Regional Characteristics of Global Solar Radiation Variation in the Recent 30 Years in Taiwan

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Abstract

Solar radiation data is an important consideration factor in building environment planning. This study focused on the regional characteristics of global solar radiation of Taiwan. The research utilized the raw meteorological data meseaursed by the Central Weather Bureau to establish reliable solar radiation data of weather stations by means of statistic analysis. A total of weather station's data are used where their geographical location are evenly distributed from northern to southern Taiwan.

The results of this study will presented the diagrams of annual and monthly averaged solar radiation in Taiwan. Geographical distribution of inter-annual trend of global solar radiation during this period was also presented in this paper. It can be used for further study of the climate zoning comparing with other climate conditions. Furthermore, researchers of solar cell design, building energy, shading design, site planning, etc. can utilize the distribution diagram to fetch reliable solar radiation values to carry on reasonable quantitative analysis.

Keywords

BIPV, Solar radiation, Green Building

1. Introduction

Solar radiation data is an important consideration factor in building environment planning. In order to understand the climatic characteristics of Taiwan, the research utilized the meteorological data from the Central Weather Bureau to establish reliable solar radiation data of every weather station through statistics. The purpose is to provide fundamental reference data for the utilization of Building Integrated Photovoltaic (BIPV) design.

2. Method

2.1 Weather Station

The research uses ten years' hourly meteorological data from 1997 to 2006 as the statistical database. The observed weather elements include: dry bulb temperature, total horizontal solar radiation, sunshine factor, cloud factor, relative humidity, wind speed, wind direction, etc. A total of twenty two weather station's data are used which evenly distributed from northern to southern Taiwan (Fig. 1). Additionally, we chose five main metropolises in Taiwan, uses 30 years' hourly meteorological data from 1977 to 2006 to compare with the near 10 years' solar radiation.

2.2 Weather Station

Investigating through the source of original weather data, there are data missing and meteorological data contradicts problem that needs to be ruled out to enhance the statistical accuracy. The data contradictions are: 1) Illogical existence of solar radiation values while in nighttime 2) Rationality check between solar radiation and the cloud factor. The study screen outs the hourly extreme weather data base on the above data logical check and the average statistics are used to establish each place's monthly averaged solar radiation and annual solar radiation.

With regards to the cloud factor, the original data are recorded on the basis of three hours, therefore, for comparing reasons the missing data have to be filled up through mathematical methods. The study uses Budyko's (1962) regression formula for missing data filling of daytime. The cloud factor can be estimated from extra-terrestrial radiation and the observed solar radiation of the ground surface through (Eq.1).

$$Q' = Ra \times (1 - 0.37C - 0.38C^2) \quad (1)$$

where as

Q'：total horizontal solar radiation (MJ/ m^2hr)

Ra：extra-terrestrial total horizontal solar radiation (cal/cm^2hr)

C: cloud factor

NO.	Station
1	Keelung
2	Zhuzihu
3	Anbu
4	Danshui
5	Banqiao
6	Taipei
7	Hsinchu
8	Wuqi
9	Taichung
10	Sun moon lake
11	Chiayi
12	Alishan
13	Yushan
14	Yongkang
15	Tainan
16	Kaohsiung
17	Dawu
18	Taitung
19	Chenggong
20	Hualien
21	Suao
22	Yilan

