# SOLAR ENERGY EFFICIENT BUILDING: A FEASIBILITY STUDY IN SOKOTO STATE OF NIGERIA

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**Abstract:** The exponential increase in greenhouse gas emission calls for a wider exploration of renewable energy resources in buildings, in a bid to obtain an energy efficient house, a solar energy system capable of cooling, natural ventilation and hot water supply is being proposed for a residence in Sokoto, Nigeria. Sokoto, is a characteristic tropical savannah climate with a mean annual temperature of 28°C, it receives an average daily radiation of 780W/m2. The system comprises of a 24m2 PV/T connected with a 42m2 flat plate collector, a 15kw adsorption chiller, and a hot water storage tank. Analysis of the system shows that it can supply over 60% the total load in the house and can meet 94% of the annual heating and cooling load. A solar COP of 0.38 was obtained for this system. Analysis of the system shows that with an annual savings of N1,740,000.00, the system has a simple pay back of 7.4 years when government incentives are received, it also has the ability to displace the emission of 37 tons of CO2 annually.

**Keywords:** greenhouse gas emission, solar energy and energy efficient building

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## 1.0 INTRODUCTION

An exponential increase in energy sourced from fossil fuels to meet increasing demand has resulted in amplified carbon dioxide emission. Buildings are believed to be responsible for the bulk of energy demand, for example, [1] suggests that buildings in the European Union, account for about 40% of the final energy consumption. Demand for energy varies with location, season of year and time of day, for instance, in Europe; demand for heating is high in the winter months while cooling is dominant in the summer months; however in a tropical country like Nigeria, space cooling is required virtually all year round. Other contributors to energy demand in buildings irrespective of location and season include hot water and electricity supply for lighting and powering other equipment. With so much effort to reduce Green House Gas (GHG) emissions in today's world, it is evident the global reduction target can only be met, if the means by which current demands for running our edifices are significantly altered. Some governments have implemented standards on limiting energy consumption in buildings however, there is still a large gap. [1]. The Integration of Renewable Energy sources (biomass and Solar power) in buildings is a major step in making buildings more efficient. Solar power captured from the sun is free and abundant in nature, supplies are sufficient for the global energy demand; however,

this source has been under-utilized due to limitations in harnessing it. Technologies used to capture solar energy are in the form of Photovoltaic cells and solar Thermal collectors. The photovoltaic cells convert sunlight directly into electrical energy in the form of Direct Current (DC).The major component of this system is the solar cell which is made of a material which acts as a semiconductor material, typically silicon. Solar thermal collectors convert the radiation from the sun into heat that is further transferred to a working fluid. A solar collector consists of a translucent cover, an absorption plate and a heat transfer system [2]. Several variations to this technology exist, depending on the intensity of heat required. Flat plate collectors are used for heating the working fluid to temperatures below 100 $^{0}$C while concentrated solar collectors can be used to achieve working fluid temperatures of up to 1000 $^{0}$C.Flat plate collectors are increasingly used in buildings for space and water heating. Another form of utilizing solar energy in buildings is the use of passive solar building design which conserves energy as much as possible – this is achievable because the building design is directly related to energy use. These passive designs naturally use the sun for free heating, cooling and lighting which reduces the need to consume energy from other sources in providing a comfortable environment.

## 2.0 RELATED WORKS

There exists a large body of research in energy efficient building such as [3, 4, 5, 6, 7, 8, 9 and 10]. The use of solar energy in buildings has been of great interest, authors [3, 4, 5 and 6] among numerous researchers have studied and presented papers on low energy buildings. The author in [7], produced the Engineer's complete Design Resource which gives an apt description of Solar Power in building design. All these, point to the fact that the use of solar energy in buildings is receiving much more attention than ever before. The authors in [8] investigated ways of incorporating solar design into multi-unit residential buildings in Canada; they also presented the different technologies used in solar building design which are passive solar heating, ventilation air heating, solar domestic water heating and shading. Authors in [9] presented a detailed literature survey on solar water heaters (SWH) which gives a concise overview of the developments in the key areas, their recommendations were that the performance of the thermo-syphon SWH could be improved by more research into the flow, They also proposed implementing a suitable aero profile design for the cover glass as a means of reducing the convective heat loss, a model of this proposal is yet to be tested. The authors [10] designed and constructed a solar-powered integrated energy system involving heating, air-conditioning, natural ventilation and hot water supply. This system had a high utilization ratio as it involved the use of the absorbed solar energy for different purposes. Evacuated tubular solar collectors were used and the air – conditioning system was an adsorption cooling technology which operated efficiently during 8 working hours under typical sunny weather condition.



