International Journal of Sustainable and Green Energy
2023; 12(3): 35-45
http://www.sciencepublishinggroup.com/j/ijsge
doi: 10.11648/j.ijrse.20231203.12
ISSN: 2575-2189 (Print); ISSN: 2575-1549 (Online)

Experimental Evaluation of Solar Powered Egg Incubator with Integrated Thermal Energy Storage: (Case Study: West Showa Zone Bako District, Ethiopia)

Duresa Tesfaye Muleta

Bako Agricultural Engineering Research Centre, Renewable Energy Engineering Team, Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

Email address:
Duresa2019@gmail.com

To cite this article:
Duresa Tesfaye Muleta. Experimental Evaluation of Solar Powered egg Incubator with Integrated Thermal Energy Storage: (Case Study: West Showa Zone Bako District, Ethiopia). *International Journal of Sustainable and Green Energy*. Vol. 12, No. 3, 2023, pp. 35-45.
doi: 10.11648/j.ijrse.20231203.12

Received: July 28, 2023; **Accepted**: August 15, 2023; **Published**: August 28, 2023

Abstract: The sun's energy is the best choice for thermal energy generation because it is accessible worldwide and is free to utilize. Poultry egg incubation requires a continuous supply of energy for efficient performance and operation. On-grid power does not reach rural areas in Ethiopia, and even in areas where it is available, electricity may be unreliable or shut off at any time, leading to incubator malfunctions, limited production, and high costs. The utilization of generators increases the operational expenses of incubators, and the natural incubation process by hens yields a very small number of chickens. A solar-powered egg incubator with a thermal energy storage system was constructed, modeled, and tested in this investigation to evaluate its performance. A solar egg incubator was developed using a solar collector with built-in sensible solid heat storage (positioned beneath the absorber plate), a 50-egg capacity incubation chamber, and a control unit. During the incubation period, there is ample sunlight that is converted into the energy required for a solar-powered egg incubator by a flat plate solar collector in the study area. The findings indicated that on the days with the highest solar radiation (629.3w/m^2), the average outlet collector temperature was 53°C, while 37°C was achieved on the days with the lowest solar radiation (397.5w/m^2). The maximum collector thermal efficiency was determined to be 44.33%. A total of 20 eggs were tested for both fertility and hatchability over a 21-day period in a solar-powered egg incubator. The incubation chamber was maintained within a temperature range of 36.5 to 39.5°C and a relative humidity range of 40 to 75% using a temperature controller (thermostat STC 1000) throughout the incubation period. The percentage of fertile eggs and hatchability were 61.11% and 27.27%, respectively.

Keywords: Collector, Incubator, Poultry, Performance, Sensible Storage, Solar Energy

1. Introduction

Numerous types of egg incubators were designed and developed by various researchers, by using several different sources of energy. Based on the source of energy, incubators could be used for electrical, biogas, solid fuel (charcoal), fossil oil (kerosene or gas, diesel generators), or solar sources. [1]. Incubators that use solid fuels, fossil fuels, oils, or biogas as a source of heat generate soot and other combustion products, resulting in lower hatch rates [1]. Chipped away at extending domesticated animals' creation in Nigeria, including the advancement of savvy bird-egg hatchery models. In their model, which included the use of still air and oil lamps as sources of heat for the egg incubator, they found that the still-air incubator is the most time-consuming, with a hatchability rate of 33% [2].

Despite the accomplished work on developing and evaluating a passive solar-powered incubation system for poultry eggs, electricity supply in developing countries like Nigeria remains inadequate and unreliable. Agricultural and poultry industries, in particular, have no reliable alternative method for obtaining energy [3]. Additionally, they noted that the use of solar thermal collectors, warm water, air, oil, or other flowing materials has a drawback in that heated material cannot be without a doubt put right into a battery, in contrast to the power produced by way of a solar panel. The issue with his system is how the thermal storage unit would be able to store and release the heat at sunset and in particular on days when the sun is hidden by clouds.

The research carried out on the 'Development of solar collectors combined with thermoelectric modules for solar drying technology has been successfully developed, analyzed, and see-beck effect is applied [4]. It means that the heat energy is converted directly into electricity. The goal of this study is to develop a sun drying technology that incorporates a solar collector and a thermoelectric generator module (TEG). Solar collectors can be the operator and produce hot air temperatures of about 70-80degree Celsius. The common bottom temperature of the collector is 45.4 Celsius, in which the ambient temperature becomes 35.4 Celsius, in regions with snow or no sunshine, masses of clouds or tree corners, dusty floral, etc.

The study on the performance evaluation of mono-crystalline photovoltaic panels in Funaab, Alabata, and Ogun State, Nigeria weather conditions was conducted, and this study made the recommendation that performance tests be conducted on the solar panels whenever they are used to power any load (egg incubator), in order to ensure that the solar PV solar panel supplied would be able to produce the power needed to power the load (egg incubator) without failing [5].

The researchers focus their efforts on the design and modeling as well as the performance assessment of various types of incubators in nearly every literature review that is presented, However, only a few of them deal with the solar integrated thermal energy storage for an egg incubator and efficient use of energy in the system. Thus, in this research, the researcher aimed to make an experimental evaluation of solar-powered egg incubator with integrated thermal energy storage and provide for the community. This will reduce the energy bill and help to use. In addition to that, it will reduce the load from the national grid and increase the need for a community to use clean energy for almost all applications of incubations.

2. Methods and Materials

2.1. Description of Experimental Site

The experiment was conducted at the Bako Agricultural Research Center, which is 250 kilometers west of Addis Abeba, the capital city of Ethiopia. It is specifically situated at 9°06' N latitude, 37°09' E longitude, and 1650 m above mean sea level. According to Ethiopia's central statistical agency (CSA), the population was 184,925 as of 2017 G. C.