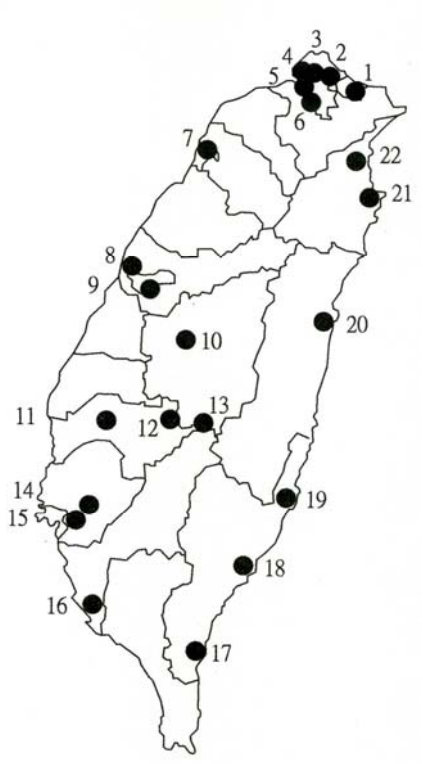

Figure 1 Weather station in Taiwan

3. Discussion of the Distribution of Solar Radiation in Taiwan

3.1 Plotting of Solar Radiation Distribution

The research established 22 weather stations' solar radiation databases as shown in table 1. Besides, for architect and designer application purpose, solar radiation distribution diagrams are plotted according to the amount of solar radiation as in Fig.2. The users must remind that there are application limits as below.

1) For the number limitation of the weather stations, some interpolations are made to a certain degree for areas where there is in lack of weather station. Moreover, there are deviations due to unknown factors during statistic and modification process of the adopted solar radiation data. Therefore, the distribution plot is more feasible in inter-comparable between macro-geometrical district rather then dealing with micro climatic quantitative research.

2) The values of the distribution plotting are of averaged long-term characteristic which is some of different from annual observed values. Furthermore, due to uncoincidences of the data observed periods, biases may be occurred between every weather station, this can be overcome by updating with more newer and longer periods of reliable data.
3) Due to most of the weather stations are situated in low altitude areas, distribution situation of mountain areas have no choice but to speculate according to other relative data (geometric contours for example). As a result, the inaccuracy may be larger than in low altitude areas.

Table 1 Database of Solar Radiation of Taiwan

Station No.	Location	Altitude (meter)	Longitude	Latitude	Yearly Solar Radiation kWh/m^2day
466880	Banqiao	9.7	121°26 '02″ E	24°59' 58″ N	2.6
466900	Danshui	19.0	121°26' 24″ E	25°09' 56″ N	2.6
466910	Anbu	825.8	121°31' 12.66″ E	25°11' 11.45″ N	3.1
466920	Taipei	5.3	121°30' 24.15″ E	25°02' 22.62″ N	2.7
466930	Zhuzihu	607.1	121°32' 10.58″ E	25°09' 53.95″ N	3.0
466940	Keelung	26.7	121°43' 55.66″ E	25°08' 05.18″ N	2.4
466990	Hualien	16.0	121°36' 17.98″ E	23°58' 37.10″ N	3.1
467060	Suao	24.9	121°51' 51.93″ E	24°36' 06.24″ N	2.7
467080	Yilan	7.2	121°44' 52.55″ E	24°45' 56.04″ N	2.4
467410	Tainan city	13.8	120°11' 49.18″ E	22°59' 42.81″ N	3.7
467420	Yong Kang	8.1	120°13' 43″ E	23°02' 22″ N	3.4
467440	Kaohsiung	2.3	120°18' 28.92″ E	22°34' 04.40″ N	3.5
467480	Chiayi	26.9	120°25' 28.21″ E	23°29' 51.81″ N	3.6
467490	Taichung	34.0	120°40' 33.31″ E	24°08' 50.98″ N	3.2
467530	Alishan	2413.4	120°48' 18.39″ E	23°30' 37.42″ N	3.5
467540	Dawu	8.1	120°53' 44.48″ E	22°21' 27.26″ N	3.2
467550	Yushan	3844.8	120°57' 06.26″ E	23°29' 21.49″ N	4.0
467571	Hsinchu	34.0	121°00' 22″ E	24°49' 48″ N	3.1
467610	Chenggong	33.5	121°21' 55.36″ E	23°05' 57.17″ N	3.2
467650	Sun moon lake	1014.8	120°53' 59.62″ E	23°52' 58.78″ N	3.1
467660	Taitung	9.0	121°08' 47.55″ E	22°45' 14.51″ N	4.1
467770	Wuqi	31.7	120°30' 54.24″ E	24°15' 31.44″ N	3.3

