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Effect of Elevation and Wind Direction on Silicon Solar Panel Efficiency

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***Abstract*—**As a great source of renewable energy, solar energy is considered to be one of the most important in the world, since it will be one of solutions cover the energy shortage in the future. Photovoltaic (PV) is the most popular and widely used among solar energy technologies. However, PV efficiency is fairly low and remains somewhat expensive. High temperature has a negative effect on PV efficiency and cooling system for these panels is vital, especially in warm weather conditions. This paper presents the results of a simulation study carried out on silicon solar cells to assess the effects of elevation on enhancing the efficiency of solar panels. The study included four different terrains. The study also took into account the direction of the wind hitting the solar panels. To ensure the simulation mimics reality, six silicon solar panels are designed in two columns and three rows, facing to the south at an angle of 30 °. The elevations are assumed to change from 10 meters to 200 meters. The results show that maximum increase in efficiency occurs when the wind comes from the north, hitting the back of the panels.

***Keywords*—**Solar panels, elevation, wind direction, efficiency.

I. Introduction

RENEWABLE energy is continually gaining interest and support in most countries around the world. For decades' scientists have been studying the different technologies of renewable energy. The studies have included all renewable energy branches. PV has emerged as the most popular and common available, and has the ability to convert the solar energy directly to electricity. A number of recent studies have investigated ways to enhance this technology. Temperature is a big issue PV technology, since high temperature has an adverse effect on the performance PV, thus, the cooling of PV is very important, especially in high temperature conditions.

Different technologies for cooling are used including air cooling, water cooling, Nanoliquid cooling etc. Cooling by natural convection heat transfer is preferred because no consuming power is required to drive the system. Wind speed is changed according to air layers, since wind speed has a positive relationship with the elevation. Wind speed changing depends on the land terrain types.

Various studies have been done with regard to solar panels and how to enhance their performance. Many factors have a direct effect on the performance of solar panels such as air temperature, wind speed, wind direction, humidity etc. Shademan [3] presented a CFD simulations study about the effect wind loading on solar panels. The study was carried out to estimate the wind loads for various wind directions. Panjwani [4] investigated how the effect of humidity. In this study, he presented humidity change according to the elevation, since humidity has different values at different altitudes. Hybrid photovoltaic/ thermal (PV/T) systems are investigated to enhancement the performance. Teo [5] built a PV/T system to increase PV efficiency, especially at high temperatures. Tung [7] studied the effect of air-cooling and water cooling on the performance of solar cells. In this study he used a novel Micro heat pipe array in solar panel cooling. Some of studies contribute the heat energy of air cooling to increase the system efficiency. Croitoru [6] presented a PV/T study and considered the energy of an outlet air as a useful energy. The study presented the effect the air duct depth on overall efficiency.

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II. Assumptions

In this study four types of land topographies are considered with different roughness lengths (Z), as shown in the Table I and Fig. 1. The results also will be for these four cases.

TABLE I
DIFFERENT TYPES OF TERRAINS WITH THEIR ROUGHNESS LENGTH [2]

Type of terrain	Symbol	Roughness length Z(m)
Water, snow or sand surface	A	0.001
Open, flat land, mown grass, bare soil	B	0.01
Farmland with some vegetation	C	0.05
Suburbs, town, forests, many trees and bushes	D	0.3

In this study many assumptions are considered as boundary conditions, listed as follows:

1- Wind speed has a constant value (5 m/s) at 10 meters high for all cases [2].
2- The atmosphere temperature changes from (297K) to (310 K) during the test.
3- Solar panel temperature is taken at highest one.
4- Solar radiation is constant for all cases.
5- Wind speed is (1m/s) for the PVs who are installed on the ground.
6- Average efficiency reduces is 0.5% with 1 K temperature increase [8].

