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Solar Energy Required and Predicted in Okayama and Giza (Egypt)

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Egypt as a developed country still has no electricity in many villages but at the same time has enough natural energy such as solar energy. Solar radiation data is not always available in many areas of the world and they have to be estimated using some sort of empirical model. The results of this prediction are compared for the measured data of two different countries: Japan (Okayama City) and Egypt (Giza City). The comparison shows an acceptable level of prediction between both of them.

On a June day, actual accumulated insolation through one day was 18.88 MJ/m^2 in Okayama and 22.79 MJ/m^2 in Giza. On the other hand on a January day, actual accumulated insolation through one day was 4.93 MJ/m^2 in Okayama and 5.49 MJ/m^2 in Giza. We can see also that in January the worst solar month, solar water heaters still provide 35.25 % of the energy for Okayama and 40.37 % for Giza. That was because in Okayama the number of sunny days was only 6 but there were 19 in Giza.

Key words : solar energy, solar radiation, energy collected, simulation

Introduction

The estimation of solar radiation is one of the most fundamental techniques used for energy calculation in the field of solar energy applications. The purpose of this study is to predict the solar energy required for agriculture such as heating (inside a greenhouse), farm use or drying, with an acceptable level of accuracy.

The models for energy calculation have been chronologically evolved with daily simulation by use of the full set of collected meteorological data[1].

Because of the influence of various meteorological parameters and their mutual interdependency on the environment, the analysis of radiation should contain some information regarding how to deal with the correlations among these parameters. Any improvement of modeling techniques requires a careful choice of meteorological data.

Hot air can be used for either heating (this study) or drying (near future). Solar energy can replace about 19 % of the electrical requirements of drying[2] and on a monthly basis the ratio of solar energy to total energy input varied between 11 and 53 % with the minimum ratio occurring in December[3]. Solar energy potential also varies among countries. For example in Madison (USA) partial or full demand could be met by solar energy depending on location and load pattern in the plant, and a collector with 3000 m^2 would be able to meet 70 % of total demand of food dehydration[4]. In the UK a solar panel area of

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6 m^2 with a 280 liter preheat storage tank was able to contribute 10 % of the annual total demand for heating or 75 % of the annual requirement for udder washing[5].

The objective of this study is:

1- To store the energy gained from the sun by solar systems during the day time and use it for heating (water or air) which can be used for some agricultural purposes.

2- To predict the amount of solar energy required using actual meteorological data and compare the amount of solar heat for both Okayama and Giza.

3- To compare the energy collected and consider its utilization for agriculture.

Experimental system and Methods

Geographical location of Okayama and Giza

Okayama is nestled between Japan's Seto Inland Sea to the south, and the magnificent Chugoku mountain range to the north. Okayama Prefecture lies in the heart of western Japan. The latitude of Okayama is 34°39′ N and the longitude of 133°56′ E. Giza is located near the river Nile which is the line border between Cairo (the capital) and Giza Prefecture. Giza has a latitude of 30°02′ E and longitude of 31°13′ N.

The meteorological data in Okayama were collected at Okayama University, Faculty of Agriculture (OUFA). The meteorological data in Egypt were collected at the Agricultural Engineering Research Institute (AERI), Dokki, Giza, Egypt.

Solar collector

The solar heat collecting system is shown in Fig. 1A. for Okayama. The collecting area of the solar collector is 4.22 m^2 , and the storage tank capacity is 219 liters. The hot water which is stored in a storage tank, was flowed into a heat exchanger. The temperatures and solar radiation were collected by a personal computer connected with a data logger.

In the case of Giza as shown in Fig. 1B, two solar collectors of 3.78 m^2 each (total area 7.56 m^2) were attached together and the storage tank capacity for each one was 180 liters. The hot water inside the solar collector is used for taking a shower when the farmers return from field work in the late afternoon during their training in the research center.

Simulation model

There are many cases in which the estimation of the radiation reaching the earth's surface is proportional to the amount of radiation that would reach the surface if there was no attenuation due to the atmosphere. Thus a method of calculating this radiation is needed.