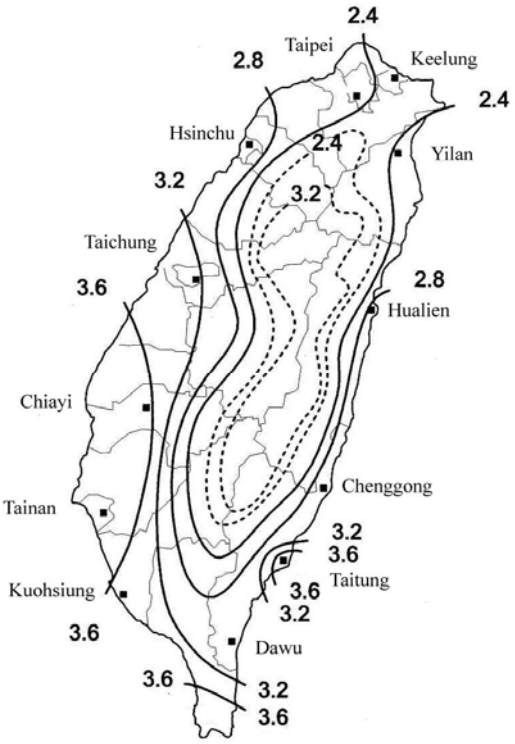

Figure 2 Solar Radiation Distribution in Taiwan（Unit：kWh/m^2 day）

3.2 Discussion of the Solar Radiation Distribution in Taiwan

General speaking, the solar radiation distribution at places below 500 meter altitude increases from northern east to southern west. In other words, the annual averaged solar radiation in Keelung where situated in northern east Taiwan is 2.3kWh/m^2 per day while it increases to 3.5kWh/m^2 in Kaohsiung where situated in southern west Taiwan. Besides, the solar radiation at long and narrow plain in the east coast area, increases along way from northern Hualien to southern Taitung. Taitung has the highest solar radiation value in Taiwan east coast area, which it's value is as high as 4.1kWh/m^2. The detail solar radiation value of every weather station is shown as table 1.

Discussion from the view point of the weather station district, the research categorized it into 5 districts, which are northern, southern, central, eastern and high altitude districts. The characteristics of solar radiation of every district are summarized as below:

1) Northern district: The shape of the monthly averaged solar radiation distribution through out the year is in bell shape (Fig.3). Namely, the peak value occurs in July and August. The peak values of this district ranging from 13,526-18,368kJ/m^{2}day. The highest value occurs in July at Suao, the monthly averaged values decrease drastically to 8,524kJ/m^{2}day before and after the peak value occurred month. The annual averaged solar radiation is around 9,590kJ/m^{2}day.
2) Central district: There are three weather stations in this district. The variation range

is apparently lower then northern district. The annual averaged solar radiation at Hsinchu, Taichung and Wuchi are 11,298、12,306 and 11,173kJ/m^2day respectively, which all more then the whole 6 weather station in northern district. The annual peak periods are from May to September, The intensity of the solar radiations is above 12,500kJ/m^2day (Fig.4). The annual averaged solar radiation is around 11,690kJ/m^2day.

