The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 01 || Series II || Pages || PP 46-67| 2020 ||
ISSN (e): 2319-1813 ISSN (p): 23-19-1805

Poultry Brooding Pen Heated By Passive Solar Energy System - Investigating the Effect of Thermal Wall Thickness on the Collection Efficiency

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--*ABSTRACT*---

A large-scale poultry chick brooding pen heated solely with the Trombe wall system was designed to make use of locally available building and energy storage materials. This study was undertaken to use computer simulation to determine the effect of the thermal wall thickness on the hourly variation of its efficiency. Trombe walls of thicknesses 20cm, 25cm, 30cm, 35cm, 40cm, and 45cm were investigated in this work. It was found that the 20cm thick wall had the highest average efficiency of 82.50 % in the month of June while the 45cm thick wall gave the lowest average efficiency of 10.30 % in the month of February. From these results, it was concluded that the thickness of the wall has significant effect on the collection efficiency of the Trombe wall system.

KEYWORDS: *Trombe wall, poultry brooding, collection efficiency, computer simulation*

Date of Submission: 20-01-2020 Date of Acceptance: 05-02-2020

I. INTRODUCTION

Poultry is an essential component of the agricultural sector in that it is a major source of protein of high biological value needed for optimum health of the citizenry. It also provides raw materials for some industries and promotes crop agriculture through provision of manure (Olaniyan 2004, Agbo 2004).

But, there is a widening gap between demand and supply of poultry products. This is attributed to such factors as high-energy consumption cost as well as inefficient and inappropriate production technology employed the farmers.

The technology includes the use of conventional sources of energy for the brooding of chicks. Common sources of electricity and fossil fuels used are not only non-renewable but also pollute the environment in which the birds are brooded (Okonkwo 1993a, Echiegu 1993, and Okonkwo and Aguwamba 1997).

The solution to this problem is to use a source of energy that is renewable, affordable, and environmentally friendly for poultry chick brooding, which is the most delicate period in poultry production. The energy from the Sun meets these requirements. Okpani (2002) found that if the irradiance on only 1 percent of the Earth's surface could be converted into useful energy with 10 percent efficiency, solar energy could provide the energy needs of all the people on Earth.

However, large-scale utilization of solar energy is fraught with problems due to the two main limitations of solar energy. The first limitation is the low flux density of solar radiation. This necessitates the use of large surfaces to collect solar energy. The second limitation is its intermittency. Solar energy has a regular daily and regular annual cycle, and is unavailable during periods of bad weather. These daily and seasonal variations in irradiance, exacerbated by variations due to weather, introduce special problems in storage and distribution of this energy which are entirely different from problems involved in the utilization of conventional energy sources as mentioned by Berg (1976) and Iqball (1983). These problems are solved by the use of a passive solar energy system, the Trombe wall system, to heat poultry brooding pens.

The passive solar thermal storage (Trombe) wall system was invented and patented by Edward L. S. Morse in the USA in 1881(US Patent 246626), but it was ignored for decades. In the 1960's the idea was revived, developed and popularized by Engineer Felix Trombe of France in collaboration with Architect Jacques Michael following the construction of a passive solar house using the principle in Odeilo, France (Shtrakov and Stoilov, 2005; Torcellini and Pless, 2004).

A typical Trombe wall consists basically of a south facing 200 – 450mm thick adobe, masonry or concrete wall coated with a dark heat absorbing material and faced with a single or double layer of glass placed 20 to 50mm from the wall to create a small sunspace. The basic structure is shown in fig. 1.

The brooding room is heated by solar energy incident on the south facing wall through the processes of convection, conduction and radiation.

Solar radiation passing through the glass cover is converted into heat when it strikes the wall's outer surface. Part of the heat generated (35 – 40%) is used to warm the air in the sunspace. The heated air rises and as it flows into the brooder room through the upper vent in the wall cold air from the room flows through the lower vent into the sunspace. In this way a natural convection current is set up.

The remaining heat generated (55 – 60%) at the outer surface of the wall is transferred by conduction to the inner surface, being driven by the temperature difference between the two surfaces. The heat transmitted to the inner surface of the wall is released by radiation to heat the brooder room.

The wall is made south facing in the Northern Hemisphere for maximum solar energy collection all the year round. For Enugu (Lat. 6.47^{O} N, Long. 7.55^{O} E) the sun is northwards only between April 10th and September 3rd, when solar declination is higher than the latitude. This is the period of the year when diffuse radiation predominates because of cloud cover. For the rest of the year the sun is southwards and direct radiation on the wall is the main contributor.

The wall is made unusually thick so that it takes some time called time lag for the heat received at the outer surface to reach the inner surface. Depending on the thickness and the material of which the wall is made the time lag is 8 to 10 hours. This means that the brooder room continues to receive slow even heating for many hours even after sunset, in fact until the next sunrise. To augment the heat supply a pebble bed bin may be incorporated into the Trombe wall system for additional solar collection and storage .

The outside surface of the wall is coated with a dark spectrally selective material. A spectrally selective surface combines a high absorbance for solar radiation with a low emittance in the infrared range. This combination of surface characteristics is possible because 98% of the energy in incoming solar radiation is contained within wavelengths below 3000nm, whereas 99 percent of the radiation emitted by the black surface is at wavelengths longer than 3000nm.

The wall is covered with one or two sheets of glass. This reduces significantly the convective and radiative heat losses of the absorber surface due to the selective transmittance of glass. It is highly

transparent to the incoming short wave solar radiation but virtually opaque to the long wave infrared radiation emitted by the absorber surface.

From the foregoing it can be seen that the effectiveness of the Trombe wall system, like any other flat plate collector, depends on the special materials used for its construction namely transparent materials, selective surfaces and thermal storage materials.

When applied to poultry brooding, the special merits of passive solar energy include the fact that (a) it is not affected by non-availability of electricity or frequent power failures (which are a very common feature in developing countries), (b) it creates a pollution-free environment conducive for poultry brooding, (c) it is free from fire hazards, (d) it produces birds of highly improved biological performance, and (e) the cost of energy for brooding is zero (beyond the capital cost of the system). Installed passive solar systems can last for decades without supplementary energy supply and with little operations or maintenance cost (Echiegu 1986, Okonkwo, 1993b).

The rational design of a solar thermal system requires knowledge of the dynamic interaction of all solar system components, namely solar collection, thermal storage fluid circulation, energy distribution, and controls. Although essential and valuable experience can be gained by testing solar systems in the field, the generalization of experimental results and their applications in other locations can best be handled by a modeling approach. A very useful and accurate type of modeling is computer simulation. Results from computer simulation of solar systems are very helpful for system design since they allow one to learn about complex interactions of a large number of variables in a short time whereas experiments are time consuming and costly.

