We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



24

Development and Application of Asphalt Bonded Solar Thermogenerator in Small Scale Agroforestry Based Industry

R. S. Bello[1], S. O. Odey[2], K. A. Eke[1], A. S. Mohammed[3], R. B. Balogun[1], O. Okelola[1] and T. A. Adegbulugbe[4]
[1]*Federal College of Agriculture, Ishiagu*
[2]*Cross River University of Technology, Obubra, Cross River*
[3]*Federal College of Agriculture, Jalingo*
[4]*Federal College of Agriculture, Moore Plantation, Ibadan*
Nigeria

1. Introduction

In today's climate of growing energy needs and increasing environmental concerns regarding energy shortages, scarcity and rapid depletion of non-renewable and environmental polluting energy resources such as fossil fuel, it is essential to diversify energy generation so as to conserve these fuels for premium applications hence the development, acceleration and use of new and renewable energy resources (Oladiran, 1999; Akarakiri and Ilori, 2003).

Recent concerns on the depletion of conventional energy sources such as agroforestry products and residuals such as wood and wood wastes have prompted interests in the use of solar energy for agricultural and forestry applications. Solar energy is an abundant and environmentally attractive alternative energy resource with enormous economic promises. In this era of energy shortages, it is noticed that the sun is an unfailing source of energy. It is free, the only disadvantage being the initial high cost of harnessing it. It is known that much of the world's required electrical energy can be supplied directly by solar power (Dennis and Kulsum, 1996).

The most commonly considered uses of solar energy are those classified as thermal processes. They include house heating, distillation of sea water to produce potable water, refrigeration and air conditioning, power production by solar-generated steam, cooking, water heating, and the use of solar furnaces to produce high temperatures for experimental studies (Encarta, 2002). Solar energy technologies such as photovoltaic cells, thermoelectric cell, thermionic cells, thermo emissive cells, etc are being used in small-scale applications on commercial projects (Encarta, 2002).

Electricity is also vital to modern day living without which there can be no meaningful development (Madueme, 2002). This is because in a technological and scientific development characteristic of the present day society, electricity is necessary for the operation of machines. The bulk of electrical power in the developing countries has been produced mainly from fossil-fuel based generating systems (Akarakiri and Ilori, 2003).

1.1 Solar energy applications

Specific areas of solar technology application has been identified to include electricity supply during power outages, telephone installations, industrial sector and drying of agricultural and forestry products like cocoa, timber etc (Akarakiri and Ilori, 2003). For instance, in Nigeria, Nitel powered the Ugonoba and the Gewadabawa repeater stations in 1997; more than 50 repeater stations in the Nigerian Network were powered by PV systems (Coker, 2004).

Solar energy has been limited mainly to low grade thermal applications in the Sub Saharan African region. For instance over 10,000 units of solar water heaters have been installed in Botswana, Zimbabwe, and South African (Akarakiri and Ilori, 2003). A project funded by the Agency for International Development (AID) in Tangaye, Africa provides fresh water and runs a grain mill for commercial production of flour (Maycock and Stirewait, 1981).

Several researches have been undertaken concerning the direct generation of electricity using the heat produced from nuclear reactors, kerosene lamps, firewood and biomass. The development of improved materials, use of multi-junction devices and novel cell designs to capture a higher proportion of the solar spectrum and use of concentration (Fresnel) lenses to focus the sunlight to high efficiency cells are areas of rapid development (Duffie, and Beckman, 1976).

The study of thermoelectric materials is a very active area of modern research that combines aspects of physical chemistry, solid state physics, and materials science. A thermoelectric material is a material that converts heat to electricity and vice versa. The main motivation for studying thermoelectricity is to find ways to improve their performance to better implement them in practical systems. The concept of thermoelectricity, a process that converts heat energy into electrical energy by using the Seebeck effect, has been used in agricultural operations.

1.2 Specific areas of thermoelectricity applications

Thermoelectric phenomenon has also been utilized for the accurate measurement of temperature by means of a thermocouple in which a junction of two dissimilar wires is maintained at a known reference temperature (for example, in an ice bath) and the other junction at the location where the temperature is to be measured. At moderate temperatures (up to about 260°C /500°F), wire combinations of iron and copper, iron and constantan (a copper-nickel alloy), and copper and constantan are frequently used. At high temperatures (up to 1649°C/3000° F), wires made from platinum and a platinum-rhodium alloy are employed (Encycl. Britannica, 1987).

Lertsatitthanakorn (2007) investigated the feasibility of adding a commercial TE module made of bismuth-telluride based materials to the stove's side-wall, thereby creating a TE generator system that utilizes a proportion of the stove's waste heat. The results showed that the system generates approximately 2.4 W when the temperature difference is 150 ^{0}C. This generated power is enough to run a small radio or a low power incandescent light bulb. Other research works (Rowe, 2006, Lertsatitthanakorn, 2007) were conducted in order to investigate the feasibility of using a TE generator in an improved biomass fired stove already developed.

The main motivation for studying thermoelectrics is to find ways to improve their performance for better implementation in agricultural systems (Champier *et al*., 2009). In areas with unreliable electricity supply, the feasibility of adding a commercial thermoelectric (TE) module to stove design is being investigated (Rowe, 2006). Nuwayhid *et*

al., (2003) considered the prospect of applying TE modules in rural domestic woodstoves in regions where the electric supply is unreliable and subject to frequent disruption. This research work investigated the potentials of the utilization of asphalt bonded thermocouples in electricity generation and its application in small scale agricultural lighting projects such as poultry house illumination. The generator design work was made using existing high-quality Peltier modules in the power-generating mode.

1.3 Project objective

Demands for energy in agricultural production processes, especially in poultry production processes and other agro-forestry processes, are growing worldwide. In animal husbandry, light is an important aspect of the animal's environment. Avian species as well as mammalian species respond to light energy in a variety of ways for growth and reproductive performance. Acceptable system economic performances through extension services (Okelola *et al.,* 2011) and system analysis (Nuwayhid *et al.,* 2005) have been demonstrated at various levels. Despite the growing worldwide demand for energy in agricultural production processes, there has been an increase in production costs coupled with depletion of nonrenewable energy resources; therefore alternative and more attractive solar energy sources becomes imperative.

The concept of thermoelectricity using asphalt heating was employed in the development of TEG for lighting in agricultural projects such as small scale poultry house. The aim is to investigate the potentials of thermocouples embedded in asphalt (heat absorber) for electricity generation and application in agricultural projects.

1.4 Project justification

Application of solar energy has speedily improved the present low level of electricity production for domestic lighting and agricultural operations in several developing nations. However, according to the United Nations Development programme, 400milion families (nearly two billion people) have no access to electricity to light their homes, among other services (SELF, 2001).

The power generation potential of several energy harvesting modalities have been investigated (Roundy, 2003). While a wide variety of harvesting modalities are now feasible, solar energy harvesting through photo-voltaic conversion provides the highest power density, which makes it the modality of choice to power an embedded system that consumes several megawatt of energy using a reasonably small harvesting module. However, the design of a solar energy harvesting module involves complex tradeoffs due to the interaction of several factors such as the characteristics of the solar cells, chemistry and capacity of the batteries used (if any), power supply requirements, application behaviour, and power management features of the embedded system etc. It is, therefore, essential to thoroughly understand and judiciously explore these factors in order to maximize the energy efficiency of a solar harvesting module.

1.5 Energy storage technologies

The two choices available for energy storage are batteries and electrochemical double layer capacitors, known as ultracapacitors. Batteries are a relatively mature technology and have a

higher energy density (more capacity for a given volume/weight) than ultracapacitors, but ultracapacitors have a higher power density than batteries and have traditionally been used to handle short duration power surges.

Recently, such capacitors have been explored for energy storage, since they are more efficient than batteries and offer higher lifetime in terms of charge-discharge cycles. However, they involve leakage (intrinsic and due to parasitic paths in the external circuitry), which precludes their use for long-term energy storage. While it is also possible to implement energy storage mechanism using an ultracapacitor and a battery, it is a tradeoff to a decrease in harvesting circuit efficiency due to the increased overhead cost of energy storage management.

2. Solar generator

Two components are required to have a functional solar energy generator; they are the collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy; either electricity and heat or heat alone. Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator. The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received.

At night or during heavy cloud cover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum availability, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container.

2.1 Thermoelectric Generator (TEG)

The conversion of sunlight into electrical energy in a solar cell involves three major processes; 1) absorption of the sunlight by solar cell (heat source) at a temperature T_H; 2) heating up of the thermocouple junction thus obtaining temperature difference between the ends of metal wires and thermoelectric potentials developed along the wire; and 3) the transfer of these separate thermoelectric potentials, in the form of electric current, to an external system.

A thermoelectric generator is a device that converts heat energy directly into electrical energy using Seebeck effect. This requires a heat source, a thermocouple and reference material. Thermoelectric generator is composed of at least two dissimilar materials, one junction of which is in contact with a heat source and the other junction of which is in contact with a heat sink. The power converted from heat to electricity is dependent upon the materials used, the temperatures of the heat source and sink, the electrical and thermal design of the thermocouple, and the load of the thermocouple (Angrist, 1982). Although TEGs have very low efficiencies (5 to 10 % in the above mentioned applications), their usage makes sense where the heat source is freely available and would otherwise be lost to the environment (Richner *et al*, 2011).

