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Thermal Behaviour of Passive Solar System Designed for Brooding and Incubating Purpose under Makurdi Weather

Ahiaba, V.U
Department of Agricultural & Environmental Engineering, University of Agriculture, P.M.B., 2373, Makurdi – Nigeria;

Email: ahiba.victor@uam.edu.ng Tel. +2348036521370

Makurdi – Nigeria, is located on latitude 7°7'**N** and 111 m above sea level. The behaviour of passive solar system for incubating and brooding purposes was examined. The experimental system had a floor area of 1 m^2 and a height of 2 m from the floor. The average solar irradiance per square meter of the earth surface for the location is 224.17 W/m^2 over an average sunshine hour of 7 hours. The system has two energy stores (thermal masses) with total surface area of 1.5 m^2 , weighing 88 Kg and made of concrete with mix ratio of 3:2:1 for cement, gravel and sand respectively. The supplementary storage was made of granites, weighing 44 Kg. The system was built with 4 mm thick plywood, with the internal surfaces covered with 6 mm thick foams used to fill the annular spaces. All materials used were pre-treated by painting them black for better heat collection. The result showed that under average ambient temperature of 31.8 °C, the thermal mass surfaces attained a maximum temperature of 95 °C between the hours of 12 noon and 3 pm, and a minimum temperature of 36.4 °C between the hours of 3 am and 6 am, with an average of 61.4 °C while that of the Chamber ranged between 30 – 49 °C depending on the time of the day and weather conditions. Also, while the ambient relative humidity was averagely 69.4 %, that of the Chamber 61.6 % with the help of a dehumidifying material (activated charcoal). This passive solar system is suitable for brooding and incubating. It is recommended that the insulation system be improved and better temperature control method be devised for this system to serve these two purposes.

Keywords: Passive, Solar, Energy, Brooding, Incubation, Thermal mass.

INTRODUCTION

The main objective of this work was to harness the abundant solar energy available in Makurdi, Benue State, North-Central Nigeria, to heat up a passive solar system for either brooding or incubating purposes. Mankind has utilized solar energy for years for domestic drying, provision of warmth and for other uses. Several engines had been run from solar-generated steam, and most of the solar collector concepts but the principle are the same. They all relied on glass, mirrors or transparent covers to trap heat as in a green house (Lunde, 1980).

The craving for alternative energy source, outside fossil fuel, has become a global phenomenon. To this effect, countries around the world are investing massively in solar energy power plants. One of such major investment in the recent times is by the USA Department of Energy which has been charged with the development and sponsoring programmes that will transform the way energy is provided in the United States. This Department has worked with Researchers from University of Arkansas and has developed high performance concrete to store thermal energy for concentrating solar power plants (Emerson *et al,* 2011).

For a thriving poultry production in developing countries such as Nigeria, where electricity supply has remained inadequate and unreliable, alternative methods of meeting the energy needs in agriculture and in the poultry industry specifically, have to be evolved. These alternative energy needs cannot be over-emphasized, as energy is required at various stages of poultry production especially during incubation and brooding.

However, it is expedient that such alternative energy source should be dependable, in abundant supply, environmentally friendly, pollution free or minimized. It should also be inexpensive and readily available to local farmers. Solar energy looks the best alternative energy option for this, because it is clean and is readily available all year round in the tropics and in North Central Nigeria, along Benue River Valley, Makurdi-Nigeria. A good solar system should be able to convert solar radiation into useful heat or electrical energy, store it and release it for utilization when needed.

Several methods of solar energy storage are available (Duffie and Beckman, 1980). These include storing as sensible and latent or concealed heats. The advantage of sensible heat storage is that materials for energy storage are locally available and inexpensive. Such materials include water, stones, masonry wall systems, gravels and local bricks walls. The technology of masonry wall system as solar energy collector and storage device in buildings has been reported (Nayak *et al.*, 1983).

In Nigeria, (Okonkwo *et al*, 1992) reported on solar heating system. The results of the analysis showed an absorber plate temperature of up to 83 ^{o}C measured and 122 ^{o}C predicted while storage medium temperature was 45.56 ^{o}C.

