AIP Conference Proceedings

scitation.org/journal/apc

Volume 2221

The 1st International Conference on Physics and Applied Physics (The 1st ICP&AP) 2019

Fundamental and Innovative Research for Improving Competitive Dignified Nation and Industrial Revolution 4.0

Medan, Indonesia • 12–13 September 2019

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The potency of solar energy on Medan city of Indonesia: Comparison of clear sky, satellite and field measurements

Cite as: AIP Conference Proceedings **2221**, 070002 (2020); https://doi.org/10.1063/5.0003482
Published Online: 31 March 2020

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The Potency of Solar Energy on Medan City of Indonesia: Comparison of Clear Sky, Satellite and Field Measurements

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Abstract. Solar energy is expected to fill the renewable energy target of Indonesia. Thus, the potency of solar energy resource in Indonesia need to be known exactly. In this study, the potency of solar energy in Medan city of Indonesia is estimated theoretically using clear sky radiation model. The estimation is compared with satellite measurement and field measurement. The solar resource satellite data drawn from the Global Solar Atlas, belongs to the World Bank Group and provided by SOLARGIS. The measurement is carried out at a location in Medan city at latitude 3°35' North and longitude 98°39' East using HOBO micro station data logger. The results shows that the theoretical clear sky radiation model, as expected, shows a higher solar irradiation. The measurement values are closer to data of satellite.

INTRODUCTION

In order to avoid the world from global warming, many mitigation actions to reduce Greenhouse gas (GHG) emission have been promoted and executed. Enhancing the utilization of renewable energy to replace fossil fuel will give significant impact on mitigation GHG emission. One of the most promising renewable energy resource is solar energy. It is abundant and can be harvested on the most all surfaces of the earth. The rate of solar energy that reaches the surfaces of the earth is about 1.08×10^{14} Watt [1]. If about 0.1% of this energy can be converted into electricity with an efficiency of 10%, would generate 10 TW of electricity. This is equivalent to four times of globally generated electricity. In addition the global energy consumption is comparable to 70 minutes of solar irradiation that reaches the earth surface. Solar energy can be harvested in two different form, photovoltaic and thermal technologies.

In the photovoltaic technologies, the solar radiation is directly converted into electricity using solar cell. The solar cells can be segregated into three generations of developments. The first development (1G) consists of crystalline silicon (c-Si) wafer-based cells. The second development (2G) encompasses thin-film technologies such as Cadmium telluride (CdTe), Copper indium gallium di-selenide (CIGS), amorphous Silicon (a-Si), and single-junction Gallium Arsenide (GaAs) cells. The third development (3G) consists of the emerging cell technologies of organic material also multi junction cells [2]. In the present time, only crystalline Silicon and thin-film technologies are present in market by mass productions. The shares of both technologies, c-Si and thin-film are 93% and 7%, respectively. In the c-Si technology, multi-crystalline cells dominates the market with share 69% and mono-crystalline share is 24%. The researches to reach more efficient and chipper solar cell is still under development.

In the solar thermal technology, the solar irradiation is converted into thermal energy using solar collector. The solar thermal technology, in comparison with solar photovoltaic, has a higher thermal efficiency. However, the technology and