2.2 The principles of thermoelectricity

When two dissimilar metals are connected (i.e. welded or soldered together) to form two junctions, the voltage generated by the loop is a function of difference in temperatures between the two junctions. Such loop is called a thermocouple and the emf generated is called a thermoelectric emf. This thermoelectric phenomenon known as 'Seebeck Effect' was discovered in 1821 by Thomas J. Seebeck (Maycock et al., 1981). If this circuit is broken at the center, the net open voltage (the Seebeck voltage) is a function of the junction temperature and the composition of the two metals.

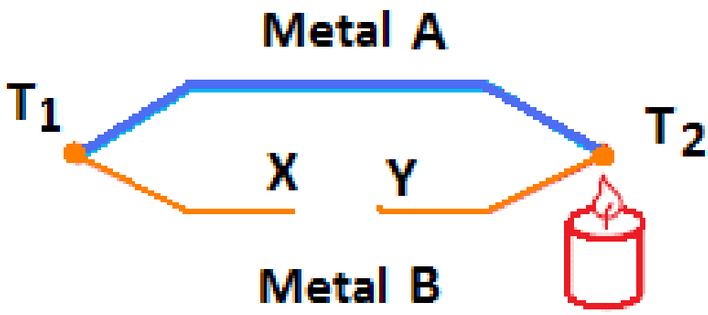


Fig. 1. A thermocouple made out of two different materials

Thermoelectric effects (Seebeck, Peltier, and Thomson)

There are three main thermoelectric effects experienced in thermo generation: the Seebeck, Peltier, and Thomson effects (Goldsmid, 1995; Nolas *et al.*, 2001). Thermoelectric effects are described in terms of three coefficients: absolute thermoelectric power (S), the Peltier coefficient (Π) and the Thomson coefficient (τ), each of which is defined for a homogenous conductor at constant temperature. Thermoelectric effects have significant applications in both science and technology and show promise of more importance in the future. Practical applications of thermoelectric effects include temperature measurement, power generation, cooling and heating (Steven, 2010).

Seebeck Effect: The Seebeck effect is responsible for the operation of a thermocouple. If a temperature gradient is applied across a junction between two materials, a voltage will develop across the junction, with the voltage related to the temperature gradient by the Seebeck coefficient.

For instance, the Seebeck coefficient of the thermocouple shown in Figure 1 as given by Steven, (2010) is:

$$\propto_{AB} = \frac{dV}{dT} \tag{1}$$

Where V is the voltage between points x and y, in the case of the thermocouple shown in Figure 1, $\Delta T = T_2 - T_1$ Then,

$$v_{xy} = \propto_{AB} (T_2 - T_1) \tag{2}$$

If T_2 is fixed and α_{AB} is known, then by measuring V_{xy}, one can determine T_1. If this circuit is broken at the center, the net open voltage (the Seebeck voltage) is a function of the junction temperature and the composition of the two metals.

Peltier Effect: The Peltier effect is the opposite of the Seebeck effect in which electrical energy is converted into thermal energy. It is observed in applications such as thermoelectric coolers. The Peltier effect is an effect whereby heat is liberated or absorbed at the junction between two materials in which a current I is flowing through. The heat liberated (or absorbed) at the junction is given by

$$Q = \Pi_{AB} I \tag{3}$$

Where Π_{AB} is the Peltier coefficient (Nolas *et al.,* 2001),**I** is current)

Thomson Effect: If there is a temperature gradient across a material and a current is flowing through the material, then heat will be liberated or absorbed. This is Thomson effect, and it is described by the following equation:

$$Q = \tau I \frac{dT}{dx} \tag{4}$$

Where τ is the Thomson coefficient (Nolas *et al.,* 2001). The following relationships hold for two materials A and B (Nolas *et al.,* 2001):

$$\tau_A - \tau_B = T \frac{d\alpha_{AB}}{dT} \tag{5}$$

$$\Pi_{AB} = \alpha_{AB} T \tag{6}$$

The coefficients α_{AB} and Π_{AB} defined above are for a system consisting of two different materials with a junction between them. However, it is often useful to define absolute thermoelectric coefficients which describe a single material. All of the above equations are generalized when a single material is being discussed (Nolas *et al.,* 2001). If a material is subjected to a temperature gradient ΔT, then $\Delta V = \alpha \Delta T$, where α is the Seebeck coefficient and ΔV is the volumetric change of the material respectively. Relations (5) and (6) also apply to absolute thermoelectric coefficients, i.e.

$$\tau = T \frac{d\alpha}{dT} \tag{7}$$

and

$$\Pi = \alpha T \tag{8}$$

2.3 Measuring Seebeck voltage

The Seebeck voltage cannot be measured directly because a voltmeter must first be connected to the thermocouple, and the voltmeter leads create a new thermoelectric circuit. Connecting a voltmeter across a copper-constantan (Type T) thermocouple and observing the voltage output: the voltmeter should read only V_1, but by connecting the voltmeter in an attempt to measure the output of Junction J_1, two more metallic junctions have been created: J_2 and J_3 (Figure 2a).

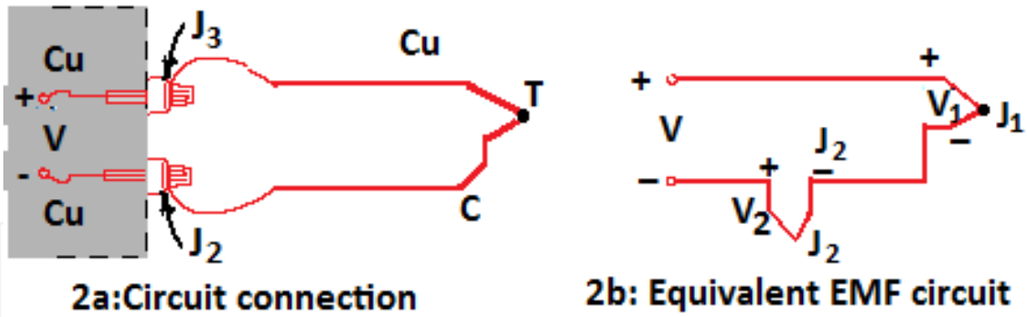


Fig. 2. Measuring Seebeck voltage

Since J_3 is a copper-to-copper junction, it creates no thermal EMF ($V_3 = 0$), but J_2 is a copper-to-constantan junction which will add an EMF (V_2) in opposition to V_1 (Figure 2b). The resultant voltmeter reading V will be proportional to the temperature difference between J_1 and J_2. This says that we cannot find the temperature at J_1 unless we first find the temperature of J_2.

In a closed circuit composed of two linear conductors of different metals, a magnetic needle would be deflected if, and only if, the two junctions were at different temperatures giving rise to an emf being generated. The magnitude of the emf generated by a thermocouple is measured on standard by an arrangement shown in figure below.

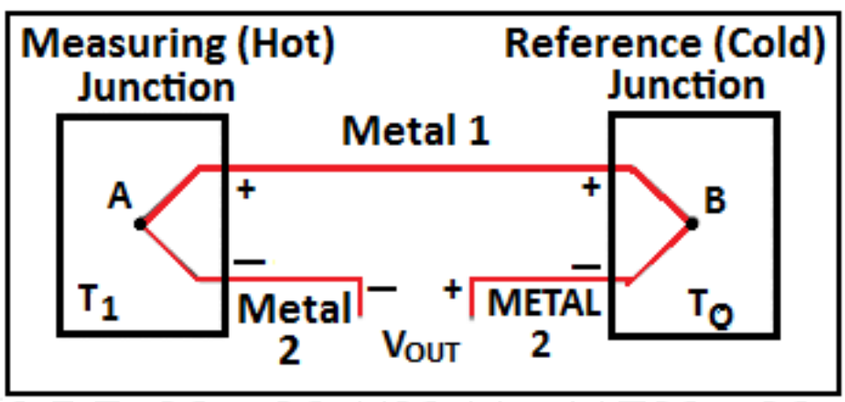


Fig. 3. Voltage measurement arrangement between two junctions

Points A and B are called junctions. Each junction is maintained at a well-controlled temperature (T_o or $T_{1)}$ by immersion in a bath (cold junction) or connected to a heat source (hot junction). From each junction, a conductor (metal 2) is connected to a measuring device (potentiometer or an amplifier of low input impedance), which measures the thermal emf.

The Seebeck emf is approximately related to the absolute junction temperatures T_0 and T_1 by

$$V = \propto (T_1 - T_o) + \gamma(T_1^2 - T_o^2) \tag{9}$$

Where α and γ are constants for the thermocouple pair.

The differential coefficient of equation above is the sensitivity, or thermoelectric power S, of the thermocouple

$$S = \frac{dV}{dT_1} = \propto +2\gamma T_1 \ (\mu V/\ 0\ c) \tag{10}$$

2.4 Measuring thermoelectric power, S

According to the experimentally established law of Magnus, the thermoelectric emf for homogenous conductors depends only on the temperatures of the junctions and not on the shapes of the samples. This emf can thus be described by the symbol E_{AB} (T_o, T_1) and is determined solely by conductor A and can be written as E_A (T_o, T_1). This emf is more conveniently expressed in terms of a property, which depends upon only a single temperature. Such property is the absolute thermoelectric power (thermo power S_a (T)) defined as in equation (11).

$$E_A(T_o, T_1) = \int_{T_o}^{T_1} S_A\,(T)dt \tag{11}$$

If E_A (T_1, T+ΔT) is known, for example, from measurements involving a super conductor, then S_A (T) can be determined from equation 12

$$S_A(T) = \lim_{\Delta T \to 0} E_A \frac{(T_1, T+\Delta T)}{\Delta T} \tag{12}$$

If equation 11 is for any homogenous conductor, then it ought to apply to both sides of the thermocouple. Indeed, it has been verified experimentally that the emf E_{AB} (T_o, T_1) produced by a thermocouple is just the difference between the emfs calculated using equation (17), produced by its two arms as follows.