## 3.0 SYSTEM CONSIDERATIONS

The proposed building is in Sokoto, Nigeria. Nigeria has been reported to have one of the world's largest gap between demand and supply of Electricity, as of February 2011, recorded power Generation in Nigeria was about 4000 megawatts – the highest figure in the last decade, this capacity is to supply a population of over a 150 million (Nigeria Power reform NPR , 2011), this puts the per capita electricity generation at about 20 watts per person which is 4 times less than the African average and about 19 times less than the world average, this low per capita supply has led to many years of incessant power outages, households, Industries and other businesses have had to rely on gasoline and diesel generators as alternative means of power supply. The use of these generators has greatly increased the $CO_2$ emissions from the country, as well as increased the cost of energy in houses. Figure 1 shows the map of Nigeria showing distribution of solar potentials.

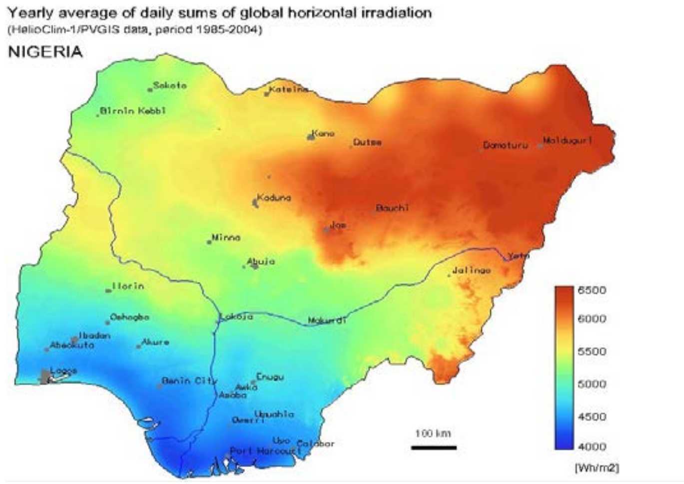


Figure 1. **Map of Nigeria showing distribution of Solar Potentials**

### 3.1 Meteorological Characteristics of Sokoto, Nigeria

Nigeria is located in the equatorial region between latitudes 4$^o$N and 14$^o$N, longitudes 3$^o$E and 15$^o$E, the annual average daily sunshine ranges from about 3.5 hours at the coastal areas to about and 9.0 hours at the far northern boundary while the annual average daily solar radiation for these locations is between 3.5 kWh/m$^2$/d and 7.0 kWh/m$^2$/d respectively [11]. The solar radiation distribution across Nigeria is shown in Figure 1.Sokoto state is in the savannah region and is characterized by two major seasons- the wet season from May to September and the dry seasons which last from October till April. Endowed with vast solar potentials, annual average temperature in Sokoto is about 28.3 °C, however, in the warmest months of February to May, Temperatures can be as high as 45 °C with the highest ever recorded temperature being 47.2 °C (Sokoto state2011). The geographical coordinates of the building is Latitude 13.067$^o$N and Longitude 5.249$^o$E, Table 1, shows a 22 year (July 1983 – June 2005) average of the solar resource of the location.

The conceptual Approach used in determining the required system are the Photovoltaic Solar panels, Building Integrated Photovoltaic thermal system and incorporating a solar passive design. Incorporating these systems into the building will reduce the energy demands from the national grid as well as stop the use of the diesel generator.