The theoretical solar radiation outside the atmosphere on a horizontal plane can be described as[6]:

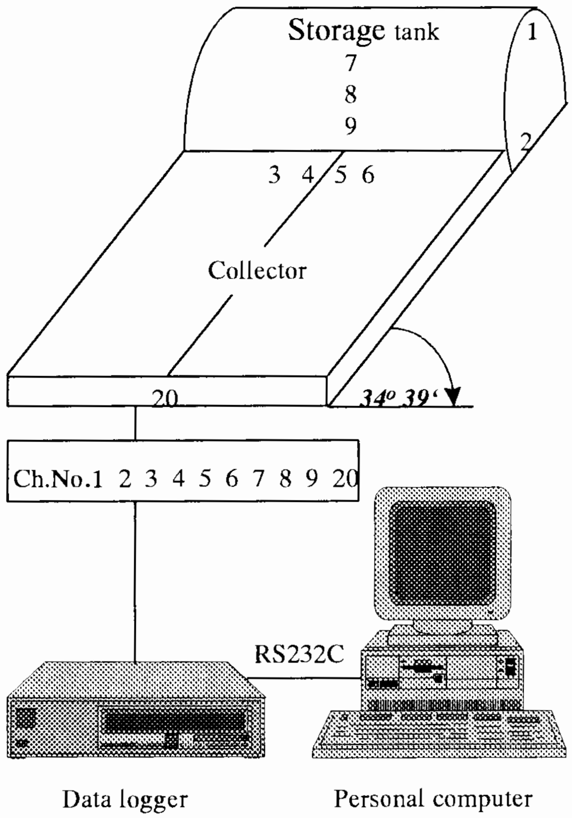

Fig. 1A Experimental system of solar collector at Okayama City.
1) Cold water in, 2) Hot water out, 3, 4, 5, 6) Water temerature inside the collector, 7, 8, 9) Water temperatures inside the storage tank, 20) Solar meter

$$I_o = I_{on} \times \text{COS}\ \theta_z \quad (1)$$

Where:

I_o = Theoretical radiation (W/m^2).

I_{on} = Extraterrestrial radiation (W/m^2).

$= I_{sc} \times (1 + (0.034 \times \text{COS}\ (360 \times n/365.25)))$

I_{sc} = Solar constant (1353 W/m^2).

$\text{COS}\ \theta_z = (\text{COS}\ \delta \times \text{COS}\ L \times \text{COS}\ \omega + (\text{SIN}\ \delta \times \text{SIN}\ L)$

$\delta = 23.45 \times \text{SIN}\ (360 \times (284 + n)/365)$

θ_z = Solar zenith (degrees).

δ = Solar declination (degrees).

L = Latitude (degrees).

ω = Hour angle (degrees).

= 15 times number of hours from solar noon[7].

n = Julian day number.

Daily accumulated solar radiation

The daily accumulated solar radiation can be estimated by integrating the equation of theoretical radiation from sunrise to sunset using the sundial hour angle[6].

$$\text{Daily accumulated solar radiation} = \sum_{sunset}^{sunrise} I_o \quad (2)$$

Results and Discussions

The results of the daily progression fit are shown for some days in June and January for Okayama and Giza in Figs. 2 and 3. It is observed that the approximation of the daily progression by the proposed simulation shows a good agreement for the total radiation with the measured results.

Next, the results of the daily progression fit are presented for bright days in June and January for Okayama and Giza. It is observed that the approximation of the daily progression by the proposed simulation shows a good agreement for the accumulated solar radiation with the measured results. For example, in a June day, actual total solar radiation was 18.88 MJ/m^2 in Okayama and 22.79 MJ/m^2 in Giza. On the other hand, simulated total solar radiation was 20.31 MJ/m^2 and 24.03 MJ/m^2 in Okayama and Giza