2.2. Materials

Materials utilized and equipment used in this experiment includes:

1. Absorber plate
2. Glazing Glass
3. Pan made from Mild steel
4. ply wood
5. Rock pebbles
6. Mesh wire
7. Thermometer
8. Infrared thermo meter
9. Control valve
10. Thermo stat

2.3. Description of the System

An integrated schematic diagram of a solar-powered egg incubator with a thermal energy storage system is shown in Figure 1. The incubating unit, flat plate solar collector with integrated thermal energy storage system, and temperature control device set (thermostat set) make up the system's main parts. Galvanized sheet metal that was 2 mm thick and lined with plywood at the edge made up the incubating cabinet. The outer box measures 50 cm in length, 50 cm in width, and 57 cm in height from the outside. To prevent heat loss, straw foam is placed between the inner and outer boxes.

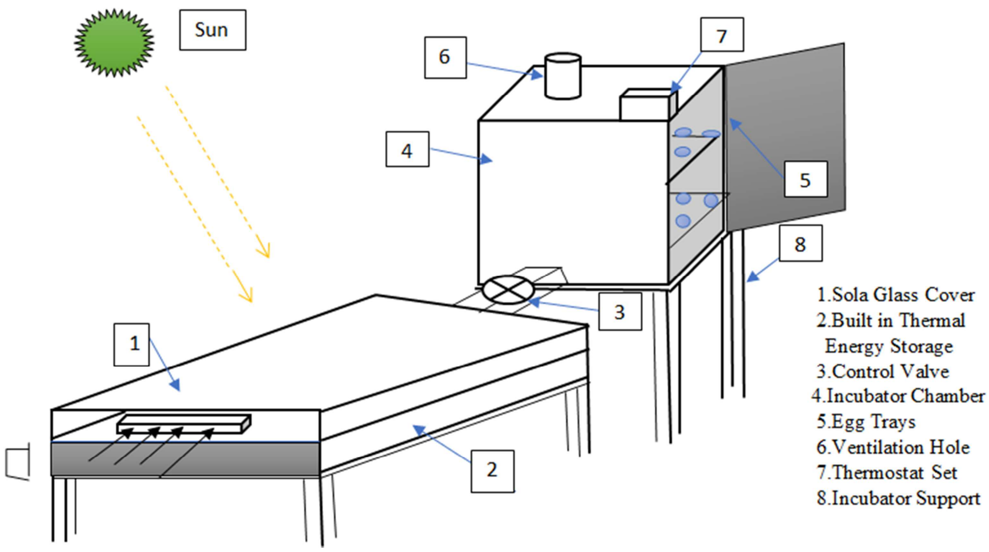

Figure 1. *A schematic diagram of a solar-powered egg incubator system studied.*

For the collector, the casing was made of plywood and the inner box was constructed using 2mm aluminum thick painted black to increase its absorption. A fiberglass substance fills the area between the outer box and the inner box was about 40 mm thick to reduce heat losses. The thermal storage unit (lower compartment) is situated between the absorber plate and the backplate, while the airflow channel (upper compartment) is situated between the absorber plate and the transparent top cover. The solar collector is 1200 mm, 680 mm in overall length, width, and height. and 250 mm, respectively. A single-layer, 4 mm-thick transparent glass sheet serves as the collector top glazing. The thermal storage contains rock pebbles of 145.5 kg.

2.4. Methodology

This study was conducted to evaluate experimentally an incubator that uses solar energy and integrates thermal energy storage for poultry production, to achieve the objective of this work, surveying the literature from related work, referring to the journals, books, and other unpublished material that were conducted. Direct solar radiation measurement during an experimental test were done. The experimental test was performed under normal weather conditions at Bako agricultural engineering research center and the result was evaluated. Before loading the physical tests were conducted. This was done for 24 hours and some modifications were done on the solar-powered system to avoid intermediate failure during the incubation period. A total of 25 eggs were purchased while 20 eggs were successfully loaded. 2 eggs out of the 20 eggs loaded were broken during the Candler test conducted on the 5^{th} day. More so, the inner temperature of the incubator was monitored using a temperature controller (thermostat STC 1000 China model), and relative humidity was measured using the digital thermo hygro-thermo meter. During the course of the 21-day incubation period, temperatures of various solar collector components and solar radiation were measured. Data were collected back then to examine how the incubator chamber's temperature affected it without any active supplemental heating systems attached.

From 8:00 to 17:00, in 1-hour time intervals, measurement data were collected over the course of 10 hours. K-type thermocouples were fixed at the absorber plate to measure the temperature of the collector (Tp), at storage (Ts), and other k-type thermocouples were attached at the outlet of the solar collector to measure hot air at collector outlet (To), in order to conduct the hourly temperature measurements. These temperature readings are taken from the table at the thermocouple's millivolt level. While the hourly solar radiation was measured for 21 days of the incubation period.

In order to measure beam radiation, the black-coated horizontal flat plate is used. The one plate is placed directly to solar irradiance. Then measure the temperature of the black surface for both plates within the time intervals by an infrared thermometer without touching.

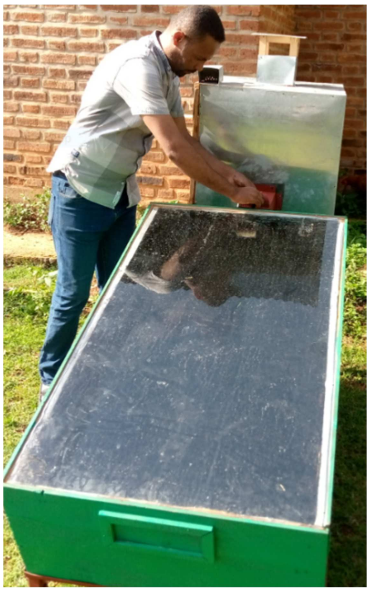

Figure 2. *hot air flow controller device adjustment and reading.*

Figure 3. *Setups of the instrument used for temperature measurement.*

To prevent egg yolk from adhering to the shell throughout this experiment, the filled eggs were flipped five times daily at intervals of three hours. However, after day 18, rotating of the eggs was stopped to give the embryos time to begin piping [6].