Employing the usual sign correction, to calculate E_{AB}(T_o, T_1), begin at the cooler bath, integrate S_A(T)dT along conductor (metal 2) at junction A up to the warmer bath and then return to cooler bath along conductor (metal 1) through junction B by integrating S_B(T)dT.

This circular loop produces E_{AB} (T_o, T_1) given by equation 13 and 14.

$$E_{AB}(T_o, T_1) = \int_{T_o}^{T_1} S_A\,(T)dt + \int_{T_o}^{T_1} S_B\,(T)dt \tag{13}$$

$$E_{BA}(T_o, T_1) = \int_{T_o}^{T_1} S_A\,(T)dt - \int_{T_o}^{T_1} S_B\,(T)dt \tag{14}$$

Alternatively, combining the two integrals in equation 14

$$E_{AB}(T_o, T_1) = E_A(T_o, T_1) - E_B(T_o, T_1) \tag{15}$$

$$E_{AB}(T_o, T_1) = \int_{T_o}^{T_1} [S_A\,(T)dt - S_B(T)]\ dt \tag{16}$$

According to equation 16, E_{AB}(T_o,T_1) can be calculated for a given thermocouple whenever the thermo powers S_A(T) and S_B(T) are known for the two constituents over the temperature range T_o to T_1.

Defining S_{AB} according to equation 16 then yields equation 17

$$E_{AB}(T_o, T_1) = \int_{T_o}^{T_1} S_{AB}\quad (T)dT \tag{17}$$

$$\Rightarrow S_{AB}(T) = S_A\,(T) - S_B(T) \tag{18}$$

These equations lead directly to experimentally and theoretically verified results that in a circuit kept at a uniform temperature (dt = 0) throughout, E= 0 even though the circuit may consist of a number of different conductors (equation 18). If E did not equal 0, the circuit could drive an electric motor and make it perform work. The only source of energy would be heat from the surrounding. A circuit composed of single, homogenous conductor cannot produce thermoelectric emf (equations 6) when S_B (T) is equal to S_A (T). Finally, equation 6 makes it clear that the source of the thermoelectric emf in a thermocouple lies in the bodies of the two materials of which it is composed rather than the junctions.

The reference junction

One way to determine the temperature of reference junction J_2 is to physically put the junction into an ice bath, forcing its temperature to be 0°C. Since the voltmeter terminal junctions are now copper-copper, they create no thermal emf and the reading V on the voltmeter is proportional to the temperature difference between J_1 and J_2.

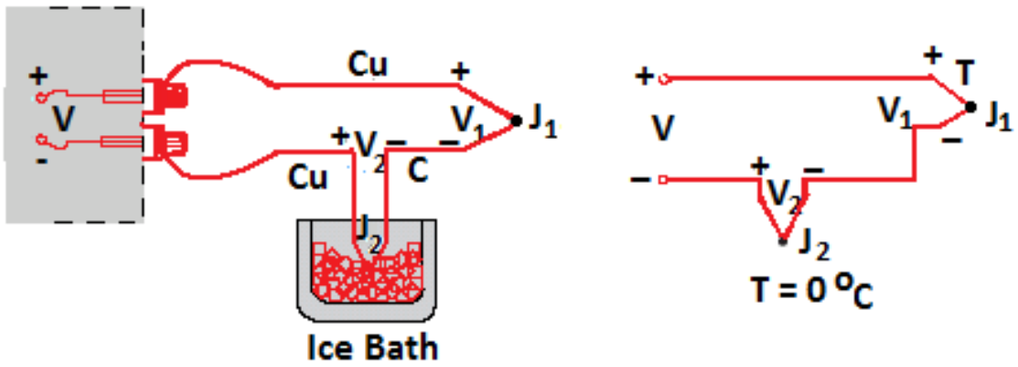


Fig. 4. External reference junction

Now the voltmeter reading is (see Figure 4):

$$V = V_1 - V_2 \cong \propto (t_{j1} - t_{j2}) \tag{19}$$

If we specify T_{J1} in degrees Celsius:

$$T_{j1}(°C) + 273.15 = t_{j1} \tag{20}$$

Then V becomes:

$$V = V_1 - V_2 = \propto [(T_{j1} + 273.15) - T_{j2} + 273.15)] \tag{21}$$

$$V = \propto (T_{j1} - 0) = \propto T_{j1} \tag{22}$$

This derivation is used to emphasize that the ice bath junction output, V_2, is not zero volts. It is a function of absolute temperature. By adding the voltage of the ice point, reference junction, we have now referenced the reading V to 0°C. This method is very accurate because the ice point temperature can be precisely controlled. The ice point is used by the National Bureau of Standards (NBS) as the fundamental reference point for their thermocouple tables, so we can now look at the NBS tables and directly convert from voltage V to Temperature T_{J1}.

Using an iron-constantan (Type J) thermocouple instead of the copper-constantan, the iron wire (Figure 5) increases the number of dissimilar metal junctions in the circuit, as both voltmeter terminals become Cu-Fe thermocouple junctions.

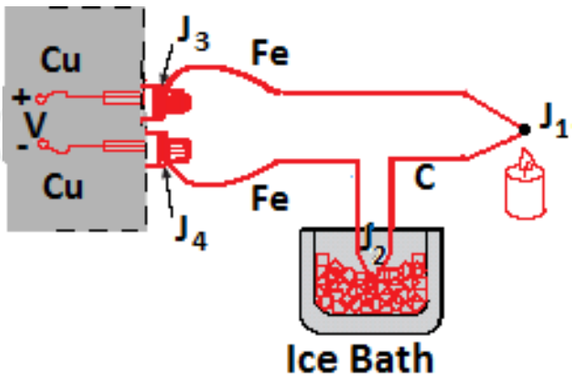


Fig. 5. An Iron- constantan couple

If both front panel terminals are not at the same temperature, there will be an error. For a more precise measurement, the copper voltmeter leads should be extended so that the copper-to- iron junctions (J_3 and J_4) are made on an isothermal (same temperature) block.

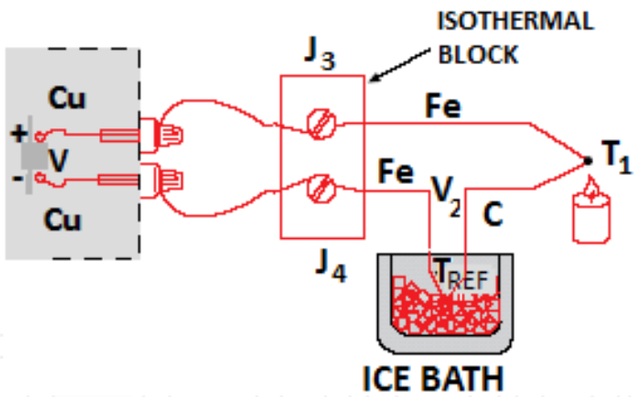


Fig. 6. Removing junctions from DVM terminals

The isothermal block is an electrical insulator but a good heat conductor, and it serves to hold junctions J_3 and J_4 at the same temperature. The absolute block temperature is unimportant because the two Cu-Fe junctions act in opposition.

Reference circuit

Replacing the ice bath with another isothermal block (Fig. 7) at J_{REF}, the new block is at reference temperature T_{REF}, and because J_3 and J_4 are still at the same temperature, we can again show that

$$V = \propto (T_1 - T_{REF}) \tag{23}$$

A thermistor, whose resistance R_T is a function of temperature, provides us with a way to measure the absolute temperature of the reference junction. Due to the design of the isothermal block, junctions J_3 and J_4 and the thermistor are all assumed to be at the same temperature.

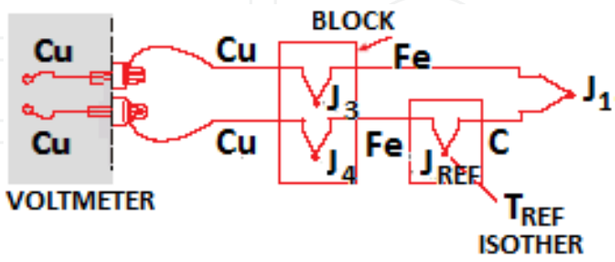


Fig. 7. Eliminating the ice bath

However, the use of thermocouples other than thermistor is more preferable in that thermocouple can be used over a range of temperatures, and optimized for various atmospheres. Thermocouples are much more rugged than thermistors, as evidenced by the fact that thermocouples are often welded to a metal part or clamped under a screw. They can be manufactured on the spot, either by soldering or welding. In short, thermocouples are the most versatile temperature transducers available and, since the measurement system performs the entire task of reference compensation and software voltage to-temperature conversion, using a thermocouple becomes as easy as connecting a pair of wires.

2.5 Thermogenerator composite parameters

The effective composite materials for thermoelectric generator include heat source, the thermocouple, the heat sink and the load. The composite parameters of the generator are the total Seebeck coefficient of the junction S, the total internal resistance r, and the total thermal conductivity k. The Seebeck coefficient can have either a positive or a negative sign. A material that has a negative S is referred to as an n-type material while a material having positive S is referred to as a p-type material.