III. The Theory

Solar panel temperature is linearly proportional to solar radiation and atmosphere temperature. Approximately it can found by [1]:

$$T_s = T_a + \frac{T_{NOCT}-20}{800} * I \tag{1}$$

where T_s is solar panel temperature K, T_a is ambient temperature K, T_{NOCT} is nominal operating cell temperature K and I is solar radiation W/m^2. Solar panels are exposed to heat transfer by convection and in these cases, it is considered as a forced convection and constant wind speed at each level is assumed. Heat loss depends on three parameters as [1].

$$Q = h\,A\,(T_s - T_a) \tag{2}$$

where Q is heat energy W, h is heat transfer coefficient by convection W/m^{2}K, A is surface area m^2. Convection heat transfer coefficient h is the most important thing to increase heat transfer. Heat transfer coefficient by confection (h) has a positive relationship with Reynolds number and the last is a function of the velocity, as shown in (3). Finally, the highest wind speed the highest heat transfer by convection [1].

$$Re = \frac{\rho V L}{\mu} \tag{3}$$

where Re is Reynolds number, ρ is air density Kg/m^3, V is the air velocity, L is the panel length m and μ is the air viscosity N.s/m^2.

$$\mathrm{Nu} = \frac{\mathrm{hL}}{\mathrm{K}} = C Re^m Pr^n \tag{4}$$

where Nu is Nussle number, K is solar panel conductivity W/m.K, C is a constant and Pr is Prandtl number.

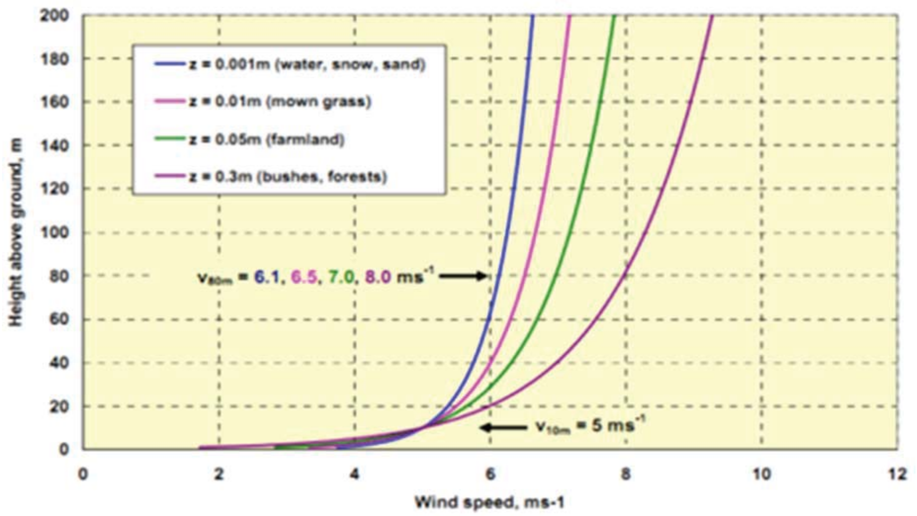


Fig. 1 Wind speeds for these terrains with elevations [2]

IV. Description of Model and Simulation

A. Description of Model

The model is six solar panels faced to the south at an angle of 30^o and dimensions of 150*100*0.45 centimeters. Silicon solar panels are chosen in this study. The materials and their thicknesses are shown in Table II.

TABLE II
The Materials and Thickness of Solar Panels

Material	Thickness (cm)
Glass	0.3
EVA	0.05
ARC	0.000008
Si	0.0325
EVA	0.05
Tedlar	0.01

B. Simulation

Six solar panels are designed and arranged in three rows and two columns. The panels are placed in an air tunnel in order to simulate the real case, as shown in the Fig 2. One face of the air tunnel considers as inlet velocity and other are frictionless walls. Five cases are executed in this study depending on wind direction. At the same time, each case has four sub cases according to the terrain types of the land. The range of solar radiation is assumed to vary from 200W to 1000W during the day.

