International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 8, August, 2013

Identification of Suitable Material for Solar Thermal Collector in Rural Areas of Zaria Nigeria

Eke, Akachukwu Ben
Department of Agricultural and Bio- Resources Engineering
Collage of Engineering and Engineering Technology
Michael Okpara University of Agriculture
Umudike, Umuahia, Abia State, Nigeria.

ASTRACT

Energy usage is indispensible inhuman development and a major determination factor in technological development. However, artificial energy supply is generally low and scarce in rural areas of Nigeria. Hence, this work is aimed at performance evaluation of commonly available solar thermal energy collector materials in Zaria, Nigeria, and to identify the most appropriate solar thermal energy collector material to enhance useful energy availability to rural dwellers. Commonly available local materials, such as wood, cement, mud and metal were each employed to fabricate a solar dryer. Thermal energy generation of the dryers were monitored and sliced tomato was utilized to test-run the dryers, while open sun drying was used as control. The average air outlet temperature for wood, cement, mud and metal solar collectors increased to 119.2, 123.1, 128.9 and 129.5 respectively over the average ambient air temperature of 30.5 ^{o}C. Tomato drying an\alysis of the solar dryers indicated that wood, cement, mud and metal dryers had 46, 47, 60 and 60 percent savings in drying time respectively, when compared with open sun drying. Likewise, the solar dryers drying efficiency of open sun drying system, wood, cement and metal solar dryers were 7.38, 19.56, 20.25, 26.91 and 27.00 percent in that order. Mud solar dryer has the lowest production cost of ten thousand naira, while the percentage increase in prices of cement, wood, and metal dryers against the mud dryer were 109.40%, 77.20% and 200% respectively. Based on the results and the cost of production of the dryers, mud was identified as commonly available, affordable and most suitable material for construction of direct mode natural convection solar dryer for rural farmers in Zaria, Nigeria.

Keywords: *Solar, Energy, Collector, Crop, Drying, Drying efficiencies*

I. INTRODUCTION

Availability and efficient application of energy is a prerequisite to individual and national development. However energy supply is generally low and scarce in rural areas of Nigeria, where majority of the farmers dwell. Nigeria is endowed with abundant renewable energy sources, such as solar energy, wind energy, biomass energy, small hydro-energy and others, which have minimal or zero supply logistic problems, (GENI, 2013). Although the Federal Government of Nigeria is increasing effort to supply electricity in rural Areas, still the farmers continued to preserve their agricultural products by drying in open sun. This is because the national supply of electricity to rural dwellers is erratic or not available. On the order hand, fossil fuel is very costly and unaffordable to the farmers. The most commonly available and affordable energy supply to the rural dwellers is solar energy. Farmers mostly employ solar thermal energy in processing agricultural materials, and for other domestic use. Nielsen (2005) gave the total solar energy intercepted on earth surface in a year as 5.5 exaJoules [EJ/y]. Zhiqiang (2000) asserted that introduction of solar energy technology in the rural areas of China will help to abate the excessive deforestation which is already causing ecological deterioration.

It was observed that farmers in Zaria and her neighbouring villages commonly spread their crops for drying on surface of rock, on top of mud roof, road sides and on local raffia baskets. These several surfaces served as solar thermal collectors. Agricultural materials spread on these surfaces are left to dry in the open sun at ambient weather conditions; therefore, the products usually take a long period to dry. Farmers reported that during the rainy and dry seasons, maize took 10 days and 7 days respectively to dry to shelf storage moisture content, similarly okra took 7 and 5 days to dry (1991). After such a long period of drying the products were contaminated, deteriorated or completely spoilt. However the abundant solar energy supply farmers normally use in open sun drying can be harnessed with solar collector for effective drying of agricultural materials.