## 4.0 DESIGN AND DEVELOPMENT

The passive solar design to be incorporated will ensure the building makes the greatest use possible of solar gains to reduce energy it will minimize direct sun exposure and heat absorption and also allow for proper ventilation, as well as make use of solar lighting available.

### 4.1 The Thermal system

The storage tank will be used to store hot water needed for running the adsorption cycle as well as that needed for domestic use. A backup gas boiler controlled by a sensor will be fitted with this tank, this will ensure the required temperature range is always maintained. The volume of tank to be integrated with this system will need to store enough water for both the adsorption cycle and domestic use. This is obtained by summing the volumes required for both purposes. The hot water requirement in Nigeria is fairly constant throughout the year, and a daily consumption of 50m³ of water at 70 °C is a good estimation. With six regular occupants in the house,

$$Domestic\ Hot\ water\ required = 6 \times 50 = 300m^3.$$

From manufacturers' specifications 2000 liters of water is more than sufficient storage for a 15KW adsorption cycle.

The Volume of storage tank needed is $2000m^3 + 3000m^3 = 2300m^3$

In case of surplus demand, a factor of safety of 200m³ is added, which brings the volume of the proposed hot water storage tank is 2500m³. Both collectors are connected to this 300mm thick insulated storage tank. Table 1 shows the initial design specification for the thermal system

Table 1: **Design Parameters for thermal system**

| Parameter | Abbreviation | Value |
|---|---|---|
| Ambient Temperature | $T_a$ | 28°C |
| Water Mass flow rate | m | 0.1kg/s |
| Average Solar Radiation | I | 775w/m² |
| Tap water Temperature | $T_1$ | 26°C |
| FPC absorber Temperature | $T_{c2}$ | 95°C |
| Outlet Temperature | $T_3$ | 90°C |
| Specific heat capacity of water | $C_p$ | 4190J/kg°C |
| Top heat loss Coefficient | $U_t$ | 3w/m²/°C |
| Collector absorptivity | α | 0.9 |
| Glass cover transmittance | τ | 0.85 |

### 4.2 Photovoltaic Thermal (PV/T) Collector

The PV/T collector is connected in series with the conventional flat plate solar collector. The PVT absorber is encased in an aluminum metallic box with 0.1 m glass wool insulation below the absorber to reduce bottom losses. A glass to glass photovoltaic (PV) module with an effective area of 24 m² containing 21 modules, each having 48 solar cells, is placed above the absorber plate. Solar radiation is transmitted through non-packing area of PV module and finally absorbed by the blackened absorber. Further, the thermal energy associated with PV module is transferred to absorber by convection for further heating of absorber; Water flowing in pipes underneath the absorber gets heated and moves in the upward direction. Because the PV/T solar collector cannot attain high water temperatures required for the adsorption cycle, it is designed to raise the temperature of the water. The water leaves the PV/T collector at temperature $T_2$ entering the conventional flat plate collector.

The size of this collector was determined by the calculated electrical load of 3.5KW (to cover 70% of lighting and appliances) to be supplied to the house. Each of the 41 modules is rated 185W and the total panel has a cumulative rating of 3.8KW There is a provision of a DC water pump connected to PV module to circulate the water between collectors and storage tank in a forced mode. [12]. The 24m² PV/T, is a mono crystalline PV panel combined with an aluminum absorber, a common feature of most PV panels is that only about 80% of the solar radiation is absorbed by the panels. Using this as an estimate, the amount of solar radiation that will be absorbed by the PV panel is

$$0.8 \times I = 0.8 \times 775 = 620w/m^2$$

About 20% of this absorbed radiation is converted to electricity, therefore about

$$0.2 \times 620 = 124w/m^2$$

Is converted to electricity, the rest of the heat gained will be dissipated, the design of the PV/T is such that as much as possible of the excess heat in the PV will be transferred to the working fluid via the thermal collector, however, some of this heat will be lost by convection and radiation. Ideally the heat lost should be calculated using the convective and radiative heat loss coefficients, however, for simplicity, it is assumed that 10% of the heat available will be lost. Therefore assumed heat lost is