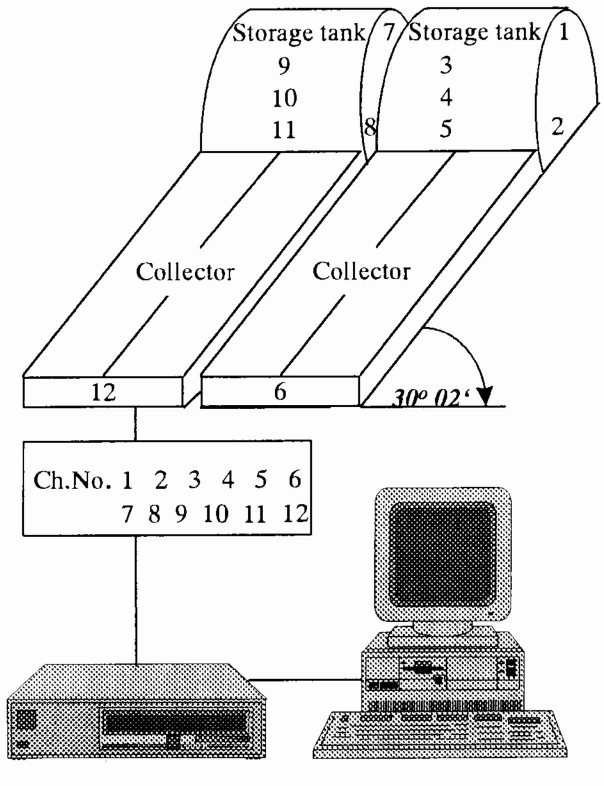

Fig. 1B Experimental system of solar collector at Giza City.
1, 7) Cold water in, 2, 8) Hot water out, 3, 4, 5, 9, 10, 11) Water temerature inside the storage tank, 6, 12) Solar meter

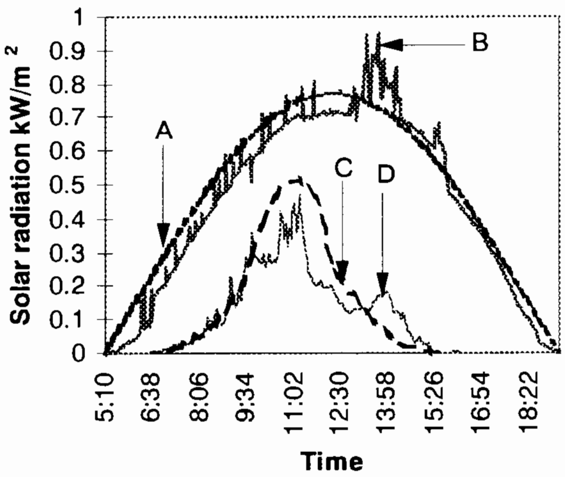

Fig. 2 Changes in solar radiation at Okayama over one day.
A: Simulated value in June
B: Observed value in June
C: Simulated value in January
D: Observed value in January

respectively.

On one January day, actual accumulated solar radiation per day was 4.93 MJ/m^2 in Okayama and 5.49 MJ/m^2 in Giza. On the other hand, the simulated values were 5.02 MJ/m^2 and 4.48 MJ/m^2 in Okayama and Giza respectively.

Daily average, maximum and minimum solar radiation observed in Okayama during July were 0.41, 0.53 and 0.06 kW/m^2 respectively and in January those values were 0.18, 0.42 and 0.02 kW/m^2 respectively. In Giza, the daily average, maximum and minimum solar radiations collected during July were 0.61, 0.66 and 0.51 kW/m^2 respectively and in January those values were 0.25, 0.35 and 0.17 kW/m^2 respectively as shown in Fig. 4.

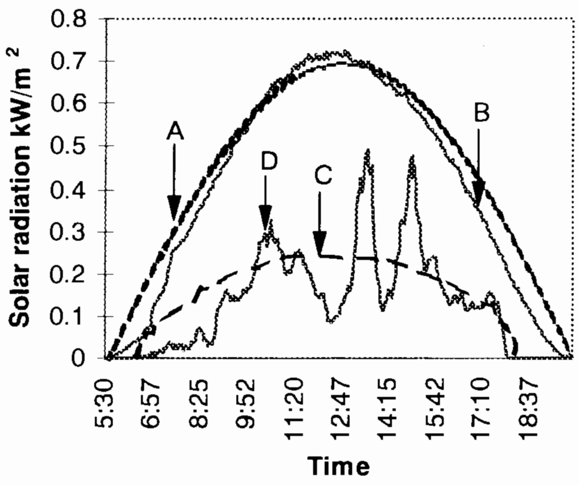

Fig. 3 Changes in solar radiation at Giza over one day.
A: Simulated value in June
B: Observed value in June
C: Simulated value in January
D: Observed value in January

Predicted energy

The amount of energy, Q, collected in the time Δt that elapses from sunrise to sunset:

$$Q\,(\text{total}) = \Sigma Q = \Sigma\,(M \times C \times (T_{max} - T_{in}) \times \Delta t) \quad (3)$$

Where:

Q = Energy collected (kJ)

M = Water mass (kg)

C = Specific heat of water (kJ/kg.°C)

T_{max} = Water temperature in the storage tank (°C)

T_{in} = Collector inlet water temperature (°C)

In the equation (3), T_{max} represents the maximum temperature of water in the storage tank and T_{in} is the temperature of water let into the solar heater at the start. On further simplification is possible as a result of the large response time of such a solar water heater: the mean water temperature turns out to be extremely close to the average of the temperatures at the start and the end of the day[8].