Wikipedia (2010) defined a solar collector as a device for converting the energy in solar radiation into a more usable or storable energy. Many researchers have designed flat plate surface solar collector with different materials. Wikipedia (2011) reported that new polymer temperate silicones flat plate collectors are now being produced in Europe. Yasser et al. (2009) equally used 9, 10-diphenylanthracene for solar cell collector which indicated an improvement in light harvesting and charge carrier transfer. Angewandte (2010) indicated that fulvalene diruthenium oercome when used as solar collector material was able to store thermal energy and release same when direct solar radiation was not available. Kruidhof and Vander (1979) reported that Cobalt oxide on bright nickel-electroplated steel was used as a spectrally selective material in solar collector with a good result. Plastic material can equally be used as a low temperature solar collector, but it deteriorates quickly due to ultra-violet radiation effect (AMECO, 2009). John (2005) stated that plastic material was successfully used as solar collector for solar swimming pool, where the water was heated up to 27 ^{0}C during the cold period. Wood, metal and Galvanically applied selective coating, such as black chrome, black nickel and aluminum oxide with nickel were used as natural convective heat flow solar collectors for solar dryers (Heindl 2010). Parker (1978) investigated the effect of plane and vee-corrugated surfaces made of zinc chromate and painted black on solar energy absorption and found it to be highly efficient. Arinze et al. (1990) fabricated solar collectors with the plate surfaces made of mild and galvanized metal sheets. Akani (1990) used cement plastered surface as solar collector. Also Eke (1991) fabricated dryers made of corrugated roofing zinc and plywood as collector surfaces for solar thermal conversion. All indicated that these materials can be used as solar collectors. However, the Researchers did not compare the thermal energy conversion efficiencies and the affordability of the solar collector materials to the farmers. Therefore this work was undertaken to evaluate the performance of commonly available solar thermal energy collector materials in Zaria and to identify the most appropriate solar thermal energy collect material for the rural farmers.

II. MATERIALS AND METHODS

The farmers spread their crops on the ground, rock surfaces, roadsides, mud roofs, flat surfaces like raffia tray and metal trays. Therefore sheet metal, cemented surface, wood and mud were selected as material for consideration. The design considerations and material selections in this work were based on thermal properties, resistance to weather effects, availability and workability of materials.

Theoretical Framework

Capacity of the Solar Dryers

Interview conducted in the North western zone of Nigeria, where Zaria is located, revealed that farmers have the greatest problems in drying tomato (Olukosi et al.,1990). This is because tomato has high moisture content with soft tissue and needs to be dried at a short time in order to avoid spoilage. The difficulties in drying tomato forced the farmers to dry between 1kg to 5kg of fresh sliced tomato at a batch in open sun, the quantity dried at a time depends on available drying space. The drying operation takes about 13 to 15 days for a batch drying of tomato. Therefore the capacity of each of the prototype solar dryers in this work was chosen to be 10 kg of fresh sliced tomato, which is double the maximum the farmers can dry per batch. Peter and Raymond (1964) gave the shelf storage moisture content of dried tomato as 4.5 percent moisture content (wet basis). Quantity of water to be removed from 10 kg fresh tomato to dry from 93 to 4.5 percent moisture content wet basis was calculated with equation 1 given by (Hendason and Pery 1980);

$$W_w = \frac{MC_i - MC_f}{100}\left(W_p - \left[\frac{W_p M_{wi}}{100}\right]\right) \quad (1)$$

Where;

W_w= weight of water removed from the product (kg),
MC_i= initial moisture content of product (percentage dry basis),
MC_f= Final moisture content of product (percentage dry basis),
W_P=Initial weight of product before drying (kg), M_{wi}=Initial moisture content of product (percentage wet basis)

The collector useful heat energy gain (Q), required to dry 10 kg of tomato from 93 to 4.5 percent moisture content wet basis was obtained using the procedure detailed by (Eke, 2003), as presented in Eq. 2.

$$Q = \left[C_p W_p (T_c - T_a) + L_v \frac{MC_i - MC_f}{100}(W_p - \frac{W_p M_{wi}}{100})\right]\left(\frac{1}{t}\right) \quad (2)$$

Where;
Q=Collector useful heat energy gain. (W),
C_p=Specific heat capacity of the product (J/kg ^{o}C),
W_P=Initial weight of product before drying (kg),
T_c=Collector air outlet temperature (^{o}C),
T_a= Ambient temperature (^{o}C),
L_v = Heat of evaporation of the product (J/kg ^{o}C) and t = Drying time (second)

Determination of the Solar Dryer Area

Duffie and Beckman (1980) gave the model equation as:

$$A_c = \frac{Q}{F_R[IT_r - U_L(T_c - T_a)]} \quad (3)$$

F_R= Collector heat removal factor (dimensionless),
I=Total solar radiation incident on the dryer (W/m),
U_L = Collector overall heat transfer coefficient ($W/m^{2o}C$),
T_r = polythene transmissivity (dimensionless),
A_c = Solar collector area (m^2),

The values of F_R, U_L, I, T_r for polythene and T_c were obtained from (Eke,2003).The area A_c of solar collector was calculated to be $0.60m^2$ while the drying chamber was $0.96m^2$.

