bonds and dry clear. The surfaces that are to be mated ought to properly fit together to achieve excellent bonding. Super glue is recommended for glass, leather, ceramics, metal, wood and even certain plastics that have a very tight bond line. Super glue is versatile because of its chemistry; it can work with any surface that contains moisture. This material was used to wrap the foil round the bucket because of its strong bonding and drying nature.

2.3.4. Top bond contact cement adhesive

This is a general adhesive that can be used to bond leather, rubber, canvas, paper, plastic, glass, wood, metal, and concrete. Clean area to be treated, apply by brush, spray, or roller. Contact cement, or contact adhesive, is a neoprene rubber adhesive that creates a fast, flexible, permanent bond. It can be used for almost anything but is especially useful for nonporous materials that other adhesives cannot glue together. Contact cement works best on plastics, veneers, rubber, glass, metal, and leather. Other glues wouldn't work because they get wet and need to dry after the parts are assembled. Contact cement is already dry on contact. There is no need for clamping, so it can be used for gluing floor tiles, as well. Contact cement is different from other adhesives because it needs to dry for 15 to 20 minutes before assembling. The cement needs to be applied to both parts so that the glue bonds to itself. Contact cement is not sticky; the glue itself is a solid substance. The solvent is added for easier applications and must evaporate completely before joining the other two parts. It is tricky to apply because the adhesive needs just momentary contact to form a permanent bond. This material was used on the glass and thin rubber to enable the glass to stick to the lid of the bucket.

2.3.5. 1 V Pu Direct- Glazing Sealant

The above sealant is applied on the rim of the lid of the bucket to close the spaces in between the glass and the plastic lid so as to make it air tight. Sealant is a substance used to block the passage of fluids through the surface or joints or openings in materials, a type of mechanical seal. Sealants, despite not having great strength, convey several properties. They seal top structures to the substrate and are particularly effective in waterproofing processes by keeping moisture out (or in) the components in which they are used. They can provide thermal and acoustic insulation and may serve as fire barrier.

2.3.6. A Sheet of Aluminum Foil

Aluminum foil often referred to with the misnomer "tin foil," is aluminum prepared in thin metal leaves with a thickness of less than 0.2 mm; thinner gauges down to 6 micrometers are commonly used. The foil is flexible and can be readily bent or wrapped around objects. Thin foils are fragile and are sometimes laminated to other materials such as plastics or paper to make them more useful. Aluminum foils thicker than 25µm are impermeable to oxygen and water. It has a shiny side and matte side.

The shiny side is produced when the aluminum is rolled during the final pass. When the sheets are later separated, the inside surface is dull, and the outside surface is shiny. Increased reflectivity decreases both absorption and emission of radiation. This material was used because the reflectivity of bright aluminum foil is 88% and it reflects heat from the bucket back into the bucket. Aluminum foil is widely used for radiation shield (barrier and reflectivity), heat exchangers (heat conduction) and cable liners (barrier and electrical conductivity).

2.3.7. Papier Mache

Papier mâché is a substance made of pulped paper or paper pulp mixed with glue and other materials or of layers of paper glued and pressed together, molded when moist to form various articles and becoming hard and strong when dry. The traditional method of making papier mâché adhesive is to use a mixture of water and flour or other starch, mixed to the consistency of heavy cream. Other adhesives can be used if thinned to a similar texture, such as polyvinyl acetate-based glues (wood glue or, in the United States, white Elmer's glue). Adding oil of cloves or other additives such as salt to the mixture reduces the chances of the product developing mold. This material acts as a lagging material in some cases and retains heat if molded well. Most common uses of paper Mache include paper boats, paper masks, etc.

2.3.8. Screw Clamp

Screw clamp is the general term given to a group of clamps which use a screw mechanism to adjust the jaws and clamp a work piece in place. Clamps hold objects firmly in place. Whether it is being used to clamp an object to a work surface or to hold two or more objects together, the purpose of a clamp is to provide a firm grip for the user to complete the required task. If a clamp has one jaw only then the device is designed to be used in conjunction with a work surface, such as a bench top, to hold an item steady. However, the clamp used for this study has two jaws and works together to hold the lid of the bucket and make it airtight. Alternatively, some types have a traditional screw which adjusts the clamp. When the screw is rotated, the clamp closes around the work piece and pressure is applied to keep it firmly into place.