3) Southern district: There are four weather stations in this district. The distribution shape of the monthly solar radiation is similar to central district (Fig.5). The solar radiation is above 10,000kJ/m^2day almost from March to October. The annual averaged solar radiation is around 13,550kJ/m^2day. Among which solar radiation at Tainan and Yongkang is often has an apparent drop during summer season. The speculated reason is due to cloud cover variations, this phenomena is also the same in the literature review from “The Estimation of Total Shortwave Radiation in Taiwan” (Yan, 1974).
4) East district: There are four weather stations in this district. The distribution shape of the monthly solar radiation is similar to northern district (Fig.6). The annual solar radiation is up to 13,098kJ/m^2day which is larger then in northern district where its value is 9,590kJ/m^2day. The solar radiation reaches to its high during June to August. The peak values of the four weather station is between 12,789 to 14,822kJ/m^2day. The highest value is 14,822kJ/m^2day which occurs in July at Taitung.
5) High altitude district: There are five weather stations in this district. The altitudes of Anbu and Zhuzihu are 825 and 607 meters. Because the solar radiation is not so relevant to cloud cover factor for its high altitude, the value of annual averaged solar radiation is 11,290kJ/m^2day which increased by 16% more then at plain area in northern district. The weather stations at Alisan and Yushan are both in mountain climate area, where their altitude are above 2000 meters. Therefore, cloud cover influence is much less here, the monthly average solar radiation is high and its perturbation is not so large as in plain area. The annual averaged value of solar radiation for Alisan and Yushan are 12,743kWh/m^2day and 14,470kWh/m^2day respectively. The annual averaged solar radiation is 11,009kJ/m^2day in sun-moon lake which its altitude is 1015 meters (Fig.7).

The above are the weather data analysis of the first class weather stations from the Central Weather Bureau. It characterized the solar radiation distribution of Taiwan. The monthly distributions of central and southern district are in hills’ shape, which means an annual power generation load photovoltaic system is the better option. The monthly distributions of northern and north eastern district are in bell shape. The intensity of solar radiation is higher in summer season, which indicates that reducing summer peak

load oriented solar cell system is encouraged to use. The solar radiation at high altitude districts has larger value and has less monthly variations.

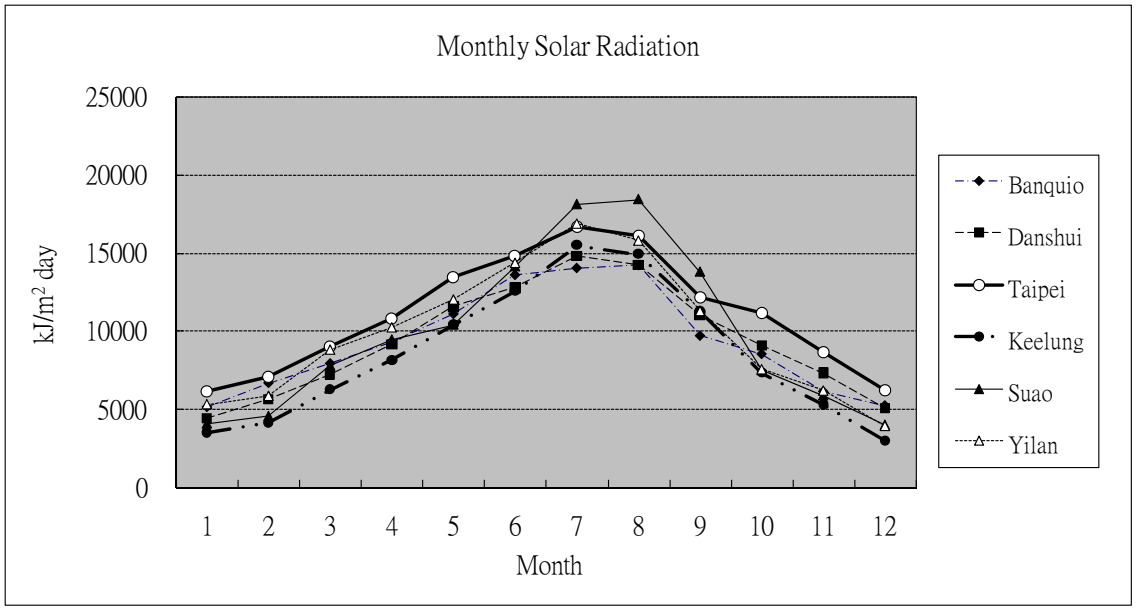

Figure 3 Distribution diagram of monthly averaged solar radiation of northern district weather stations