System Drying Efficiency

The performances of the four types of solar crop dryers were evaluated by considering their system drying efficiencies and the drying product quality. Brenndorfer et al. (1987) in Akani (1990) gave the expression for System Drying Efficiencies (E_{sd}) as the ratio of the heat required to evaporate a given quantity of moisture from the product to useful heat gain generated by the solar dryer. Thus;

$$E_{sd} = \frac{W_w L_v}{IT_e A_c t} \qquad (4)$$

Feature of the Solar Dryers

Equation 1 to 3 were employed to achieve the size configuration of the direct mode free convection wood –type, cement –type, mud –type and metal –type solar dryers, in the Department of Agricultural Engineering , Ahmadu Bello University ,Zaria. Each of the four dryers consisted of a solar collector of 0.60 m wide, 1.00 m long and a drying chamber of 1.60 m long with same width as the collector, as well as air plenum of 0.065m. The inlet and outlet air plenum provided free convection air flow through the dryer. Transparent polythene sheet of thickness 0.12 mm was used as the collector and drying chamber top cover material.

Wood, cement mud and metal solar collectors (absorber surfaces) were made of plywood, cement mud and metal materials respectively. They were painted black with black oil paint, while polystyrene board was used to insulate the bottom and side parts of the metal collector. The dryers were mounted at an angle of 15^o to the horizontal and truly facing south. The dryers were similar in size and shape but only differ from each other in the materials used for their construction. Hinged cover was attached to aid in loading and unloading crops for drying. The dryers are shown in figures 1 to 4.

Figure 1: Solar dryer with metal plate solar thermal collector

Figure 2: Solar dryer with wood solar thermal collector

Figure 3: Solar dryer with cement solar thermal collector

Figure 4: Solar dryer with mud solar thermal collector

Tomato samples were sliced into average thickness of 15mm and spread in a single layer on the crop trays in the drying chamber. A set of the sliced tomato was spread in a single layer in open sun, which served as control. Market surveys on prices of materials used to fabricate the dryers were conducted in Zaria and the environs.

Instrumentation

Ambient air, collector and drying chamber air outlet's temperatures for the four dryers were measured with digital Omega type T –Thermocouples Thermometer with 24 –channel outlet. Solar radiation at the inclination of the dryers was measured with Haenni solar 118 Delta Radiometer with digital read out. Relative humidity was monitored with digital Omega Hygrometer. Digital anemometer was used to measure ambient wind speed, at the height of one meter above the ground.

Collector air outlet temperature of wood, cement, mud and metal, as well as ambient temperature and weather conditions were monitored. The measurements were made in three replicates and the average values presented in figure 5. Thereafter Ripen but firm tomato was washed and sliced to average thickness of 15mm. The sliced tomato sample was loaded in single layer on a crop tray in each of the four dryers with different collector materials and in open sun as a control. The drying sliced tomato in the dryers and open sun were sampled out periodically for determination of moisture content in wet basis by oven drying method, these were replicated three times.

III. RESULTS AND DISCUSSION

Figure 5 indicated the results of temperature Tcw, Tcc, Tcm and Tct generated by solar collector sections made of wood, cement, mud and metal respectively, as well as Ta for ambient temperature.