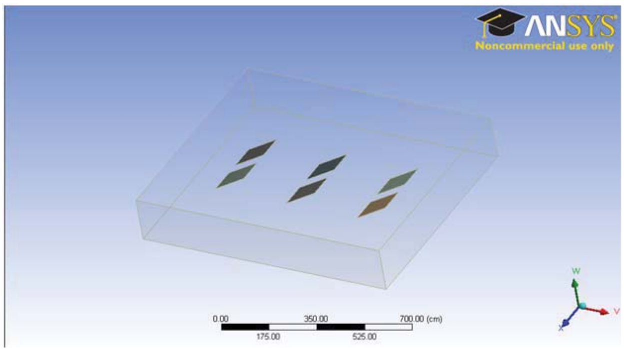


Fig. 2 The geometry of the solar panel inside the air tunnel

V. Results and Discussion

Temperature is the most important thing in this study. Fig. 3 shows temperature distribution on the solar panels.

Air velocity plays a role in reducing the temperature of solar panels. The relation is negative because convection heat transfer coefficient depends directly on the velocity. The velocity contour is shown in Fig. 4.

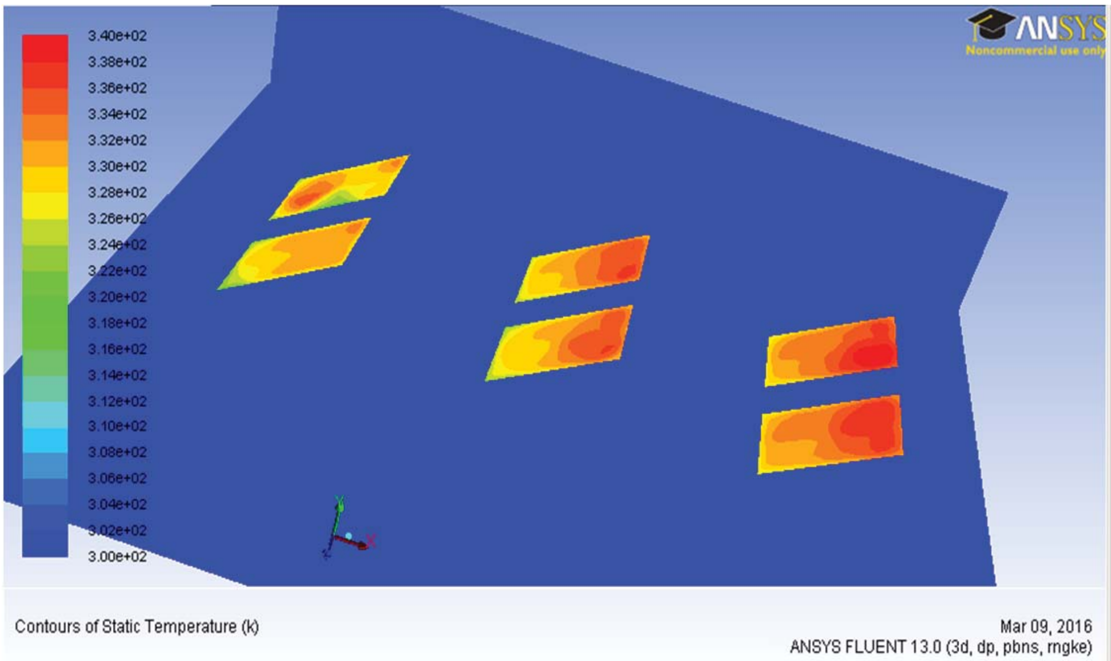


Fig. 3 Static temperature contour distribution on the solar panels

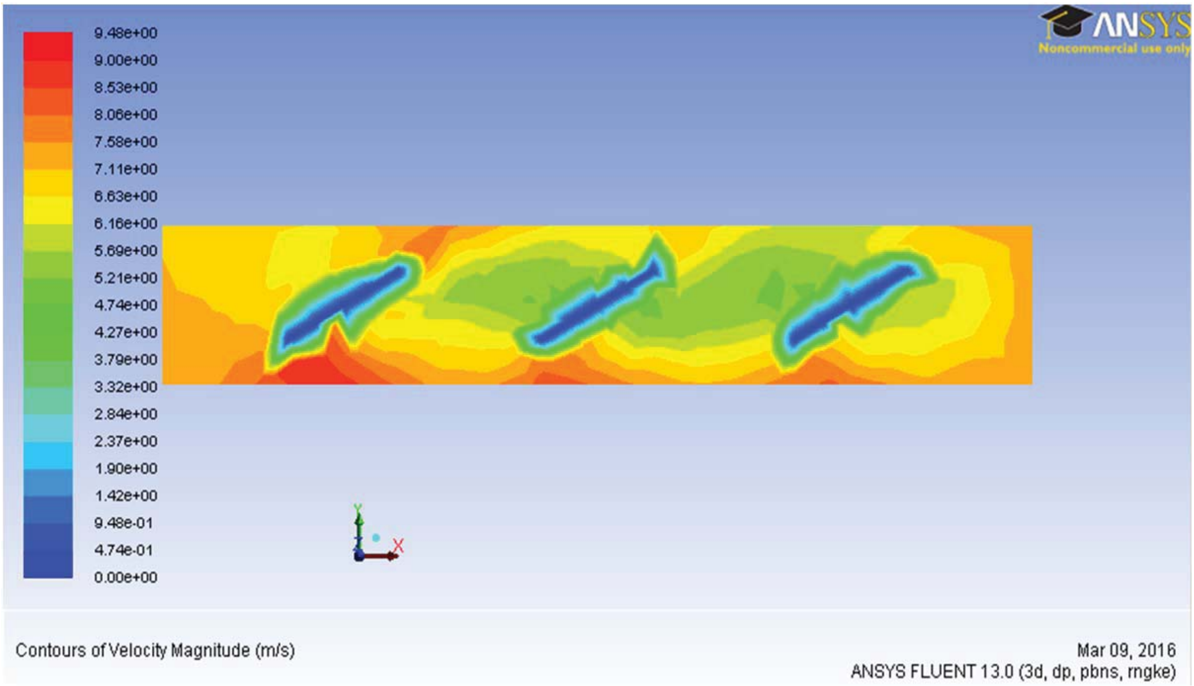


Fig. 4 Velocity contours distribution in the case the wind blows from the north, normally to the back of the solar panels