The average, maximum and minimum values of collected solar energy in Okayama during July were 17, 23 and 2.5 MJ/m^{2}d respectively and the same values in Okayama during January were 7,

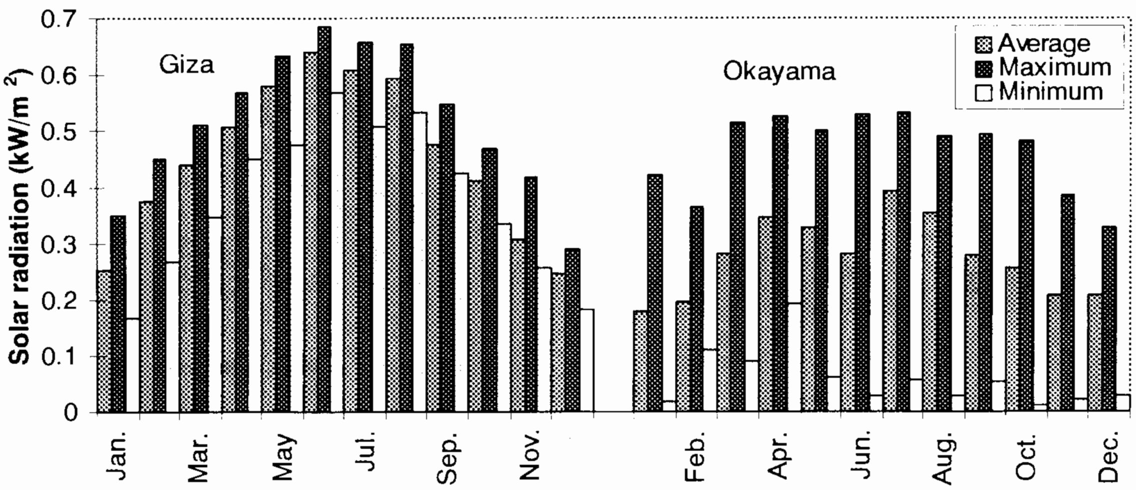

Fig. 4 Monthly average, maximum and minimum solar radiation of Okayama and Giza in 1996.

14.7 and 0.74 MJ/m^2d respectively. In Giza the average, maximum and minimum values of collected solar energy in July were 26, 28 and 22 MJ/m^2d respectively and in January were 10, 14 and 6.7 MJ/m^2d as shown in Fig. 5.

The number of clear days in Okayama were 29 in July and 6 in January 1996. On the other hand the number of clear days in Giza were 31 in July and 19 in January. The number of cloudy or rainy days in Okayama was 2 in July and 25 in January. On the other hand the number of cloudy or rainy days in Giza was 0 in July and 12 in January as shown in Fig. 6.

For the sake of simplicity, we took the starting cold water temperature as equal to the mean monthly ambient air temperature at the location in question. This assumption is not necessary in order to solve the equations - it simply makes them simpler - but it will often be a good approximation to the real situation.

The results of this study for each month of the year are listed in Tables 1 and 2 for both Okayama and Giza respectively.

The first column for both tables contains the observed values of monthly-daily-average solar radiation figures for a south facing plane tilted at 34°39′ for Okayama and 30°02′ for Giza. The second column tabulates monthly-daily-average ambient temperatures obtained from the local meteorological service for Giza, but in the case of