$$0.1 \times 620 = 62w/m^2$$

The heat available can be obtained by subtracting the radiation converted to electricity and the heat lost from the absorbed radiation, Therefore heat available per unit area is

$$620 - (124 + 62) = 434w/m^2$$

And the total useful heat of the absorber is

$$434 \times 24 = 10416w$$

To obtain the average outlet temperature of the PV/T collector, the second law of thermodynamics which implies that heat lost = heat gained will used. The heat gained by water in the PV/ T can be expressed by

$$q_1 = mc_p(T_2 - T_1)$$

Rearranging to make $T_2$ the subject of the formula and evaluating

$$T_2 = T_1 + \frac{q_1}{mc_p} = 26 + \frac{10416}{0.1 \times 4190} = 50.86°\text{C}$$

This is the temperature of water leaving the PV/T and entering the FPC

### 4.3 Flat Plate Collector

The flat plate collector consist of an absorber made of copper and coated with a selective surface, this makes its absorptivity very high and its emissivity low, it will have a single glass cover with the back and edges well insulated with rock wool to prevent heat losses by conduction from the absorber. Using the design parameters presented in Table 2, the surface area of the absorber required to raise the water to the temperature range suitable for the adsorption cooling kit is calculated below.

Heat absorbed by the absorber is given by

$$I \times \alpha \times \tau = 780 \times 0.9 \times 0.85 = 596.7w/m^2$$

The heat lost from the top of the collector can be calculated by

$$q_{top} = U_t(T_C - T_A) = 3(95 - 28) = 201w/m^2$$

Sides and back of collector are well insulated hence the heat loss by conduction is negligible.

Therefore the total useful heat is given by

$$q_{useful} = 596.7 - 201 = 395.7w/m^2$$

Also, the total heat required to heat the water to the required temperature can be given as

$$Q = mc_p(T_3 - T_2) = 0.1 \times 4190 \times (90 - 50.86) = 16400w$$

Therefore the total surface area required to achieve this can be calculated by

$$A_{c2} = \frac{Q}{q_{useful}} = \frac{16400}{395.7} = 41.5m^2$$

Therefore a collector with absorber surface area of 42m² will be requested from the supplier

## 5.0 SYSTEM ANALYSIS

The performance analysis and economic analysis are presented in this sub-section

### 5.1 Performance Analysis

To estimate the performance of this system, the f chart method is proposed. The f-chart was developed for 75 liters of stored water per m² of collector area, however systems with storage between 37.5-100 liters/m² can be determined by multiplying the non-dimensional "X "parameters by storage correction factor $\frac{X_c}{X}$ from the expression:

$$\frac{X_c}{X} = \left(\frac{Actual\ Storage\ Capacity}{Standard\ Storage\ Capacity}\right)^{-0.25}$$

The storage volume per m² of collector area of the proposed system is $=\frac{2500}{66} = 37.9\ litres/m^2$

Thus this method is appropriate for analysing this system. The correction factor will be

$$\frac{X_C}{X} = (37.9/75)^{-0.25} = 0.84$$

Corrected X values will be given $X_c = 0.84X$

This technique provides a viable estimation of fractional the monthly useful heat produced from the solar energy system. The main two non-dimensional parameters defining the f-chart are given as:

$$X = F_R U_L \times \frac{F_R'}{F_R} \times (T_{REF} - \bar{T}_a) \times \Delta t \times \frac{A_c}{L}$$

$$Y = F_R(\tau\alpha)_n \times \frac{F_R'}{F_R} \times \frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} \times \overline{H_T} N \times \frac{A_c}{L}$$

Where:

$A_c = collector\ Area\ in(m^2)$

$F_R' = collector\ heat\ exchanger\ efficeicy\ factor$

$U_L = collector\ plat\ overall\ heat\ loss\ coefficient(W/m^2°\text{C})$

$\Delta t = total\ number\ of\ seconds\ in\ the\ month$

$T_{ref} = Empirically\ derived\ reference\ temp(100°\text{C})$

$\overline{(\tau\alpha)} = monthly\ average\ transmittance - absorbtance\ product$