The purpose of this paper is to use computer simulation to determine, for a whole year, the hour-by-hour efficiency of the designed poultry brooder pen heated by the Trombe wall system. But since only monthly mean daily values of meteorological data are available, calculations are performed for the representative or characteristic day of each month.

II. MATERIALS AND METHODS

For the purpose carrying out the thermal analysis of the Trombe wall system, various models have been used to represent the system. Examples include those of Shtrakov and Stoilov (2005), Okpani et al, 2008; Zrikem and

Bilgen (1987), Bansal and Gour (1997), Knowles(1983), Duffin and Knowles(1981), Balcomb et al (1977) and Bilgen and Chaaban(1982), Duffin and Knowles(1985).

The modeling equations were derived from consideration of heat and mass balances for each component element of the system as depicted in Fig. 2 (Shtrakov and Stoilov, 2005).

In forming the equations, the following assumptions were made

1. The heat transfer in the massive wall is one dimensional. This is justified by the fact that there is very little vertical temperature variation in the wall (Shtrakov and Stoilov, 2005).
2. The heat transfer through the glass cover is at steady state whereas that through the wall is time dependent(Sehold and Clinton,1979).
3. Material thermophysical properties are independent of temperature because of the small temperature variation involved (Zrikem and Bilgen, 1987).
4. All surfaces are considered as grey bodies with diffuse reflection and emission (Shtrakov and Stoilov, 2005).
5. Air is considered as a nonparticipating medium in radiation heat exchange (Kreith and Kreider,1978).
6. Heat gain by the brooder room is only through the outer surface of the Trombe wall but heat loss is through all the surfaces of the room – floor, ceiling, walls, doors and windows. This results in a slight under simplification of the heat gain since there are actual heat gains through the building walls and windows and internal heat generation. But these are negligible compared to heat gain through the outer surface of the thermal wall.

Figure 1 shows the Trombe wall system heat transfer parameters.

The temperatures designated are sky (T_{sk}), ambient (T_{am}), glass cover (T_{gc}), air gap (T_{ag}), Trombe wall front surface (T_{fs}), Trombe wall back surface(T_{bs}), brooding room(T_{rm}) and brooding room surfaces (T_{rs}). The heat transfer coefficient designated are h_{cf}, the radiation heat transfer coefficient between the glass cover and the Trombe wall front surface; h_{cw}, the wind convection heat transfer coefficient from the glass cover; h_{cg}, the convection heat transfer coefficient from the glass cover to the air gap; h_{cs}, the radiation heat transfer coefficient between the glass cover and the sky; h_{fg}, the convection heat transfer coefficient from the Trombe wall outer surface to the air in the air gap; h_{br}, the radiation heat transfer coefficient from the back surface of the Trombe wall to the brooder room; h_{bk}, the radiation heat transfer coefficient between the Trombe wall back surface and the surfaces of the room; h_{br}, the radiation heat transfer coefficient from the back surface of the Trombe wall to the brooder room; h_{bk}, the radiation heat transfer coefficient between the Trombe wall back surface and the surfaces of the room.

For full details of the thermal analysis of the Trombe wall system see Okpani (2009).

The hourly efficiency η_H of the Trombe wall system is given by (Bansal and Gour, 1997; Knowles,1983)

$$\eta_H = \frac{Q_{ud}}{Q_{gc}} \qquad \mathbf{1}$$

where Q_{ud} is the total useful energy delivered into the room during the hour and Q_{gc} is the solar energy incident on the glass cover during the same hour. The total energy delivered to the room is given by

$$Q_{ud} = Q_{ag} + Q_{tr} \qquad \mathbf{2}$$

where Q_{ag} is the heat transferred into the room by the heated air in the air gap and Q_{tr} is the heat transferred to the room by conduction through the Trombe wall.

The solar energy incident on the glass cover during the hour is given by

$$Q_{gc} = A_{gc} I_{gc} \qquad \mathbf{3}$$

where A_{gc} is the glass cover surface area and I_{gc} is the hourly total solar radiation on the glass cover.

The design parameters and the meteorological data used are shown in Tables 1 and 2, respectively.

A computer program is drawn to use the design parameters meteorological data for the representative day of the month as inputs and calculate the hourly and daily efficiencies of the system. The flow chart for the computer program is shown in Figure 3.

III. RESULTS

Figures 4 to 15 show the hourly efficiency of the systemfor Trombe wall thicknesses of 20cm, 25cm, 30cm, 35cm, 40cm and 45cm for the characteristic day in the months of January to December respectively. Table 3 shows the average hourly efficiency of the systemfor Trombe wall thicknesses of 20cm, 25cm, 30cm, 35cm, 40cm and 45cm for the characteristic day in the months of January to December.

IV. DISCUSSION

A careful examination of the graphs in Figures 3 to 14, shows that the daily swing of the hourly efficiency decreases as the wall thickness increases from 20cm to 45cm for all the months of the year.

From Table 3, it can be observed that the system hourly efficiency has the lowest average value of 10.3% in February for the 45 cm thick wall and the highest average value of 82.5% in June for the 20 cm thick wall.

These figures show clearly that it is possible to create an environment heated with solar energy but independent of fluctuations of weather. This is the ideal condition for poultry brooding. The temperature comfort zones for poultry brooding are 35^{O}C for week 1, 31 – 29^{O}C for week 2, 29 – 27^{O}C for week 3 and 25^{O}C (ambient) from week 4 onwards. (Okpani, 2009; Okpani and Nnabuchi, 2009)

Comparing the variation of efficiency with that of solar radiation (Tables 2 and 3) we can see that generally the months that have high solar radiation are associated with low efficiency and vice versa. This trend is the opposite of what is obtainable with ordinary solar collectors(Kreith and Kreider, 1978). But the Trombe wall system is not an ordinary solar collector because it incorporates energy storage. Hence for the period when solar radiation(the input energy) is low the total energy transmitted to the brooder room(the output energy) a large part of which is the stored energy is relatively high. Therefore the efficiency, i.e. the ratio of output energy to input energy is relatively high. This is in harmony with the results obtained by Pine(1997). The comparatively high efficiency of the system indicates that the project is worth the effort and finance needed to construct it. Hence it is highly recommended.

This research work undertaken here is not just on the use of solar energy system but on the use of a passive solar energy system,the Trombe wall system, whose advantages include the following:

1. The system is easy to build and requires little special knowledge to construct since it relies so closely on traditional methods of building construction.
2. The initial cost is relatively low since the system is simple and the building materials are readily available.
3. The system is very reliable and easy to maintain because of the absence of complex mechanical equipment as valves, fans, pumps, electric control devices, etc.
4. The system has inherently high collection efficiency as we have seen since it normally operates with low temperature rises in the collector system.
5. It. is easy for the users of the system to understand and operate because there are no complex mechanical parts.
6. A passive solar system is, in its basic form, independent of other energy supplies in operation. This is because there are no pumps, fans etc, relying on electricity. Hence the system is not subject to energy supply disturbances

V. CONCLUSION

The major finding of this study is that the thickness of the thermal wall has significant effect on the efficiency of the system. For a thermal wall of given thickness the temperature of back surface of the wall is almost constant irrespective of weather conditions. This helps to maintain the brooder room temperature at any desired value which is usually above ambient for proper chick brooding.