Candling is a technique used to notice the development and advancement of an incipient organism inside an egg which utilizes a brilliant light source behind the egg to show subtleties through the shell [15]. On days five, fourteen, and seventeen, a Candler was used to determine the rate richness of the eggs, and break, fruitless, and dead developing organisms were noted [6, 7].

The percentage fertility and hatchability were obtained from the equations below respectively.

$$\%\ \text{Fertility} = \frac{\text{Number of fertile eggs}}{\text{Number of eggs loaded}} * 100\% \quad (1)$$

$$\%\ \text{Hatchability} = \frac{Number\ of\ egg\ hatched}{Number\ of\ fertile\ eggs} * 100\% \quad (2)$$

2.5. Design Calculation

2.5.1. Total Heat Requirement in Incubator

The sum of the thermal energy needed to increase the temperature of the air (Q_a) and egg (Q_e) from 22°C to 37.5°C, as well as the heat lost via the building's wall (QS), the egg tray, and the ventilation (Q_V), makes up the incubator's total heat need (Q_T).

$$Q_{T=Q_a+Q_s+Q_e+Q_v} \quad (3)$$

In determining the heat load of the egg incubator, the following assumptions were made:

1) Incubator materials have a constant thermal conductivity.
2) The incubator is a closed system at a constant temperature.
3) The required incubator temperature is 37.5°C
4) The room temperature is 22°C
5) The required humidity is 60%

i) Heat required raising the temperature of the air on the incubator: measured air was flowing at the average velocity wind of $0.01m/s$ with density $1.22kg/m^3$ and per unit area.

$$ma = 0.01m/s \times 1.22kg/m^3 \times 0.816m^2 = 0.04851\text{kg/s}$$

$$Qa = m_a(T_r - T_a) \quad (4)$$

$$Qa = 155.5w$$

ii) Heat required raising the temperature of egg on the incubator: An egg's average mass was determined to be 60 g, and its specific heat capacity was estimated to be 3.18 KJ per kilogram.

$$Qe = m_e c(T_r - T_a) \quad (5)$$

$$Qe = 3.08\text{KJ}$$

This is the total heat required to raise the temperature of the eggs from 22°C to37.5°C. So, the total heat required for 50eggs = *3.08*KJ×50 = 154 KJ.

This is the total heat required to raise the temperature of the eggs from 22°C to 37.5°C. But this type of heat is provided gradually to prevent the eggs from boiling. Eggs transferred directly from the storage room to the incubator are heated at a rate of 0.30°C / min. whereas the pre-warmed eggs warmed at rates of 0.13°C and 0.16°C/min for the storage to room and room to incubator treatments, respectively. Now we considered our egg directly from storage with room temperature 22°C the time required to raise this temperature to the incubator temperature is calculated.

$$t = \Delta T/warming\ rate$$

$$t = 51.66\text{min} = 3100\text{sec}$$

$$Qe = Q_t\ \text{e/sec} = 49.677\text{w}$$

iii) Heat loss of incubator

a) Heat loss on both sides of the incubator: The heat loss on both sides of the incubator can be calculated because they have the same surface area and are composed of the same material (plywood).

$$Q = \frac{A*K(\Delta T)}{L} \quad (6)$$

$$Q_s = 0.952\text{W}$$

but it was the opposite side

$$Q_s = 1.9\text{W}$$

b) Heat loss at the top and bottom surfaces of the incubator: The top and bottom surfaces of the incubator were equal and opposite made of the same material. Area, A=0.262m^2 Since there were two equal surfaces,

$$A = 2\times0.262m^2 = 0.524m^2$$

$$Q_{bt} = 1.9\text{W}$$

Heat Loss at the Front and Back of the Incubator

$$Q_{fb} = 1.9\text{w}$$

Therefore, the total heat loss: Q_{loss}= (1.9*1.9*1.9) =6.86w

c) Heat required raising the temperature of egg tray (structure) on the incubator: There is an outer and inner box built from galvanized sheet metal of $k=45W/mK^{-1}$. In between the wooden boxes is an insulation material (fiberglass) of $k=0.043W/mK^{-1}$

QS was calculated using the equation:

$$Qs = \frac{As\Delta T}{\frac{Lwi+Lwo}{Kw}+\frac{Lins}{Kins}} \quad (7)$$

Where, A_s=0.262m2
$L_{wi}=3*10^{-3}$m
$L_{wo}=3*10^{-3}$m
$L_{ins}=40*10^{-3}$m

$$Qs = \frac{0.262(37.5-22)}{\frac{0.003+0.003}{45}+\frac{0.04}{0.043}} = 4.36\text{w}$$

There are four similar sides in the structure so total Qs=4.36*4=17.46 w

d)Heat loss through ventilation (Qv)

Qv was calculated using equation

Where, V - ventilation rate =$ach \times volume\ of\ incubating\ unit/3600$

$ach = air\ changes\ per\ hour$

Therefore, the volume of the incubating unit (v) =0.149m^3

A suitable value of 2 air changes per hour was chosen.

Therefore, the ventilation rate =2 ×0.149m^3/3600 =0.827 $\times10^{-4}m^{3/}s$

$$\rho a\ at\ 37.5°\text{C}\ was\ found\ to\ be\ 1.135kg/m3$$

$$QV = \rho a \times V \times \Delta T$$

$$= 0.00146W$$

$$QT = Qa + Qe + QS + QV$$

$$= 155.5 + 49.677 + 17.46 + 0.00146$$

$$QT= 222.6W$$

2.5.2. Flat-Plate Solar Collector

Solar collectors are used to converting direct and diffuse radiation from the sun into thermal energy. its special quite device transforms alternative energy to heat. Energy is moved from an abroad wellspring of energy to a liquid. The following relationship can be used to represent how much energy the solar collector has collected [8]:

$$Qu=\tau\alpha ItAc-U_L A\ c\ (Tc - Ta) \quad (8)$$

Where, Ac = area of transparent cover (m^2)

I_t = total incident radiation collector surface ($W.\ m^{-2}$)

U_L = overall heat loss for the collector ($W.\ m^{-2}.\ K^{-1}$)