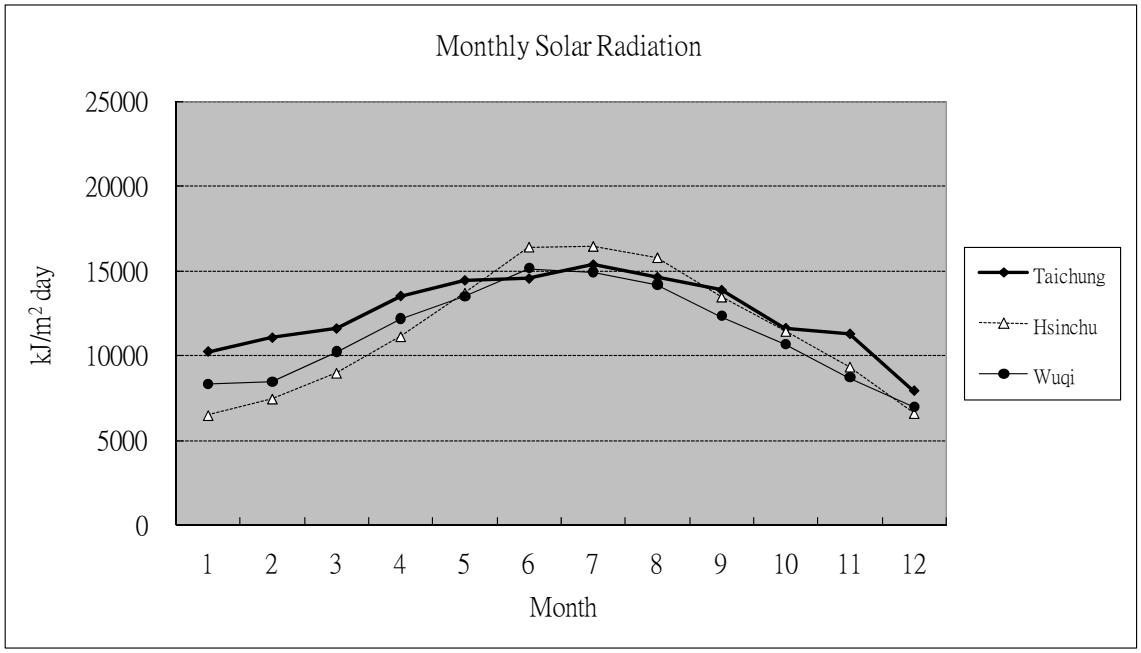

Figure 4 Distribution diagram of monthly averaged solar radiation of central district weather stations