$\bar{T}_a = monthly\ average\ ambient\ temperature(°\text{C})$

$\overline{H}_T = monthly\ average\ daily\ incident\ radiation\ on\ collector(J/m^2)$

L = Monthly total heating load for space heating and hot water(J)

N= Days in the month

$$\frac{F_R'}{F_R} = collector\ heat\ exchanger\ factor\ for\ various\ collector - tank\ temp\ drop.$$

$$\frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} = \frac{monthly\ average(\tau\alpha)}{normal(\tau\alpha)}$$

$F_R = Collector\ Heat\ Removal\ factor$

The fraction "f" of monthly total load supplied by the solar space and water heating system is given by

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3$$

The curves for this equation are shown in figure 2 which is the f – chart.

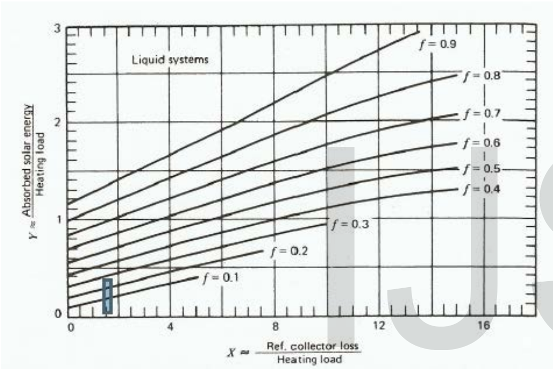


Figure 2: The F chart for systems using liquid heat transfer and storage media

The monthly values for x and y are calculated and estimated in Table 2 using the equations

$F_R(\tau\alpha)_n = 0.74 \quad F_R U_L = 4\ (W/m^2°C) \quad \frac{F_R'}{F_R} = 0.97. \quad \frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} = 0.96$

Table 2: Monthly and annual performance of the proposed system

| MONTH | $\overline{H}_T$(MJ/m²) | $\overline{T}_a$(°C) | L (GJ) | X | Y | F | fL (GJ) |
|---|---|---|---|---|---|---|---|
| JAN. | 19.69 | 27 | 20 | 2.10 | 1.39 | 0.88 | 17.70 |
| FEB. | 23.08 | 29 | 19 | 2.31 | 1.55 | 0.94 | 17.94 |
| MARCH | 24.73 | 33 | 16 | 2.41 | 2.18 | 1.00* | 16.00 |
| APR. | 25.74 | 36 | 18 | 1.98 | 1.95 | 1.00* | 18.00 |
| MAY | 25.31 | 35 | 20 | 1.87 | 1.78 | 1.00* | 20.00 |
| JUNE | 24.88 | 32 | 20 | 1.90 | 1.70 | 1.00* | 20.00 |
| JULY | 22.54 | 29 | 20 | 2.05 | 1.59 | 0.98 | 19.55 |
| AUG. | 20.63 | 28 | 17 | 2.44 | 1.71 | 1.00* | 17.00 |
| SEPT | 21.64 | 30 | 19 | 2.05 | 1.55 | 0.96 | 18.28 |
| **OCT.** | 21.71 | 31 | 22 | 1.81 | 1.39 | 0.90 | **19.88** |
| **NOV.** | 20.84 | 30 | 22 | 1.77 | 1.29 | 0.86 | **18.86** |
| **DEC.** | 18.9 | 29 | 19 | 2.15 | 1.40 | 0.89 | **16.89** |
| **TOTAL** | | | **232** | | | | **220.1** |

The fraction of the annual heating load supplied by system can be given by

$$F = \frac{sum\ of\ monthly\ solar\ energy\ contribution}{Sum\ of\ monthly\ heating\ load(Annual\ load)} = \frac{\sum f_i L_i}{\sum L_i}$$

$$F = \frac{220.1}{232} = 0.94$$

This implies that the system can supply 94% of the annual load demand; this high performance is achieved due to the excellent solar resource of this location.

### 5.2 Economic Analysis

The installed air conditioner shave an annual consumption of approximately 55,000kwh of electricity out of the buildings approximate total of 76,0000KWh.