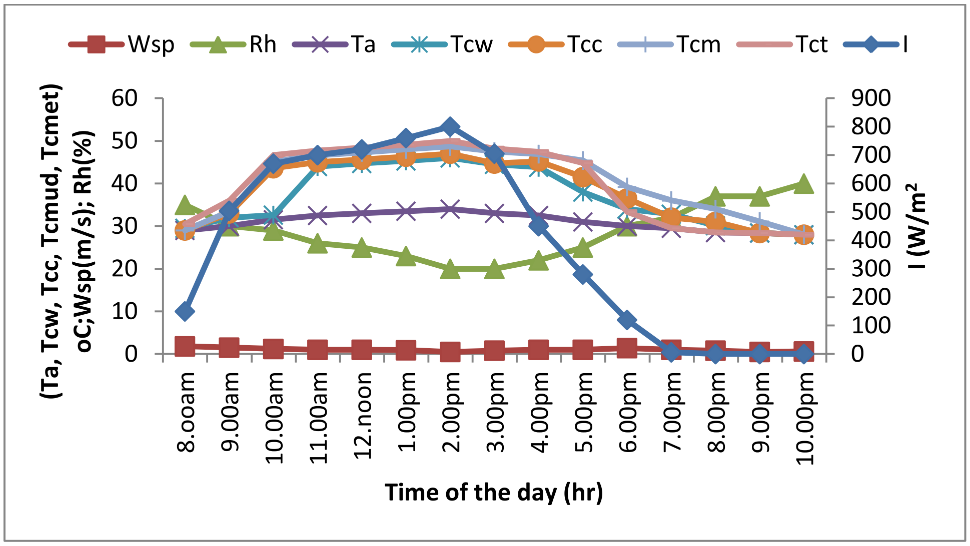

Figure 5: Average values of Solar collectors' temperature generation under the same effect of some weather conditions measured at on hourly intervals. Ambient air temperature (Ta), wind speed (Wsp), relative humidity (Rh), solar radiation (I). Air outlet temperature for wood, (Tcw); cement, (Tcc); mud, Tcm and Tct collectors.

It was observed that the corrugated roofing zinc which served as the metal collector generated high thermal energy at high solar radiation intensity, but loss same as soon as the solar radiation abated. This might be due to the fact that zinc which has high thermal conductivity of 109 W/m K (Zintek, 2013), can easily generate and conduct heat for raising the temperature of air in the collector unit and can equally give up same immediately the source is cut off. Likewise the solar thermal energy generation of the wood and cement solar collectors were found to diminish immediately after the availability of solar radiation. Thus, the temperature of wood and cement solar collectors dropped to ambient temperature, 1 hour and 2 hours respectively after solar radiation. The thermal behaviour of wood and cement solar collectors might be attributed to their thermal conductivities given as 0.043 for wood (Henderson et al, 1997) and 0.035 for cement floor slab, KNAUF (2013). However, the mud solar collector which has it's thermal conductivity as 0.34 NEVA (2013) retained heat until 4 hours after solar radiation before it fail to ambient temperature. The analysis of figure 5 also showed that the average air outlet temperature of wood, cement, mud and metal solar collectors increased to 119.2, 123.1, 128.9 and129.5 percent respectively over the average ambient air temperature of 30.5^{0}C.

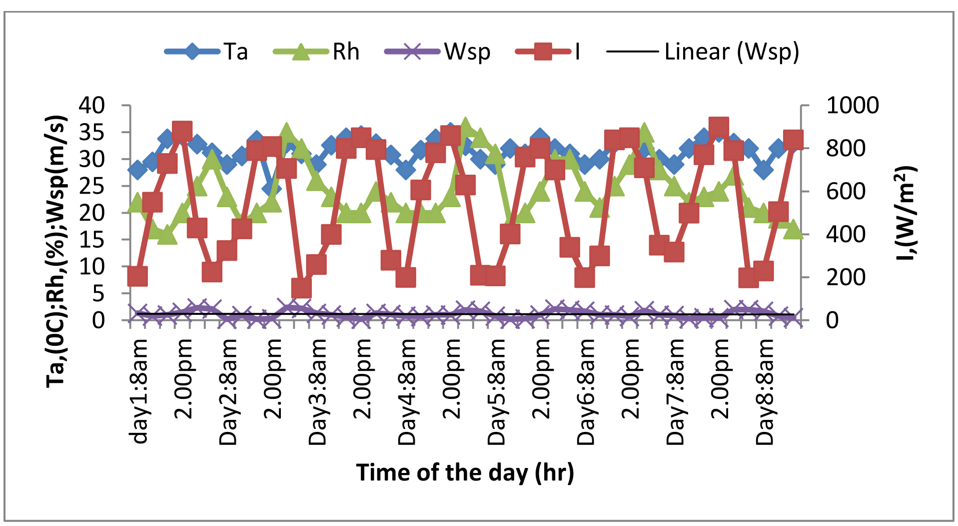

Figure 6: Curves of average values of some weather conditions measured during drying processes. Ambient air temperature (Ta), wind speed (Wsp), relative humidity (Rh), solar radiation (I).