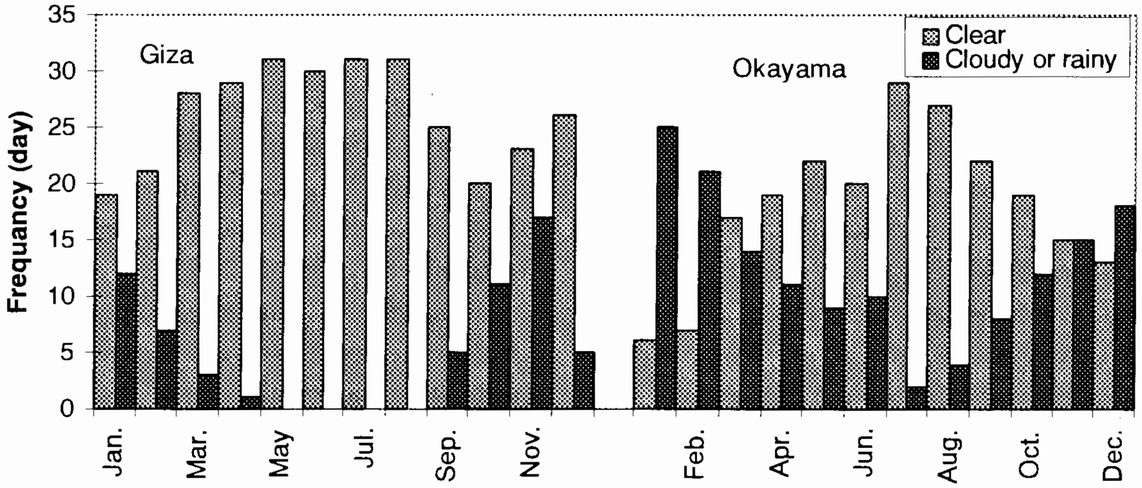

Fig. 5 Monthly average, maximum and minimum collected energies of Okayama and Giza in 1996.

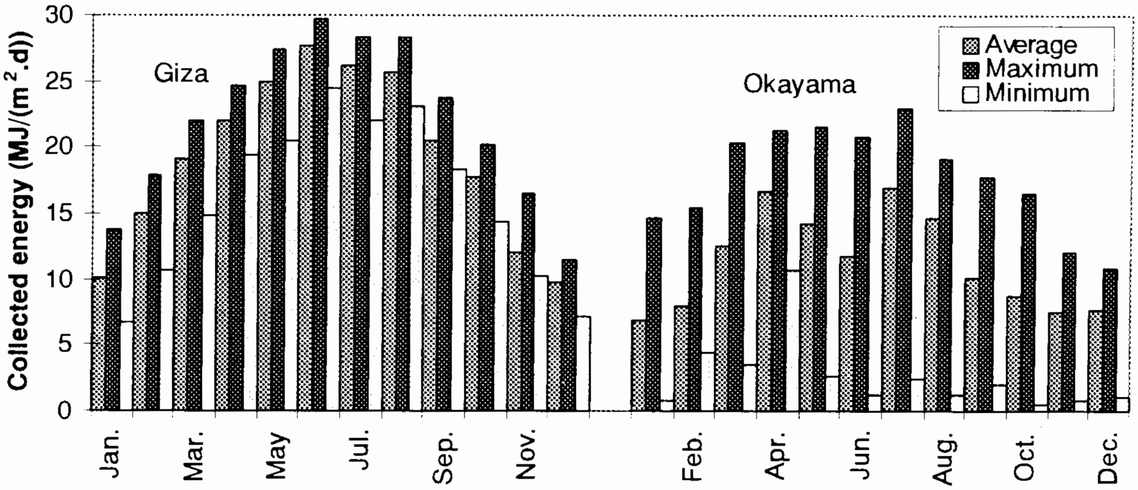

Fig. 6 Number of clear and cloudy or rainy days of Okayama and Giza in 1996.

Table 1 Observed performance of a no-flow solar water heater at Okayama City

Month	I_c*(Δt)	T_a	Δt	T_{max}
	MJ/m²	°C	s	°C
January	6.92	4.76	37080	20.71
February	8.01	4.35	39600	23.68
March	12.62	8.31	43200	32.15
April	16.64	11.89	46800	41.18
May	14.23	19.08	49320	51.23
June	11.77	23.41	50400	53.68
July	17.03	27.65	49320	58.89
August	14.67	29.47	46800	61.87
September	10.03	24.02	43200	52.86
October	8.80	18.26	39600	47.69
November	7.54	11.54	37080	34.59
December	7.61	7.45	36000	29.45