Though the solar incubating and heating systems are not generally common in Nigeria, the built-in thermal storage solar water space conditioning system could serve as a good example of utilizing solar energy in Nigeria as illustrated by some researchers (Okonkwo *et al*, 1992 and Okonkwo, 1998).

Several other researchers - Okonkwo *et al* (2007), Fagbenle (1990), Pelemo *et al* (2002) worked on estimation of daily radiation in Nigeria using meteorological data. Yohanna *et al* (2011), Itodo(2007), Adeyemo (1988), among others had also made contributions in this area. Owokoya (1992) designed and constructed solar air heater. Adaramola *et al* (2001) worked on solar cooker and was able to generate and maintain temperature up to 170 °C. Odia (2006) effectively designed a solar assisted refrigeration system.

This study shows the thermal behaviour of a passive solar system as seen in temperature changes within the chambers that can provide suitable conditions for incubation of poultry eggs and brooding of day old chicks, using solar energy and locally available materials.

MATERIALS AND METHODS

For a material to be effective as a thermal mass, it must have a high heat capacity, a moderate conductance, a moderate density, and a high emissivity. Table 1 shows the various materials used, selected on the basis of their properties suitable for the development of the solar system for incubation and brooding..

Table 1: Materials and their usage

S/N	Materials	Usage
1.	Plane Glass	Cover Plate
2.	Concrete Slab	Main Thermal Mass
3.	Granite Stones	Supplementary Thermal mass
4.	Plywood	Insulating body
5.	Insulation foams	Insulation purpose
6.	PVC troughs	Heat Exchanger
7.	Activated Charcoal	Dehumidifier
8.	Testing materials	Candler, fertile eggs

MATERIAL TREATMENT

The exposed surfaces of the thermal masses were painted black. Coating the surfaces of the outer cover plates, inner face, absorber surface, heat conduction materials are necessary to allow optimal heat collection, absorbance and transmittance. Dark surfaces have high absorptances between 0.95 – 0.99. Hence, the thermal masses made of concrete and granite stones were painted black for optimum heat absorption. Similarly, in order to improve heat quality, the heated air was dehumidified for a dry hot air into the Chamber. The material used was Powdered Activated Carbon (PAC), otherwise known as grinded charcoal of diameter of between 0.15 and 0.25 mm. Thus they present a large surface to volume ratio with a small diffusion distance.

2.3 BRIEF DESCRIPTION OF THE COMPONENTS OF THE PASSIVE SOLAR SYSTEM

The passive solar system under consideration is made of six main components as shown in Figure 1 . Plate 1 shows the photograph of the system.

The Cover plate (Normal plane glass) – A: The plane glass has been used as a solar collector for ages (Lunde, 1980), owning to its unique properties. The plane glass has high solar transmittance of 0.84 to 0.91, longwave transmittance of 0.03; Neat appearance; Cleans easily; Abrasion resistance; High heat tolerance (up to 204^{o}C); Excellent weathering resistance and Low flammability. Its job is to allow the passage of shortwave solar radiation into the heat storage chamber and preventing the longwave energy being accumulated within the storage chamber from escaping from the storage chamber.

The absorber/thermal mass – B – concrete slab: The concrete is a mixture of cement, sand, gravel and water. The water stirs the reaction between the cement, sand and gravel, hence binding them together into what is known as concrete slab. The mix ratio of 3:2:1 for cement, gravel and sand respectively, was adopted according to the pattern of that of Emerson *et al.* (2011) The property of concrete that makes it ideal for heat storage are: Heat capacity of 1000 J/Kg ^{o}C; Density of 2000 Kg/m^3; Thermal conductivity of 0.18 KJ/Kg.K.

The supplementary heating system – C – granites stones: The granite stones serves as the supplementary storage with the useful properties such as; Heat Capacity of 790 J/Kg^{o}C, Thermal conductivity of 2.8 W/m.K and Density of 2403.4 kg/m^3.

The incubating or brooding chamber (The Chamber) – D: The incubating chamber is made of 4 mm thick plywood, lined at the internal surface with insulation foam. These two materials helps to keep the heat energy delivered into the Chamber from escaping into the atmosphere. The desirable properties for this purpose are; very low thermal conductivity of 0.045 W/m-K increases the insulation provided by plywood.