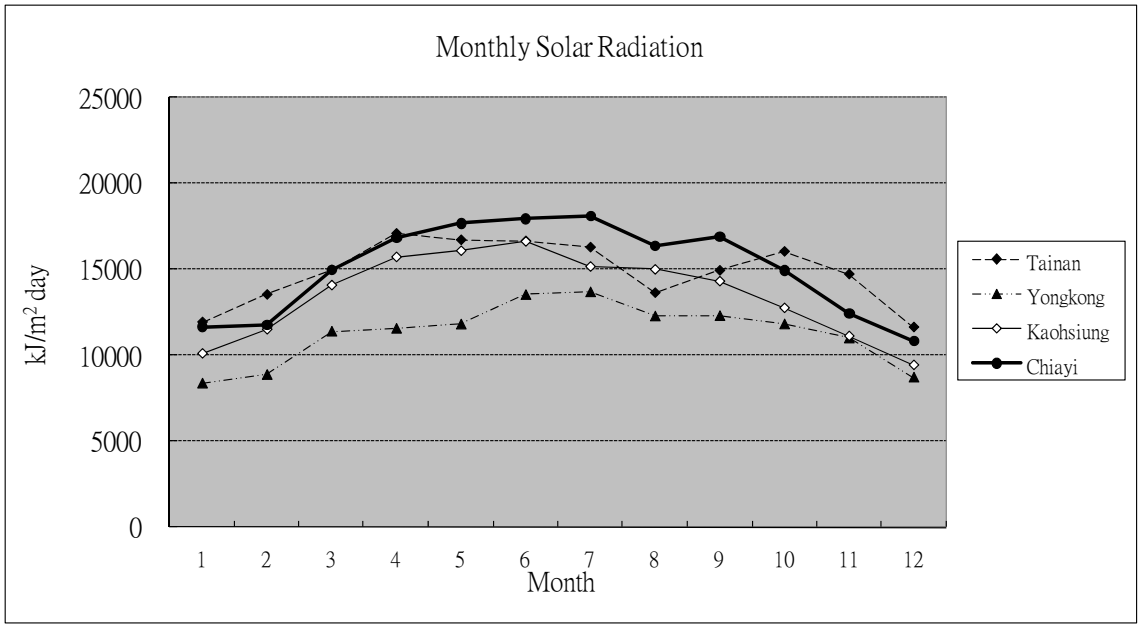

Figure 5 Distribution diagram of monthly averaged solar radiation of southern district weather stations

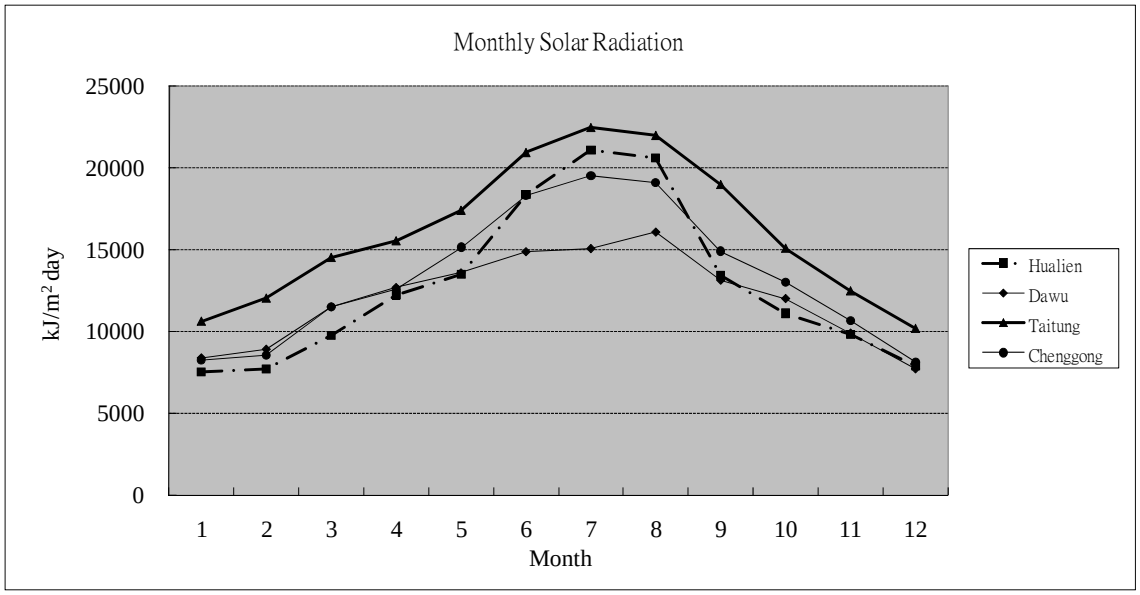

Figure 6 Distribution diagram of monthly averaged solar radiation of eastern district weather stations