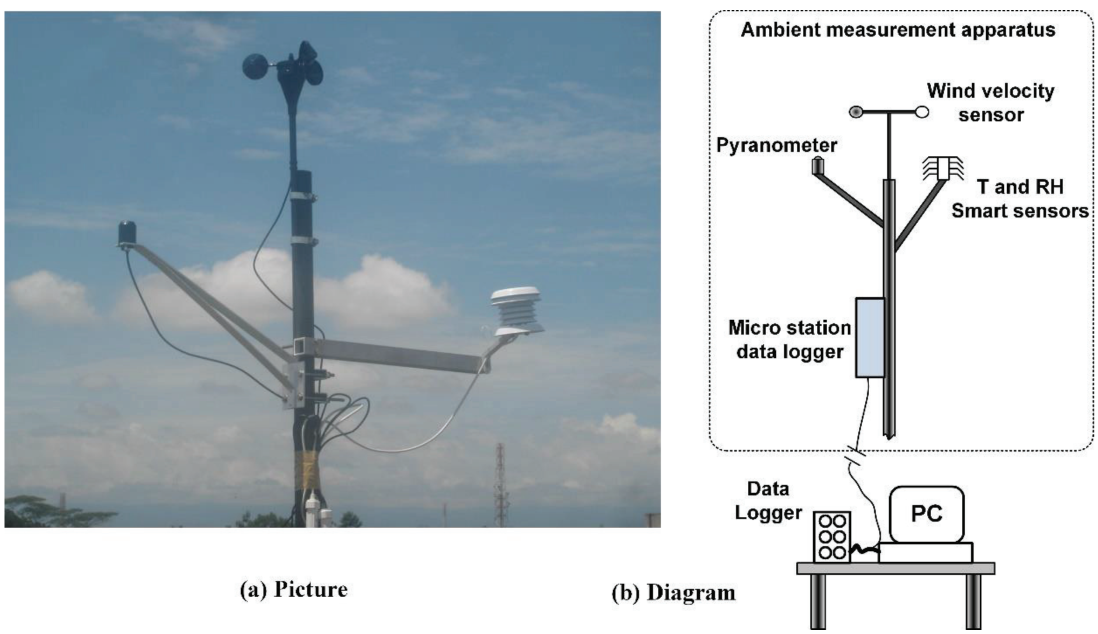
The 1st International Conference on Physics and Applied Physics (The 1st ICP&AP) 2019
AIP Conf. Proc. 2221, 070002-1–070002-6; https://doi.org/10.1063/5.0003482
Published by AIP Publishing. 978-0-7354-1980-3/$30.00

the cost are relatively lower. In particular, Urban et. al examined the routes implementation of solar energy in China by comparing two different technologies, they are solar photovoltaic technology and solar water heater (as a representative of solar thermal technology). It is stated that Chinese solar photovoltaic is predominantly produced for the export market andthe development based on intellectual property-intensive technology and has received significant financial support. On the other hand, solar water heater is an originatingChinese technology that is present everywhere across China and developed from grass-roots levels to mass products with a very little support from the government. However, the solar thermal technology in solar water heater could contribute significantto China's low carbon transitions that gained at local level [3]. This fact motivates many researchers to keep focus on development solar thermal technology. The converted heat can be used as energy source in many applications such as solar water heater [3, 4, 5], solar cooker [6], solar cooling [7, 8], solar drier [9, 10], solar desalination [11, 12], etc.

In both technologies, the information of modeling solar radiation is extremely needed. The objective of this study is to explore the characteristic solar radiation on the horizontal surface on earth surface. The clear sky estimation will be developed. The measurement on the surface in Medan city will be carried out. The results from both clear sky estimation and measurements will be compared with data from satellite. The results are expected to supply the necessary information on development solar energy utilization, in particularly in Indonesia.

APPARATUS AND METHODS

Three different methods will be compared, they are clear sky radiation model, measurement and solar resource satellite by SOLARGIS. In the experiment, data microstationdatalogger will be used. The experimental equipment is shown in Fig.1. It consists of four different sensors. The daily air temperature around the equipment and relative humidity (RH) are recorded using HOBO temperature RH smart sensor. The accuracies are 0.2°C and ± 2.5% RH, respectively. The speed of the air flow around the equipment is recorded using HOBO wind speed smart sensor with an accuracy of ± 1.1 m/s. The solar radiation is recordedby employing Silicon Pyranometer Smart Sensor. The resolution and accuracy of the sensor is 1.25 W/m^2 and ± 10 W/m^2, respectively.



(a) Picture (b) Diagram

FIGURE 1. Measurement apparatus and data acquisition system

CLEAR SKY RADIATION

The clear sky radiation can be divided into Beam and Diffuse radiations. Both radiations are calculated using the following equations. The first step is to calculate the solar radiation entering the atmosphere as given below [12].

$$G_{tot} = G_{on} \cos\theta_z \left[\tau_b + 0{,}271 - 0{,}294\,\tau_b\right] \quad (1)$$

where G_{on} is extraterrestrial radiation before entering the atmosphere, θ_z is zenith angle of the sun at calculate time, and τ_b is the atmospheric transmittance for beam radiation. The zenith angle is calculated by using the below equation.