Figures 5 and 6 indicated that the ambient air relative humidity during the drying period was low in afternoon when the ambient air temperature was high. This response of relative humidity to temperature variation agrees with the point established by Loewer et al, (1994) which stated that the relative humidity decreases as the temperature increases and vice-versa.

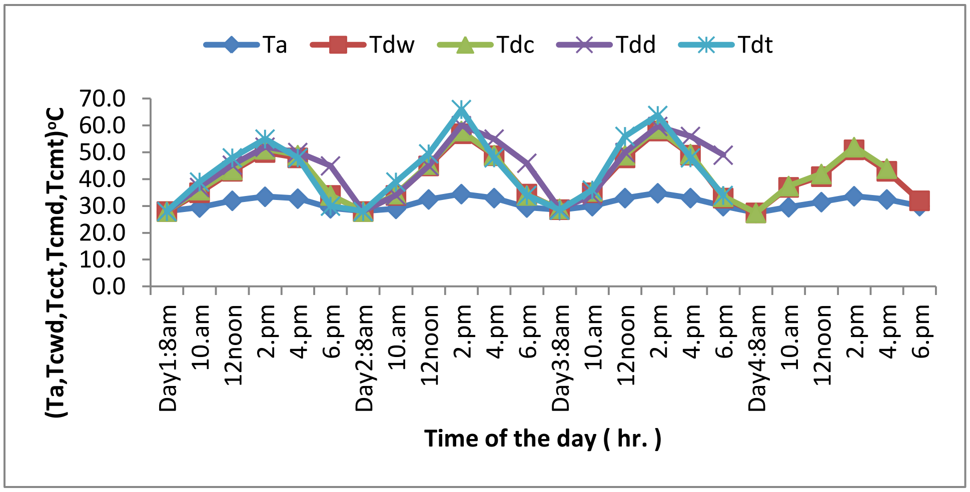

Figure 7: Curves of average values of air outlet temperature for wood, (Tcw); cement, (Tcc); mud, (Tcm) and metal, (Tct) Drying chambers.

The results in figure 7 showed that the air outlet temperature of the drying chambers of wood, cement, mud and metal raised the temperature to 30.8 %, 35.1 %, 43.9 % and 43.3 % respectively above the average ambient temperature of 31.5 ^{0}C. The metal collector indicated the highest increase in temperature during the hours of high solar radiation intensity. This can be mainly attributed to the fact that the lactic structures of the metal is easily excited to vibrate at a higher frequency than wood, cement and mud. Therefore the frictional force that occurred during the high frequency vibration in the metallic lactic produced the higher thermal energy, which resulted to higher temperature more than the other collectors, when exposed to the same solar radiation intensity. The temperature in the drying chamber was generally increased as indicated in figure 7 because the dryers were direct mode, this enhanced the drying rate of the product.

The drying behaviour of tomato used in testing the drying performance of the four different materials of solar collectors is presented in figure 8.