Hence the Trombe wall system can be used to avert the inefficient and inappropriate production technology employed by the farmers to heat the chick brooding room and to solve the problems that fraught large-scale utilization of solar energy due to its limitations.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to the management and staff of the Nigerian Meteorological Agency South East Zone, Akanu Ibiam International Airport Enugu, for their cooperation in willingly giving him access to their records.

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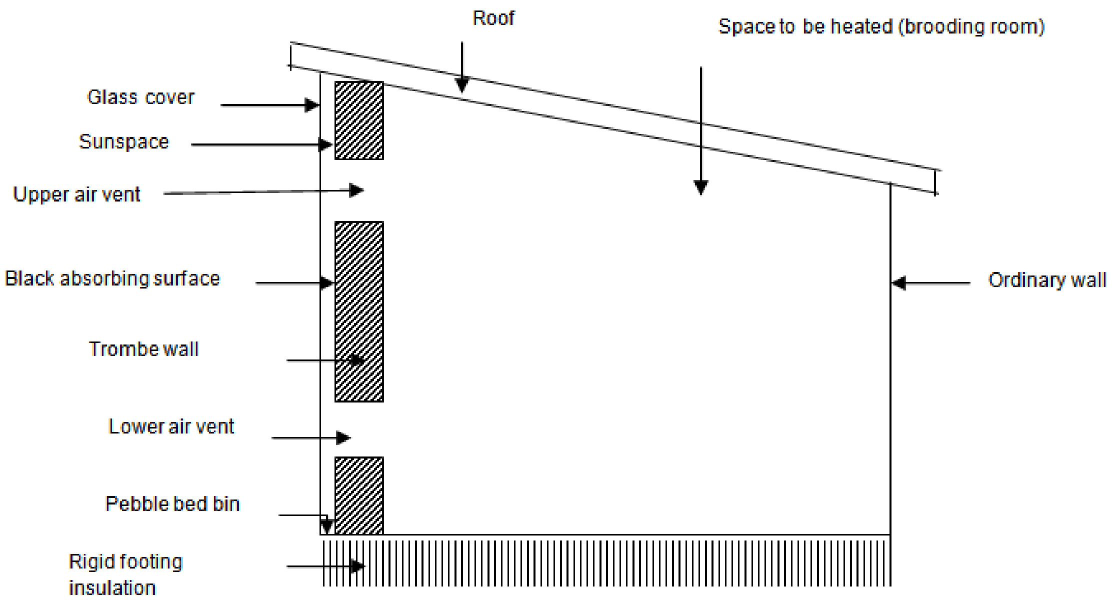