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (2)$$

where $\phi = 3^o34'$ is the latitude in at Medan city, δ is declination angle depend on the day measured, and ω is hour angle. The declination angle is estimated byusing the equation (3).

$$\delta = 23{,}45\sin\left(360\,\frac{284+n}{365}\right) \quad (3)$$

where n is the day of the year. The hour angle is calculated by using equation (4).

$$\omega = 15(STD-12)+(ST-STD)\times\frac{15}{60} \quad (4)$$

In the above equation STD and ST arethe standard time and the solar time, respectively. The solar time is calculated equation (5).

$$ST = STD - 4(L_{st} - L_{loc}) + E \quad (5)$$

In equation (5), L_{st} is defined as the standard meridian for the local time zone and L_{loc} is longitude of the location being calculated. The parameter E is the equation of time and calculated by the following equation.

$$E = 229{,}2(0{,}000075\ + 0{,}001868\ \cos B - 0{,}032077\ \sin B - 0{,}014615\ \cos 2B - 0{,}04089\ \sin 2B \quad (6)$$

while B is given by

$$B = (n-1)\frac{360}{365} \quad (7)$$

The atmospheric transmittance for beam radiation can be estimated by using below equation.

$$\tau_b = a_0 + a_1\exp\left(\frac{-k}{\cos\theta_z}\right) \quad (8)$$

Where,

$$a_0 = r_0\left[0{,}4237 - 0{,}00821\,(6-A)^2\right] \quad (9)$$

$$a_1 = r_1\left[0{,}5055 + 0{,}00595\,(6{,}5-A)^2\right] \quad (10)$$

$$k = r_k\left[0{,}2711 + 0{,}01858\,(2{,}5-A)^2\right] \quad (11)$$

As suggested by Hottel [13], for Medan city the parameters in the above equations are $r_0 = 0.95$, $r_1 = 0.98$, and $r_k = 1.02$. The altitude of the present experimental apparatus is $A = 0{,}054$ km. The total solar energy radiation during the measurement is calculated by

$$I = \int_{t_0}^{t} G\,dt \quad (12)$$

RESULTS AND DISCUSSIONS

The estimation will be performed using the fabricated solar box cookers at a location in Medan city of Indonesia. The latitude and longitude Medan city are 3° 35'N and 98° 40'E, respectively and the elevation of experimental is 54 m above sea level. Experiments have been carried out, several results are shown below. Figure 2 shows the estimating solar radiation and measurement on January 1st.

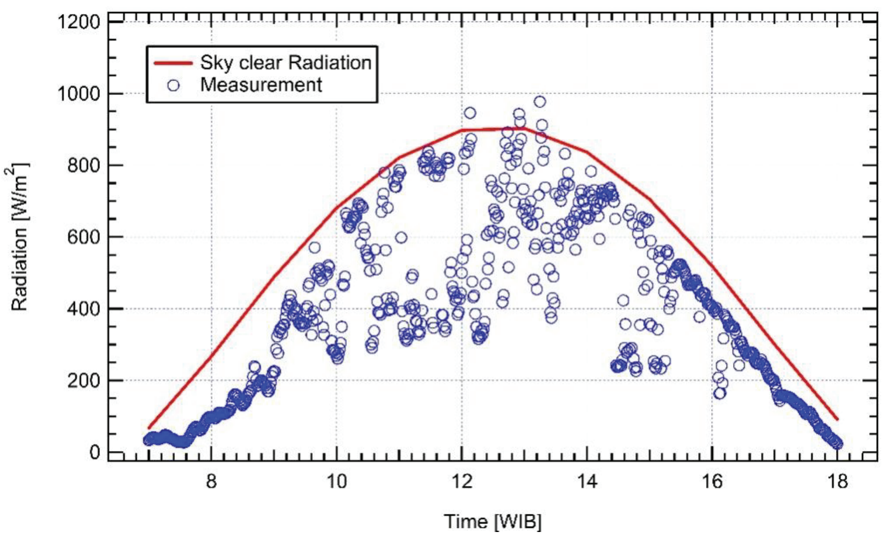


FIGURE 2. Estimating Radiation and Measurements on January 1st

The clear sky radiation shows that the solar radiation increases as time increasing and reaching the maximum value at around 12.30. After reaching the maximum value, it decreases as time increasing. The similar trend is also shown by the measurement. However, in several hours, the solar ration falling down due to clouds. During the experiment, the solar energy irradiation by clear sky radiation and measurement are 6.19 kWh/m^2 and 4.33 kWh/m^2. This values suggest that the theoretical estimation is higher that the experiment in order of 42.79%.