Assuming that all the composite parameters are independent of temperature, and the Seebeck coefficients of the legs of thermocouple are S_n and S_p, and the electrical resistivity of each leg is ρ_n and ρ_p, and the thermal conductivities of each leg is k_n and k_p, then the parameters are defined by the following equations.

$$S = S_P - S_n = |S_p| + |S_n| \tag{24}$$

$$r = \frac{\rho_n l_n}{A_n} + \frac{\rho_p l_p}{A_p} \tag{25}$$

$$k = \frac{k_n A_n}{l_n} + \frac{\rho_p A_p}{l_p} \tag{26}$$

Where l_n, A_n, and l_p, A_p, refers to the length and area of the n-type and p-type materials respectively, the heat source has a temperature T_n, and the heat sink has temperature T_c.

2.6 Thermogenerator efficiency

The efficiency η of generator is the power output I^2R divided by the heat input Q_{in}.

$$\eta = p_{out}/Q_{in} = l^2R/Q_{in} \tag{27}$$

R is the electrical load resistance. Heat input Q_{in} consists of the Peltier heat ST_nI plus the conduction heat K (T_n-T_c) less one-half of the Joule heat I^2r librated in the thermocouple legs, i.e.

$$Q_{in} = ST_n l + k(T_n - T_c) - \frac{l^2 r}{2} \tag{28}$$

Losses in maintaining the temperature T_n are not considered by this efficiency and thus it is not a total efficiency including heat source losses.

The ratio of load resistance R to internal resistance r is defined as $m = R/r$

The open-circuit voltage,

$$V_o = S(T_n - T_c) \tag{29}$$

The current,

$$I = \frac{V_o}{R+r} \tag{30}$$

Using these quantities, and selecting m to give optimum loading, the optimized efficiency, the efficiency expression becomes

$$\eta = \frac{T_n - T_c}{T_n}\left\{\frac{M-1}{M+{}^{T_c}/_{T_n}}\right\} \tag{31}$$

Where

$$M = m|_{d_n/d_{m=0}} = \sqrt{Z}(T_h - T_2)/2) \quad M = m|_{d_n/d_{m=0}} = \sqrt{Z}(T_h - T_2)/2) \tag{32}$$

Z is the figure of merit.

This efficiency for an optimum load consists of a Carnot efficiency η_c and device efficiency η_d thus

$$\eta_c = \frac{T_n - T_c}{T_n} \tag{33}$$

$$\eta_d = \frac{M-1}{M+{}^{T_c}/_{T_n}} \tag{34}$$

The device efficiency η_d will be a maximum for the largest value of M, for a fixed T_n and T_c; this requires a maximum value of Z. For most good thermoelectrics, Z (T_n+T_c)/2 ≈1, so for T_n/T_c ≈1, the efficiency is about 20% of the thermodynamic limit.

2.7 Figure of merit

This is a measure of the ability of a given thermoelectric material in power generation, heating or cooling at a given temperature T. ZT is given by the equation.

$$ZT = S^2\sigma T/k \tag{35}$$

Where
S = the thermo power of the material
σ = The electrical conductivity
K = The thermal conductivity

The largest values of ZT are attained in semimetals and highly doped semiconductors, which are the materials normally used in practical thermoelectric devices. Figure of merit for single materials and thermocouples formed from two such materials varies hence one thermocouple can be better than another at one temperature but less effective at a second temperature.

Z depends upon the material parameters S_p, K_p, ρ_p S_n, K_n, ρ_n and the dimensions of the two legs A_p, ℓ_n, ℓ_p ,A_n . Maximizing Z with respect to the area-to-length ratio of the legs gives

$$Z|_{d_z/d_{x=0}} = \frac{(S_p - S_n)^2}{[(k_p l_p)^{1/2} + (k_n l_n)^{1/2}]^2} \tag{36}$$

When equation

$$\left[\frac{k_n l_n}{k_p l_p}\right]^{1/2} = \left[\frac{A_p l_n}{A_n l_p}\right] \tag{37}$$

For the optimum area-to-length ratio Z depends only upon the specific properties of the thermoelectric material. Generally, the parameters S, *K*, and ρ are not independent of temperature, and in fact the temperature dependence of the n and p legs may differ radically. The most widely used generator materials are lead telluride, which has a maximum figure of merit of approximately $1.5x10^{-3}$ K^{-1}. It can be doped to produce both p-type and n-type material and has a useful temperature range of about 300-700K (80-800^oF). In material development, existing thermoelectric p and n materials operates from 300 to 1300K (80 to 1900^oF) and yield an overall theoretical thermal efficiency of 18%.

To maximize power output, it is necessary to produce the largest possible voltage, thus Seebeck coefficient S should be made large, and hence proper selection of materials are required. Materials should have low electrical resistance in the generator. The legs should also have low thermal conductivities *K* since heat energy is carried away by thermal conduction. Hence the requirements for materials to be used in thermoelectric power generators are high S, low ρ and *K* and high figures of merit Z. Since the figures of merit Z for single materials vary with temperature, so do the figures of merit for thermocouples formed from two materials.

3. The thermocouple system

Thermocouples are differential temperature-measurement devices. They are constructed with two wires of dissimilar metals. One wire is pre-designated as the positive side (Copper,

Iron, Chromel) and the other as the negative (Constantan, Alumel). Basic system suitable for the application of thermoelectricity in power generation is that of several thermocouples connected in series to form a thermopile (a device with increased output relative to a single thermocouple). The junctions forming one end of the thermocouple are at the same low temperature T_L and the other junctions at the hot temperature T_H.

The thermopile is connected to a device in which the temperature T_L is fixed when connected to a heat sink. The temperature T_H is determined by the output of the heat source and the thermal output of the thermopile. The load is run by the charges generated. With a thermopile, the multiplication of thermocouple involves a corresponding increase of resistance, hence it follows that one thermocouple can be better than another at one temperature but less effective at a second temperature. In order to take maximum advantage of the different materials, the thermocouples are cascaded, producing power in stages and increase power output.

3.1 The choice of thermocouple

A primary consideration in choosing which thermocouple type to use in a given circumstance is the range of temperatures over which the device is to be used. Some of the other selection factors among others to be addressed include:

- Suitability for conditions of use, expected service life and compactable installation requirements
- Adequate sensitivity S over a wide range of temperature, stability against physical and chemical changes under various conditions of use and over extended periods of times,
- Availability, moderate costs, abrasion and vibration resistance.

Thermocouples can either be sheathed or beaded with bare thermoelements (Figure 8).

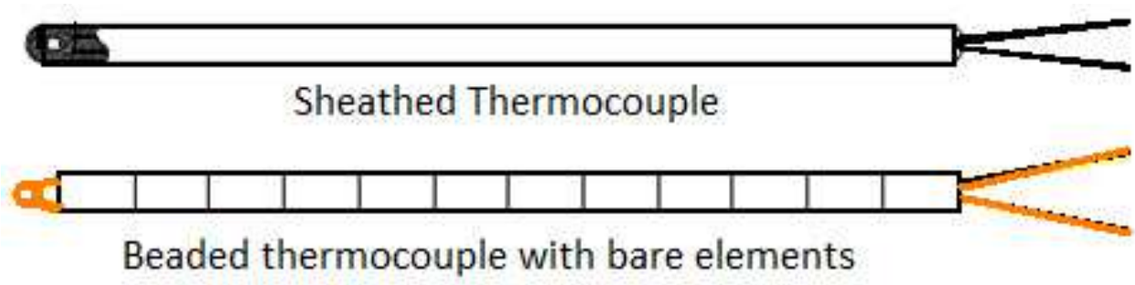


Fig. 8. Thermocouple materials

Sheathed thermocouple probes are available with one of the three junction types:

Grounded Junction Type: This is recommended for gas and liquid temperatures and for high-pressure applications. It has faster response than the ungrounded junction type.

Ungrounded Junction Type: This is recommended for measurements in corrosive environments where it is desirable to have the thermocouple electronically isolated from and shielded by the sheath.

The Exposed Junction Type: This is recommended for the measurement of static or flowing non-corrosive gas temperature where fast response time is required.

ANSI Polarity: In the thermocouple industry, standard practice is to colour the negative lead red. The negative lead of a bare wire thermocouple is approximately 6mm (‘4’’) shorter than the positive lead and the large pin on a thermocouple connector is always the negative conductor (Omega Eng., 2001) Standard Diameters of thermocouple available are: 0.25mm (0.010’’), 0.50mm (0.020’’), 0.75mm (0.032’’), 1.0mm (0.04’’), 1.5mm (1/16’’), 3mm (1/8’’), 4.5mm (3/16’’), 6 mm (1/4’’). With two wires 8mm and 9.5mm standard Omega thermocouples have 12-inch (300mm) immersion lengths. Other lengths are available.

3.2 Standard thermocouple types

ASTM and ANST standards explicitly stated that the letter designations identifying only the reference tables might be applied to any thermocouple with a temperature-emf relationship that complies with the table within the specified tolerances, regardless of the chemical composition of the thermocouple (Quinn, 1983). Any randomly chosen pair of dissimilar wires will produce some kind of thermal emf when subjected to a temperature difference from end to end, however, the emf so produced may be unpredictable and of little use. Hence certain thermoelement combinations have been commercially developed over the years that have proved to be useful, reproducible, and readily available.