Solar radiation is another factor affecting the temperature of solar panels, since most of them convert into heat. Fig. 5 shows changing the PV temperatures at different solar radiation levels assumed at ground level.

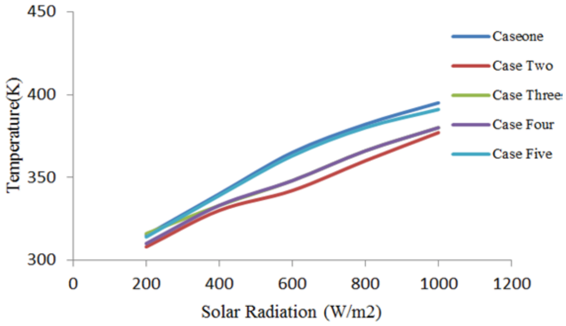
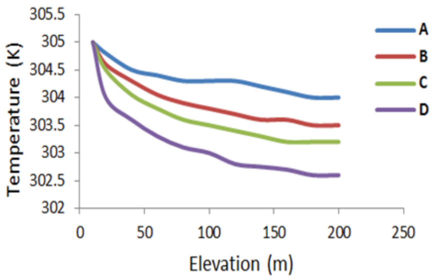


Fig. 5 Changing temperature due to solar radiation at ground level

The five cases below show the results according to wind direction.

A. Case One (Frontal Wind Direction)

In this case the wind comes from the south and hits the front of the solar panels. The figures below show the change in temperature with the elevation for different solar radiation levels.



