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# Development of Novel Building-Integrated Photovoltaic (BIPV) System in Building Architectural Envelope

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/60574>

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## 1. Introduction

The saving and usage of green energy have been an emphasized research topic in various nations including Taiwan: an island nation located in a subtropical zone with 90% of the population living in regions with mean sea-level elevations of 400 m or lower. Limitations of some geological factors and climatic conditions cause a large population to be crowded in buildings that are concentrated in metropolitan areas.

Hence, large buildings cover by a glass shell which must rely heavily on artificial central air conditioning systems to resist outside heat loadings had become popular. Such a building takes a heavy toll on energy consumption. These buildings experience the problems of poor indoor air circulation, an inefficient cooling system in maintaining a comfortable indoor environment, as well as excessive energy consumption. Ninety-eight percent the energy consumed in Taiwan is imported.

Recent worldwide concerns on global warming and emphases on environmental protection have made it urgently necessary to develop sustainable energy sources for replacing conventional petroleum energy. Solar energy [1–4] is renewable, inexhaustible and abundant. The Earth receives an incredible supply of solar energy. It provides enough energy in one minute to supply the world's energy needs for one year [5]. Hence how to effectively use solar energy is becoming an active research topic in various nations today.

Solar energy can be utilized as either heat or light, with the majority of the research and application focusing on photoelectrical conversion of light into electricity. Using solar cells made of special materials of semi-conductance, the incident solar beam can be directly converted into electricity. The efficiency of electricity generation depends on the clarity of the solar panel. Additionally, storage of the electricity generated for later use must be considered.

In recent years, the booming semi-conductor industry had led to rapid advances in manufacturing and implementing solar energy projects more cost effectively. Hence, solar energy is expected to be an important and a major source of energy in the future.

In Taiwan, central air conditioning systems are used in large buildings that accommodate offices, hotels, department stores and hospitals. These buildings, which are considered as “air-conditioned buildings”, have fixed office hours, similar occupants and application modes, and hence comparable heat generated from illumination and occupants. Additionally, these buildings adopt a glass shell to shield the structure so that natural lighting is available during daytime for saving electricity.

The expected benefits of using solar panels on buildings include lowering building costs, reducing energy consumption, and providing a more comfortable indoor environment. The greenhouse effectiveness in glass buildings is also applied in cold zones for saving heating energy. Additionally, large glass windows also provide excellent views for occupants to assist in improving their moods and work efficiency. Hence, in recent years, buildings covered in glass panels are becoming popular in the US and some European nations. Influenced by the global trend, the architecture in Taiwan has adopted this type of buildings. However, when irradiated under direct sunlight, this type of building is considered to be badly insulated, so that a huge quantity of energy is needed to provide adequate air conditioning for resisting the outdoor heat loadings.

More intensive solar radiation causes either higher indoor temperatures, heavier loading on the air-conditioning unit, or higher consumption of electric energy. If solar energy is available, more intensive solar rationing means that more electricity can be generated. Hence, if the building is covered with solar panels instead of glass windows, the incoming solar radiation can be intercepted for generating electricity that will provide building cooling in addition to reducing the indoor air temperature caused by direct sunshine. The excess electricity can be sold back to the power company to offset the peak loading period. Hence, in this research, the energy audit for the buildings covered with glass panels and cooled with central air conditioners will be carried out for developing three types of “integrated solar panel” systems.

In this research, the results of analysing indigenous climates and examining building materials are used to propose the replacement of conventional glass plate by solar photoelectric panels to be an integrated part of the building shell proposed as the BIPV (Building-Integrated Photovoltaic) system in building architecture. Results of laboratory studies proved that in addition to providing electrical energy to the building, the BIPV building shell is also effective in thermally shielding and isolating the building.

The BIPV system proposed in this research will greatly alleviate the electricity burden during peak hours; its application will promote the development of sustainable energy sources. Comparisons of these solar panels to be used on buildings will be conducted based on their material, angle, temperature, and panel clarity. The results will be used to access the actual cost-effectiveness of installing and using these solar panels on existing buildings.

## 2. Development of integrated sunshading board and Building-Integrated Photovoltaic (BIPV)

Previous research results published in literature [6–8] shows that if based on the total CO<sub>2</sub> emission from a building with 50-year life cycle, about 80% of CO<sub>2</sub> emission is caused by the air conditioning. The energy saving regulations enforced in Taiwan stipulated that the building shell energy consumption index be used for designing an energy-saving building. In other words, the annual thermal loadings is the thermal loading for providing air conditioning to maintain a healthy and comfortable room; the loading is based on the outdoor thermal environment adjacent to windows, walls, and wall openings.