Figure 3 shows the theoretical clear sky radiation and measurement on June 13th. The comparison of the measurement and theoretical clear sky radiation show that from 7.00 WIB to 10.00WIB, the theoretical clear sky radiation agree very well with experiment. This is because, at the measured time, there was no cloud in the sky. The calculation has been made, the total theoretical solar irradiation and measurement are 6.41 kWh/m^2 and 5.31 kWh/m^2. This values reveals that the theoretical clear sky irradiation is 20.8%.

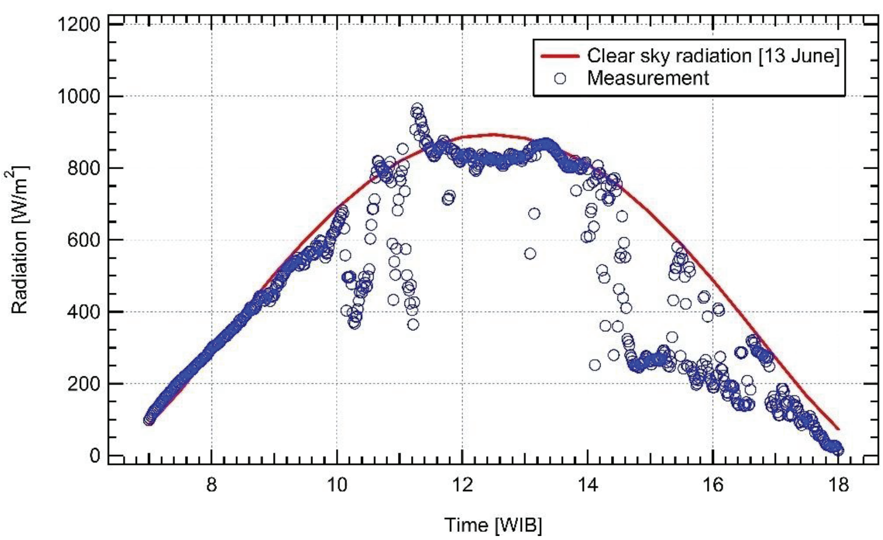


FIGURE 3. Estimating Radiation and Measurements on June 13th

Figure 4 shows the theoretical clear sky radiation and measurement on August 21st. The comparison of the measurement and theoretical clear sky radiation show that from 7.00 WIB to 10.00WIB, the experiments, in some hours, are lower than theoretical clear sky radiation. This is because, at the measured time, there was cloud in the sky and blocking the radiation to reach the earth. From 10.00 WIB to 14.00 WIB, the sky was quite clear. Thus the measurement agree with theoretical clear sky radiation. The calculation has been made, the total theoretical solar irradiation and measurement are 6.59 kWh/m^2 and 2.61 kWh/m^2. This values suggest that the measured values at the experiment was way lower than theoretical clear sky radiation. In other words, the clouds were blocking the solar radiation from the sky to the earth surface.