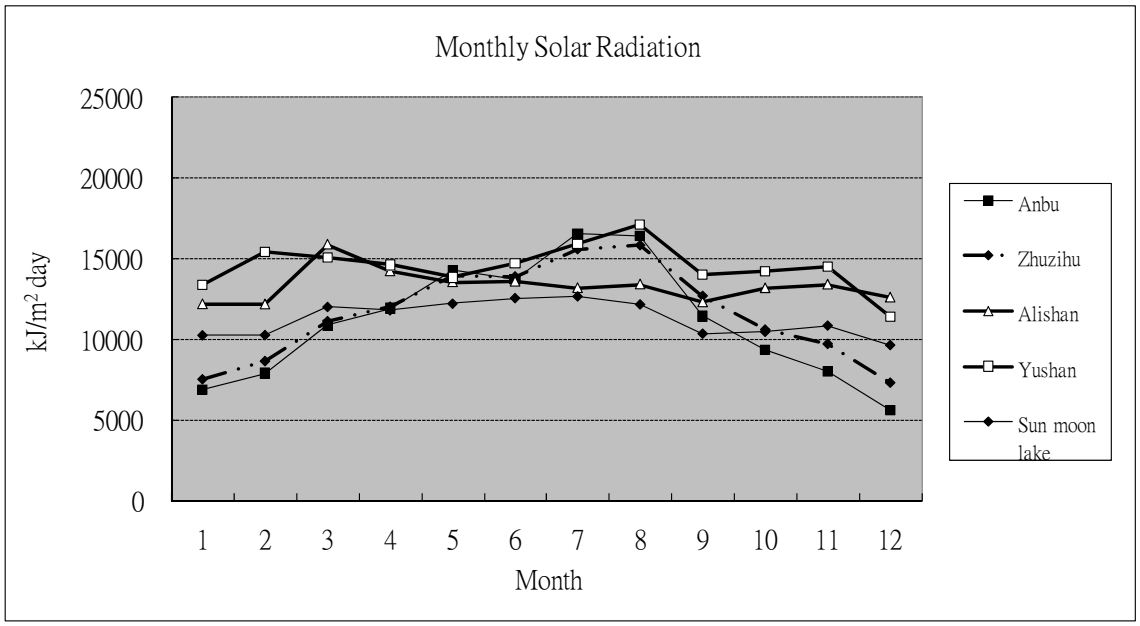

Figure 7 Distribution diagram of monthly averaged solar radiation of high altitude district weather stations.

3.3 Discussion of the Solar Radiation Distribution in Taiwan

We use 30 years' hourly meteorological data to compare with the near 10 years' solar radiation. The research select five main metropolises weather station data in Taiwan, there are Taipei, Taichung, Kaohsiung, Hualien and Taitung, to compared solar radiation on difference duration. The five weather station 30 years' annual solar radiations were 2.8, 3.6, 3.7, 3.4 and 4.3kWh/m^2day, respectively.

Discussion from the view point of the weather station an era, the 30 years' solar radiation in comparison with near 10 years' solar radiation was decreases about 5% to 15%, as shown in table 2.

Table 2 Solar Radiation on Difference Duration of Taiwan（Unit：kWh/m^2 day）

Duration	Taipei	Taichung	Kaohsiung	Hualien	Taitung
1977-2006	2.8	3.6	3.7	3.4	4.3
1997-2006	2.6	3.2	3.4	2.9	4.1

4. Conclusion

The conclusion results of the research can be concluded as below:

1) The research plotted the distribution diagram of annual and monthly averaged solar radiation in Taiwan. It can be further study the climate zoning together

with other climate conditions. Also, academic researchers of solar cell design, building energy, shading design, site planning, etc. can utilize the distribution diagram for fetching reliable solar radiation values to carry on reasonable quantitative analysis.

2) The solar radiation distribution at where its altitude is below 500 meters increases from northeast to southwest roughly. The research also describes the solar radiation characteristics by six districts.
3) Solar radiation description in high altitude districts is as follows: the annual averaged solar radiation of the northern high altitude areas is around 15% more then northern plain district. Alishan and Yushan are both in high mountain climate district, which has larger solar radiation values and has less monthly variations. It is same situation in Sun Moon Lake where it is also at high altitude.
4) In general, Taiwan five metropolises 30 years' solar radiation in comparison with recent 10 years' data was decreases about 5 to 15%.

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6. Presentation of Author

Dr. Wen-Sheng Ou: Assistant Professor of Chia-Nan University, Taiwan licensed Interior Designer and Architect, has continued Research of Constructed Wetland, Solar Radiation Evaluation and Building Integrated Photovoltaic from 1995 to now.