Installing the adsorption cooling cycle will displace the 55,000 kWh of electricity needed to run the electrical compressor air conditioners.

The Cost of electricity in Nigeria is ₦30/kwh

Gas costs an equivalent of ₦6 /KWh

A conversion factor is 0.542 kg CO2 saved for each kWh produced from a carbon free source.

Table 3: Economic analysis of the system

| Item | Quantity | Amount(₦) |
|---|---|---|
| Savings by the adsorption chiller | 55,000 KWh | 1,650,000 |
| Savings by the PV panel | 13,000 KWh | 390,000 |
| Gas for augmenting the boiler | 50,000 Kwh | -300,000 |
| Annual savings | | 1,740,000 |
| Payback | 7.4 years | |
| Environmental contribution | 37 tonnes of $CO_2$ yearly | |

## 6.0 DISCUSSION AND EVALUATION

Using basic energy balance equations and computer based thermal models [12], derived different analytical

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expressions for N collectors connected in series and parallel, For this Case which involves Identical set of collectors with $N_m$ collectors fully covered by PV module and $N_c$ collectors fully covered by glass cover (all connected in series). The expression for the outlet fluid temperature can be given as

$$T_{foN}=\left[\frac{(\alpha\tau)_{c,eff}I(t)}{U_{L,c}}+T_a\right]\left[1-\exp\left(\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right]\times\left[\frac{1-\left\{\exp\left(-\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right\}^{N_c}}{1-\exp\left(\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)}\right]+\left[\left(\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}}+T_a\right)\times\left\{1-\exp\left(-\frac{N_mF'A_mU_{L,m}}{\dot m_fC_f}\right)\right\}+T_{fi}\exp\left(-\frac{N_mF'A_mU_{L,m}}{\dot m_fC_f}\right)\right]\left[exp\left(-\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right]^{N_c}$$

Where $PF_1$ is a dimensionless penalty factor first due to the glass cover of PV module and $PF_2$ is a dimensionless penalty factor second due to the absorber below PV module, they can be obtained by

$$PF_1=\frac{h_{c,p}}{U_{tc,a}+h_{c,p}}\quad\text{and}\quad PF_2=\frac{h_{p,f}}{U_{L1}+h_{p,f}}$$

$$U_{tc,a}=5.7+3.8V,\ \ U_{L1}=\frac{U_{tc,a}\cdot h_{c,p}}{U_{tc,a}+h_{c,p}}$$

$$U_{Lm}=\frac{U_{L1}\cdot h_{p,f}}{U_{L1}+h_{p,f}}$$

$$h_{c,p}=5.7+3.8V,\ \ V=0\text{ m/s}$$

They also derived the expression for the useful heat yield from the mixed combination as,

$$\dot Q_{u,N}=\dot m_fC_f\left[\frac{(\alpha\tau)_{c,eff}I(t)}{U_{L,c}}+T_a\right]\left[1-\exp\left(-\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right]\times\left[\frac{1-\left\{\exp\left(-\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right\}^{N_c}}{1-\exp\left(\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)}\right]+\left[\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}}+T_a+T_{fi}\right]\times\left[1-\exp\left(-\frac{N_mF'A_mU_{L,m}}{\dot m_fC_f}\right)\right]\left[\exp\left(-\frac{F'A_cU_{L,c}}{\dot m_fC_f}\right)\right]^{N_c}$$

Substituting values of average conditions in the equations, the outlet fluid temperature is gotten to be 92°C and the useful heat yield of the system is gotten to be 25.8KW