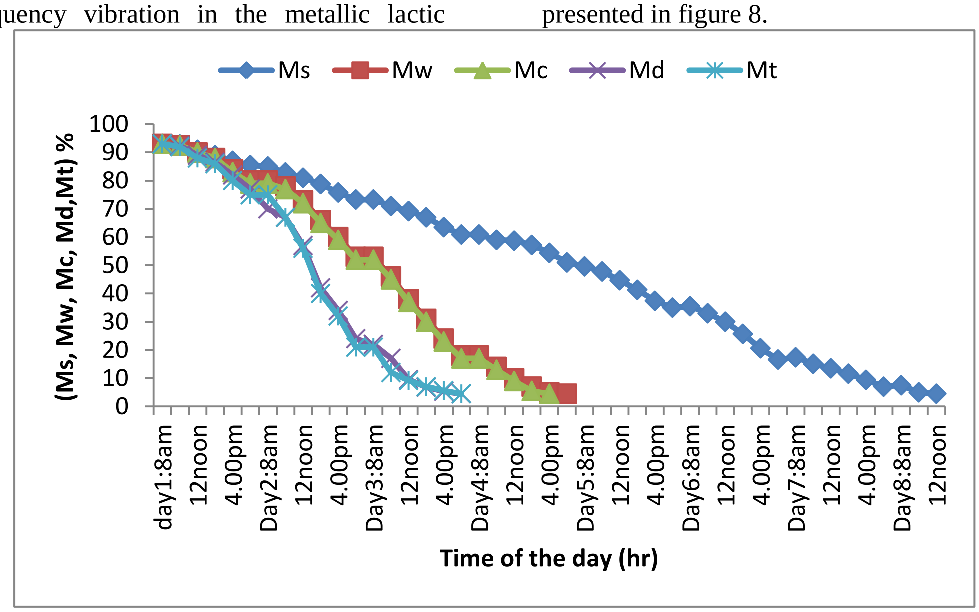

Figure 8: Curves of average values of the moisture content (wet basis percent) for tomato dried in; Ms – open sun; Mw-wood, Mc-cement, Md-mud and Mt-metal dryers.

Analysis from figure 8 showed that the dryers' savings in drying time when compared with the open sun drying for wood, cement, mud and metal dryers were 46, 47, 60 and 60 percent respectively. Moisture from the sliced tomato was driven out by natural convection which resulted in long drying time. The samples dried from initial moisture content of 93 percent wet basis to 4.5 percent wet basis. The average ambient wind speed during the drying period was 1.1 m/s, while that of relative humidity was 24 percent and the solar radiation was 554.9 W/m^2. The dryers generated higher heat energy at the drying chambers because they were direct mode natural convection solar dryers hence the drying principle was non-adiabatic.

The wood, cement, mud and metal solar dryers dried the sliced tomato sample within 45, 44, 30 and 30 hours behind the open sun drying which served as a control . Although metal solar collector generated thermal energy faster and higher than the mud solar collector in the presence of solar radiation, mud solar collector retained more thermal energy after the of solar radiation. Therefore, the mud solar dryer exhibited longer drying period than metal dryer. Hence mud and metal solar dryers dried the tomato samples at the same time. Evaluation of the System Drying efficiencies of the dryers indicated 7.38, 19.56, 20.25, 26.91 and 27. 00 percent, for open sun, wood, cement, mud and metal in that order. The system drying efficiency is generally low because tomato can only be effectively dried in slices and spread in single layer which occupies a large area of space. There was no statistical significant difference between the mud and metal solar dryers, as well as wood and cement dryers. However the production cost of fabrication of wood, cement, mud and metal solar dryers amounted to 17,720.00; 20,940.00; 10,000.00 and 30,000.00 Naira respectively, while the open drying was at almost zero cost. Analysis of the construction cost revealed that mud solar dryer has the lowest production cost of ten thousand naira, while the percentage increase in prices of wood, cement, and metal dryers over the mud dryer were 77.20, 109.40, and 200 percent respectively. It was also observed that farmers normally use mud for erecting structures. Thus out of these local materials, mud is most commonly available, easiest to work on and affordable to farmers. The overall performance of the dryers indicated that the mud solar dryer can be rightly suggested as the most suitable local material for fabrication of natural convection direct mode solar dryer in rural areas of Zaria and other locations with the same geographical features.

CONCLUSION

Wood, cement and mud and metal which are commonly available local materials were used to fabricate four similar solar thermal dryers. Thermal energy generation of the dryers were monitored and sliced tomato was utilized to test-run the dryers, while open sun drying was used as control. Performances of the dryers were critically analyzed and based on the results and the cost of production of the dryers, mud was identified as commonly available, affordable and most suitable material for construction of direct mode natural convection solar dryer for rural farmers in Zaria, Nigeria. It is therefore recommended that commercial direct mode natural convection solar mud dryer be built for the rural farmers in this area.

REFERENCES

[1]. Akani, O. A. (1990) Evaluation of various designs of natural convection solar dryers. Unpublished M. Sc. Thesis. Dept. of Agric. Engr. ABU-Zaria, Nigeria.