Eight of the most widely used of these combinations have been assigned letter-designations for ease of reference, Base metal thermocouples types designated as E, J, K, and T. The rear (Noble) metal thermocouple types are S, R, and B types.

3.3 Base metal types

Type E, Chromel (nickel-10% chromium) (+) vs. Constantan (nickel-45% copper (-)). Type E is recommended for use to 900°C (1600°F) in oxidizing or inert atmospheres. Type E has been recommended as the most suitable of all standardized types for general low-temperature use, about -230°C (-380°F), since it offers the best overall combination of desirable properties i.e. high thermopower, low thermal conductivity, and reasonably good thermoelectric homogeneity typical values for the thermopower of type E at 4, 20, and 50K are 2.0, 8.5 and 18.7μVK^{-1} respectively (Spark *et al*., 1972).

Type **J,** Iron (+) vs. Constantan (nickel-45% copper (-)) is one of the most commonly used thermocouples in industrial pyrometry due to its relatively high thermopower and low cost. These thermocouples are suitable for use in vacuum, air, reducing, or oxidizing atmospheres to 760°C (1400°F) in the heavier gage sizes. Rapid oxidation of the iron wire at temperatures above 540°C (1000°F) limits the expected service life of the finer sized wires.

Types K (Chromel (nickel-10% chromium) (+) vs. Alumel (nickel-5% aluminum and silicon (-)) and T (Copper (+) vs. Constantan (nickel-45% copper) (-) thermocouples are often used below 0^{o}C, but type J is not suitable for general low-temperature use because the positive thermo element (noted as JP) is composed of iron and thus is subject to rusting and embrittlement in moist atmospheres. Type K is more resistant to oxidation at elevated temperatures than types E, J and T and consequently it finds wide application at

temperatures above 500°C. Type E has the highest thermopower above 0°C of any of the standardized types.

Type N, Nicrosil (nickel-14% chromium, silicon) (+) vs. Nisil (nickel-4% silicon, magnesium) (-). This type differs from type K by having silicon in both legs and containing magnesium in the negative leg. It was developed to be more stable (exhibit less calibration drift) than type K when used at temperatures above about 1000°C (1800°F). Both type N wires are similar in color and both are non-magnetic, so identification is usually made by gently heating the junction and observing the polarity of the resultant emf.

3.4 Noble metal types

Thermocouples employing platinum and platinum-rhodium alloys for their thermoelement (Noble-metal thermocouple types B, R and S) have been used for many years and exhibit a number of advantages over the base metal types. They are most resistant to oxidation, their thermoelements have higher melting points, and they have generally been found to be more reproducible at elevated temperatures in air. They are therefore used when higher accuracy and longer life is sought, though more experience with lower thermopowers.

Of all the standardized thermocouples, Type **S,** Platinum-10% rhodium (+) vs. Platinum (-) is the oldest and perhaps the most important. Type B, Platinum-30% rhodium (+) vs. Platinum-6% rhodium (-), was adopted as a standard type in the US in the late 1960s primarily to serve requirements in the 1200 to 1750°C range. At elevated temperatures, it offers superior mechanical strength and improved stability over types R and S, and it exhibits comparable thermopower. Its thermopower diminishes at lower temperatures and is vary small in the room-temperature range.

Identification of noble metal thermocouple wires is made difficult by the fact that all alloys are nearly identical in colour and all are non-magnetic. Sometimes it is possible to distinguish the positive wire from the negative one for types R or S by observing the 'limpness' of the wires. Pure platinum wires tend to be slightly more soft, or limp, while the rhodium-alloyed conductors are a little stiffer, enough so to permit identification. The differences, however, are subtle, and it is not possible to tell one rhodium alloy from another by these means. Proper connections for these thermocouples can be reliably determined by gently heating the junction and observing the resulting polarity on a sensitive indicator.

4. Solar harvest circuit design

The core of the harvesting module (solar panel) is the harvesting circuit, which draws power from the solar panels, manages energy storage, and routes power to the target system. The most important consideration in the design of this circuit is to maximize efficiency and there are several aspects to this. Solar panels have an optimal operating point that yields maximal power output. The harvesting circuit should ensure operation at (or near) this maximal power point, which is done by clamping the output terminals of the solar panel to a fixed voltage.

A DC-DC converter is used to provide a constant supply voltage to the embedded system. The choice of DC-DC converter depends on the operating voltage range of the particular

battery used, as well as the supply voltage required by the target system. If the required supply voltage falls within the voltage range of the battery, a boost-buck converter is required, since the battery voltage will have to be increased or decreased depending on the state of the battery. However, if the supply voltage falls outside the battery's voltage range, either a boost converter or a buck converter is sufficient, which significantly improves power supply efficiency.

4.1 Material consideration for fabricating solar panel

4.1.1 Choice of composite material

A material for fabricating solar cells should be cheap to acquire and must be pure. Attempt on polymer and composite material based cell is a good development. Composites in general showed good physical properties and improved mechanical strength, 0-3 type super conducting composites with epoxy and phenolic thermosetting plastics have advantages of high toughness, superior abrasion, dimensional stability and heat, water and chemical resistance.

The composition of naturally occurring or pyrolytically obtained composite material (Bitumen), is complex but separation, by both physical and chemical methods, into different chemical groups has been made (Oyekunle, 1985). The fractions so obtained consist of asphaltic hydrocarbons (asphaltenes) viscous naphtheno-aromatic hydrocarbons (heavy oils), heterocyclic and polar compounds (resins). Asphaltenes are hard, non plastic high, molecular weight compounds ranging between 1200 and 200,000 and are thus responsible for temperature susceptibility (Gun, 1973).

4.1.2 Asphalt composition

135cl by volume of emulsified (Cutback) asphalt (mixture of bitumen and mineral aggregates of 0/5mm size) were sourced locally. The bitumen is heated in a container (hot-mix plant) and mixed thoroughly with aggregates to form asphalt concrete. The composition is as shown in table 1.

Material	**Property**
Mineral Aggregate Sieve Size	No. 40
Mixture type	A
Percentage Passing	0-8
Bituminous Material:	MC Liquid asphalt, MC 250

Table 1. Asphalt Properties and Compositions

4.1.3 Asphalt preparation

The mineral aggregates and bituminous material is in proportions by weight. The aggregate is ensured clean and surface dry before mixing. The mixing period is sufficient to produce a uniform mixture in which all aggregate particles are thoroughly coated. Asphalt cement content of mixes is an important physical characteristic and influences the performance life

of asphaltic concrete. Too much asphalt cement results in mixture stability problems, while too little asphalt cement results in a mixture that is not durable, (Robert *et al.,* 1996; Gordon 1997).

4.1.4 Thermocouple material

Thermocouple: Type E thermocouple has good stability, highest sensitivity among the common metals and thus has high emf output. Based on ASTM set recommended upper temperature limits for various wire sizes, selected diameter for the E type thermocouple is AWG24, 0.51mm diameter. Upper temperature limits for E type is 427^{o}C. Type E has the highest thermopower of 6.317mV/^{o}C in the temperature range (0 -100) ^{o}C among any of the standardized types. The thermocouple properties are as shown in Table 2.

Property	Nickel- Chromium (Constantan)	Copper – Nickel (Chromel)
Composition	90% Ni, 10% Cr	60% Cu, 40% Ni
Thermal conductivity, *k*	22.7-w/m^2 ^{o}C	17.1-w/m^2 ^{o}C
Thermal diffusivity, α	61.2 x10^4 m^2/s	44.4x10^4 m^2/s
Density, ρ	8922 kg/ m^2	8666kg/ m^2
Electrical conductivity	58.14 x10^6 m^{-1} Ω^{-1}	-
Useful temperature range	-200 to 980	-
Total thermal conductivity	5.4 x10^{-4} W/ m^2 ^{o}C	
Diameter	0.51mm (0.00051m)	
Length	15mm (0.015m)	
Figure of merit	1.0 x 10^{-6}	
Thermopower at (31-80)^{o}C	3.116 mV/^{o}C	

Table 2. Thermocouple Material Properties

4.1.5 Extension wire

Thermocouple alloy wire is recommended to be used always to connect a thermocouple sensor to the instrumentation to ensure accurate measurements. Due to the high cost of thermocouple wire, a copper wire was used with assurance of no significant change in the emf produced.

4.1.6 Heat source

The mixture is compressed into small pallets (0.5cm) with thermocouple junctions cascaded and embedded into it. A glass screen is to be provided to prevent escape of long wave radiation from the absorber surface.

4.2 Modeling the generator

The following assumptions are used in determining the open circuit voltage: The heat source is a flat plate collector, thus an assumption of maximum temperature of 80^{o}C is considered for the heat source, a black body absorber. An ambient temperature of 31^{o}C was considered for the isothermal block because ice baths are often inconvenient to maintain at 0 ^{o}C and not always practical.