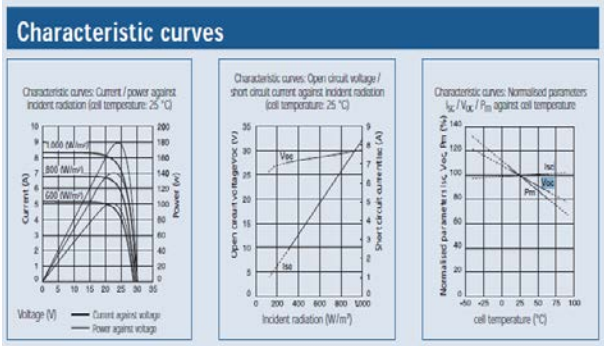
The Instantaneous efficiency of the whole system with total collector area $A_N$ can be calculated by

$$\eta_i=\frac{Q_{U.N}}{A_N\times I}$$

Thus the average efficiency will be $\frac{25800}{775\times 66}=50.4\%$

With the intense solar radiation of the location, this is low efficiency of the system, a plausible excuse for this is the unaccounted energy converted to electricity in the PV panel.

The characteristic curves and electrical data of the Sharp PV panels used in the PVT are shown in Figure 3




**Electrical data**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Module production in the EU | | NU-185 (E1) | NU-180 (E1) | | | | |
| Module production in Japan | | NU-S5 (E3E) | NU-S0 (E3E) | NU-S0 (E3Z) | NU-R5 (E3Z) | NU-R0 (E3E) | |
| Rated power | | 185 $W_p$ | 180 $W_p$ | 180 $W_p$ | 175 $W_p$ | 170 $W_p$ | |
| Open circuit voltage | $V_{oc}$ | 30.2 | 30.0 | 30.0 | 29.8 | 29.4 | V |
| Short circuit current | $I_{sc}$ | 8.54 | 8.37 | 8.23 | 8.29 | 8.37 | A |
| Voltage at maximum power | $V_{pm}$ | 24.0 | 23.7 | 23.7 | 23.2 | 22.4 | V |
| Current at maximum power | $I_{pm}$ | 7.71 | 7.6 | 7.6 | 7.55 | 7.60 | A |
| Module efficiency | $\eta_m$ | 14.1 | 13.7 | 13.7 | 13.4 | 13.0 | % |
| Temperature coefficient - open circuit voltage | $\alpha V_{oc}$ | -104 | -104 | -104 | -104 | -104 | mV/°C |
| Temperature coefficient - short circuit current | $\alpha I_{sc}$ | +0.053 | +0.053 | +0.053 | +0.053 | +0.053 | %/°C |
| Temperature coefficient – power | $\alpha P_m$ | -0.485 | -0.485 | -0.485 | -0.485 | -0.485 | %/°C |

The electrical data apply under standard testing conditions (STC): Incident radiation 1000 W/m² mit Lichtspektrum AM 1.5 with AM 1.5 light spectrum at a cell temperature of 25 °C. The power output is subject to a manufacturing tolerance of - 5 % and + 10 %. The modules manufactured in Europe and Japan are identical.

Figure 3: Characteristic Curves and Electrical data of the PV panels

The fill factor of the proposed solar cells is given by

$$\frac{W_{max}}{V_{oc}\times I_{sc}}=\frac{185}{30.2\times 8.54}=72\%$$

Which implies the cell is good but not excellent.

The estimated annual production from the PV panel will be

$$3780W\times 12 hours\ of\ sunhine\ \times 350\ days\ \times 80\%\ peak = 13{,}000 kwh\ annually.$$

This figure cannot meet the total annual demand of electricity however it offsets more than 60%.

## 7.0 CONCLUSION

The proposed solar system which involves, electricity generation, air-conditioning, natural ventilation and domestic hot water supply is a fairly high solar energy integration system with an increased utilization ratio of solar energy. The system will have a high yield due to the excellent solar potentials available in Sokoto. The implementation is very expensive; however, with the incentives received from both the Federal and State

Governments, the project has a simple payback period of about 7.4 years. The proposed system is complex so the mathematical models and inevitable assumptions used in this analysis cannot be relied upon. It is recommended that a computer simulation using the Transys Software be used to analyze the system before implementation. In conclusion, implementing the proposed system in the building will make it much more energy efficient, totally eliminate the use of the diesel generator which is a greater source of CO2 emission. More than 60% of the energy requirements of this house will be supplied by Solar Energy and about 37 tons of $CO_2$ emissions will be saved annually.

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