Table 2 Observed performance of a no-flow solar water heater at Giza City

Month	I_c*(Δt)	T_a	Δt	T_{max}
	MJ/m²	°C	s	°C
January	10.11	10.63	37780	30.56
February	14.94	11.32	39900	35.89
March	19.08	14.98	43800	42.03
April	21.97	20.86	47580	47.59
May	25.01	23.85	50760	56.89
June	26.66	27.18	52140	64.59
July	27.21	30.53	51060	70.87
August	27.67	30.86	48120	71.76
September	20.54	24.32	44460	57.18
October	17.69	20.56	40620	49.08
November	12.14	15.87	37200	44.13
December	9.83	11.23	36460	37.18

Okayama, it was obtained by observation apparatus using a personal computer during the experiment. The third column contains the approximate sunshine hours for each month at the site of question. Finally, the fourth column tabulates the observed maximum daily temperature inside the storage tank.

In Okayama, for the worst month (January), the solar water heater still provides 35.25 % of the heat energy.

In Giza, the water is required each evening at a temperature of 60 °C for taking showers when the farmers return from field work in the late afternoon during their training in the fields of the research center. Using same way as before, in the worst solar month (January) the solar water heater still provides 40.37 % of the energy.

The daylight in Giza is more than in Okayama because of the different latitude, where Okayama is 34°39′ and Giza is 30°02′. We can see that in Table 1, the daylight (Δt) in Okayama during January was 37080 seconds and in Giza was 37780 seconds. During July the daylight in Okayama was 49320 seconds and in Giza was 51060 seconds.

Because of the above reason, the average ambient temperature, maximum temperature inside the storage tank and energy collected by solar systems were different in Okayama and Giza. For example, during January in Okayama the average ambient temperature was 4.76 °C, maximum temperature inside the storage tank was 20.71 °C and energy collected was 6.92 MJ/m². On the other hand in Giza, the average ambient temperature was 10.63 °C, maximum temperature inside the storage tank was 30.56 °C and energy collected was 10.11 MJ/m².

During July as another example, the average ambient temperature, maximum temperature inside the storage tank and energy collected were 27.65 °C , 58.89 °C and 17.03 MJ/m² in Okayama and 30.53 °C , 70.87 °C and 27.21 MJ/m² in Giza respectively.

Conclusions

The comparison of the proposed simulation method with the measured data showed a good agreement. Moreover, in order to update the measurement data, it is also possible to include the local climate changes. As presented here, the result of the proposed simulation method belongs to the class of random processes, and in this sense is an extension of the means which have been applied so far to energy calculations.

For example, in a June day, actual total insolation was 18.88 MJ/m² for Okayama and 22.79 MJ/m² for Giza. On the other hand, simulated total insolation was 20.31 MJ/m^2 and 24.03 MJ/m^2 for Okayama and Giza respectively.

In a January day, actual total insolation was 4.93 MJ/m^2 for Okayama and 5.49 MJ/m^2 for Giza. On the other hand, simulated total insolation was 5.02 MJ/m^2 and 4.48 MJ/m^2 for Okayama and Giza respectively.

During January, in Okayama the average ambient temperature, maximum temperature inside the storage tank and energy collected were 4.76 ℃, 20.71 ℃ and 6.92 MJ/m^2 respectively. On the other hand in Giza, the average ambient temperature, maximum temperature inside the storage tank and energy collected were 10.63 ℃, 30.56 ℃ and 10.11 MJ/m^2 respectively.

During July for example, the average ambient temperature, maximum temperature inside the storage tank and energy collected were 27.65 ℃, 58.89 ℃ and 17.03 MJ/m^2 in Okayama and 30.53 ℃, 70.87 ℃ and 27.21 MJ/m^2 in Giza respectively.

We can see also that in this worst solar month in January the solar water heater still provides 35.25 % of the energy for Okayama and 40.37 % for Giza. That was because in Okayama the number of clear days were 6 only but there were 19 days in Giza.

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岡山とギザにおける太陽エネルギーの所要量と推定

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太陽エネルギーを農業に有効利用する目的で，岡山とエジプト・ギザを観測地点として，獲得できるエネルギーの量を観測し，2地点での比較を行った。岡山とギザでは緯度が，34°39′と30°02′と異なるために集めることができる太陽エネルギーの量に差が生じ，その量はギザの方が多くなり農業への有効利用の可能性が大である。