Insulating casing – E – plywood: The ply wood is the overall casing of the incubator, covering all the chambers. It forms the wall of the incubating and the heat storage chambers, with desirable properties being very low thermal conductivity of 0.13 W/m-K.

Ventilation: the air circulation through the system was by natural ventilation. The ambient (fresh) air enters through the inlet openings (located down the windward side of the incubator) into the system where it is heated up by the accumulated solar energy within the system. This brings a temperature difference between the air at the lower and upper ends of the collector. The difference in temperature results in pressure difference and density variation, hence resulting to buoyancy force which in turn causes the heated air to flow through the Chamber and out through the outlet openings located at the leeward side of the Chamber but above the inlet opening as measured from the floor of the system. Small inlet openings were provided to induce natural ventilation. Ventilation is needed to remove unpleasant smells and excessive moisture, and to prevent stagnation of the interior air. Ventilation includes both the exchange of air to the outside as well as circulation of air within the system. It is one of the most important factors for maintaining acceptable indoor air quality in buildings and other enclosures.

Orientation of the solar collector: The collector is always tilted and oriented in such a way that it receives maximum solar radiation during the period of use. Since the collector is not a sun-following type, the best stationary orientation is due south in the northern hemisphere and due north in the southern hemisphere. Hence, the solar collector in this work was oriented facing south and tilted at 45^{o} to the horizontal. This inclination allows average solar collection all day and also allows easy run off of water. It also enhances heat movement into the incubating chamber.