4.2.1 Output voltage

To determine the output voltage X of the thermocouple at 31.0 ^{o}C and 80.0^{o}C, the thermoelectric emf at 31.0^{o}C is interpolated (S_{31} = 1.867 mV/^{o}C) and the difference used to determine S = $S_{80} - S_{31}$ = 3.116 mV/^{o}C. The output (open-circuit) voltage, V of the thermocouple junction is given by V = S ($T_{80} - T_{31}$) = 152.68 mV

4.2.2 Thermocouple (heat sink) reference junction

With accurate thermocouple measurements required, it is common practice to reference both legs to copper lead wire at the ice point so that copper leads may be connected to the emf readout instrument. This procedure avoids the generation of thermal emfs at the terminals of the readout instrument. The emf generated is dependent on a difference in temperature, so in order to make a measurement the reference must be known. The reference junction is placed in an ice water bath at a constant 0^{o}C (32^{o}F). Because ice baths are often inconvenient to maintain and not always practical, several alternate methods are often employed (Omega Engineering, 2001)

4.2.3 Solar cell configuration

Under bright sunlight, all silicon PV cells have an open circuit output of approximately 0.5V irrespective of cell surface area. The voltage is a function of the cell's physical composition, while amperage is affected by area of cell and the amount and intensity of light falling upon it. Increase in the voltage and amperage output of PV cells depends on the mode of connection of the cells in a module. For higher voltage, the cells are linked in series (net voltage is the sum of the individual voltages of the cells) (Figure 8a). The net current is however the same as that of a single cell. To boost amperage, the cells must be connected in parallel (Figure 8b)

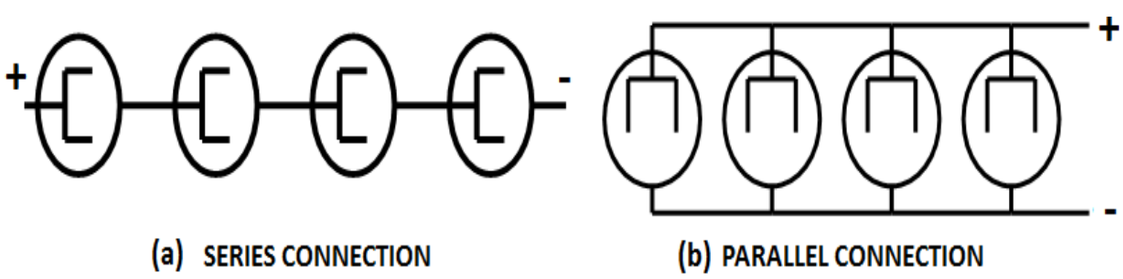


Fig. 8. Solar cell connections

4.3 Construction of thermocouple circuit

The thermocouple wires (Type E) made of different metal alloys (Nickel-Chromium copper-constantan) is joined together by soldering. The number of thermocouples required to generate an output voltage of 15V is required. Knowing the output voltage of one thermocouple (type E) given as 153mv (0.153v), dividing 15 by 0.153 to give 98.04 = 98 junctions. There are six modules with 15 junctions each (Fig 9). These thermocouples were joined together in series to form cascaded thermopile consisting of a number of thermocouples.

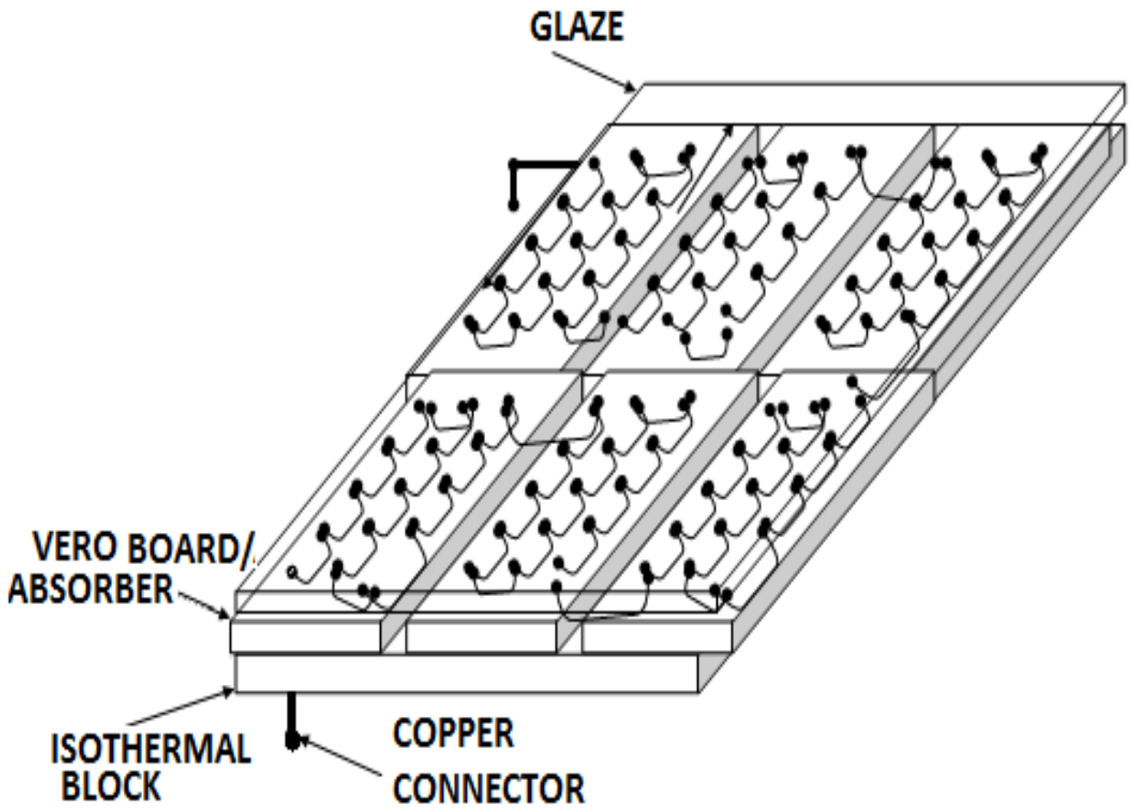


Fig. 9. Thermocouple solar panel

The construction of the solar power module was simple and convenient employing modular approach in which the entire system is divided into modules. The design is to generate high voltage, thus the cells are connected in series in the module. The voltage is a function of the cell's physical composition, while the amperage is affected not only by the area of the cell, but also by the amount and intensity of light falling upon it.

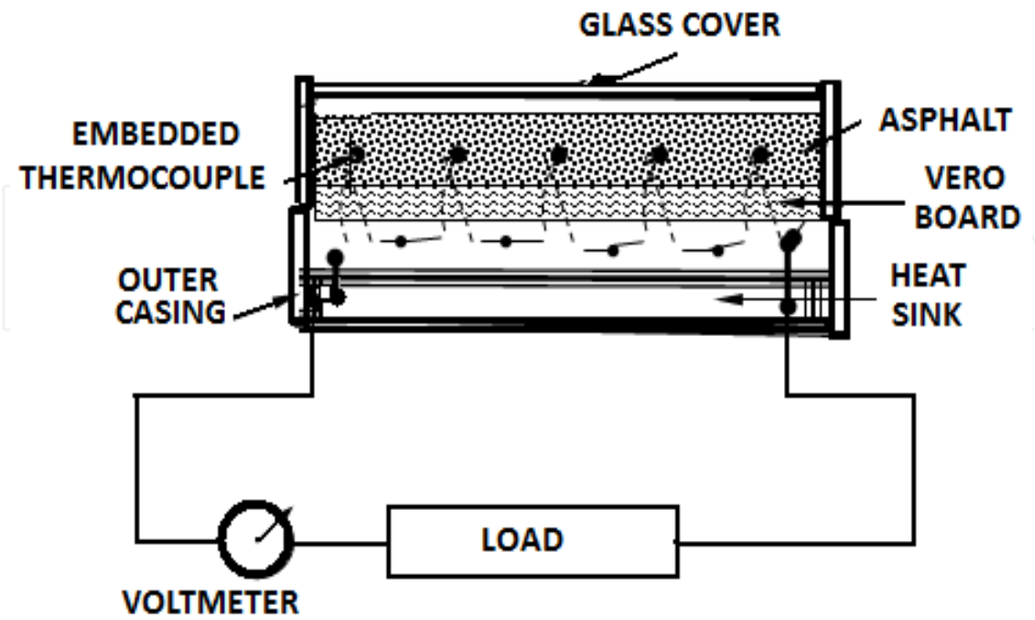


Fig. 10. A section through the solar panel

For high amperage, the cells must be connected in parallel. The net voltage is the sum of the individual voltages in the cell. Increase in the voltage and amperage output of the thermocouple cells depends upon the mode of connection in the module. The efficiency and power output requirement is determined by the power output of one thermocouple given by the equations above, the number of thermocouples in series, and the surface area of the solar cell were thus determined.

4.4 System fabrication

The entire system is divided into modules as shown in Figure 11. Vero board is used as the circuit boards for the solar panel and the charge control system.

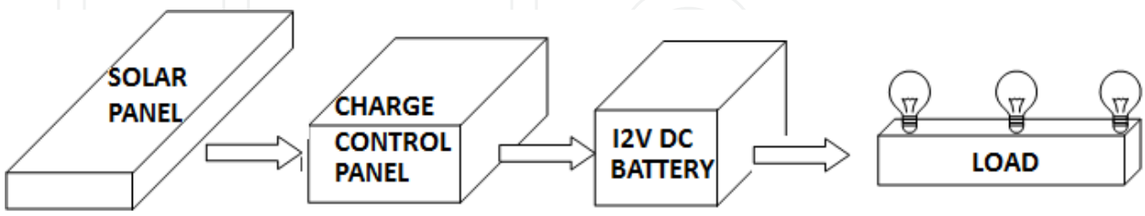


Fig. 11. Block diagram of the system

The charge control system uses the LED control charging system to charge a 12v lead Acid battery. An electrical diode, D_1 ensures unidirectional voltage flow when battery is under charge (Fig 10). For simplicity of construction and convenience the modular approach of constructing solar energy harvest modalities is used. Photovoltaic conversion provides the highest power density, which makes it the modality of choice to power an embedded system using reasonably small harvesting module.