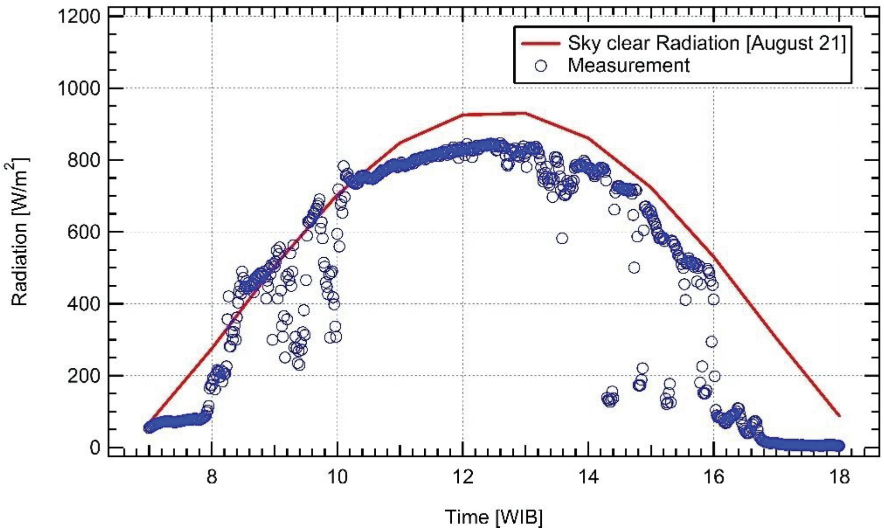


FIGURE 4. Estimating Radiation and Measurements on August 21st

In order to make comparison with satellite data, the solar irradiance on the horizontal surface in Indonesia islands is shown in Fig.5. The solar resource data obtained from the Global Solar Atlas, owned by the World Bank Group and provided by SOLARGIS [15]. The figure shows that daily solar irradiation in Indonesia varies from 3.2 kWh/m^2 to 6.2 kWh/m^2. In a year it can be 1300 kWh/m^2 to 2200 kWh/m^2. The lowest of solar irradiation captured in the middle part of Irian Jaya (eastern part of Indonesia). On the other hand, the highest is shown by the West Timur and Sumbawa islands (in the figure shown by red areas). The solar irradiation in Indonesia islands, in comparison with Middle East and North Africa, can be categorized as medium. In the Middle East countries, the solar irradiance can be up to 7 kWh/m^2 per day or yearly total up to 2500 kWh/m^2. Based on the data drawn from the SOLARGIS , the daily solar irradiation in Medan city of Indonesia varies from 3.60 kWh/m^2 in June to 5.25 kWh/m^2 in February.

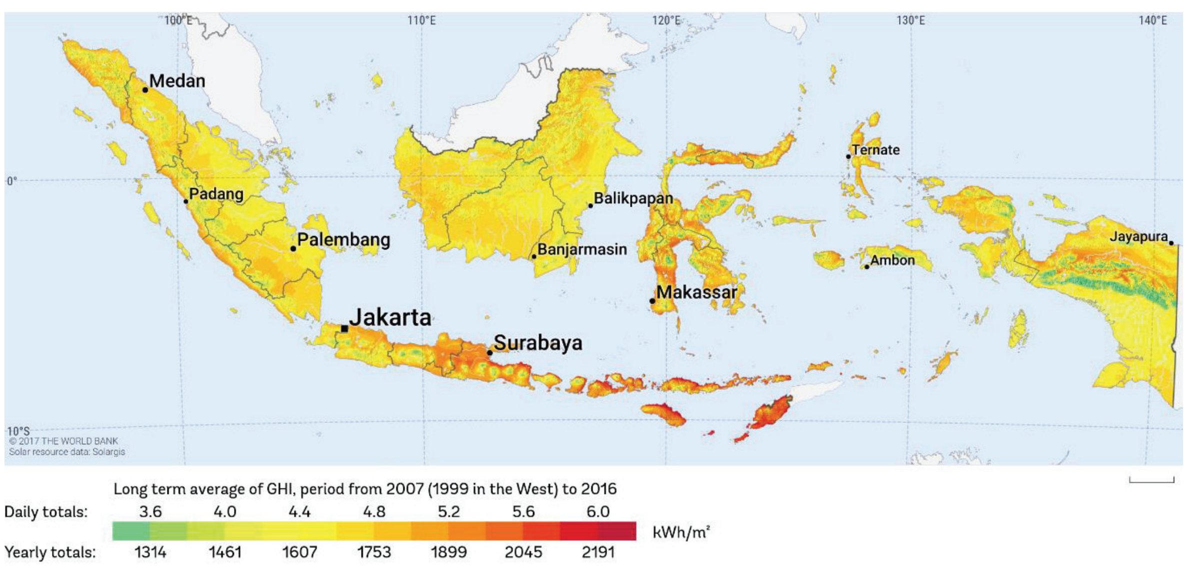


FIGURE 5. Global horizontal solar Irradiation

CONCLUSIONS

In this work, the potency of solar irradiation in Medan city of Indonesia has been explored in three different methods, they are theoretical clear sky radiation, field measurements and SOLARGIS satellite data. Several days of measurements have been carried out. The conclusions are as follows. The clear sky radiation model estimates the solar irradiation is higher than measurement and data satellite. Thus, the model can only be used to give additional data for analysis. The measurement data and satellite data agree well. It is suggested to develop a model that can predict a better solar irradiation in Medan city of Indonesia.

ACKNOWLEDGEMENT

This study is funded by the Ministry of Research and Higher Education of Republic of Indonesia under the Scheme of Hibah Kompetensi with contract No 57/UN5.2.3.1/PPM/KP-DRPM/2019 Year of 2019.

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