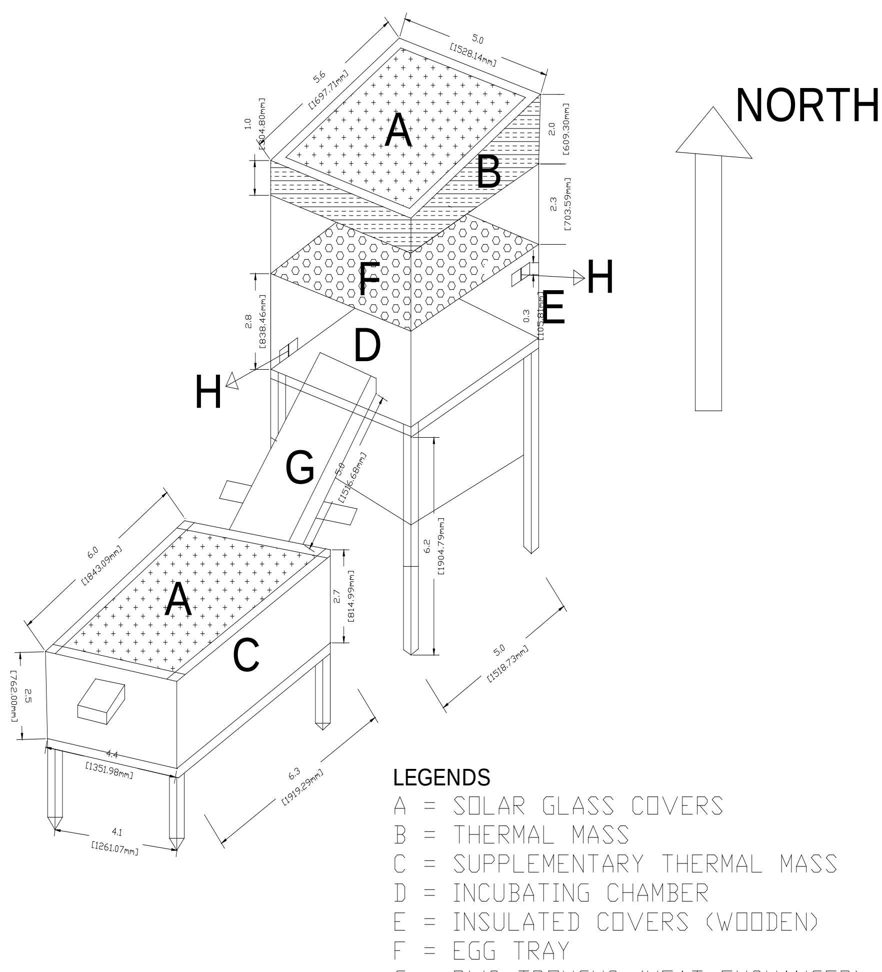

Figure 1: Description of the Passive Solar System

Plate 1: Picture of the developed Solar System

THERMAL PERFORMANCE EVALUATION

The passive solar system was constructed and assembled as shown in Figure 1. The environmental measuring instruments used were positioned such that the inner condition of the system and ambient conditions (temperature and relative humidity only) were taken simultaneously. The passive solar system was monitored for twenty one (21) days in each month (January – April) by taking measurements of the temperature and relative humidity in the system within the period for a total period of four months. The 21 day period was chosen because, normal incubation period of the common fowl is 21 days and day old chicks has been brooded experimentally for 21 days in the region. The readings were taken for 24 hours each day and at a regular interval of 3 hours; that is, at 6 am, 9 am, 12 noon, 3 pm, 6 pm, 9 pm, 12 midnight, and 3 am. The interval of 3 hours was chosen because, all temperature and relative humidity variation within 3 hours has been found not to have detrimental effect on either incubation or brooding processes.

The activated charcoal (dehumidifier) was present in the heat collector chambers throughout this study. This is to prevent condensation within the collector chambers, so as to deliver clean and dry heat into the Chamber. The activated charcoal was only placed within the Chamber only when increased relative humidity was observed within the Chamber. Where the relative humidity tends to go below the required range of 55 – 65 %, the activated charcoal was removed and a warm tray of water placed at the floor of the incubator. This raises the relative humidity as well as the temperature of the Chamber within few minutes.

RESULTS AND DISCUSSION

The effect of heat collected and transferred from the collector/storage chamber is reflected in temperature increase in the Chamber. Table 2 shows the results for average temperature, relative humidity at 3 hours interval (6am, 9am, 12 noon, 3pm, 6 pm, 9pm, 12 midnight, and 3 am) respectively. Figure 2 shows the Temperature behaviour against time while Figure 3 is that of Relative Humidity against Time of the Day.

Variations of Major Parameters within the Incubator

Temperature— a maximum temperature of 95 ^{o}C was obtained at the surface of the thermal masses around the hour of 3 pm on a certain day. Higher temperature was recorded between 12 noon and 3pm every day. The minimum temperature obtained was between the hours of 3 am to 6 am. This result competes favourably with other researchers (Bukola, 2008).

Table 2: Average Temperature and Relative Humidity of ambient, Chamber and Storage at various time of the day

Time of the day	T_{am} °C	Amb. R-H %	T_{tm} °C	T_{tmds} °C	R-H of incubating room, %
6am	28.4	84.3	37.1	36.9	56.1
9am	31.9	76.0	60.4	37.9	59.7
12 noon	36.5	78.1	84.1	43.5	64.2
3pm	36.6	69.2	91.5	56.6	64.0
6pm	33.1	60.5	68.6	48.9	62.7
9pm	31.1	61.6	59.4	55.4	62.6
12 am	29.0	62.9	50.6	47.5	62.5
3am	28.3	61.3	39.4	38.1	61.3

Key: T_{am} =Ambient Temperature, Amb.R-H = Ambient Relative Humidity, T_{tm} = temperature of the thermal mass, T_{tmds} = temperature of the thermal mass at discharged point inside the Chamber, R-H = Relative Humidity.