Fig. 1 **the Trombe Wall System**

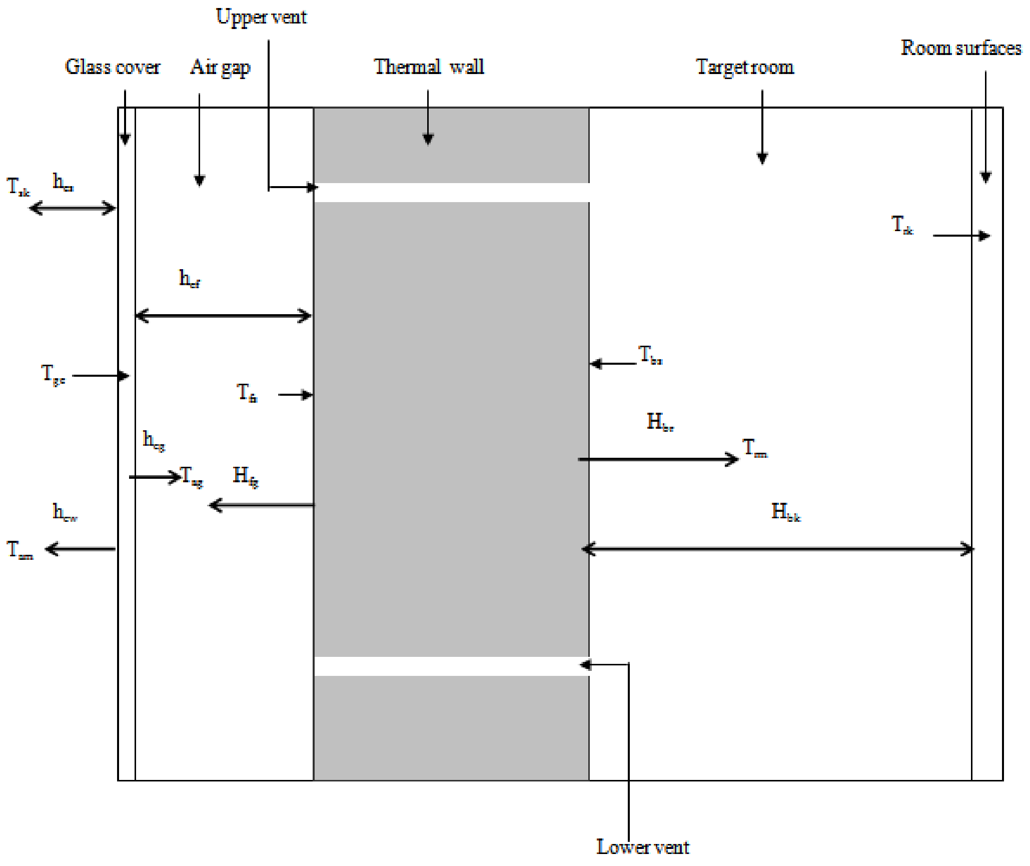

Table 1 : Design parameters

Description	Value
Room floor area, A_{fl}	11.925 m^2
Room walls area, A_{wl}	23.520 m^2
Room roof area, A_{rf}	11.925 m^2
Room total surface area, A_{rm}	47.370 m^2
Floor U-value, U_{fl}	0.72 $Wm^{-2}K^{-1}$
Wall U-value, U_{wl}	2.92 $Wm^{-2}K^{-1}$
Roof U-value, $_{Urf}$	0.115 $Wm^{-2}K^{-1}$
Room mean U-value, U_{rm}	1.660 $Wm^{-2}K^{-1}$
Door crack length, L_{cd}	4.50 m
Window crack length, L_{cw}	2.70 m
Door area, A_{dr}	1.190 m^2
Window area, A_{wd}	0.455 m^2
Trombe wall surface area, A_{tw}	6.30 m^2
Trombe wall height, H_{tw}	1.40 m
Trombe wall thickness, D_{tw}	Variable: 0.20m, 0.25m, 0.30m, 0.35m, 0.40m, 0.45m
Trombe wall specific heat capacity, c_w	880 $Jkg^{-1}K^{-1}$
Trombe wall density, ρ_w	2720 $kg\ m^{-3}$
Trombe wall thermal conductivity, κ_w	1.41 $Wm^{-1}K^{-1}$
Trombe wall surface coating absorbance, α_{ss}	0.87
Trombe wall outer surface IR emittance, ε_{fs}	0.09
Trombe wall inner surface IR emittance, ε_{bs}	0.88
Trombe wall upper vent area, A_{uv}	0.096 m^2
Distance between upper and lower vents, D_v	1.155 m
Air gap width, Wag	0.050 m
Glass cover short wave absorbance, α_{gc}	0.065
Glass cover IR emittance, ε_{gc}	0.941
Glass cover short wave transmittance, τ_{gc}	0.896
Ground reflectance, ρ_{gr}	0.35
Air viscosity at 300K, μ_a	$1.983 \times 10^{-5}\ kgm^{-1}$
Air density at 300K, ρ_a	1.7774 kg^{-3}
Air specific heat capacity at constant pressure, c_{pa}	1005.7 $Jkg^{-1}K^{-1}$
Air conductivity, κ_a	0.0262 $Wm^{-1}K^{-1}$
Space interval, Δx	0.02 m
Time interval, Δt	3600 s
Tilt angle, β	90º ($\pi/2$ rads)
Latitude(Enugu), ϕ	6.47 º N

Table 2 : Meteorological data

Month	[a] Monthly mean daily solar radiation on a horizontal surface (MJ m^{-2} day^{-1})	[b] Monthly mean wind velocity (ms^{-1})	[b] Monthly mean daily maximum temperatures (°C)	[b] Monthly mean daily minimum temperatures (°C)	[b] Monthly mean daily average temperatures (°C)	Characteristic day number for the month
JAN	16.0992	2.81	34.5	24.6	29.0	17
FEB	17.6508	3.03	36.7	28.8	31.8	45
MAR	18.0468	3.37	35.1	26.6	31.7	74
APR	18.9316	3.37	34.6	27.2	30.9	105
MAY	17.9316	3.05	33.8	25.9	29.6	135
JUN	15.5952	2.95	32.7	25.3	29.0	161
JUL	14.2344	3.12	30.9	24.9	27.8	199
AUG	14.3748	3.28	30.0	24.4	27.3	239
SEP	15.2424	3.75	31.3	24.4	27.9	261
OCT	14.5800	2.50	31.8	24.6	28.3	292
NOV	17.2980	2.39	33.8	26.0	29.8	322
DEC	16.4556	2.87	34.0	25.3	29.6	347

[a] From *Renewable Energy for Rural Industrialization and Development in Nigeria*, Abuja: UNIDO (Dec. 2003).

[b] From the records of the Nigerian Meteorological Agency, South Eastern Zone, Akanu Ibiam International Airport, Enugu.