2.3.9. Black Oil Paint

Black is the darkest color, the result of the complete absorption of visible light. It is a type of slow drying paint that consists of particles of pigment suspended in a drying oil, commonly linseed oil. The viscosity of the paint may be modified by the addition of a solvent such as turpentine or white spirit, and varnish may be added to increase the glossiness of the dried oil paint film. Common modern applications of black oil paint are in finishing and protection of wood in buildings and exposed metal structures such as ships and bridges. However, its hard-wearing properties and black color make it desirable to be used for this study, to allow heat absorption.

2.4. Precautions Taken During Construction

Wear a glove to avoid being cut by the sharp edge of the glass. It is good to adhere to the recommended safety tips when using super glue in various applications. These tips include selecting a well-ventilated area, opening the container with care, wearing gloves, avoiding wool and cotton in proximity, etc. Solvent based contact cement releases volatile organic compounds, which are regulated by the US Environmental Protection Agency because they are toxic and flammable. Make sure your work area is well ventilated. Try not to allow the 1 v pu direct- glazing adhesive to touch the surface of the glass. Wear a glove when applying the paint and make sure it does not touch the surface of the glass.

2.5. The Stage-by-Stage Process Includes:

Stage 1: A plastic translucent bucket that is about 21 liters was brought. The lid of the bucket was cut out, leaving only the lid of the bucket and a 1-centimeter gap where the glass was placed.

Stage 2: A 1.93mm and 4.93mm transparent glass was cut out in a circular form using a glass cutter. A small hole was made beside the glass using a drilling instrument. This is where the probe the thermometer was inserted for measurement.

Stage 3: A thin rubber was cut out from a used tyre in a circular form and gummed on the 1centimeter gap on the rim of the lid of the bucket. Any gum can be used for this provided it sticks. This was done to make the bucket airtight when covered.

Stage 4: A top bond adhesive was applied 1 centimeter on both the glass and on the thin rubber. The gum was applied plentifully on the glass and thin rubber using a slim stick, a tiny brush can be used as well. It was left to dry for about 45 minutes. The glass was carefully placed on the top of the thin rubber that was glued to the 1centimeter gap on the lid of the bucket. Then it was pressed down gently for about 15 minutes for it to stick perfectly. Using clean foam, the glass was cleaned to remove the gum that might have touched the surface of the glass. A 1 v pu direct-glazing adhesive was applied round the glass from the outside to seal up any space and block water or other fluids from passing through openings of the lid of the bucket.

Stage 5: A foil was used to wrap up the outside of the bucket with the shiny part facing inward and the dull side facing outward, so that the heat trying to escape from the bucket will be reflected into the bucket. The purpose of the foil is to retain the heat of the water just like that of a flask.

Stage 6: A papier mâché was prepared and used to mold the bucket with the foil wrapped around it. The surface was then smoothened manually (by hand) and left to dry under the sun.

Stage 7: A black oil paint is used to paint the bucket and allowed to dry. The bucket is then covered, and the screw clamp was then placed and tightened to make the bucket airtight.

3. RESULTS AND DISCUSSIONS

3.1. Testing and Data Presentation

Heat transfer equation, otherwise known as Fourier's law, is given in equation 3.1 as

$$O = \frac{kA(T_2 - T_1)}{d}$$

Where:

k is the thermal conductivity of the material (glass) in watts per meter per Kelvin =1.05w/mk
d is the thickness of the glass in meter
A is the area of the glass in meter square (m^2)

$\boldsymbol{T_1}$ ***and*** $\boldsymbol{T_2}$ are the temperatures in Kelvin but measured in degree Celsius. The S.I unit of rate of heat transfer Q is in watts (w) or joules per second (J/s)

To find the area, we first find the diameter of the circular glass.
Circumference = πd
Where: π = 3.142, d = diameter, and circumference = 1.078m

$$\frac{circumference}{\pi} = d$$

Therefore Area:

$$A = \pi r^2 = \frac{\pi d^2}{4}$$

Therefore, heat transfer through the 1.43 glass is 2191.7w using the equation below.

$$Q = \frac{kA(T_2 - T_1)}{d}$$

Heat transfer through a 4.93-millimeter glass is 802.9watts from the equation.

$$Q = \frac{kA(T_2 - T_1)}{d}$$

Figure 2. Testing of the solar bucket under the sun with a thermometer measuring the water in the solar bucket, the temperature of the environment, and the humidity.