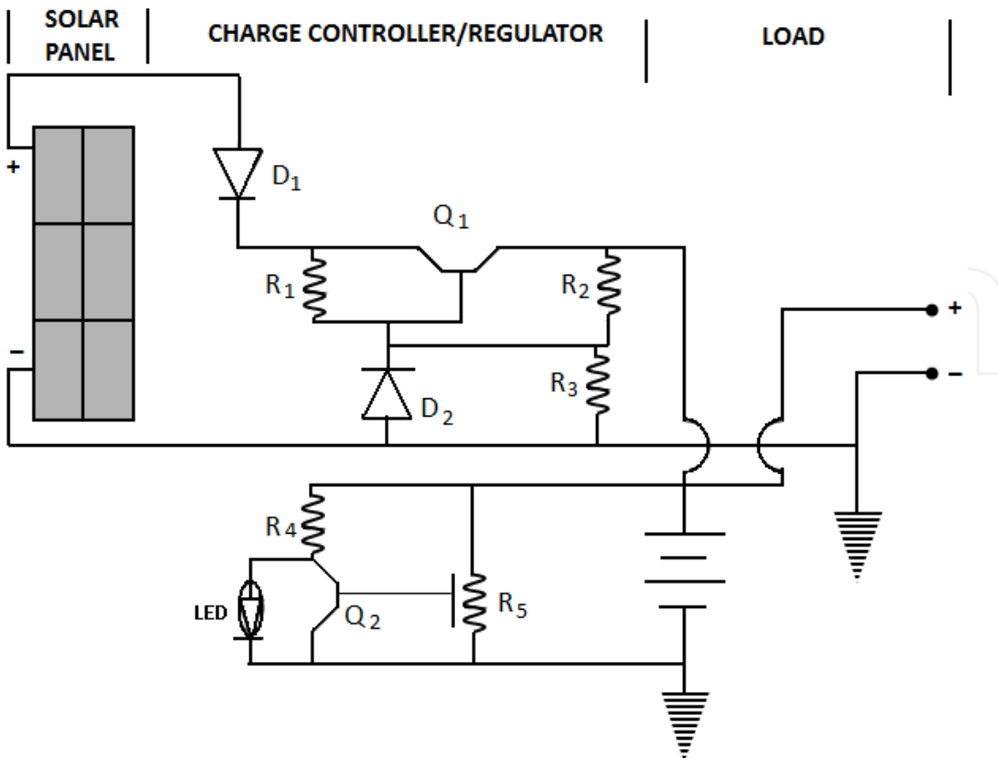


Fig. 11. Circuit Diagram of the solar power supply

The components of the electrical circuit and ratings are as follows:

D_1, D_2 = Diode (MA2J728 or MA3x704), Q_1, Q_2 = FET transistor (IRFZ44), R_1 = Resistor =220kΩ, R_2 = Resistor = 12kΩ, R_3 = Resistor = 2.7kΩ, R_4 = Resistor = 4.5kΩ, R_5 = Variable Resistor = 1000kΩ, LED (Green/Red), Battery = 12V Rechargeable Lead Acid.

Since the thermocouple array is expected to charge the battery on sunny days when output exceeds the load, but on cloudy days or at night, the load is expected to exceed the array output and drain the battery- Hence the array must be sized to ensure that the balance is positive and the battery is recharged when discharged. The array delivered an average daily output equal to the average daily system load (including all losses) plus approximately 10% to ensure that the battery is recharged.

5. System test result

5.1 Collector surface temperature

The daily total solar energy Q_t received per unit surface area of the absorber at the location (Ishiagu, South East Nigeria) as evaluated by Bello and Odey (2009) is 747.67 W/m². The useful components of the global solar radiation at the location are: direct solar radiation q_D = 680.67 W/m², diffuse solar radiation q_d = 64.21 W/m² and ground reflected radiation q_r = 2.34 W/m². The collector heat transfer coefficient between the absorber and cover expressed as the heat loss per unit area of the collector surface per temperature change is 3.06 W/m² °C. Total absorbed heat energy per unit surface area of absorber q_u = 592.43 W/m²

Measurements were taken on a clear day without cloud cover and surface temperatures were measured at five different spots every hour. According to measured temperature data, the average daily surface temperature increases with increase in sunshine hour reaching its peak between 1300hr and 1400hr (Fig 12) and then decline. On the average, 10hrs of sunshine hours is available per day, but for useful solar harvest, 8hrs of sunshine may is assumed because of difference in temperature between the collector surface and the ambient. The full sun (peak sun) hour value monitored at the site during raining season and dry season were found to be 4hrs and 5hrs respectively, agreeing with Onojo *et al.,* (2004).

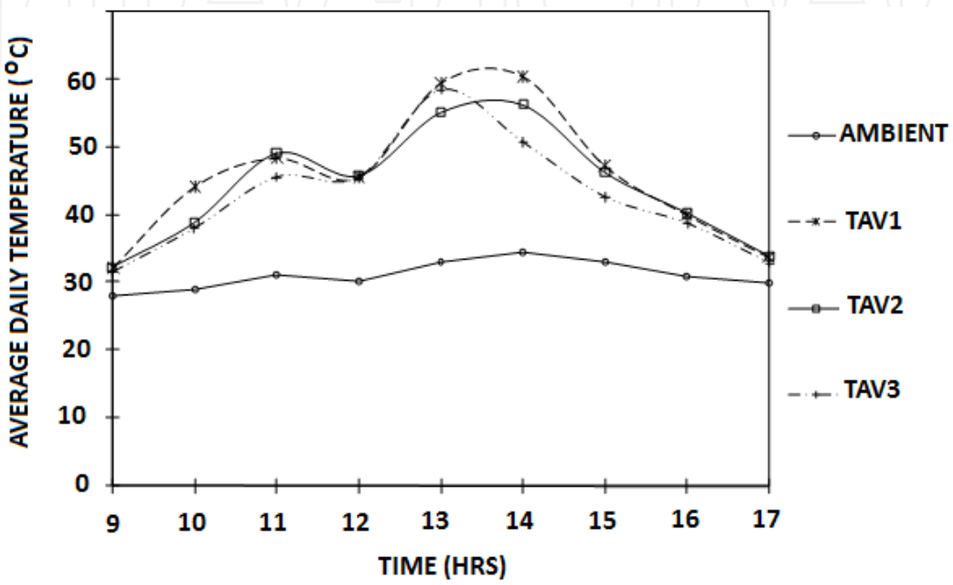


Fig. 12. Average daily temperature in collector

Three surface areas were used for the test as follows 0.6m², 1.0m² and 1.5m². There appeared to be no significant difference in spot temperatures in each of the surfaces per hour (Fig 12), it can be concluded that the surface temperature is independent of surface area. There appeared to be no significant difference in spot temperatures measured in each of the collectors per hour (T_{AV1}, T_{AV2}, T_{AV3}), hence, it can be concluded that the surface temperature is independent of surface area. The average cell surface area used in computation is 1.03 m² and the total surface area of the module is 6.2 m².

Material density constitutes to heat retention within the system and hence increases in surface temperature and higher potential difference. The collector compaction test shows that a densely packed material retains more heat and hence increases surface temperature, which obviously will produce higher potential difference.

5.1.1 Thermocouple sizing

The process of PV array sizing was utilized in determining the number of thermocouples to give the desired amount of electrical power required. To achieve this, the amount of electrical power required by the load and the amount of solar energy available at the site are necessary. The amount of ampere load energy demand required for a fixed load such as 2 DC T8 2ft fluorescent tube is 5.14Ah. Therefore the total demand in ampere-hours is 5.14Ah.

5.1.2 Battery size requirement and efficiency

When sizing the battery bank, the ampere-hours efficiency (columbic efficiency) of new battery is considered to be 100%. During the charge/discharge cycle of the battery, the battery is charged by receiving an input voltage from the thermocouple system and the same number of voltage is delivered at a lower output voltage. The battery efficiency (battery's voltaic efficiency) is expressed as the ratio of average voltage output to the average input voltage.

The daily load requirements determine the necessary battery bank capacity while the system voltage determines the battery bank voltage and the number of cells to be connected in series. The product of Daily Load (DL) requirement and the number of no-sun days (N) gives the total useable capacity (TUC) of the battery i.e.

Total Useable Capacity = DL X N (Ah)

The ampere-hours efficiency (columbic efficiency) of new battery is considered to be 100%. The daily load requirement determines the necessary battery bank capacity. The total useable capacity (TUC) of the battery is 22.84Ah

5.1.3 Daily load requirement

An assumption of a lighting programme in poultry house where power is needed for four out of every seven days in a week was made, and the inverse relationship between voltage and amperage was used to determine the average daily current requirement by multiplying current by a factor of 4/7 to yield a net value in Ah, the average daily current required to satisfy the load demand of 5.14Ah as calculated from given relations. An average of 4½ hrs of full sunshine hours per day round the years is taken for a non-critical system. The thermocouple array load capable of generating the required load demand is obtained by dividing the average daily current requirement by 4.5.