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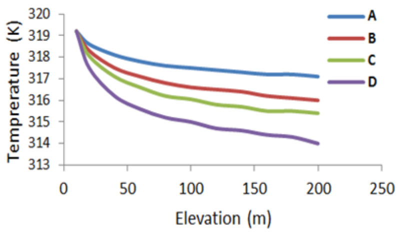

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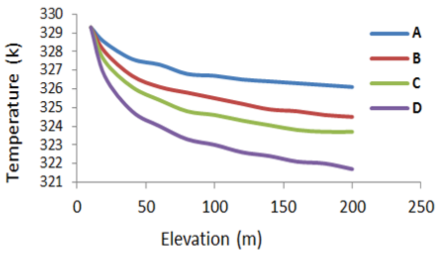

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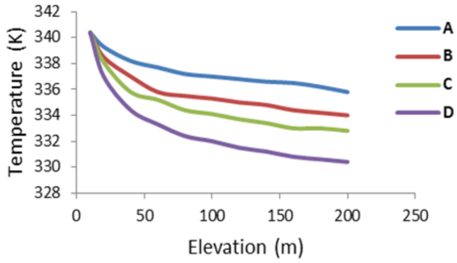

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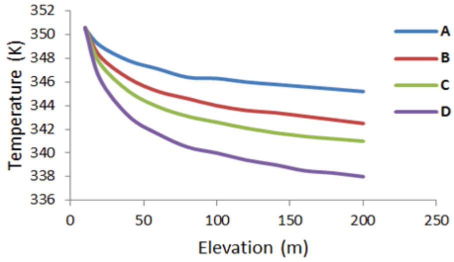
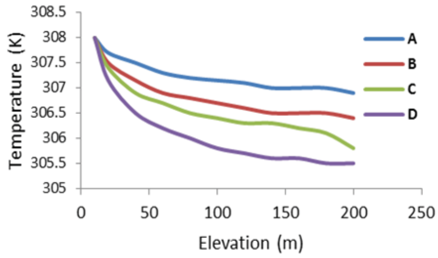


(e)

Fig. 6 Changing temperature with elevations at different solar radiation levels for case one (frontal wind direction) (a) At 200 W/m^2 (b) At 400 W/m^2 (c) At 600 W/m^2 (d) At 800 W/m^2 and (e) At 1,000 W/m^2

B. Case Two (Rear Wind Direction)

Wind direction is assumed comes from the north in this case. Wind strikes the panels normally from the back. The figures below show the change in temperature with elevation and with different solar radiation levels.



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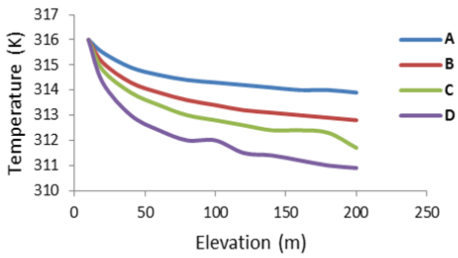

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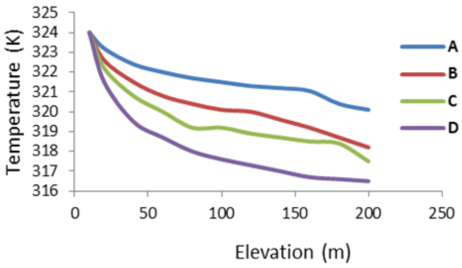

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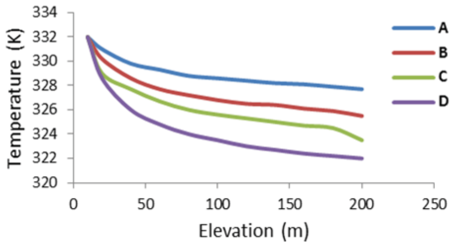