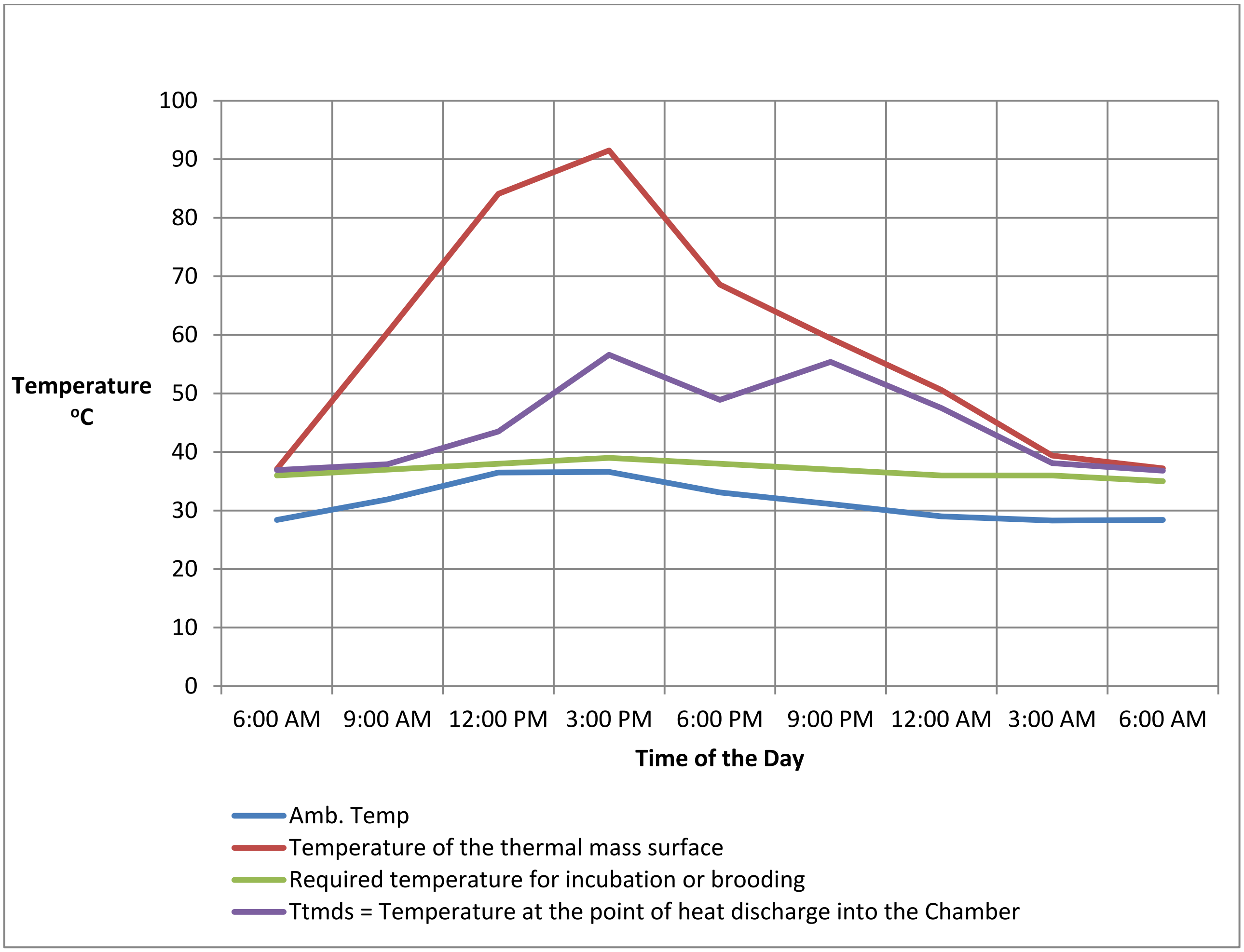

Figure 2: Graph of Temperature against Time of the Day

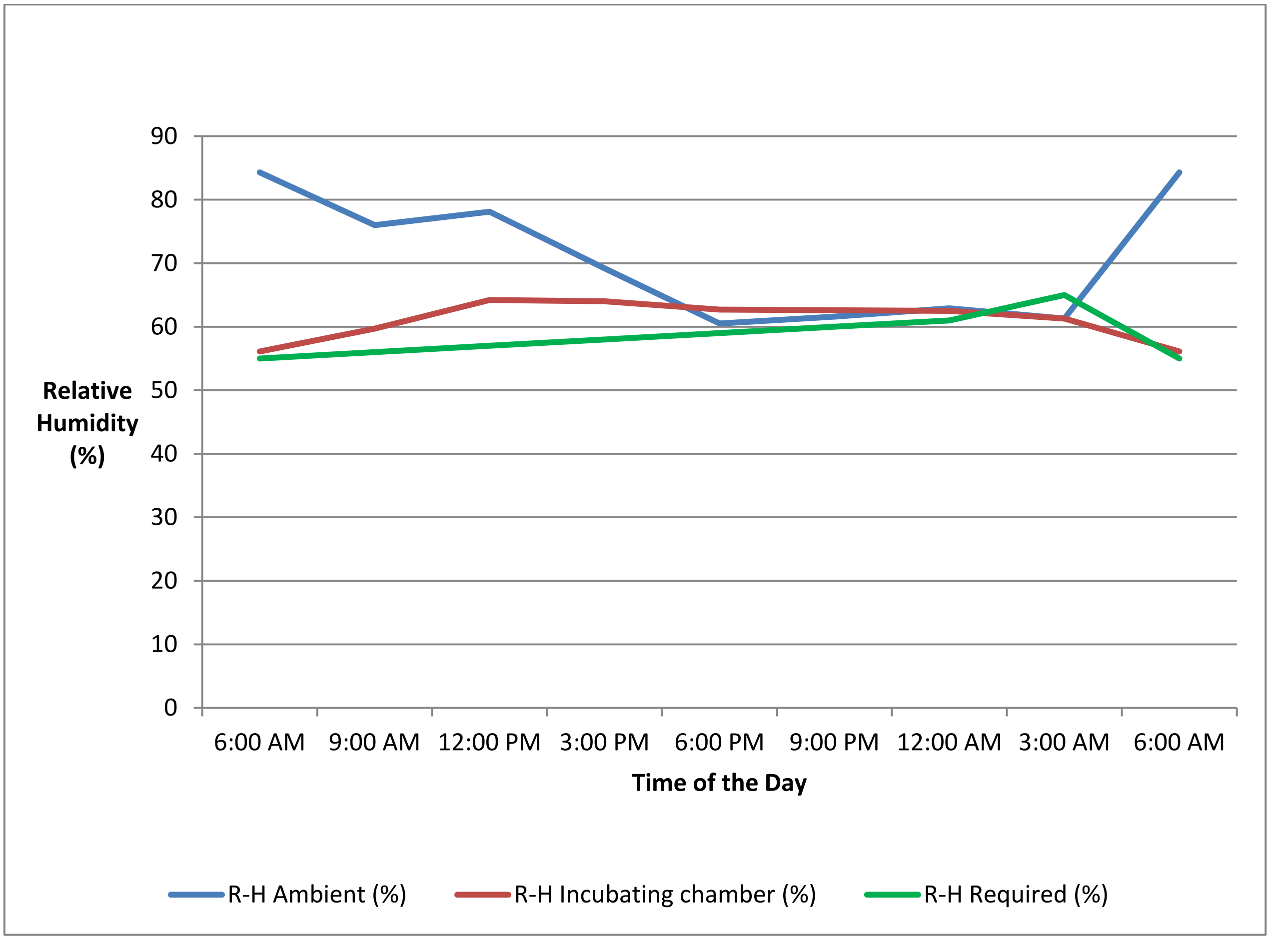

Figure 3: Graph of Relative Humidity against Time of the Day

Relative Humidity—the relative humidity of the Chamber of the system at various points was determined using the hygrometer (wet and dry thermometer type). The required relative humidity level during normal incubation or brooding is usually between 50 to 65 percent, with an increase to about 65 to 70 percent about the last 3 days for incubation. The relative humidity of Makurdi is overly high, however, where there was need for increased humidity, a pan of warm water was placed in the Chamber while decrease in relative humidity was achieved using a locally produced dehumidifier made of activated charcoal. The water pan surface was half as large as the surface of the floor of the system.

CONCLUSION

In conclusion, the development of a passive solar system for poultry egg incubation and brooding of day old chicks using local materials was found to be suitable for this location. The result of the internal environment of the solar system shows promising temperature range that can incubate fertile eggs and also brood day old chicks. It is recommended however that the insulation materials be improved upon to allow minimal loss of the stored heat to the surrounding via the walls of the system. A better heat controlled and automatic device can be included if intended for incubation which requires turning of the fertile eggs.

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