3.2. Data Presentation

Day One

Table 1. Temperature and Humidity Values with Time 7.62cm Air gap

Time (minutes)	Temperature (in) ºCelsius	Temperature (out) ºCelsius	Humidity (%)
0	29.0	29.7	80
20	32.8	39.4	49
40	33.3	38.8	47
60	35.8	46.2	31
80	36.1	40.8	40
100	38.4	46.4	30
120	38.7	44.4	30
140	37.7	39.4	44
160	39.8	45.8	31
180	40.5	43.8	32

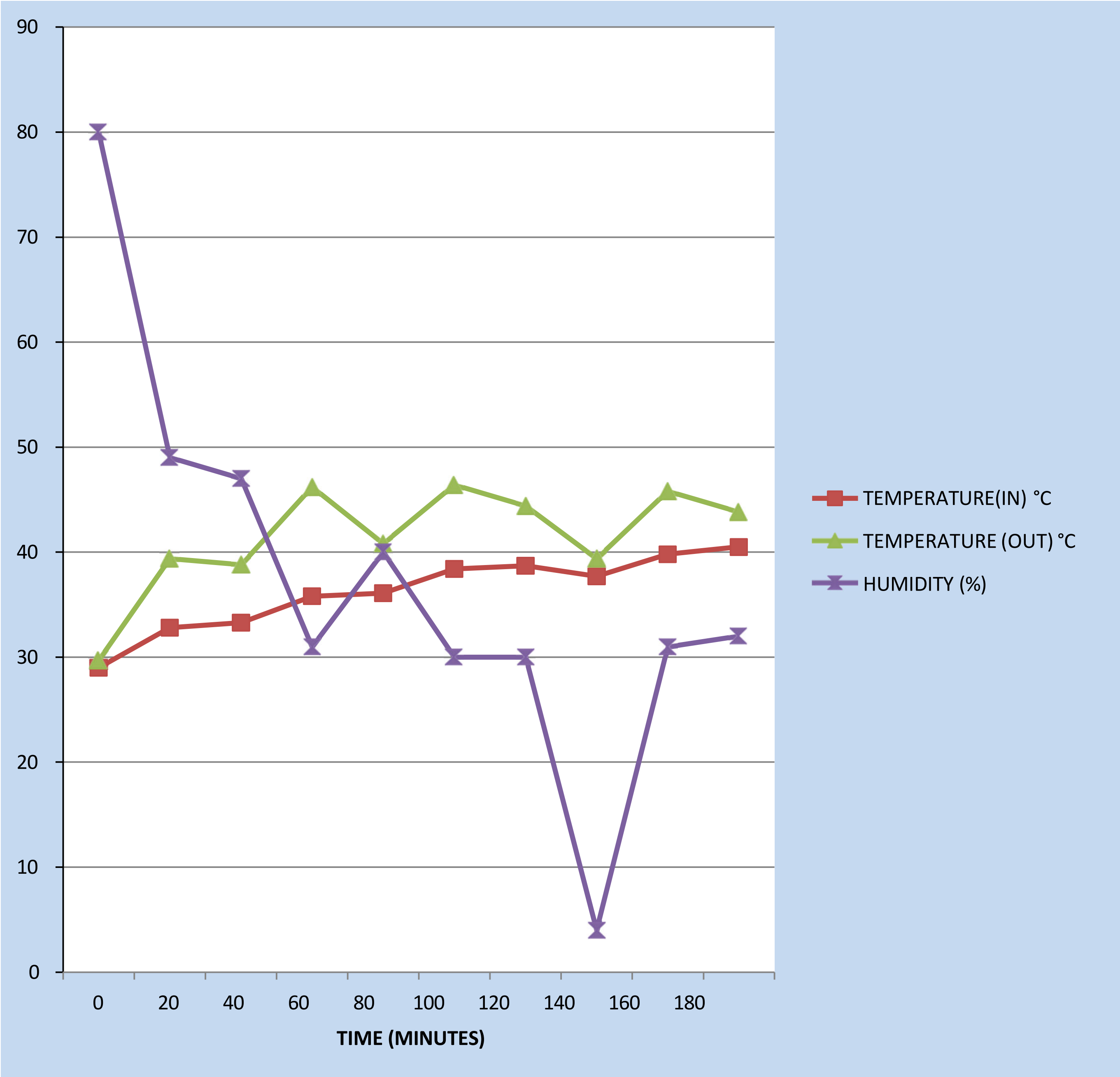

Figure 3: 15 litre volume (7.62cm height) beginning from 12:00 noon-17th November.

Figure 3 shows that the temperature (in) increases linearly with respect to time. It also shows that temperature (out) increases with time. In addition, the humidity decreases with an increase in temperature and increases with decrease in temperature.

Day Two

Table 2. Temperature, Humidity, and Time with 7.62 cm Air gap.

Time (minutes)	Temperature (in) °Celsius	Temperature (out) °Celsius	Humidity (%)
0	29.5	32.2	67
20	33.5	40.7	43
40	36.3	40.1	42
60	38.9	44.5	41
80	41.9	43.5	32
100	41.8	45.1	33
120	42.2	44.3	36