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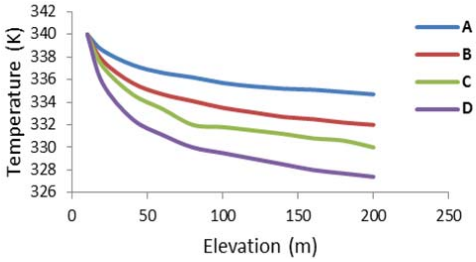
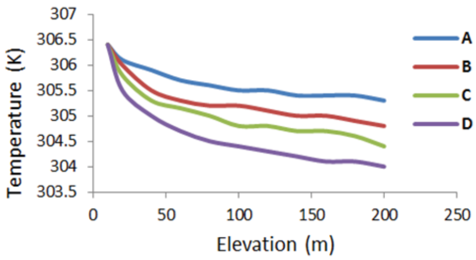


(e)

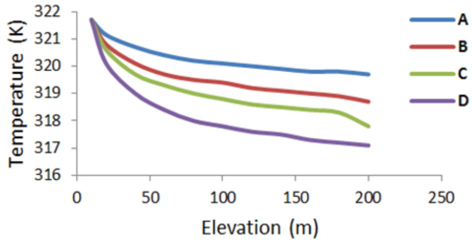
Fig. 7 Changing temperature with elevations in different solar radiation for case two (rear wind direction) (a) At 200W/m^2 (b) At 400W/m^2 (c) At 600W/m^2 (d) At 800W/m^2 and (e) At 1,000W/m^2

C. Case Three (Side Wind Direction)

Wind direction is assumed to come parallel to the solar panels from the side. Air flows on both sides but without collision. The figures below show the change in temperature with the elevation and with different solar radiation levels.



(a)



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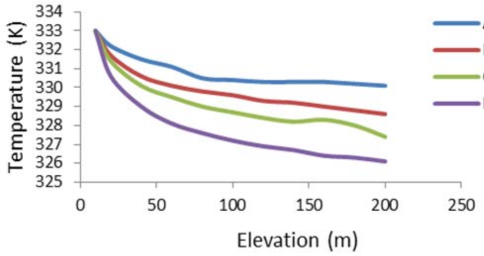

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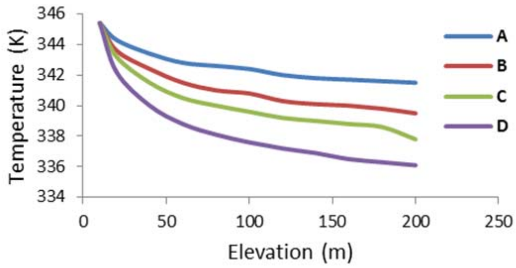

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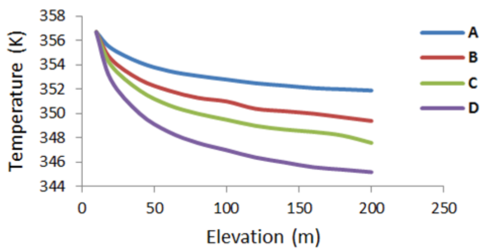
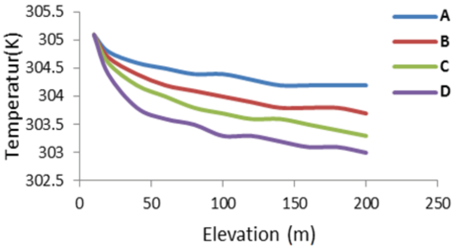


(e)

Fig. 8 Changing temperature with elevations in different solar radiation for case three (side wind direction) (a) At 200W/m^2 (b) At 400W/m^2 (c) At 600W/m^2 (d) At 800W/m^2 and (e) At 1,000W/m^2

D. Case Four (45^o from the Rear Direction)

Wind direction is assumed comes from the northwest or northeast (inclined at an angle of 45^o north). The figures below show the change in temperature with elevation and with different solar radiation levels.