[2]. AMECO (2009) http://www.solar expect. com/ heatpanel.html

[3]. Angewandtehttp://www.buildsolar.net/

[4]. Arinze, E. A., Adefila, S. S.,Eke, A. B. and Akani, O. A. (1990). Experimental evaluation of various designs of free convective solar crop dryers with and without thermal storage. Paper presented at the national Conference of the 'NASE'University of Agriculture. Makurdi. Nigeria .12-15 September.

[5]. Bronndorfer, B; Kennedy, L; Bateman, C. O. O; Trim, D. S; Mrema, G. C and Wereko, B. C. (1987)Solar dryer their role in post-harvest processing Commonwealth SC. Council: 3(45): 30-45.

[6]. Duffie, J. A. and Beckman, W. A. (1980). Solar engineering thermal processing . John Wiley,New York pp56-60, 115-200.

[7]. Eke, A. B. (1991) Experimental performance evaluation of laboratory and field solar and hydrid crop dryer. Unpublished M Sc thesis. Dept of Agric. Engineering, ABU Zaria, Nigeria.

[8]. Eke, A. B. (2003). Performance evaluation of natural convection solar dryer for sliced tomato. Unpublished Ph D thesis. Dept. of Agric. Engineering, ABU Zaria, Nigeria.

[9]. GENI (2013) Nigeria Energy issues: geni.org/:/Nigeria/ (accessed on 1st May 2013.)

[10]. Heindl (2010) http://www. solarserver. Com

[11]. Henderson, S. M. and Perry, R. L. 1980 . Agricultural Process Engineering. John Wiley and Sons. Inc, London, pp. 303-335.

[12]. Henderson, S. M., Perry, R. L. and Young, J. H. (1997) Principles of process Engineering. The Society for Engineering in Agricultural, Food and Biological Systems, (ASAE). Fourth Edition. PP. 151.

[13]. John, P. (2005). Solar evaluation < perlin@rahus.org>

[14]. KNAUF (2013) Thermal floor slabs http://www.knaufinsulation.co.uk/en-gb/

[15]. Kruidhof, W. and Vander, L. M. (1979) Cobalt oxide as a spectrally elective material for use in solar collectors. Solar Energy Materials. 2:69-79.

[16]. Loewer, O.J., Bridges, T.C. and Bucklin, R.A. (1994) On-Farm Drying and storage Systems American Society of Agricultural Engineers ASAE publication 9;pp 41-70.

[17]. NEVA (2013) Architecture and Comfort building Materials. http://unu.edu accessed on 10/05/2013

[18]. Nielsen, R (2005) Solar Radiation< http:// home.iprimus.com.au/nielsens/.>

[19]. **Olukosi,** J.O, Arinze, E. A., Eke, A. B., Freudenbergert, K. S. and Matanmi, M.B (1990) Determination of solar Crop Dryer Needs of Farmers in Nigeria Using the Rapid Rural Appraisal (RRA) Technique. Newsletter National farming Systems Reseach Network, IAR/ABU Zaria Nigeria.

[20]. Parker, B. F. (1978) Performance test of three solar air heaters. Transaction of the 'ASAE' special Edition Vol. 21 pp. 530-535.

[21]. Peter, G. G. and Raymond, B. (1964) Tomato paste puree, juice and powder. Food Trade Press Ldt; London. pp 140 148

[22]. Ryu, M. S., Hyuk, J. C. and Jang, J. (2010) Improvement of operation lifetime for conjugated polymer. Solar Energy Materials and Solar Cells. 94(2):152-156

[23]. Wikipedia (2010) Solar Thermal Collector< http://en.wikipedia.org/wiki/Wikipedia>

[24]. Wikipedia (2011) Solar thermal collectorhttp://Wikimedia foundation.org/last modified on 6th February, 2011.

[25]. Yasser, A., Ismail, M., Soga, T. and Jimbo, T. (2009) Improvement in light harvesting and performance of P3HT:PCBM cell by using 9, 10-diphenylanthracene. Solar Energy Materials and cells. 93 (9):1582-1586

[26]. Zhiqiang, Y. (2000). Solar thermal application in China. World Renewable Energy Congress. 6:912-916

[27]. Zintek (2013) Technical properties, Quality control Guidelines and norms. www.Zintek.it accessed on 2nd May 2013.