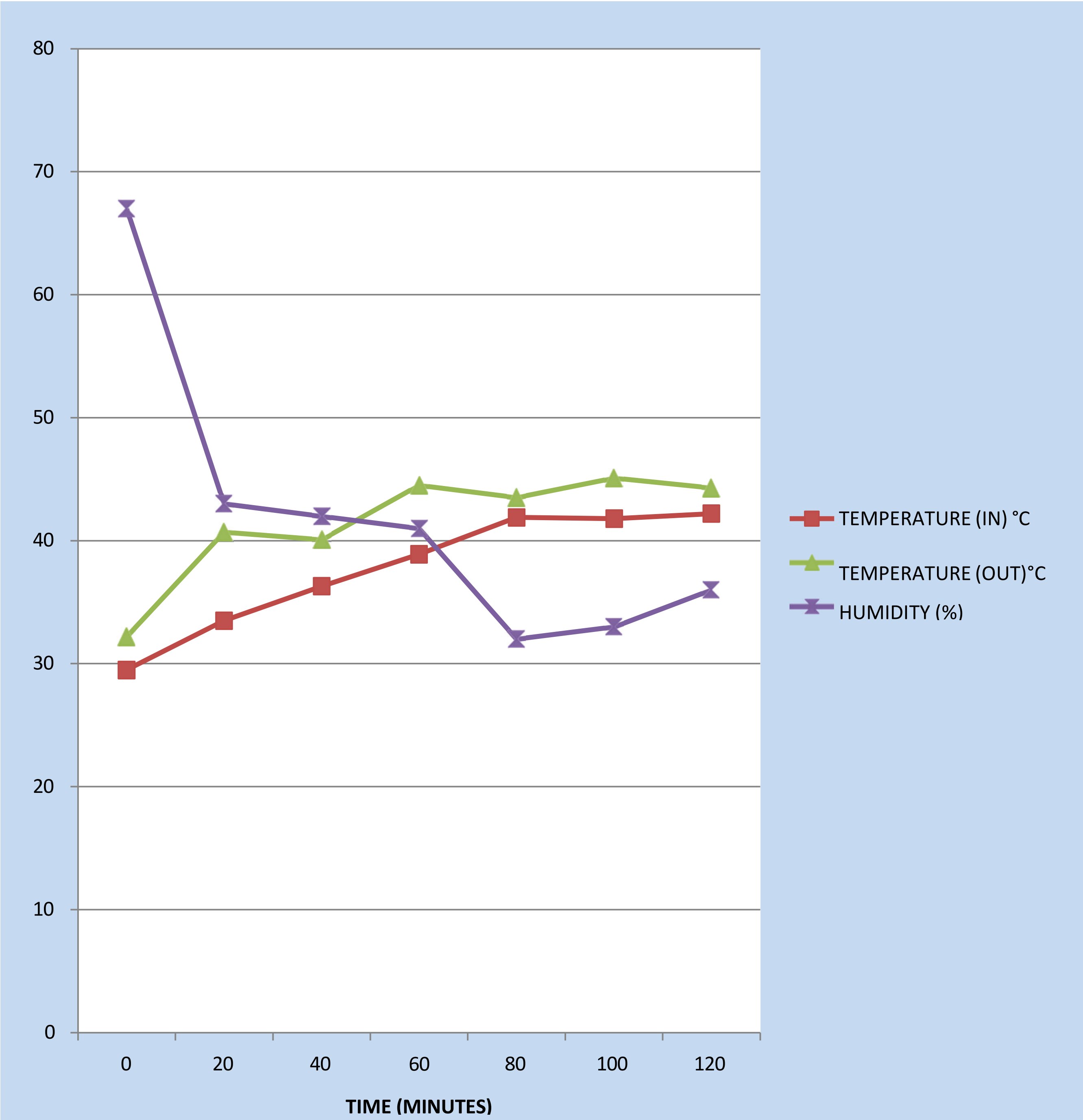

Figure 4. 15 litre volume (7.62 cm height) beginning from 12:00 noon-18th November.

Figure 4 shows that the temperature (in) increases linearly with respect to time. It also shows that temperature (out) increases with time. In addition, the humidity decreases with an increase in temperature and increases with decrease in temperature.

Day Two

Table 3. Temperature, Humidity, and Time with 6.71 cm Air gap.

Time (minutes)	Temperature(in) °Celsius	Temperature(out) °Celsius	Humidity (%)
0	29.1	42.4	39
20	31.4	41.9	38
40	32.0	39.3	45
60	37.8	43.1	35
80	40.1	42.5	40
100	41.4	46.3	33
120	38.7	42.8	34