α = solar absorptance

τ = transmittance

T_c = collector temperature (K)

Ta = ambient air temperature (K)

Overall loss coefficient and heat transfer correlations

According to an insightful perspective, it is helpful to utilize the complete misfortune coefficient characterized by the recipe to communicate the warmth misfortune from the authority.

$$Q_L = U_L A_c(T_{pm} - T_a) \quad (9)$$

Where T_{pm}- the average temperature of the absorber

The heat lost from the collector is the sum of the heat lost from the top, the bottom, and the sides. Thus,

$$Q_L = Q_{b+}Q_{t+}Q_s \quad (10)$$

Each of these losses is also expressed in terms of coefficients called the top loss coefficient, the bottom loss coefficient, and the side loss coefficient

(i) Top Loss Coefficient

The upper misfortune coefficient Ut is assessed by considering the convection and re-radiation loss of the assimilation plate the vertical way. It is assumed that the temperature drop in the thickness of the roof is negligible, and the interaction between the incident solar radiation absorbed by the roof and the emission loss is negligible. The outgoing re-radiation is long-wavelength. For these wavelengths, the transparent cover will be assumed to be almost opaque.

$$U_t= (\frac{1}{h_{c,p-g}-h_{r,p-g}}+\frac{1}{h_w-h_{r,g-amb}})^{-1} \quad (11)$$

Based on the maximum plate temperature is 73°C and cover glass temperature is 43°C. The mean temperature between them is 58°C, so the air properties on this temperature: the property of air at 58°C are not available on-air property table so it was calculated by interpolation. The value obtained was:

ρ (density of air) = 1.065kg/m^3

Cp (specific heat of air) = 1007KJ/kg*k

K (thermal conductivity) = 0.027934w/m*k

α (thermal diffusivity) = $2.503*10^{-5}$ m^2/s

ν (kinematic viscosity) = $1.876 *10^{-5} m^2$/s

μ (dynamic viscosity) = $1.988*10^{-5}$ kg/m. s

pr (Prandtl number) = 0.72

a) Radiative Heat Transfer Coefficient:-The radiative heat transfer coefficient from the plate to the glass cover is expressed as:

$$h_{r,p-g} = \frac{\sigma[(T_P+273)^2+(T_g+273)^2][(T_P+273)+(T_g+273)}{[\frac{1}{\varepsilon\rho}+\frac{1}{\varepsilon g}-1]} \quad (12)$$

$$\varepsilon_{eff}=(\frac{1}{\varepsilon\rho}+\frac{1}{\varepsilon g}-1)^{-1} \quad (13)$$

$$h_{r,p-g} = \frac{5.669 * 10^{-8}(346^2 + 316^2)(346 + 316)}{\frac{1}{0.84}+\frac{1}{0.95}-1}$$

$$= 6.64\ w/m^2k$$

b) From cover to the ambient

The effective temperature of the sky is usually calculated from the following simple empirical relation in whom temperatures are expressed in Kelvin

$$T_{sky} = T_{amb} - 6 \quad (14)$$

The radiative heat transfer coefficient from the glass cover to the ambient is expressed as:

$$h_{r,g-amb} = \frac{\sigma\varepsilon g(T_g+273)^4-(T_{sky}+273)^4}{(T_g-T_{amb})} \quad (15)$$

$$= 5.01 w/m^2k$$

c) Convective Heat Transfer Coefficient from the plate to the cover: The natural convection heat transfer coefficient h_1c is related to three dimensionless parameters, the Nusselt number Nu, the Rayleigh number Ra, and the Prandtl number Pr, that are given by:

$$Nu = \frac{hL}{K}\ Ra = g\beta\left(\frac{\Delta T}{v\alpha}\right)L^3$$

$$pr = v/\alpha \quad (16)$$

h- heat transfer coefficient [W/m^2 K, L – is the plate spacing, (0.35), g – The gravitational constant, β– is the volumetric coefficient of expansion of air.

$$Ra = g\beta\left(\frac{\Delta T}{v\alpha}\right)L^3$$

$$Ra = 9.81 * \frac{30*0.72*0.035^3}{2.503*1.876*10^{-10}} = 333334$$

The convective heat transfer coefficient is,

$$N_u=0.54*Ra^{0.25}=12.97$$

$$h_{c,p-g}= Nu * \frac{k}{L}=12.97*0.0278/0.055$$

$$=6.56 w/m^2k$$

Wind heat transfer coefficient is given as

$$h_w = 2.8 + 3v \quad (17)$$

$$h_w = 3.04$$

Where, v is the average velocity of air at the inlet, for Bako, v=0.08m/s

$$U_t = \left(\frac{1}{h_{c,p-g}+h_{r,p-g}} + \frac{1}{h_w+h_{r,g-amb}}\right)^{-1}$$

$$U_t = \left(\frac{1}{6.56+10.8} + \frac{1}{3.04+7.92}\right)^{-1} = 6.71w/m^2k$$

(ii) Bottom Heat Loss Coefficient

Assume that the heat flow is steady and one-dimensional. The majority of the time, conduction-related thermal resistance predominates due to the thickness of the insulation that is given. Therefore, disregard the convection resistance at the collector casing's base:

$$U_b = \frac{Ki}{\delta i} \quad (18)$$

where Ki - thermal conductivity of the insulation, δi - back insulation thickness

$$U_b = 1.07w/m^2k$$

(iii) Side Loss Coefficient

As on account of the base misfortune coefficient, it was accepted that the conduction obstruction overwhelms and that the progression of warmth is one-dimensional and consistent.

$$U_s = \frac{A1Ki}{Ac\delta e} \quad (19)$$

U_s= 3.68*0.043/0.816*0.04=4.8w/m^2k

Where: A_1- P*d e =3.68m^2

P – the perimeter of the absorber plate. (m)

de – the height of the edge. (0.64m)

δe- an edge insulation thickness. (0.04m)