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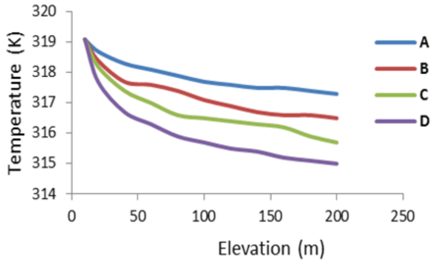

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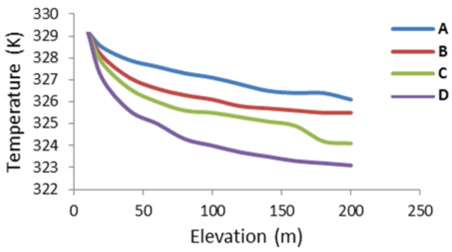

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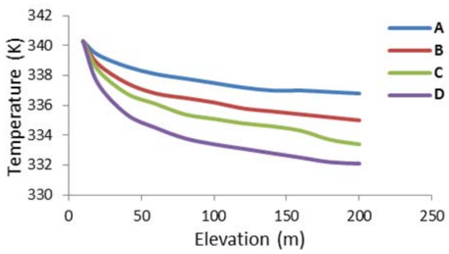

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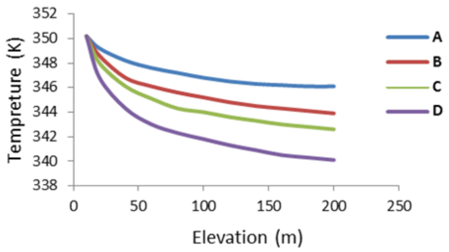
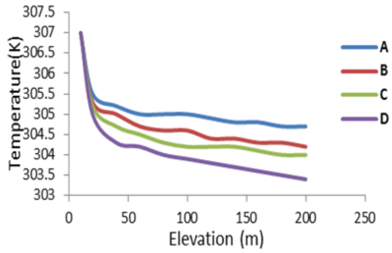


(e)

Fig. 9 Changing temperature with elevations in different solar radiation for case four (45° from the rear direction) (a) At 200W/m^2 (b) At 400W/m^2 (c) At 600W/m^2 (d) At 800W/m^2 and (e) At 1,000W/m^2

E. Case Five (45° from the Frontal Direction)

Wind direction is assumed comes from the southwest or southeast (inclined at an angle of 45° south). The figures below show the change in temperature with elevation and with different solar radiation levels.



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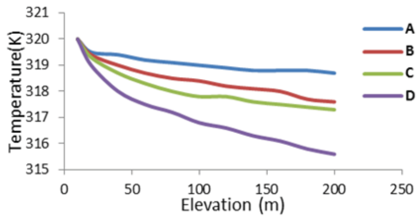

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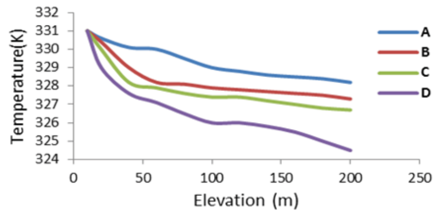

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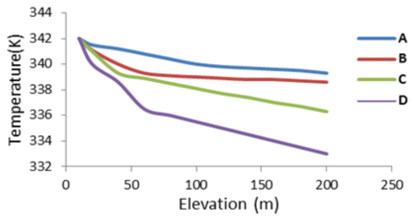

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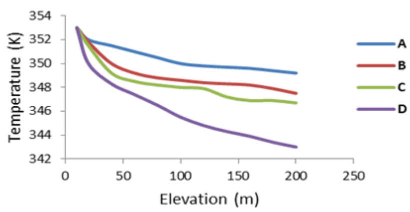
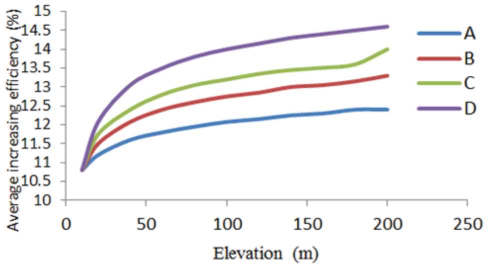