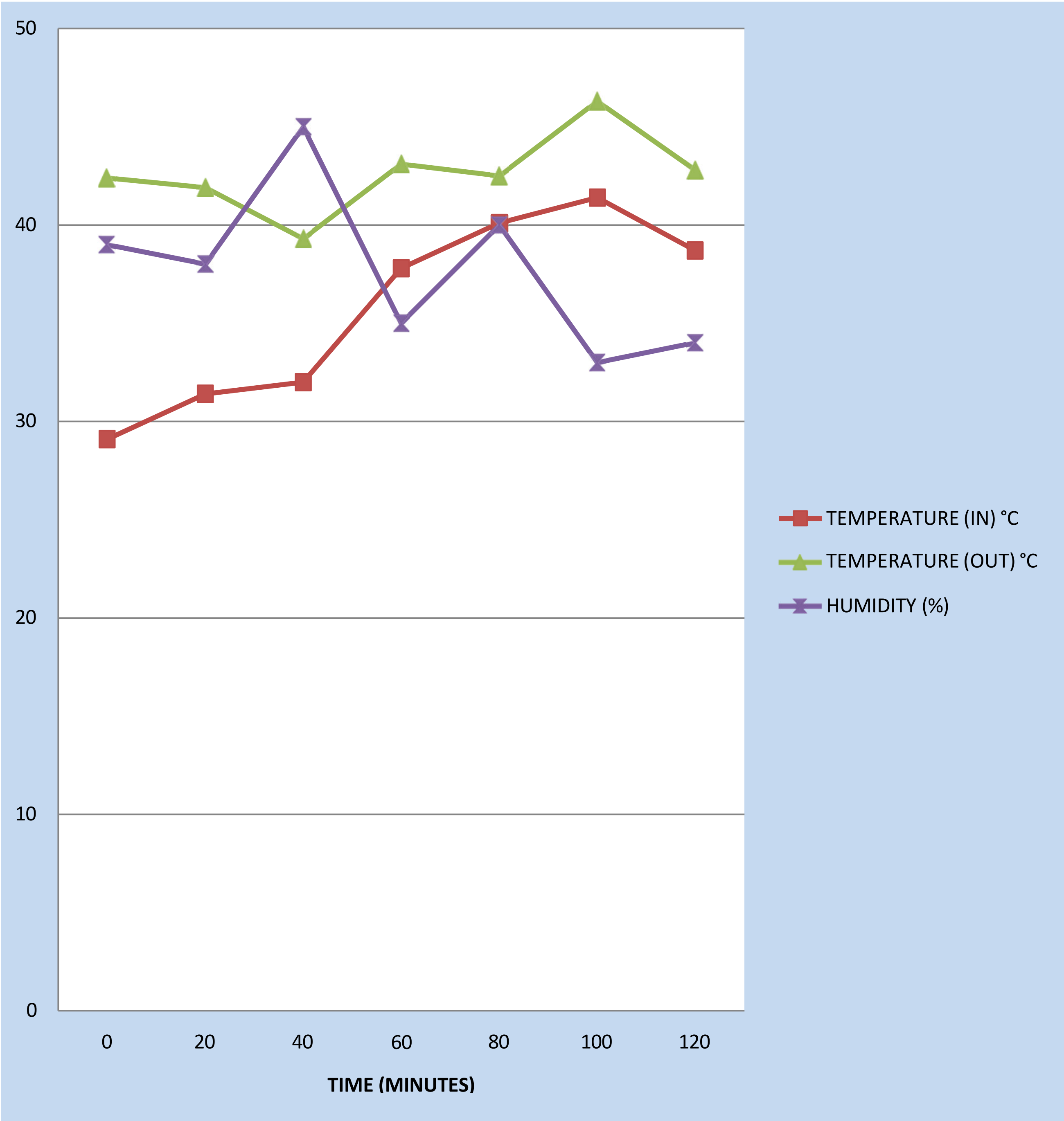

Figure 5. 16 liters volume (6.71 cm height) beginning from 12:00 noon-18th November.

Figure 5 shows that the temperature (in) increases linearly with respect to time. It also shows that temperature (out) increases with time. In addition, the humidity decreases with an increase in temperature and increases with decrease in temperature.

Day Three

Table 4. Temperature, Humidity, and Time with 7.62 cm Air gap.

Time (minutes)	Temperature(in) °Celsius	Temperature(out) °Celsius	Humidity (%)
0	29.8	36.4	57
20	31.7	35.8	56
40	33.4	39.3	45
60	34.3	41.5	46
80	36.3	47.2	32
100	38.4	48.9	25
120	41.5	47.2	21
140	41.0	43.8	35
160	42.8	44.9	34
180	40.8	40.4	40