Thermocouple load = average daily current requirement /4.5 (A).

When a peak sunshine hour of 4.5 hours/day is required, the thermocouple array designed is capable of generating a measured 1.14A, capable of providing a glow continuously to satisfy the load demand of 5.14Ah. At increased number of sunshine hours above 4 ½ hours, more current generation is possible whereby the battery could be recharged.

5.1.4 The system conversion efficiency

The conversion efficiency is defined as the ratio of electrical power output and the heat flux through the entire TEG surface.

$$\varepsilon = \frac{P}{Q} = \frac{P}{\Delta T.A.h} \tag{38}$$

ΔT corresponds to the temperature difference between the hot and the cold side of the TEG, A is the TEG area and h is the overall heat transfer coefficient given by (the ratio of total thermal conductivity (5.4 x 10^{-4} W/m^2/°C) of the materials of the thermoelectric generators and the thickness (0.015m) of the TEG. The electrical power output (P=174.06 W h). The

measured heat flux through the entire TEG surface is 10.94 W. The overall conversion efficiency of the system calculated is 15.91%. The cost of system production is estimated at average N20, 000.00

6. Summary

The conversion efficiency of the cell is 15%. This is comparable to other solar TEG system efficiency. The research work indicates the possibility of the utilization of asphalt bonded thermocouples to generate enough current for lighting programme in small scale agricultural undertaking such as poultry house illumination. The output voltage across the thermocouple generator can be increased to higher value enough to provide energy for other low thermal processes. Asphalt heat absorber will be a promising solar harvest cell when the surface is polished and made more sensitive to wider photon energy range (1.3-1.5eV) for increased efficiency.

From the economical point of view, there exists a huge discrepancy between the costs of commercial thermoelectric generators compare with asphalts embedded TEG. The commercial TEG is by a factor of 10 more expensive than the asphalt TEG. The properties of asphalt TEGs are comparable with that of commercial TEG, even though the asphalt TEG used in this study has a smaller area than most commercial TEGs, therefore more asphalt TEGs per unit area can be mounted for increased overall performance at a cheaper price. Further research on antireflection coatings and stacking of different cells with band gaps covering the incident energy of the photons would be a good attempt at achieving higher efficiency.

7. References

Afolabi M. O., Ajayi, R. I. and Siyanbola W. O., 2004. Photo-voltaic cells, efficiency and optimization. *Global J. pure & Applied Sc*. Vol 10. No.3 P 435-439.

Akarakiri J. B. and Ilori M. O., 2003. Application of photovoltaic technology in developing countries. *Nig. Jour. of Industrial & Systems Studies (NJISS)* vol.2 No.2

Angrist S. W., 1982. Direct Energy conversion. 4th Ed.

Bello S. R. and Odey S. O., 2009. *Development of Hot Water Solar Oven for Low Temperature Thermal Processes*. Leonardo Electronic Journal of Practices and Technologies ISSN 1583-1078 Issue 14, January-June 2009 p. 73-84

Champier D., Bedecarrats J. P., Rivaletto M., Strub F., 2009. Thermoelectric power generation from biomass cook stoves. Energy (2009) 1–8. doi:10.1016/ j.energy.2009.07.015 http//: www.elsevier.com/locate/energy

Coker J. O., 2004. Solar energy and its Applications in Nigeria. Short Communication, *Global Jour. pure & Applied Sc.* Vol. 10 No 1 P 223-225.

Dennis A. and Kulsum A., 1996. The Case for Solar Energy Investments. *World Bank Technical Paper Number* 279. Energy Series.

Duffie, J. A. and Beckman, W. A., 1976. Solar Energy Thermal Processes. John and Sons Pub NY.

Encyclopedia Britannica Inc., 1987: Thermocouples. Vol. 11 pp 250-251, Vol. 15 pp 226-227, Vol. 8 pp 193 William Benton publisher.

Gun R. B., 1973. Petroleum Bitumen (in Russian), khimiya, Moscow.

Goldsmid H. J., 1995. Conversion efficiency and figure-of-merit. In D. M. Rowe, editor, CRC Handbook of Thermoelectrics, pages 19-25. CRC Press,

Lertsatitthanakorn C., 2007. Electrical performance analysis and economic evaluation of combined biomass cook stove thermoelectric (BITE) generator. Bioresource Technology 2007; 98:1670–4.

Madueme T. C., 2002. Independent power producers and the power sector in Nigeria. *Nig.J. Ind & Sys. Studies (NJISS)* vol.1 no2. P.38-45.

Maycock D. Paul, Edward N., Stirewait, 1981. A guide to the Photovoltaic revolution. Rodale Press, Emmans, Pa.

Nolas G. S., Sharp J., and Goldsmid H. J. 2001. Thermoelectrics: Basic Principles and New Materials Development. Springer, Berlin,

Nuwayhid R. Y., Rowe D. M., Min G., 2003. Low cost stove-top thermoelectric generator for regions with unreliable electricity supply. Renewable Energy 2003; 28:205–22.

Nuwayhid R. Y., Shihadeh A, Ghaddar N., 2005. Development and testing of a domestic woodstove thermoelectric generator with natural convection cooling. Energy Conversion and Management 2005; 46:1631–43.

Okelola, O. E., Bamgbade., B. J. Balogun, R. B., Bello S. R., (2011). Qualitative Analysis of Rice Storage System in Yala Local Government Area of Cross River State. *Proc. of the 1st International Conference on Rice for food, Market and Development*, held in Abuja Nigeria. http://www.rice-africa.com/acceptedpapers/index.html#bv000030

Oladiran M. T., 1999. New and renewable Energy Education in Sub. Saharan Africa. *Proc. of renewable Energy Conf. Perth, Austria-energy 16*.

Omega Eng., 2001. Introduction to thermocouples. http://www.omega.com/techref/themointro.html /Omega Engineering. Date modified 8/12/2009.

Onojo O. Chukwudebe G. A. and Nwodo T. C., 2004. Development of solar power supply for domestic electricity. NJISS, Vol 3, No 2, 2004 pp 37-44

Oyekunle L. O., 1985. Effect of temperature on rheological properties of petroleum Bitumens. *Jour. Nig society chem. Engr*. Vol 4 pp 124-129.

Quinn T. J., 1983. Temperature, Academic press.

Richner P., Pedro D. G., Luís C. G. and David A., 2011. Experimental Results Analysis of the Energy Conversion Efficiency of Thermoelectric Generators. Electromechanical Engineering Department – Engineering Faculty University of Beira Interior Edifício 1 das Engenharias, Calçada do Lameiro, 6201-001 Covilhã (Portugal). http//www.312-richer.pdf . Date modified 8/12/2011.

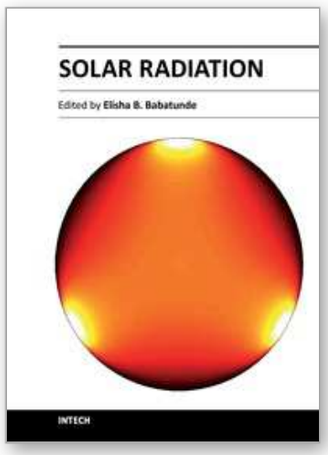
Rowe D. M., 2009. Thermoelectric waste heat recovery as a renewable energy source. International Journal of Innovations in Energy Systems and Power 2006; 1(1).

Solar Electric Light fund (SELF), 2002. Solar Electricity and Renewable Energy Technology. *Washington D.C, solar Electric light Fund*.

Steven A. Moses, 2010. The Design and Construction of Two Experimental Setups to Measure Thermoelectric Properties of Novel Materials. A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science, Honors (Physics) at the University of Michigan

Suharta, H, Senam P. D. Satighm A. M. and Komarudin D., 1999. The social Acceptability of solar cooking in Indonesia. *Renewable energy* vol. 6 1151- 1154.

Zulovich J. M., 2005. Poultry Farm and Processing Plant Lighting. Published by University of Missouri extension



Solar Radiation

Edited by Prof. Elisha B. Babatunde

ISBN 978-953-51-0384-4
Hard cover, 484 pages
Publisher InTech
Published online 21, March, 2012
Published in print edition March, 2012

The book contains fundamentals of solar radiation, its ecological impacts, applications, especially in agriculture, architecture, thermal and electric energy. Chapters are written by numerous experienced scientists in the field from various parts of the world. Apart from chapter one which is the introductory chapter of the book, that gives a general topic insight of the book, there are 24 more chapters that cover various fields of solar radiation. These fields include: Measurements and Analysis of Solar Radiation, Agricultural Application / Bio-effect, Architectural Application, Electricity Generation Application and Thermal Energy Application. This book aims to provide a clear scientific insight on Solar Radiation to scientist and students.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

R. S. Bello, S. O. Odey, K. A. Eke, M. A. Mohammed, R. B. Balogun, O. Okelola and T. A. Adegbulugbe (2012). Development and Application of Asphalt Bonded Solar Thermogenerator in Small Scale Agroforestry Based Industry, Solar Radiation, Prof. Elisha B. Babatunde (Ed.), ISBN: 978-953-51-0384-4, InTech, Available from: http://www.intechopen.com/books/solar-radiation/development-and-application-of-asphalt-bonded-solar-thermogenerator-in-small-scale-agroforestry-base

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the Creative Commons Attribution 3.0 License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen