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Technical Note

Research of BIPV optimal tilted angle, use of latitude concept for south orientated plans

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ABSTRACT

The present study analyzes the correlation between the optimal angle for a fixed Building Integrated Photovoltaic (BIPV) system and the latitude of the system's site as measured in degrees according to estimates made with PVSYST 3.41 software. Calculations were made for a BIPV south orientated tilted roof at 20 different locations in 14 countries, ranging from 0° to 85° latitude in the Northern Hemisphere. In order to prove the reliability of using the latitude angle as the angle for the tilted panel, the correlation was made between the performance obtained with the system using the optimal angle and the system with the site's location angle. Results indicate that an average of 98.6% a system's performance with the optimal angle can be obtained using the latitude angle for the tilted panel.

1. Introduction

The use of photovoltaic (PV) panels was originally planned as a type of technology to be used for outer space applications [1], and its use was not considered to be suitable for commercial purposes. However, recent technological advancements have stimulated the development and use of PV panels in the commercial market for its use in building appliances. PV panels allow the production of electricity using photovoltaic cells that convert solar irradiation into useable electricity and, as a result, have become one of the most reliable sources of low – pollutant energy in the world. Regardless of its requisite high primary costs, PV systems have been adopted in many countries as an efficient means of producing energy in rural and urban areas that show a higher output in rural areas [2]. They are particularly valuable in locations in which it is difficult to obtain a connection to a grid.

Building Integrated Photovoltaic systems present different advantages when compared with centralized grid systems; they can reduce costs in electric cables and, when used on external walls, can reduce a building's cooling load and the heating absorption through the facades [3]. Oliver and Jackson [1] refers to the following three main benefits of BIPV systems over centralized grid connected PV systems:

1. When PV panels are installed in the structure of the building, the costs of land and structures to maintain the panels are avoided;
2. Because BIPV systems produces electricity near the point of use, losses associated with the transmission and distribution of the electricity are avoided. This represents an important aspect of commercial buildings, where the time of highest power demand coincides with the time of electricity supply from the PV panels;
3. The PV panels of a BIPV system can be used as important components of the building's facades or roofs, thus reducing materials' costs.

Another benefit of using BIPV systems is that the process of charging and discharging batteries can be avoided and, therefore, more power can be used with the connection of the system to a local grid [4].

Due to its aforementioned advantages and the fact that BIPV systems energy payback periods oscillate between 4 and 16.5 years [5], new policies have been practiced in many countries to promote the acquisition of PV systems in residential and commercial buildings. Japan and Germany lead the countries with installed PV power, having over 1,421,000 kW of cumulate energy. Tax reductions for the purchase of PV panels, and the use *net metering* systems (a system that allows consumer to get credit for the extra power produced by PV modules that is returned to the grid), are some examples of these strategies practiced for governments and private agencies in order to promote the use of PV technology [6].

Currently photovoltaic technology has improved its effectiveness, reporting over 22% on the module efficiency (the highest reported module efficiency) [7]. However, important factors that reduce the last amount of power produced can affect the system. Some of these factors, such as the cloudiness and shadows

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Nomenclature

G_{d-h}	Daily global horizontal irradiation (Wh/m^2 d)
G_{y-h}	Annual global horizontal irradiation (kWh/m^2 y)
MSL	Mean sea level
NASA G_{d-h}	Daily global horizontal irradiation (kWh/m^2). Data obtained from NASA's database
NASA G_{y-h}	Annual global horizontal irradiation (kWh/m^2). Data obtained from NASA's database
P	System's output power
$P_y(\beta = \Phi)$	System's yearly power output using the site's latitude as the tilted angle
$P_y(\beta_{opt}y)$	System's yearly power output using $\beta_{opt}y$
PVS-G_{d-h}	Daily global horizontal irradiation (kWh/m^2). Data obtained from PVSYST 3.41 software
$\%(P_y\beta_{opt}y)$	Percent of the β_{opt} performance obtained using $\beta = \Phi$
β	Angle for tilted PV planes measured in degrees
β_{opt}	Optimal angle for tilted PV panels
$\beta_{opt}y$	Yearly optimal angle for tilted PV panels
Φ	Latitude of the site measured in degrees

produced by the surrounding environment, are impossible to manipulate. Further factors, such as the orientation and inclination of the system depend entirely on the system's design [8], which, if not properly designed, can be affected by its own geometry producing shadows over itself and, therefore, reduce the amount of output energy [9]. It is widely acknowledged that a Southern orientation for PV panels in the Northern Hemisphere is optimal [10]. On the other hand, the optimal tilt angle for PV panels varies according to the site's latitude and requires a series of specific calculations [11]. Fordham [12] states that the optimal slope angle is equal to the latitude of the site minus 20° ($\beta_{opt} = \Phi - 20°$); although, this assumption was made for a single place, using the location of Eskdalemuir, Scotland[1]; and its range is, therefore, very limited.

Design parameters for optimal tilt angle and optimal orientation are applied to the planning of a variety of solar collector systems, including flat collectors and parabolic collectors [10]. Since the principles for a solar collector's optimal orientation are focused to obtain the maximum solar irradiation, previous research in this area can be used as a reference for the present study. These previous studies revealed a correlation between the location angle in degrees (Φ) and the optimal tilt angle (β_{opt}) for the panel. According to Yellott (as cited in Shariah et al, 2002 [13]), β_{opt} can be assumed to have two variations, corresponding to the seasons. For summer, the optimal angle is equal to the angle of the latitude minus 20° ($\Phi - [0 \rightarrow 20°]$) and for winter it is equal to the angle of the latitude plus 20° ($\Phi + [0 \rightarrow 20°]$). These previous data support the direct correlation between the site's latitude and the optimal angle for a solar collector's tilted panel since, even with the yearly variations, β_{opt} and Φ remain correlated.

In order to maintain the optimal inclination of the panel along the year Gunerhan and Hepbasli [10] recommends that solar collector systems must be adjusted with the optimal angle every month. These variations in the angle of the tilted plane are not always a possibility for BIPV systems since the tracking system, even if used with the monthly average tilt angle, involves extra costs and use of extra energy [14]. Therefore, in order to avoid those extra costs, the average of the yearly optimal angle must be used in fixed systems.

2. Methodology

The methodology of this study focuses on the validation of the reliability of a BIPV system using $\beta = \Phi$. The theory was proved by means of experimentation and comparison of results provided by computer simulation testing.

The experimentation process can be resumed in the following three steps:

i Analyze previous BIPV evaluation methods, formula (in this case the cosine model [15]) and software application, in order to establish tools for the experimentation;
ii Simulation and system performance evaluation for different international locations;
iii Validation of the thesis and conclusions.

During the calculation process, the use of software tools allows the obtaining of worldwide data for the evaluation of the correlation between P_y (β_{opt}) and $P_y(\beta = \Phi)$, without local experimentation. For data collection, sites distributed along the parallels from the Equator to the North Pole were used in order to provide a more extensive range of information.

The yearly optimal tilted angle ($\beta_{opt}y$) was calculated via a comparison process using the angle that provides the highest output energy as the optimal sloped angle, according to the data provided by the PVSYST 3.41 software [16]. The calculations to obtain this data were made every 10° and for the location's latitude angle, as well. After this step, the data of the yearly output power for the angle with the highest output and the data for the angle of the location were compared to obtain their correlation. In this way, a validation of the effectiveness of using $\beta = \Phi$ could be made.

3. Experimentation

In order to analyze the correlation between the optimal angle for slope panels and its latitude, sites with different latitude must be used during the calculation process. Through the first stage of the process, 20 cities located in 14 countries were chosen (Fig. 1). These cities have different latitude angles (from 00° 07′ to 85° 47′, Northern latitude) and their solar irradiation data can be calculated using the software application PVSYST 3.41. However, not all of the sites are included in the locations' list of the software; the ones that are not included were added as new locations.

The locations range was determined by the following criteria:

- The selected sites must be located in the same hemisphere (in this case the Northern Hemisphere);
- All the selected sites have to be populated or habitable. The applications of this study are focused on BIPV; therefore, the existence of an important number of buildings on the site is essential;
- All the selected sites must be distributed from 0° to 90° Northern latitude, as equally as possible. It is important to consider that it is not always possible to locate a place each specific number of degrees since many areas above the parallel 60, in the Northern Hemisphere, are uninhabited; and, therefore, are considered useless for this study;
- The selected sites also have to be located in different altitudes, in order to provide a more wide range of information;
- The selected areas must be contained in the location options of the software PVSYST 3.41. In case the location is not included, it

[1] The data provided declares a latitude angle of 55° 19′ North and an optimal tilt angle of 36° for the panel.

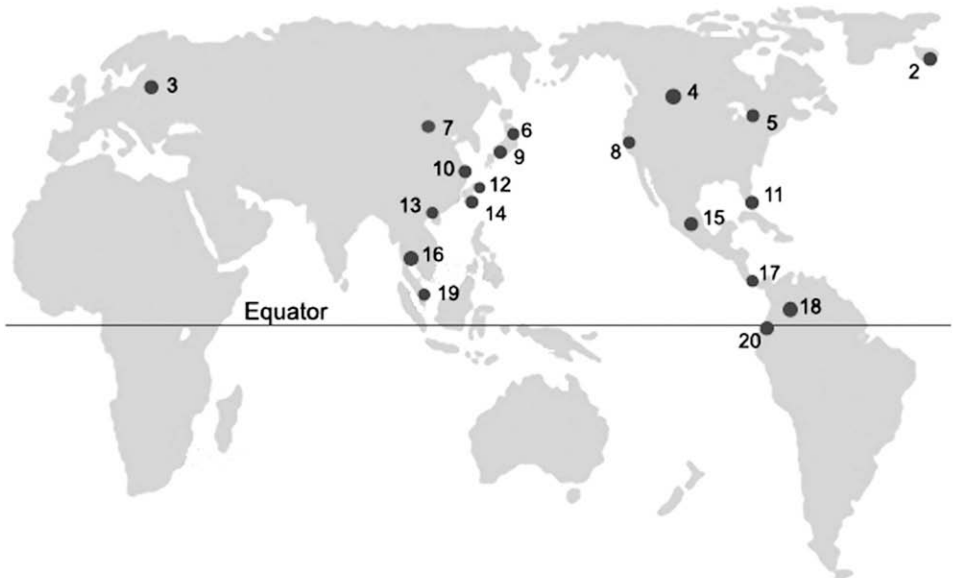

Fig. 1. World map with the international locations.

Table 1
International solar irradiation database comparison chart for Taipei City.[a,b]

Source	Month												Annual average
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
NASA	49.91	43.68	51.46	66.9	88.97	123.6	191	166.8	116.4	90.83	77.4	74.4	95.10
University of Massachusetts	66.96	70.28	93.93	108.9	137.3	137.1	144.2	148.5	118.8	122.5	103.2	81.22	111.06
Taiwan Central Weather Bureau	48.42	50.31	70.17	83.25	102.5	104.8	125.5	123.1	101.4	83.89	62.86	52.22	84.03

[a] Solar irradiation data for Taipei coordinates 25° 2′ N, 121° 32′ E.
[b] Data provided in kWh/m^2. Monthly average.

must be possible to integrate it as a new location in the software's database. However, this is not always an option since the software can invalidate the imputed data.

3.1. International solar database comparison

Nowadays, several technical resources are available regarding the attainment of solar irradiation data for PV and BIPV applications. For this study, three of these sources of data were selected according to the reliability and update of the sources. The following is a list of the international databases analyzed in order to obtain the must reliable source of solar irradiation information.

- NASA Surface Meteorology and solar energy database [17];
- Solar Energy database, University of Massachusetts [18];
- Taiwan Central Weather Bureau [19].

The solar database from the University of Massachusetts and the NASA Surface Meteorology and Solar Energy database were compared to a local source of data. In this case, the solar irradiation data was provided by the Taiwan Central Weather Bureau. This last database was used as a reliable comparison reference and considered the most precise for Taiwan. Table 1 and Fig. 2 shows a comparison chart made with the three solar databases using the information provided for Taipei City, Taiwan, R.O.C. (coordinates 25° 2′ N, 121° 32′ E).

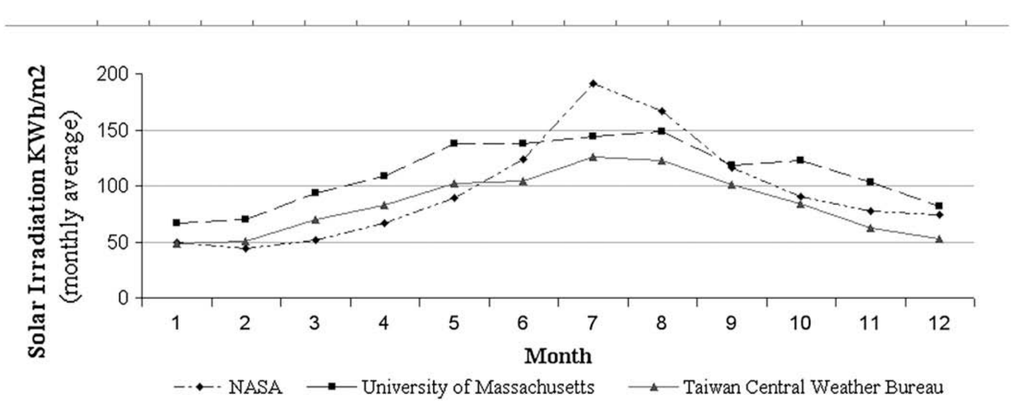

Fig. 2. Solar irradiation database comparisons for Taipei City.

Table 2
A comparisons of international solar irradiation data for the 20 international locations as found on the NASA Surface Meteorology and Solar Energy Database and PVSYST 3.41 software.

	City	Latitude	Longitude	Altitude (MSL)	NASA G_{d-h} (kWh/m^2)	NASA G_{y-h} (kWh/m^2)	PVS–G_{d-h} (kWh/m^2)	PVS–G_{y-h} (kWh/m^2)
1	Arctic	N 85° 47′	E 154° 45′	70	NP	NP	1.7	620.5
2	Reykjavik, Iceland	N 64° 15′	W 21° 14′	5	1.71	624.15	2.15	784.75
3	Helsinki, Finland	N 59° 34′	E 24° 24′	5	3.43	1252	2.63	959.95
4	Edmonton, Canada	N 53° 15′	W 79° 07′	206	3.8	1387	3.6	1314
5	Toronto, Canada	N 43° 29′	W 115° 12′	75	5.01	1828.7	3.79	1383.35
6	Sapporo, Japan	N 43° 03′	E 141° 21′	17	3.98	1452.7	3.37	1230.05
7	[a]Beijing, China	N 39° 54′	E 116° 23′	44	5.08	1854.2	3.68	1343.2
8	San Francisco, California	N 37° 28′	W 122° 06′	5	6.04	2204.6	4.72	1722.8
9	Tokyo, Japan	N 35° 41′	E 139° 46′	5	3.4	1241	3.49	1273.85
10	Shanghai, China	N 31° 10′	E 121° 28′	5	3.11	1135.2	3.86	1408.9
11	Miami Florida, USA	N 25° 35′	W 80° 02′	5	5.82	2124.3	5.27	1923.55
12	Taipei, Taiwan	N 25° 04′	E 121° 50′	10	2.55	930.75	3.99	1456.35
13	Hong Kong, China	N 22° 17′	E 114° 08′	0	3.07	1120.6	3.91	1427.15
14	[a]Ping Dong, Taiwan	N 22° 00′	E 120° 44′	10	4.37	1595.1	3.99	1456.35
15	Mexico City, Mexico	N 19° 11′	W 99° 05′	2227	4.82	1759.3	5.05	1843.25
16	Thailand, Bangkok	N 13° 32′	E 100° 29′	10	4.58	1671.7	4.81	1755.65
17	[a]San Jose, Costa Rica	N 09° 56′	W 84° 05′	1170	4.35	1587.8	4.91	1792.15
18	Bogotá, Colombia	N 04° 14′	W 73° 29′	2650	2.75	1003.8	4.85	1770.25
19	Kuala Lumpur, Malaysia	N 02° 34′	E 101° 35′	50	3.87	1412.6	4.32	1576.8
20	Quito, Ecuador	N 00° 07′	W 78° 13′	2818	3.08	1124.2	5.06	1846.9

NP: Information not provided by the database.
[a] Locations added to the PVSYS3.41 software.

The results of this comparison show a high rate of similarity between the three different sources, with parallel variations along the year. Compared to the Taiwan National Weather Bureau's database, the most dependable data is the one provided by the NASA Surface Meteorology and Solar Energy database. Besides the months of July and August, these two solar irradiation databases present the same behavior along the year with variations of less than 12% in the annual average. The divergence between the two sources can be attributed to the differences in the calculation methodology.

This comparison process was completed to prove the reliability of NASA's international solar irradiation database compared with actual local experiments. The use of an international solar irradiation database is mandatory in a study like this, since local accurate data obtained from real experiments is not always available. Consequently NASA's international solar irradiation database is used as a reference for the verification of the solar irradiation database provided by the PVSYST 3.41 software.

3.2. Calculations with PVSYST 3.41

Prior to the experiment process, a comparison was made in order to prove the reliability of the solar database provided by PVSYST 3.41 software. The NASA Surface Meteorology and Solar

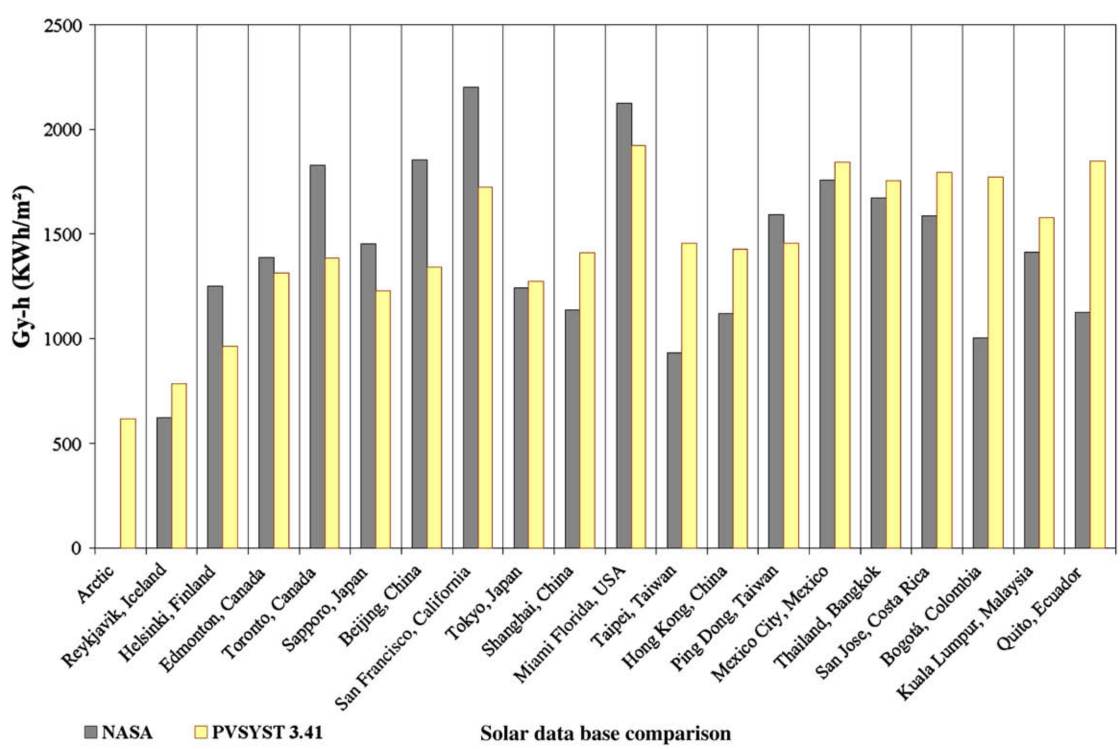

Fig. 3. Solar database comparisons for the 20 international locations.

Table 3
Panel's technology efficiency and costs rates, according to PVSYST 3.41 software.

Panel type	Price per m^2 of panel	Price per kWh
Mono-crystalline	1148 EUR/m^2	0.79 EUR/kWh
Poly-crystalline	1034 EUR/m^2	0.82 EUR/kWh
Thin film	686 EUR/m^2	0.94 EUR/kWh

Energy database was used as a reference for this comparison, because of its previous proven reliability. After this verification process, calculations of system performance for the 20 previously selected cities were used in order to analyze the correlation between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$. During the evaluation of the solar database provided by PYSYST 3.41 the 20 locations selected previously for the experiment were used. Table 2 shows the information provided by the NASA Surface Meteorology and Solar Energy database and by the PVSYST 3.41 software.

The comparison of the solar irradiation data from NASA and from PVSYST 3.41 reveals only scant discrepancies. As can be seen in Fig. 3 and Table 2, only Toronto, Beijing, San Francisco, Taipei, Bogotá and Quito showed noticeable variations between the two data sources. However, even with these variations, the information provided by PVSYST 3.41 is considered by the authors as reliable, since both data sources present a similar pattern of variants along the year. The reasons for the discrepancies between these two databases can be attributed to the different types of methodology applied in their calculation process. The solar irradiation data for the Arctic were not included in the NASA Surface Meteorology and Solar Energy database and, therefore, was not possible to make a comparison with the PVSYST 3.41 solar irradiation data.

3.3. Experimentation using PVSYST 3.41[2]

PVSYST 3.41 software is a practical tool for evaluation and calculation of a PV and BIPV system's performance, and earlier versions of the software has been used to obtain data for BIPV systems with high accuracy rates [20]. Prior to conducting the calculation process the software offers two options according to the detail of the information provided for the system, "Project design" and "Preliminary design". The latter was selected for the calculations in the present study.

For each of the 20 sites, the calculations were made every 10° using the site's latitude angle. The following is a description of the parameters inputted to the PVSYST 3.41 software in order to obtain the system's output electricity in different locations and with different tilted angles.

- Project: preliminary design;
- Area = 1 m^2;
- Module type = standard 180 watts;
- Mounting disposition = façade or tilt roof;
- Orientation = South;
- Technology = Mono-crystalline;
- Ventilation property = ventilated.

These parameters were applied equally for all of the experimentations in order to obtain the same conditions for the calculations. Mono-crystalline panel technology was selected due to its high conversion efficiency (Table 3). Regardless of its relative first high inversion, mono-crystalline panel technology can provide more energy at a lower price per square meter than poly-crystalline or thin film panels [7].

[2] An authorized copy of the software with license was used for these experimentations.

Table 4
Verification of computer simulation data with real condition experiments.

Location	Panel's slope angle	Experimentation P_y (kWH/y)	Experimentation %($P_y\beta_{opt}$y)	PVSYST 3.41 %($P_y\beta_{opt}$y)	Discrepancy (Exp-PVSYST)
Taipei, Taiwan	$\beta = \Phi$ 25	537.1	96.62%	99.30%	2.68%
	β_{opt} 20	555.9			
Ping Dong, Taiwan	$\beta = \Phi$ 22	661.4	98.65%	99.30%	0.65%
	β_{opt} 20	670.5			
Average			97.63%	99.30%	1.67%

3.4. Verification of computer simulation data with real condition experiments

The verification of the data obtained with the computer simulation was made applying real experiment data for the two locations in Taiwan included in the original list of sites, Taipei and Ping Dong. Using previously conducted tests developed by the National Taiwan University of Science and Technology [15] it was possible to calculate the system's performance using $\beta = \Phi$ compared with

Table 5
Output data for a BIPV system using β_{opt}y and using $\beta = \Phi$. Correlations and discrepancies.

City	Site's latitude (Φ)	β_{opt}y	P_y β_{opt}y (kWh/m^2)	$\beta = \Phi$	P_y $\beta = \Phi$ (kWh/m^2)	%P_y (β_{opt}y)	Discrepancy
1 Arctic	N 85° 47′	60°	72	85°	65	90.30%	−9.70%
2 Reykjavik, Iceland	N 64° 15′	40°	88	64°	82	93.20%	−6.80%
3 Helsinki, Finland	N 59° 34′	40°	109	59°	104	95.40%	−4.60%
4 Edmonton, Canada	N 53° 15′	50°	162	53°	161	99.40%	−0.60%
5 Toronto, Canada	N43° 29′	30°	149	43°	147	98.70%	−1.30%
6 Sapporo, Japan	N 43° 03′	30°	131	43°	129	98.50%	−1.50%
7 Beijing, China	N 39° 54′	30°	152	39°	151	99.30%	−0.70%
8 San Francisco, California	N 37° 28′	30°	186	37°	185	99.50%	−0.50%
9 Tokyo, Japan	N 35° 41′	35°	133	35°	133	100.00%	0.00%
10 Shanghai, China	N 31° 10′	20°	143	31°	142	99.30%	−0.70%
11 Miami Florida, USA	N 25° 35′	25°	200	25°	200	100.00%	0.00%
12 Taipei, Taiwan	N 25° 04′	20°	144	25°	143	99.30%	−0.70%
13 Hong Kong, China	N 22° 17′	22°	143	22°	143	100.00%	0.00%
14 Ping Dong, Taiwan	N 22° 00′	20°	143	22°	142	99.30%	−0.70%
15 Mexico City, Mexico	N19° 11′	19°	186	19°	186	100.00%	0.00%
16 Thailand, Bangkok	N 13° 32′	13°	173	13°	173	100.00%	0.00%
17 San Jose, Costa Rica	N 09° 56′	10°	175	9°	175	100.00%	0.00%
18 Bogotá, Colombia	N 04° 14′	4°	171	4°	171	100.00%	0.00%
19 Kuala Lumpur, Malaysia	N 02° 34′	2°	152	2°	152	100.00%	0.00%
20 Quito, Ecuador	N 00° 07′	0°	178	0°	178	100.00%	0.00%
Average						98.61%	−1.39%

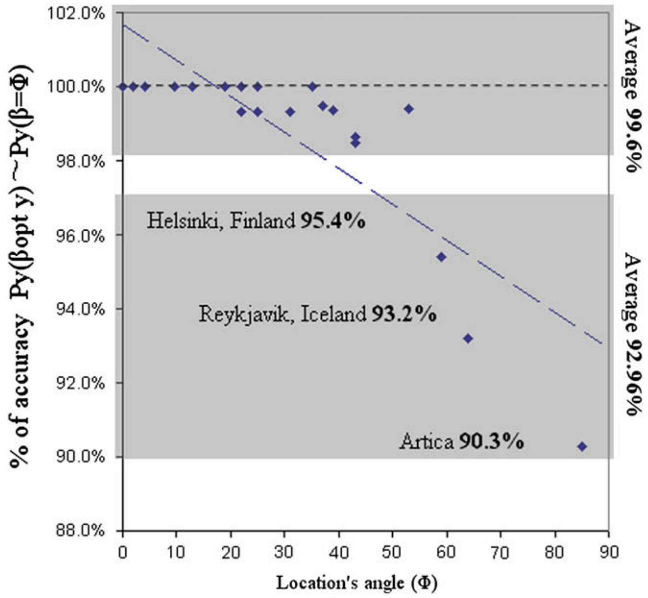

Fig. 4. Correlation of the accuracy between $P_y(\beta_{opt}y) \sim P_y(\beta = \Phi)$ and the site's latitude angle.

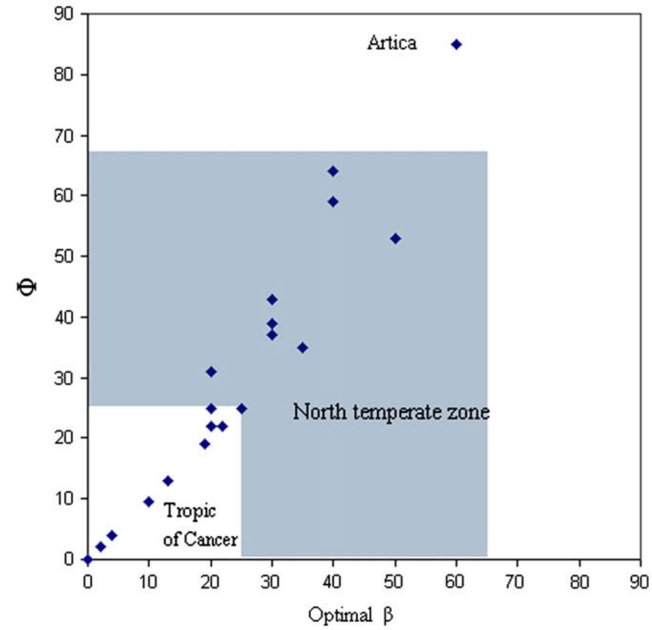

Fig. 5. Correlation between $\beta_{opt}y$ and $\beta = \Phi$.

a system using the optimal inclination angle and their corresponding percentile correlation. In the previous experiments the output data for a BIPV system in six different locations in Taiwan was calculated based on real measurements made for seven different inclination angles (0°, 15°, 30°, 45°, 60°, 75°, 90°), Table 5 includes the calculated system's output P_y (kWH/y) and the percent of output correlation between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$, expressed as $\%(P_y(\beta_{opt}y)$), according to the practical experiment. The discrepancy between this correlation and the correlation obtained with the software PVSYST 3.41 (Discrepancy Exp-PVSYST) is included in Table 4, showing a difference of 2.68% for Taipei and 0.65% for Ping Dong, with an average of 1.67%.

4. Results and discussion

This study used computer simulation data to analyze the correlations between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$ for 20 locations in the Northern Hemisphere and with the same BIPV systems.

The use of the location's latitude angle as the tilted angle ($\beta = \Phi$) for a BIPV system, in the 20 locations discussed in this study revealed that a system can obtain an average of 98.61% of its performance when using the yearly optimal angle (Table 5). From the 20 locations analyzed, in the sites located below the parallel 59 Northern latitude, the similitude of the system's energy output working with $\beta_{opt}y$ and the output of the system working with $\beta = \Phi$ presents an average of 99.61% (Fig. 4). As shown in Fig. 4, for locations above 59° Northern latitude (Arctic; Reykjavik, Iceland; and Helsinki, Finland), the similarities between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$ decrease, with an average of 92.96% compatibility. This suggests a tendency for the discrepancy between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$ to increase as the latitude angle increases, moving from 0%, in the case of Quito, Ecuador, to 9.7% for the Arctic (Table 4). However, this tendency was found to be irregular along the 20 locations; presenting less than 1% of the discrepancy for locations under the 59th parallel (with the exception of Toronto, Canada, which presents a discrepancy of 1.30%, and Sapporo, Japan, with 1.50%). It is only above the 59th parallel that the discrepancy

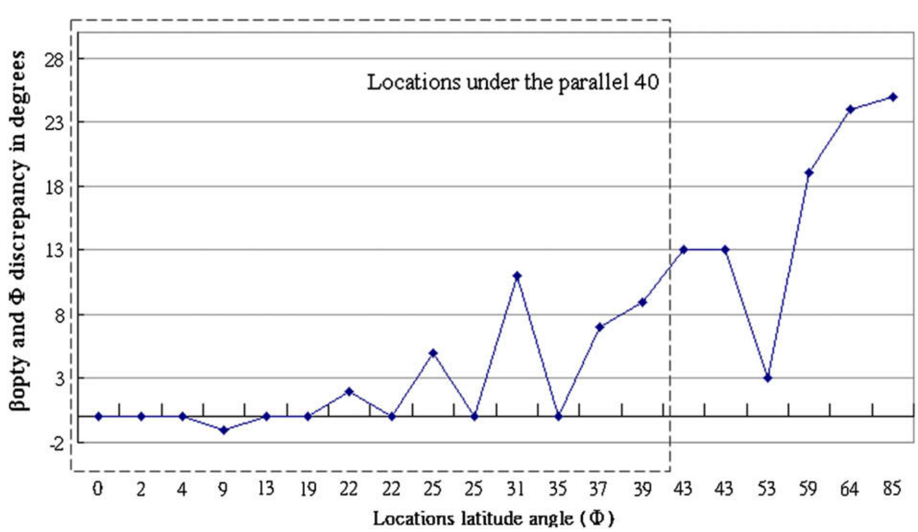

Fig. 6. Discrepancy in degrees between $\beta_{opt}y$ and β.

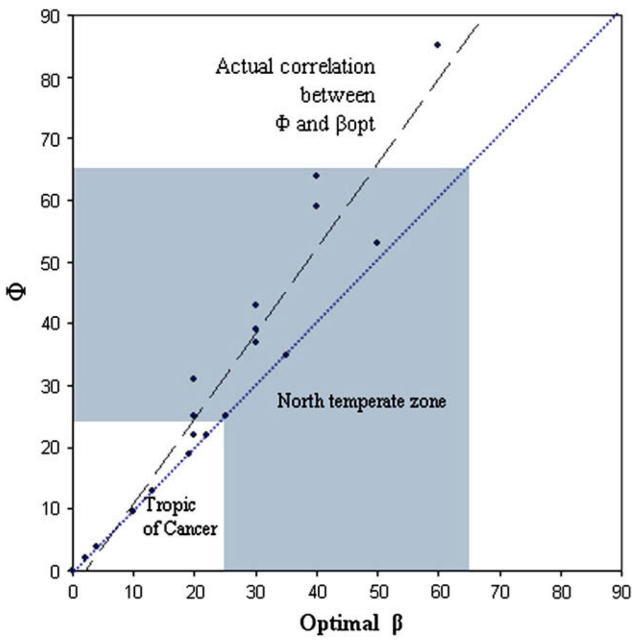

Fig. 7. Theoretical and actual correlation between $\beta = \Phi$ and β_{opt}y.

between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$ reaches more than 4.5%. Table 4 also shows a 100% similarity between $P_y(\beta_{opt}y)$ and $P_y(\beta = \Phi)$ in nine of the 20 sites.

Referring to the correlations between a site's latitude angle (Φ) and the panel's yearly optimal tilted angle (β_{opt}y), in eight of the nine locations that present $P_y(\beta_{opt}y) = P_y(\beta = \Phi)$, the yearly optimal tilted angle and the sites' latitude angle are identical ($\beta_{opt}y = \Phi$). Seven of these eight systems' sites are located along the Tropic of Cancer (Fig. 5), which, together with the Tropic of Capricorn, are known to have the highest levels of global solar irradiation on Earth. Few differences are presented in correlations between β_{opt}y and Φ, with variations of 11° or less for sites from 0° to 40° North latitude (Fig. 6). Therefore, 13 of the locations under the 40th parallel (excluding San Jose, Costa Rica, which presents a correlation of $\beta_{opt}y = \Phi + 1°$) β_{opt}y can be assumed to be $\Phi - [0° \rightarrow 11°]$.

Fig. 7 presents a theoretical correlation between β_{opt}y and Φ, where the yearly optimal tilted angle is equal to the location's latitude angle ($\beta_{opt}y = \Phi$). This hypothetical association was made in order to compare its tendency line with the actual tendency line of the correlation between β_{opt}y and Φ according to the results obtained in this study. As shown in Fig. 7, the two tendency lines remain close for sites located along the Tropic of Cancer, and increase their separation as the latitude angle increases.

5. Conclusions

The calculation process of the optimal tilted angle plays a pivotal role in the designing of a successful BIPV system. Designers who are aware of the correlation between β_{opt}y and Φ can assume a highly efficient titled angle for PV panels without having to conduct additional calculations and only by knowing the site's latitude angle. The purpose of the validation of this theory, as presented in this study, is to reduce calculations for optimal tilted angles and to demonstrate the reliability of a system using $\beta = \Phi$.

The correlation between β_{opt}y and $\beta = \Phi$ and the reliability of a system using $\beta = \Phi$ was demonstrated to indicate that more than 98.5% of a system's performance with the optimal angle can be achieved using the latitude angle as a reference for the tilted panel in sites located in the Northern Hemisphere. In addition, a validation of the correlation with real measurements was completed with a discrepancy factor of 1.67% in comparison with the data obtained from the computer simulation.

While this study shed much needed light on the correlations between β_{opt} and Φ, we believe that this is a topic worthy of future research and exploration. Future investigations, for example, could conduct experiments outdoors in real conditions for more sites located at different latitude angles. Although this type of experimentation would require considerable resources and much time to obtain the necessary data, the information obtained could be compared with the data provided by computer simulations to improve the reliability of software tools and the accuracy of BIPV systems working with $\beta = \Phi$.

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