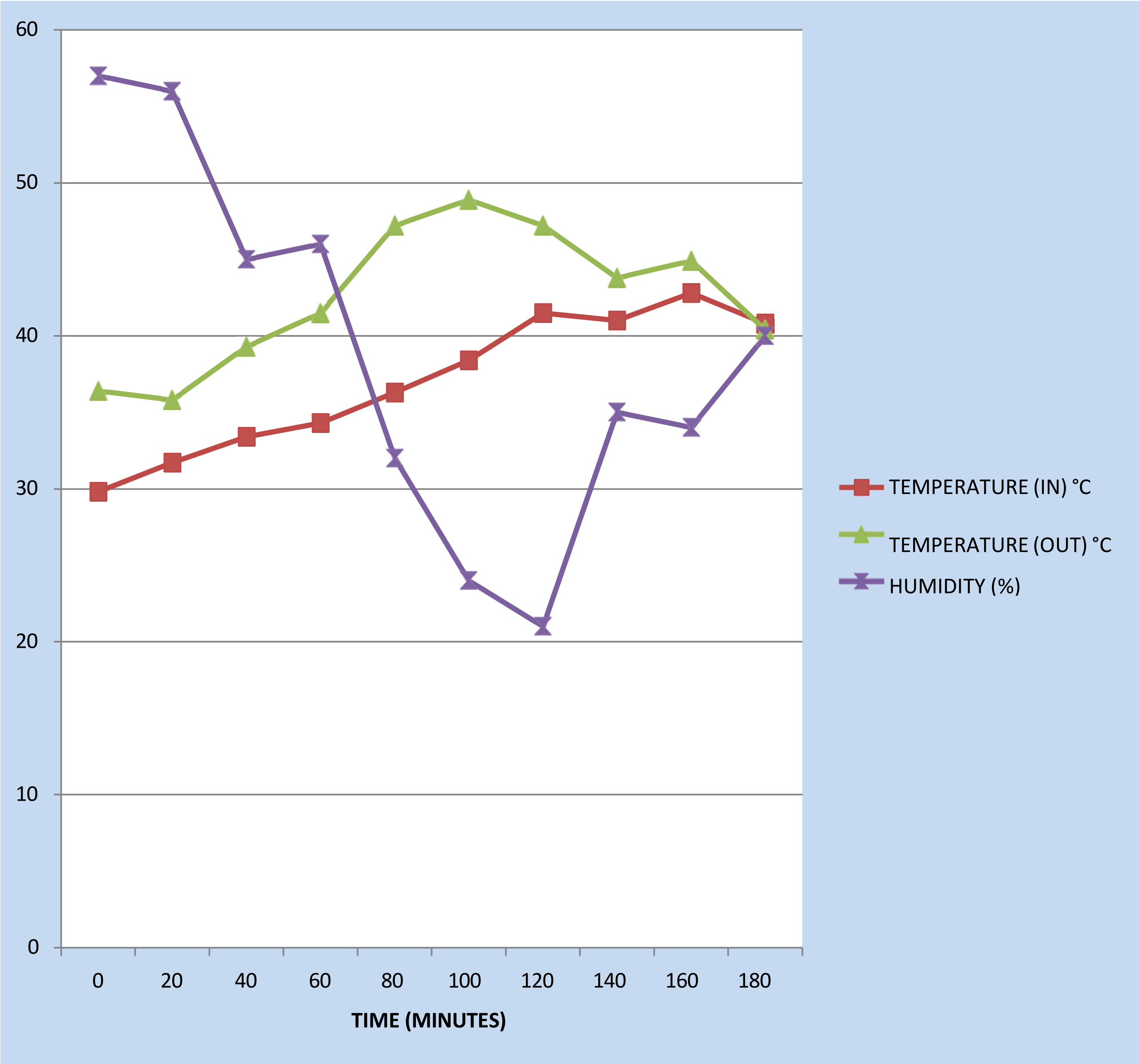

Figure 6. 15-liter volume (7.62cm height) beginning from 12:00 noon–18th November using a 4.93-millimeter-thick glass.

Figure 6 shows that the Temperature (in) keeps rising with time, while Temperature (out) rises and falls at different time intervals, and humidity rises and falls as well with time.

Solar water heating systems have become one of the major ways of reducing global warming and saving cost. The solar bucket was designed, constructed, and tested in Owerri, Nigeria. This device was able to heat water to 42.8°C with an average sunlight of 44.9°C. From figure 13, it could be seen that the temperature of the water in the device was a little higher than the temperature of the sun at 40.8°C and 40.4°C respectively, when a 4.93-millimeter-thick glass was used.

Even though the heat transfer rate of the device is not that big, it can still heat up water when a thicker glass is used. On a sunny day and harmattan periods when the temperature of the sun is high, this device can be used to heat water up to 42.8°C. As the temperature of the sun increases, the temperature of water also increases, so does time. The lagging material of the solar bucket makes it more efficient in terms of trapping heat.

The heat transfer is not much, but it was able to heat the water to a temperature of 42.8ºC. At a temperature of 32ºC, condensation takes place. From the data, the humidity decreases rapidly as the temperature of the sun increases. As time passes, the temperature of the sun increases, leading to an increase in the temperature of the water in the device. It was observed from the data that the thicker the glass, the hotter the water becomes. The thickness of the glass contributes to the rate of heat transfer in the device.

4. CONCLUSIONS

This device can be modified using thick cellophane like material or the windscreen of a vehicle to effectively trap more solar energy. Furthermore, increasing the thickness of the glass creates more room for heat to be trapped by the device. This device cannot be used during a cloudy or rainy day. This is because it is designed to trap energy from the sun to heat the water.

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