(e)

Fig. 10 Changing temperature with elevations in different solar radiation for case five (45° from the frontal direction) (a) At 200W/m^2 (b) At 400W/m^2 (c) At 600W/m^2 (d) At 800W/m^2 and (e) At 1,000W/m^2



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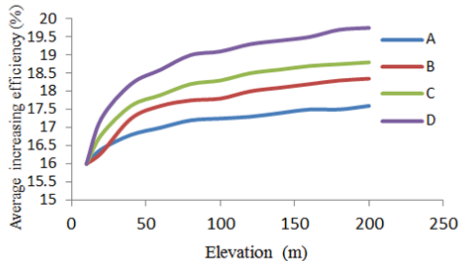

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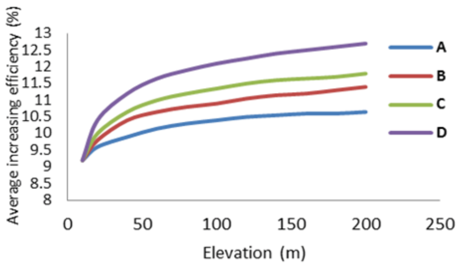

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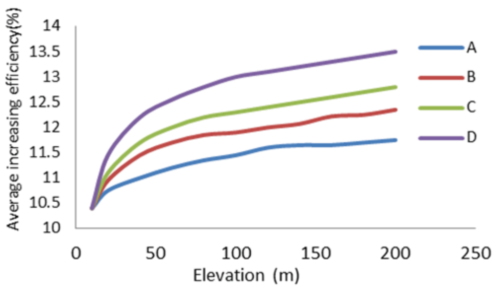

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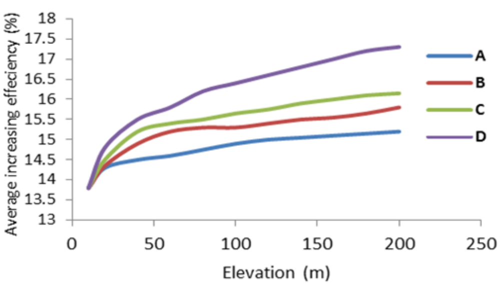

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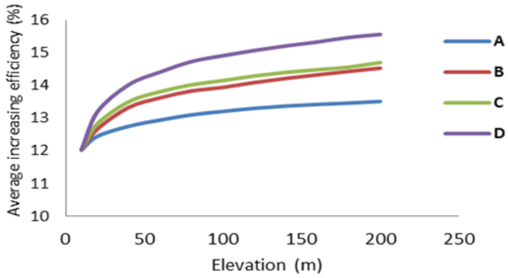

(f)

Fig. 11 Average increase in efficiency with elevation for the cases (a) Case one (b) Case two (c) Case three (d) Case four (e) Case five (f) Average cases

According to the assumption, since the efficiency increases about (0.5 %) with a reduction in temperature (1 K°), the figures below show the average increase in efficiency with elevation for all cases. The last figure depicts the average cases.

VI. Conclusions

From the results, and as are expected, PV efficiency increases with elevation as a result of an increase in wind speed. Maximum increase efficiency is realized when the wind blows from the north direction and normally hits the solar panels from the back, with the resulting swirling air creating greater heat transfer. Above 200 meters, the effect of altitude is relatively indifferent because the change in wind speed is slight. According to the four terrain types, the installation of solar panels in open land areas with water, snow, or sand surfaces is recommended. In the second case, when the wind comes from the north direction with the solar panels at an altitude of 200 meters, efficiency increased by about 20%. This increasing in the efficiency encourages people to install solar panels in the recommended terrains and at the suggested levels.

Acknowledgments

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