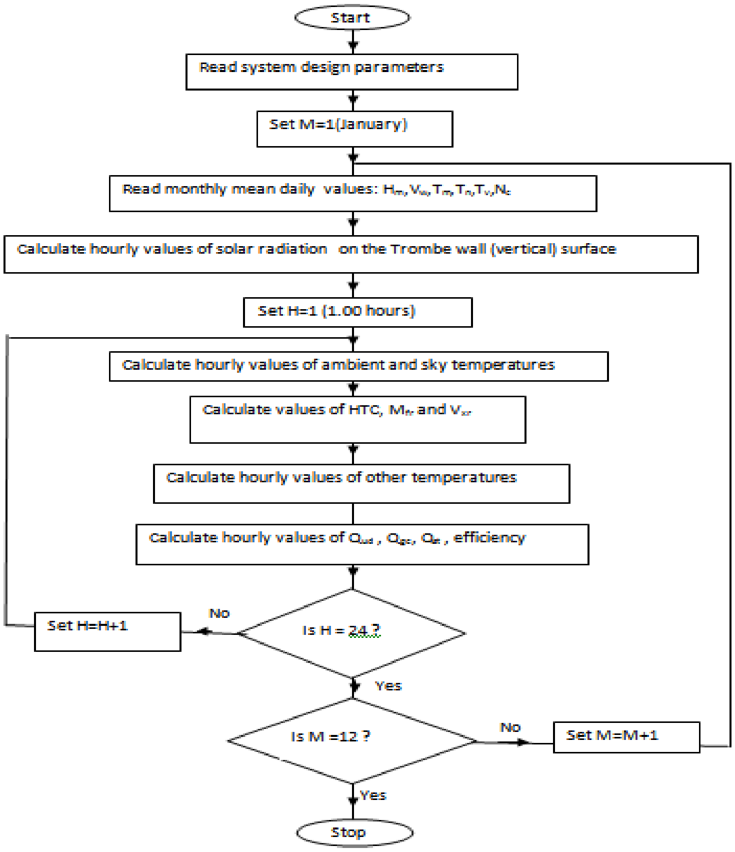

Fig.3: Flow Chart for the Computer Program

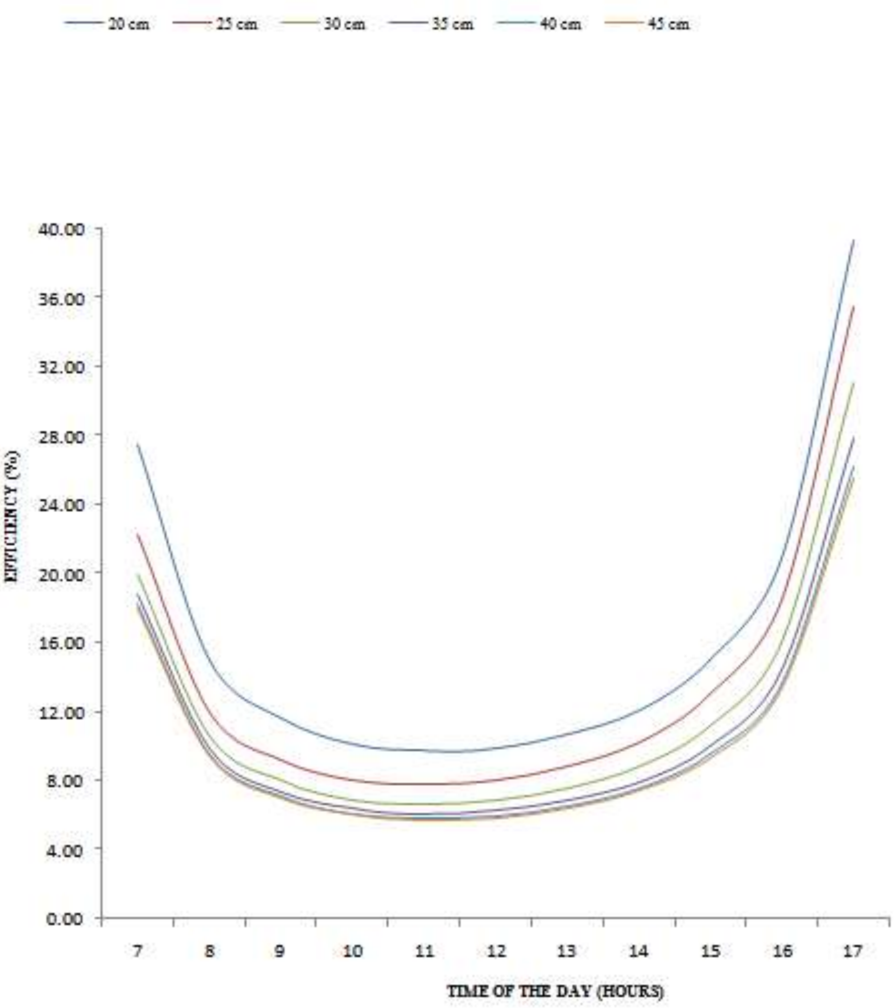

Fig. 4: Hourly variation of the system efficiency for the month of January

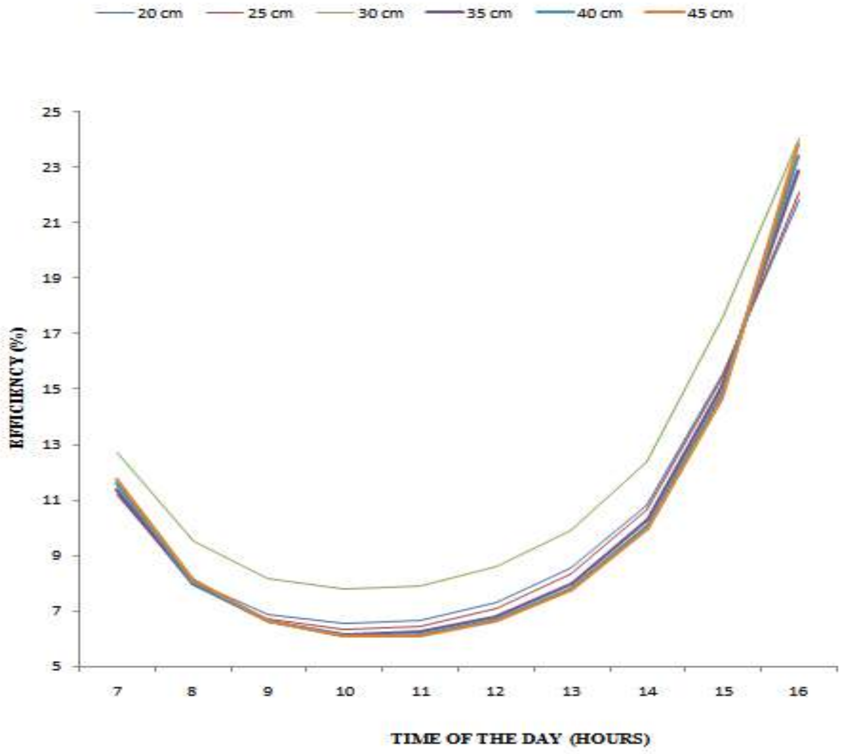

Fig. 5: Hourly variation of the system efficiency for the month of February

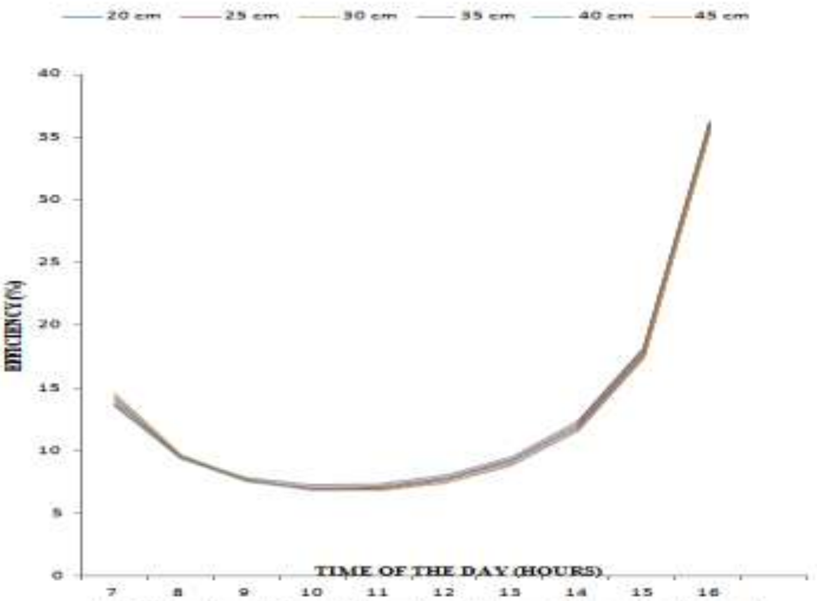

Fig. 6: Hourly variation of the system efficiency for the month of March

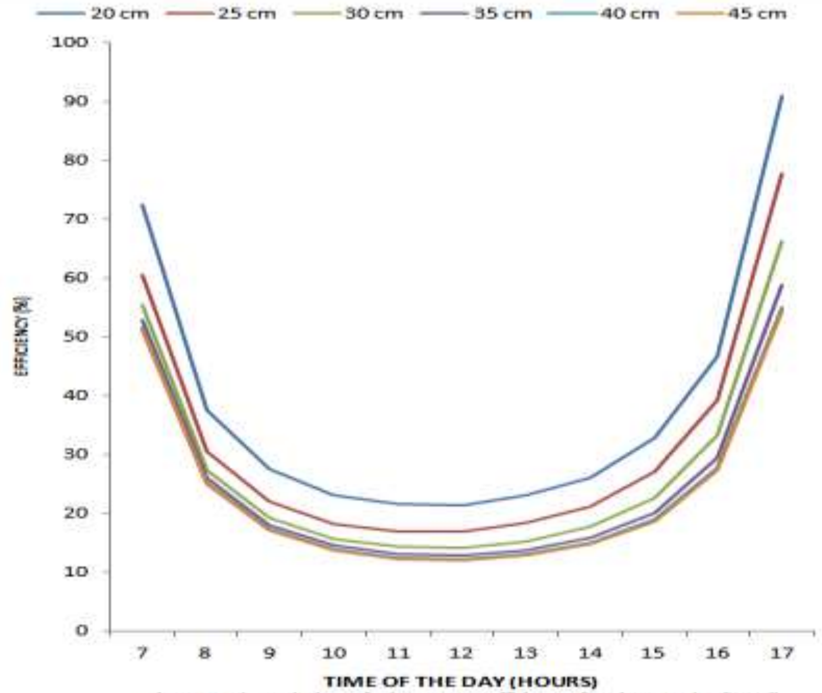

Fig.7: Hourly variation of the system efficiency for the month of April

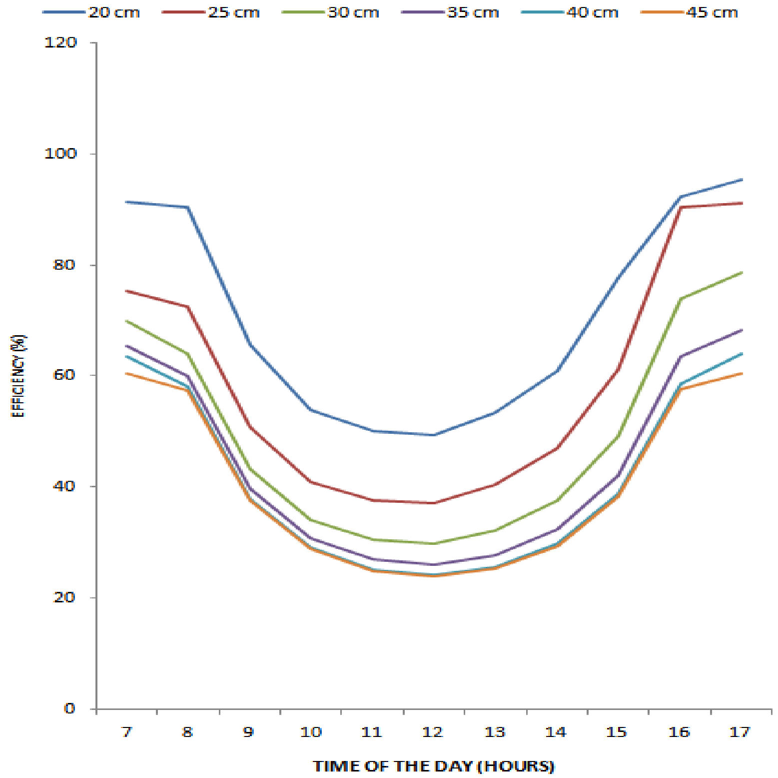