Overall heat coefficient

The overall heat loss coefficient UL is the sum of the top, bottom, and edge loss coefficients. That is:

$$U = U_t + U_b + U_s = 6.7 + 1.075 + 4.8 = 12.02w$$

Over all heat loss

Assume; mean temperature of collector 43°C and mean air temperature is 22°C

$$Q_L = 12.02(43-22) = 252w$$

Where, Ta = air temperature and Tm = mean temperature of the collector

According to metrological data, the annual average daily radiation in an area reaching the ground is; E=6.01kwh//m^2/day*day/6h=995w/m^2. To change E into w/m^2 average sunshine hour 6 hr. One part of the heat is transmitted due to cover glass and absorptive surface material selection for cover glass is Plexiglas

τ= 0.8 and $\propto$ =0.95

$$Qu = \propto\tau E = 0.95\times0.8\times995\ w/m^2 = 794w/m^2$$

$$qopt = E - Qa = 995w/m^2 - 794w/m^2 = 201\ w/m^2$$

Usable heat derived from the collector

$$Qu = \alpha.\ \tau.\ E - k[Tm - Ta] \quad (20)$$

Qu = 542w

The thermal efficiency of the collector is calculated as the solar radiation impacting on the absorber of the solar collector divided by the usable energy gained by the air [1]

$$\eta = \frac{Qu}{I_t A_c} \quad (21)$$

$$\eta_{th} = \frac{542}{995*0.816} = 44.33\%$$

2.5.3. Thermal Storage Capacity

Once the incubator is maintained with the required temperature the amount of heat supply is equal to the sum of heat loss through the incubator and ventilation loss

$$Qloss + Qv = 6.859 + 0.00148 = 6.86W$$

This is continuously supplied for 21 days. The total amount of energy stored on storage material = 6.86W ×use time 18hour×3600sec = 444.528KJ.

The amount of heat that can be stored by the ballast pebbles (Q_b) was calculated as shown below:

$$Qb = m_b C_{pb} [Tr - Ta] \quad (22)$$

Where m_b - a mass of the ballast pebbles (kg), C_{pb} - specific heat capacity of the ballast pebbles (J/kgK^{-1})

But m_b=0.75$\rho_b V_b$

Where ρ_b- density of the ballast pebbles (kg/m^3), V_b - the volume occupied by the ballast pebbles (m^3)

0.75 = Void factor to correct for calculation of V_b Using the properties of ballast pebbles

$$C_{pb} = \frac{680+880}{2} = 780J/kg.\ K^{-1}$$

$$\rho_b = \frac{2760+2770}{2} = 2765kg/m^3$$

The ambient temperature (T_i) was at 22°C and the maximum temperature of ballast (T_b) is 50°C.

$$Qb = mb \times 780 \times (50-22)\ °C$$

m_b =145.5kg Volume needed = $mb/\rho b$ = 145.5$kg/2765kgm3$ = 0.053m^3

The average sunshine hour of Bako in year month is 7.125 hrs = 7.125×3600sec = 25200sec.

$$= 444528kJ/25200sec.$$

$$= 17.64W$$

On an average lower sunny day, the sunshine hours are for 3.4 hours. Time =3.4 hours = 12240 seconds. Hence the rate of heat gained by the ballast pebbles is

$$Q_b = \frac{444.528kJ}{12240Sec} = 36.31w$$

3. Result and Discussion

3.1. Experimental Results on Solar Beam Measurements

In May (05, 10, and 15, 2021), the experiment was done for

21 days for eleven hours each day in the research area's typical weather. The selection of days was based on the intensity of solar radiation estimated before experiments (i. e highest, lowest radiation, and monthly average daily solar radiation). The measured data for three days was recorded. The following figure shows the variation of beam obtained from measured temperature by the black painted plate at the same time interval in three days.

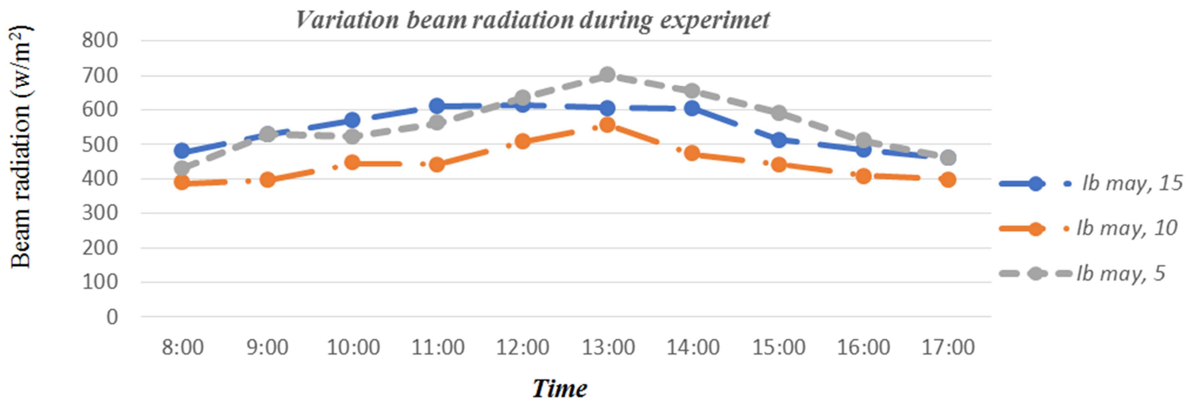

Figure 4. *Variation of solar radiation results from measured temperatures by the black painted horizontal plate.*

The maximum values of the beam solar radiation observed during the experiment are 669.7 W/m^2 at 13:00 May 05,2021 and the minimum values of beam radiation obtained May 10.2021 at 8:00 am. The results of solar thermal energy depend on the intensity of solar radiation, and the solar radiation may be affected by the weather condition such as the presence of clouds and the angles of sun forms to the earth. During the experimental studies, the weather condition of the study area for the first day of May 05 is a clear sky, sunny and no cloud was seen. For this purpose, relatively higher solar radiation was observed on this day. However, on May 15 sunny, but the small scattered cloud has seen about 9:00 am to 11:00 am. Additionally, on May 10, the Bako weather condition is a clear sky and sunny before and afternoon. However, the passing cloud was seen around solar noon. Figure 5 shows the comparison of average experimental solar beam radiation results with average estimated.

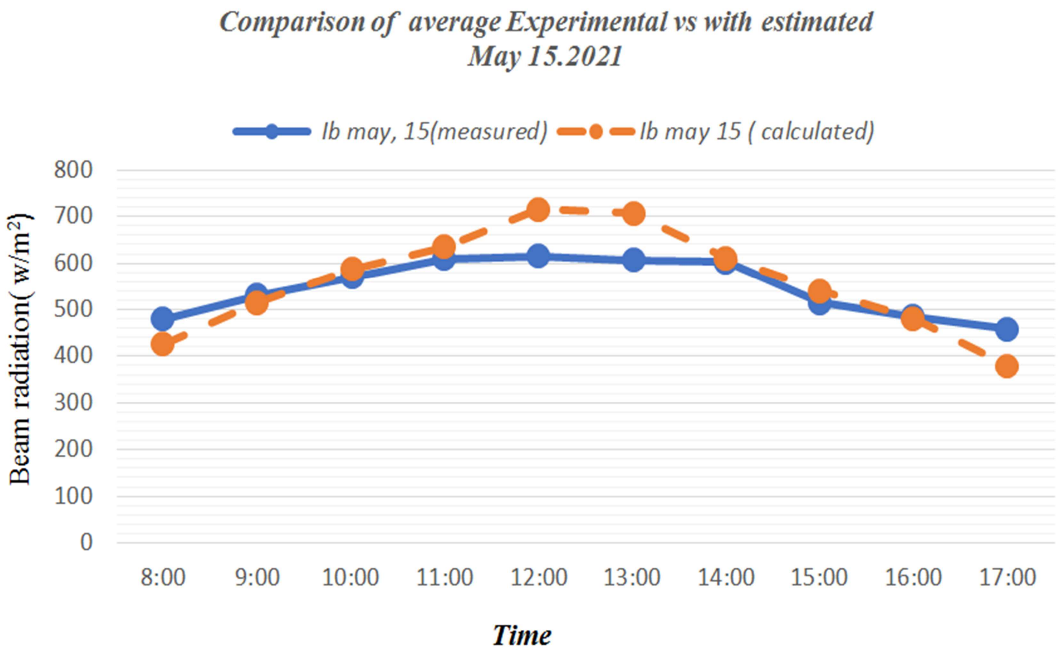

Figure 5. *The comparison of experimental data with calculated.*

A significantly similar solar radiation results between the experimental data and calculated. However, the experiment is conducted for a few days and it may be difficult to decide the monthly data by three-date data. The maximum average beam radiation observed from experimental and calculate are 613.3W/m^2 and 716 W/m^2 at 13:00 respectively.

3.2. Experimental Results After Loading Egg into the Incubator

During the experiment, various parameters were recorded in a variety of days starting from May 1 up to 22, 2021. Among those days' typical data were taken for analysis for three days only (05, 11, and 15 May). The selection of days was based on the intensity of solar radiation (i. e highest, lowest radiation, and monthly average daily solar radiation).

3.2.1. Results of Measured Collector Outlet, Ambient Air Temperatures, and A Typical Day of Highest Solar Radiation (May 05, 2021)

Figure 6 displays the fluctuations in ambient temperature, collector outlet temperature, and solar radiation intensity for typical days of greatest solar radiation throughout the course of the incubation period of 21 days. For the day with the most solar radiation, the highest collector outlet temperature and the highest ambient air temperature recorded were 55°C and 27°C at 12:00 am and 14:00, respectively, while the lowest values recorded for the day with the least solar radiation were 38oC and 20°C during daylight. A maximum collector thermal efficiency of 44.33% was attained throughout the test. The solar collector's high temperature aids in maintaining the incubating chamber's intended temperature of 37.5°C with just minor changes between +2°C and -2°C over the course of the incubation time.

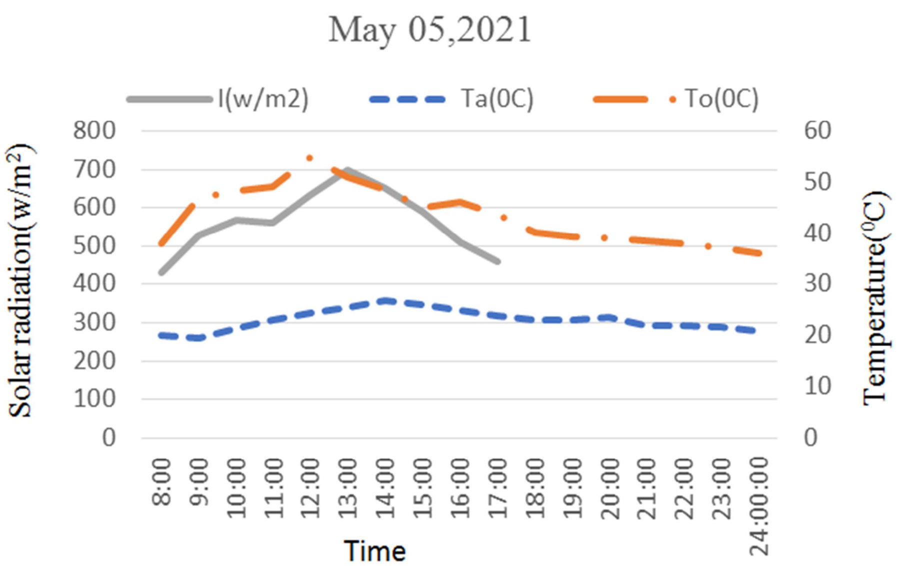

Figure 6. *Variation collector outlet, ambient air temperatures, and solar radiation.*

3.2.2. Results of Measured Outlet Air, Ambient Air Temperatures, and Lowest Solar Radiation Day (May 10, 2021)

Figure 7 depicts the changes in ambient temperature, collector output temperature, and solar radiation intensity on typical days of lowest solar radiations throughout the course of 21 days of incubation. On the day with the least amount of solar radiation, the maximum collector outlet temperature and the maximum ambient air temperature were 48°C and 25.5°C at 12:00 am and 13:00, respectively. The minimum values for the day with the least amount of solar radiation were 22oC and 15.10C at 18:00 and 24:00, respectively. A maximum collector thermal efficiency of 23.2% was attained throughout the test.

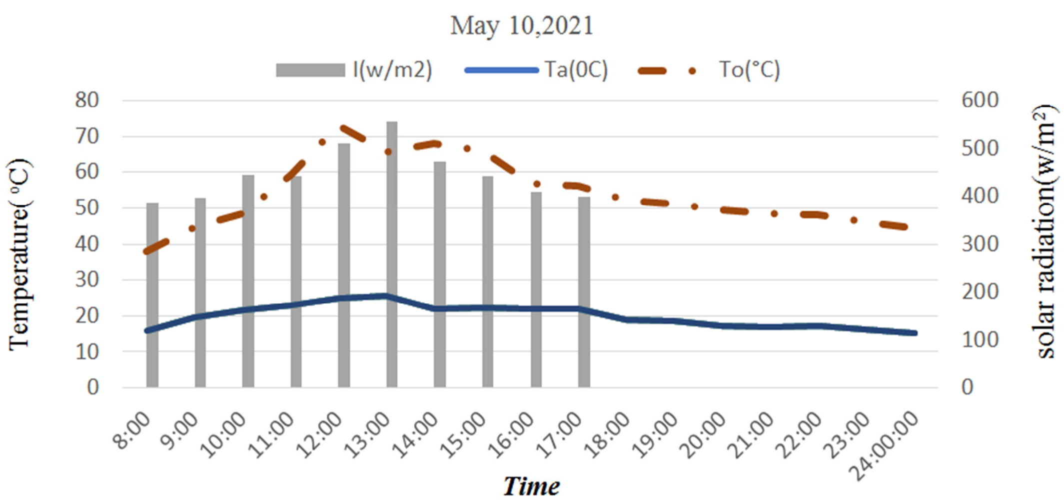

Figure 7. *Variation collector outlet, ambient air temperatures, and lowest solar radiation.*

Figure 8 depicts the fluctuation in the average temperature of the glass cover, absorber plate, and surrounding air throughout an experimental test period from 8 AM to 17 AM. It is clear that the temperature of the absorber plate varied according to the strength of the solar radiation, rising in the morning, peaking at midday, and then gradually falling in the afternoon. At midday, the highest outflow air temperature was measured to be 55°C. During the experiment, the solar radiation intensity ranged from 460 to 699.5 W/m^2.

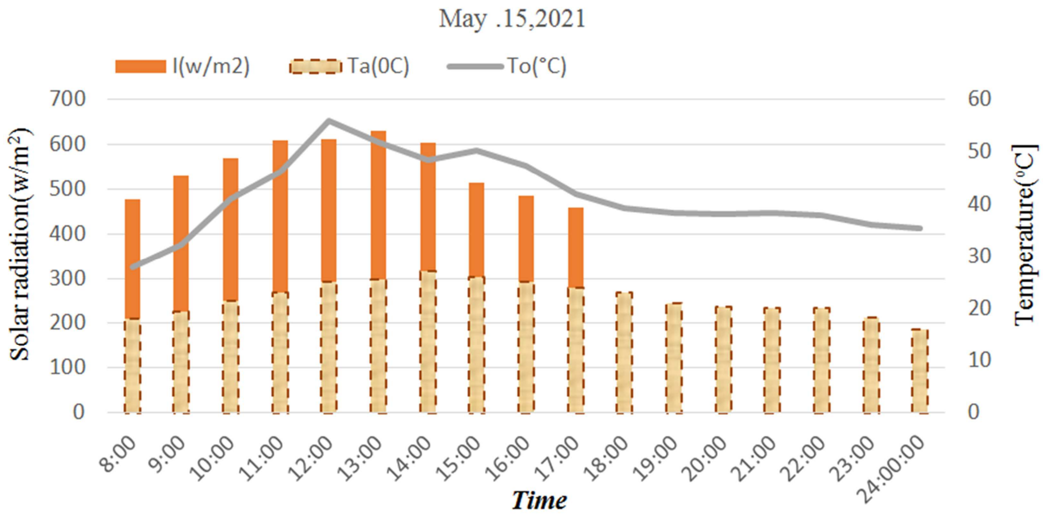

Figure 8. *Average of air outlet temperature, and ambient against solar radiation.*

3.3. Thermal Efficiency of Solar Collector

As the solar intensity of the study area increases, more useful energy is captured. As the energy captured to increase the plate temperature raises and heat captured by the plate is partially transmitted to the storage compartments that were increased the temperature of the thermal storage systems. System thermal calculation results for the experimental measurements of average solar radiation in the time intervals to calculate the efficiency of the solar collector were discussed in the following figure.

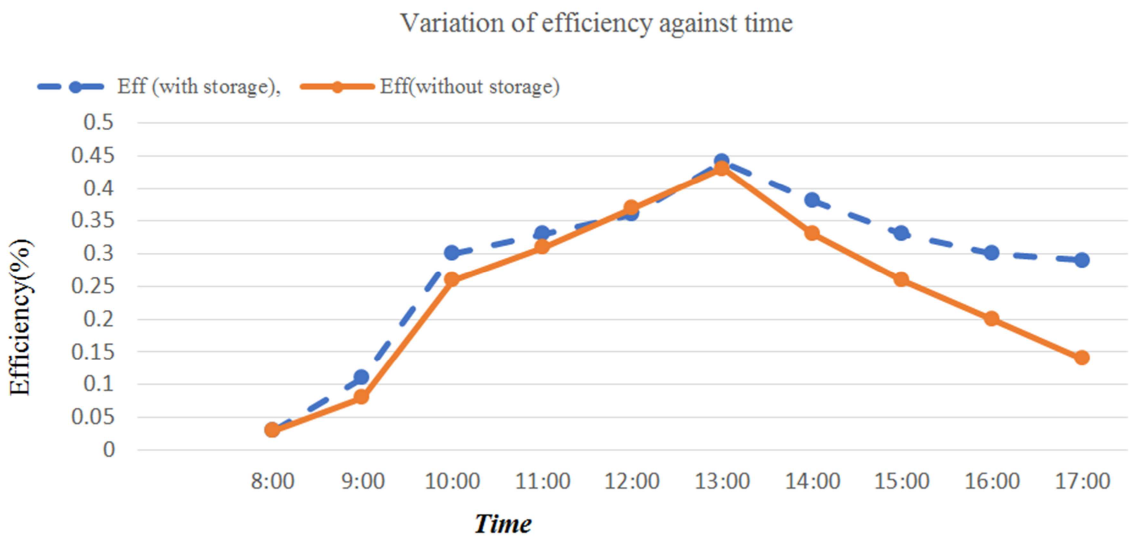

Figure 9. *Variation of collector efficiency with time.*

Figure 9 depicts the variation of thermal efficiency and useful heat energy leaving the collector with the beam radiation throughout the monthly average day of May 15, 2021. During the experiment, from 8:00 am to 17:00, the beam radiation varies in the range of 460 W/m^2 to 629.3 W/m^2. Most of the time, the peak value of collector temperature is observed at maximum solar intensity about solar noon. The maximum thermal efficiency was found to be 44.33% at the maximum solar radiation intensity with storage and 43% with no storage materials at 13:00. When there is no energy storing material, the maximum temperature reached by air is comparatively less and during the evening there was a high fall rate in the temperature, at that time the efficiency of the system falls with the fall of temperature.

In natural convection solar collectors, no-load efficiency of 66.95% has been recorded [9]. Further, [10] flat plate collectors' thermal efficiency was found to be 62% at an airflow rate of 0.03 kg/m2s. With time, it was discovered that the immediate efficiency was declining. According to Eq. (11), the efficiency depends on the temperature differential between the glass cover and air as well as the plate. The values of (Tp-Ta) and (Ta-Tg) decrease as time goes on because the temperatures of the plate, the surrounding air, and the glass cover are all rising. Once more, the afternoon saw a significant reduction in radiation intensit

3.4. Candling Test Result

According to the calculations in Table 1, the percentages of hatchability and fertility of the eggs were determined. Seven of the 18 eggs placed in the incubator were infertile, according to the test results, which were acquired. Egg fertility as a percentage was 61.11%. Additionally, 3 of the 11 viable eggs were successfully hatched, yielding a percentage hatchability of 27.27%. When compared to prior studies on incubator hatchability, the incubator was medium as the primary test. Using Tibetan and Dwarf chickens, [11] found a hatchability range of 26.23 percent–79.72 percent, whereas [12] found a hatchability range of 47 percent–76 percent using Fulani-ecotype birds. The hatchability of chicken eggs is influenced by a variety of parameters such as egg age, storage temperature, mother hen age, management and raising technique, mating method, incubation relative humidity, and egg rotation angle [13]. The eggs obtained from the farm have a high rate of infertility, which might be due to low fertility caused by the farm's frequent mating. Other issues such as incorrect mating ratios, breeder age, and poor management/social stress such as the insufficient floor, feeding, and water space, among others, maybe at work [14].

Table 1. *Candling test of incubation.*

Candling check on the 5th day of incubation			
No of eggs	**Development**	**Observation**	**Remark**
2	Not visible	Clear	Infertile
5	Not visible	Large air space	Infertile
7	Visible at one end	Lines strolling across	Fertile
4	Visible on the center	Visible purple of red stains	Fertile
Candling test on the 14th day of incubation			
7	Not visible	Clear	No development
7	Dark appearance	Clear air space	Development in progress
4	The whole egg is dark	No air space	Development has ceased
Candling test on the 17th day of incubation			
2	Dark appearance	Beak is Visible	Development near completion
1	Dark appearance	Clear air space	Development in progress

4. Conclusion and Recommendation

In this present study experimental evaluation of a solar-powered egg incubator with integrated thermal energy storage for the study area was carried out. The system prototype was constructed using locally sourced materials at Bako agricultural engineering research center laboratory and tested on latitude 9.06°N. The incubator is made up of a solar collector with built-in thermal storage and a 50-egg capacity incubation chamber. The first solar energy potential of the study area was measured. During the incubating period, there is sufficient sunlight that is converted into the energy required for a solar-powered egg incubator by a flat plate solar collector in the study area. The result showed that on the highest solar radiation days, the average outlet collector temperature was 55°C and 37°C was obtained on the lowest solar radiation days. The collector thermal efficiency was found to be 44.33%. The fertility and hatchability of eggs were tested using a total of 20 eggs over 21 days in a solar-powered egg incubator. The incubating chamber was maintained by using a temperature controller (thermostat STC 1000) throughout the incubating period within a temperature range of 36.5 to 39.5°C and a relative humidity range of 40 to 75%. The percentage fertility and hatchability of eggs were 61.11% and 27.27% respectively. For the future, I have recommended that Detail cost analysis with material selection for better system performance, to get monthly and hourly data values of solar radiation for the study area by horizontal flat plate, measurements need for many days repeatedly, Further analysis and biological test needed to know the characteristics of egg embryo growth, and using all the necessary materials, the project is exactly profitable and developmental.

Acknowledgements

The authors acknowledge the significant work of the lab technicians of renewable energy technologies. Additionally, I'd like to thank the Energy Engineering Team of the Bako Agricultural Engineering Research Center for helping to gather the data that supported the manuscript, and for providing insightful comments and suggestions on the research. I'd also like to thank the technicians in the metal and wood workshops, especially Mr. Lelisa Tsageye and Mr. Habtamu, for their significant contributions to the development of the technology. My thanks go out to everyone in the Oromia Agricultural Research Institute for their financial assistance and input in reviewing the paper across our chain.

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