Fig.8: Hourly variation of the system efficiency for the month of May

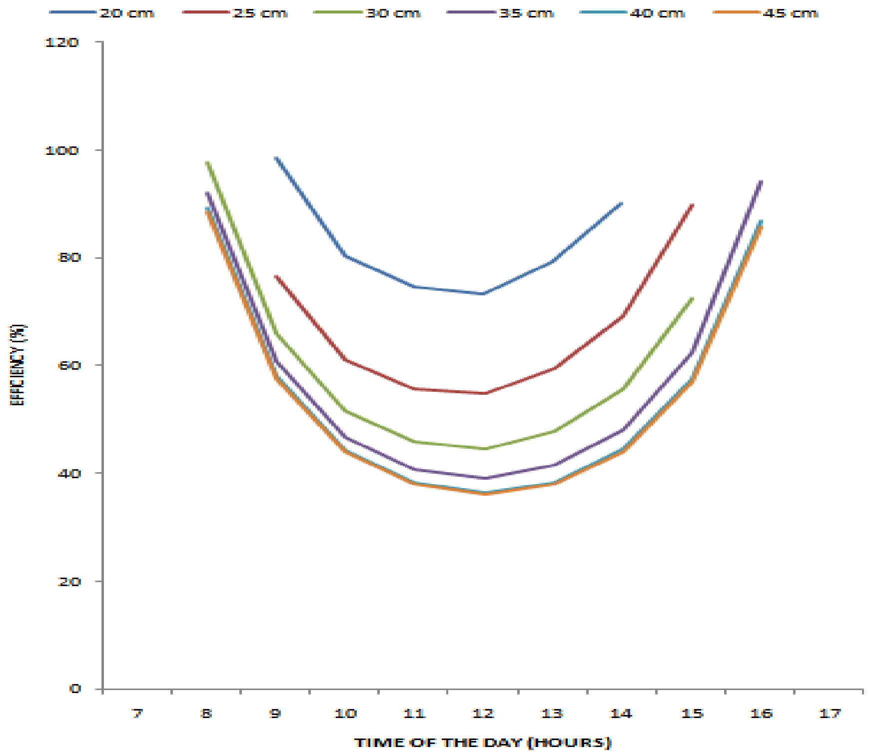

Fig.9: Hourly variation of the system efficiency for the month of June

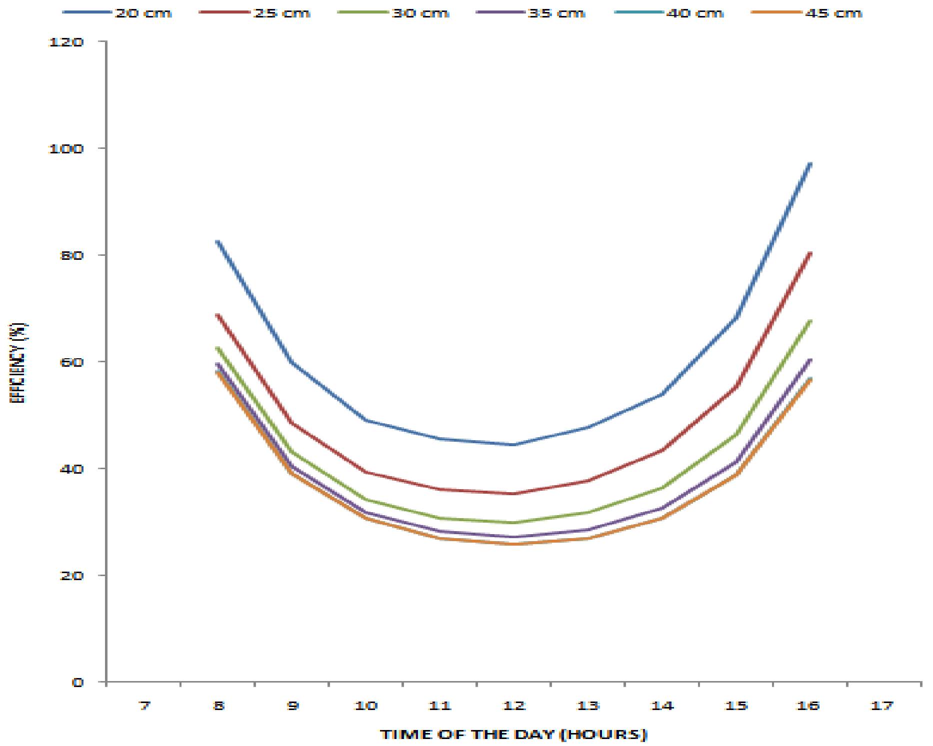

Fig.10: Hourly variation of the system efficiency for the month of July

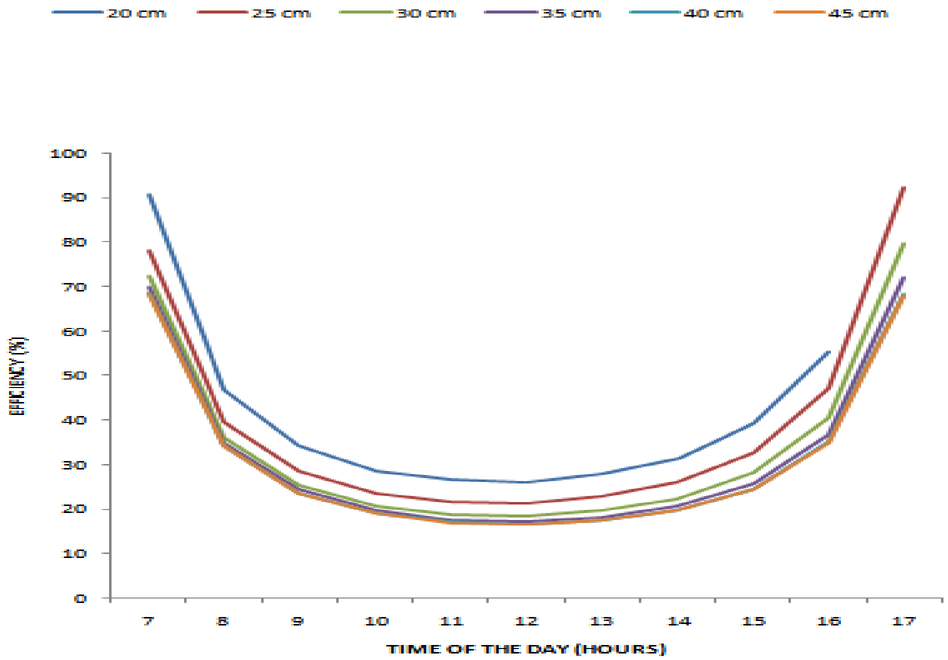

Fig.11: Hourly variation of the system efficiency for the month of August

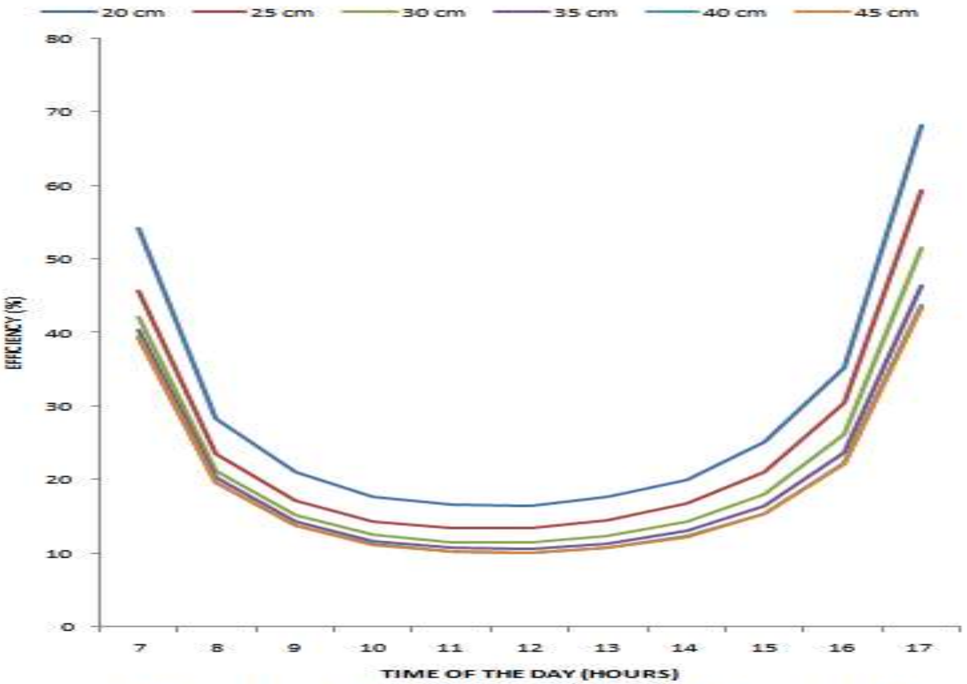

Fig.12: Hourly variation of the system efficiency for the month of September

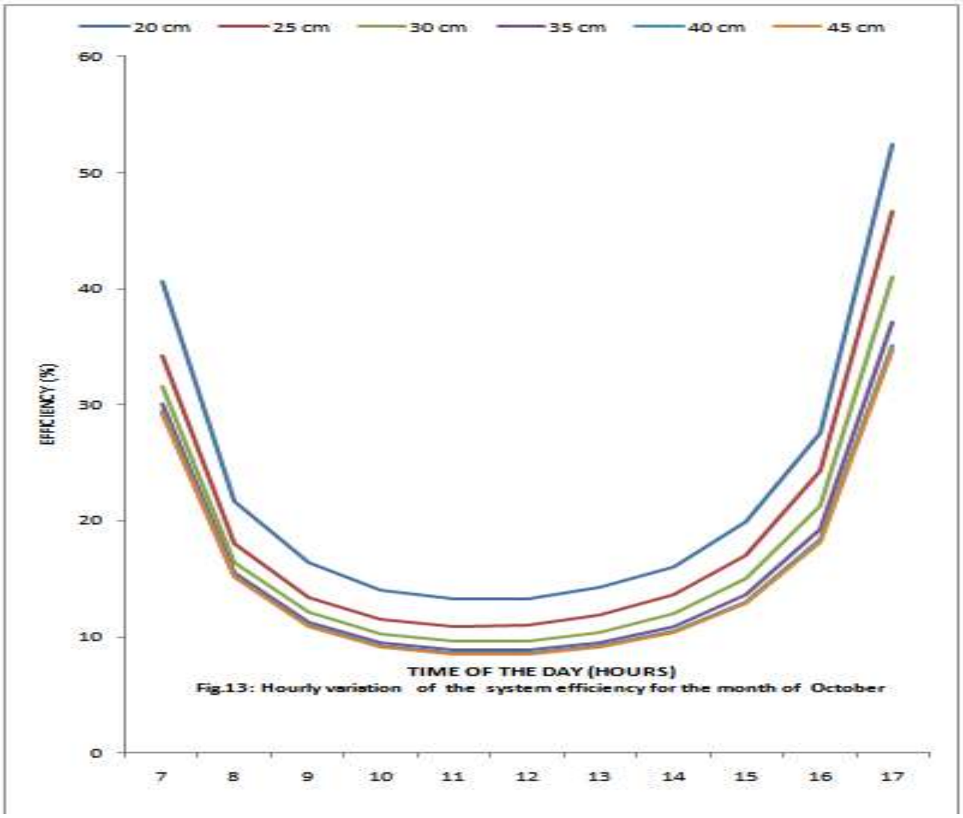

Fig.13: Hourly variation of the system efficiency for the month of October

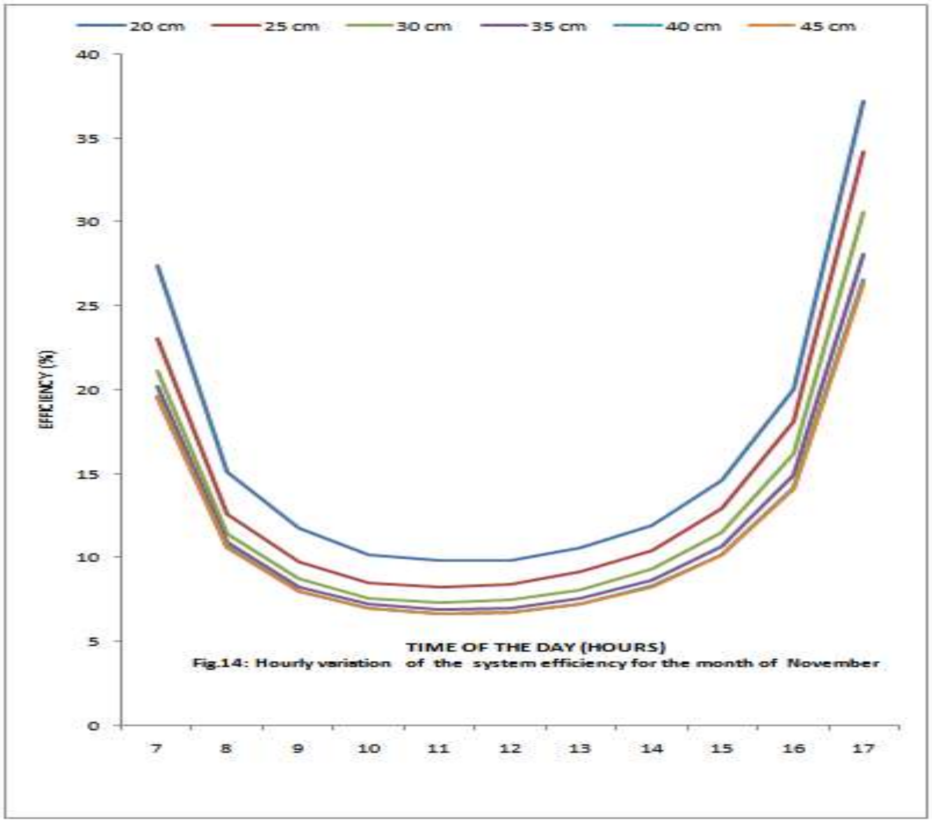

Fig.14: Hourly variation of the system efficiency for the month of November

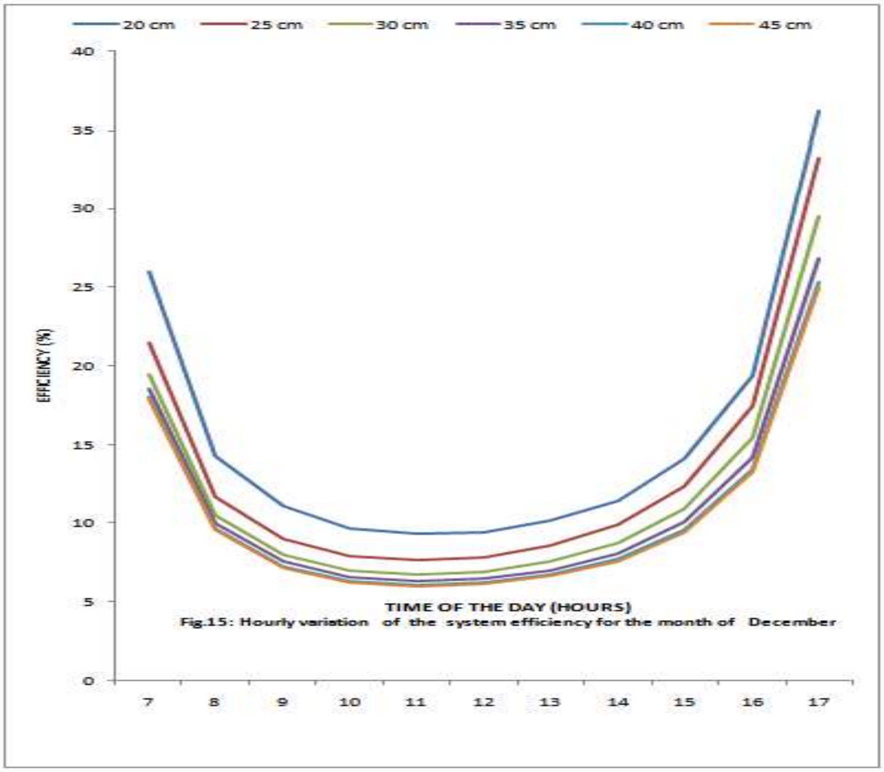

Fig.15: Hourly variation of the system efficiency for the month of December

Table 3 : Average hourly efficiency of the systemfor Trombe wall thicknesses of 20cm, 25cm, 30cm, 35cm, 40cm and 45cm for the characteristic day in the months of January to December

MONTH	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm
JAN	16.55	13.96	12.17	11.09	10.58	10.37
FEB	10.41	10.3	11.92	10.25	10.27	10.3
MAR	13.02	12.89	12.79	12.72	12.67	12.66
APR	38.52	31.71	27.46	25.02	23.81	23.61
MAY	71.03	58.45	41.41	49.41	41.34	40.42
JUN	82.5	66.7	60.23	58.35	54.85	54.29
JUL	61.01	49.33	42.55	38.89	37-23	37.02
AUG	40.8	39.39	34.88	32.39	31.24	31.09
SEP	29.23	24.54	21.59	19.9	18.98	18.94
OCT	22.69	19.32	17.16	15.89	15.26	15.15
NOV	16.22	14.13	12.7	11.84	11.39	11.31
DEC	15.53	13.39	11.92	11.02	10.55	10.45

P. E. Okpani"Poultry Brooding Pen Heated By Passive Solar Energy System - Investigating the Effect of Thermal Wall Thickness on the Collection Efficiency " *The International Journal of Engineering and Science (IJES)*, 9(01) (2020): 46-67.