The thermal flow caused by “difference between outdoor and indoor temperatures” and “solar radiation” is the major factor causing air conditioning energy loadings. Hence, the technology of insulating the building and shading the solar radiation is an important factor for designing the energy-saving features of a building. The effectiveness of solar panels is affected by environmental factors such as solar illumination and temperature, among many others, which affect the voltage and current of the electricity produced, causing unusual movement of Fly-back Converters.

A solar panel combined with a shading board is proposed in this research to increase the building shading effect so that the cost-effectiveness of the solar panel can be augmented. A current convertor to convert the produced DC (direct current) into AC (alternate current) and electricity storage to overcome the inherited problem of unstable energy source for solar panels are also integrated into the BIPV building in order to raise the cost-effectiveness of the proposed system.

### 2.1. Design of external shading

Taiwan is located in subtropical region; research results indicate that the major factors affecting the air conditioning energy consumption for buildings in the hot and humid environment are the “percentage of window opening” and “window shielding factor” About 62–85% of the building’s air conditioning energy is affected by these two factors whereas only 10–15% depends on the orientation of the building in question. Among these factors, the “opening percentage” is the most influential factor; buildings with higher opening percentage will waste more energy on air conditioning.

Regardless of the type of glass used for windows, a 1% increase of the glass window area will cause the energy consumption to rise by 1.0%. In contrast, the “window shielding factor” will save energy consumed for air conditioning in addition to preventing reflective light to ensure good natural lighting and views. The studies in this research were conducted in South Taiwan. Based on local climatic and geographic conditions, and incident angle of solar radiation, the outside window shielding system will be designed as blinds with 1:4 horizontal to vertical ratio (the horizontal shielding depth is 60 cm for a 240 cm French window) to evaluate its thermal insulating efficient.

## 2.2. Solar photoelectrical system

The integrated system consists of several modules: including the solar electricity-generating module, an integrated parallel connection module to connect to the municipal power system, an emergency power supply module to convert direct and alternate currents, and a battery module to store excess energy produced during the daytime.

### 2.2.1. Solar photoelectrical system

The basic principle of solar electricity generation is to convert solar light with wavelengths between 0.7 to 0.9 micrometer irradiating on a semiconductor. Inside the semiconductor, negatively charged electron and positively charged electron holes will be generated and accumulated at the P-type and N-type layer regions, respectively, thus producing an electromotive difference depending on their unique characteristics. If connected to an external loading, the semiconductor cell produces electricity that can be used for a variety application in the building

### 2.2.2. Integrated parallel connection to municipal power system and exchanger to provide emergency direct and alternate electric currents

The electricity produced by solar panels and batteries is direct current (DC) whereas the general appliances use alternate current (AC). Hence, the solar generated DC must be converted into AC with an electric converter so that the electric energy can be widely supplied to household appliances. Additionally, solar electricity generation depends on the solar intensity and angle that the output electrical current and voltage are unstable. If used as an independent electric source, the energy system lacks stability and will not provide a reliable source of energy. Hence, a converter must be used to change the pattern of electricity; in addition to converting the solar generated DC into AC, the solar electricity generation module will be connected to municipal power system to maintain a steady supply of electricity. When the solar energy becomes insufficient, the municipal power system will kick in to provide the needed electricity. If the solar energy is greater than the loading, the excess electricity can be sent back to other consumers through the municipal power system. This arrangement will greatly elevate the stability of solar energy generation system to fully extend its cost-effectiveness.

### 2.2.3. Battery module

When the electric system is operated steadily, changes in the solar electricity generated and the system operation in response to variations of external conditions will be compensated by using the battery module. If the solar system produces more electricity than is needed, the excess electricity will charge the battery model, or it will be sent back to the municipal power system.

When the solar electricity is insufficient (such as at night) to meet the building's demands, the electricity stored in the battery module will supply the needed power before obtaining power from the municipal system. Thus, the battery module will allow the solar system to be flexible

in response to various conditions. Additionally, when the solar power system malfunctions, or the electrical voltage becomes 10% higher or 15% lower than the normal level, the battery can temporarily kick in to make the adjustment so that the solar power system combined with the battery module will depend less on the municipal system to provide steady electricity to meet the loadings.

### 2.3. Integrated Photovoltaic (BIPV)

The integrated photoelectrical solar panels used in this experiment have 30kW capacity consisting of 8.58kW, 8.82kW, and 12.6kW panels. Figure 1 shows the system (System I) equipped with multiple crystal silica arrays.

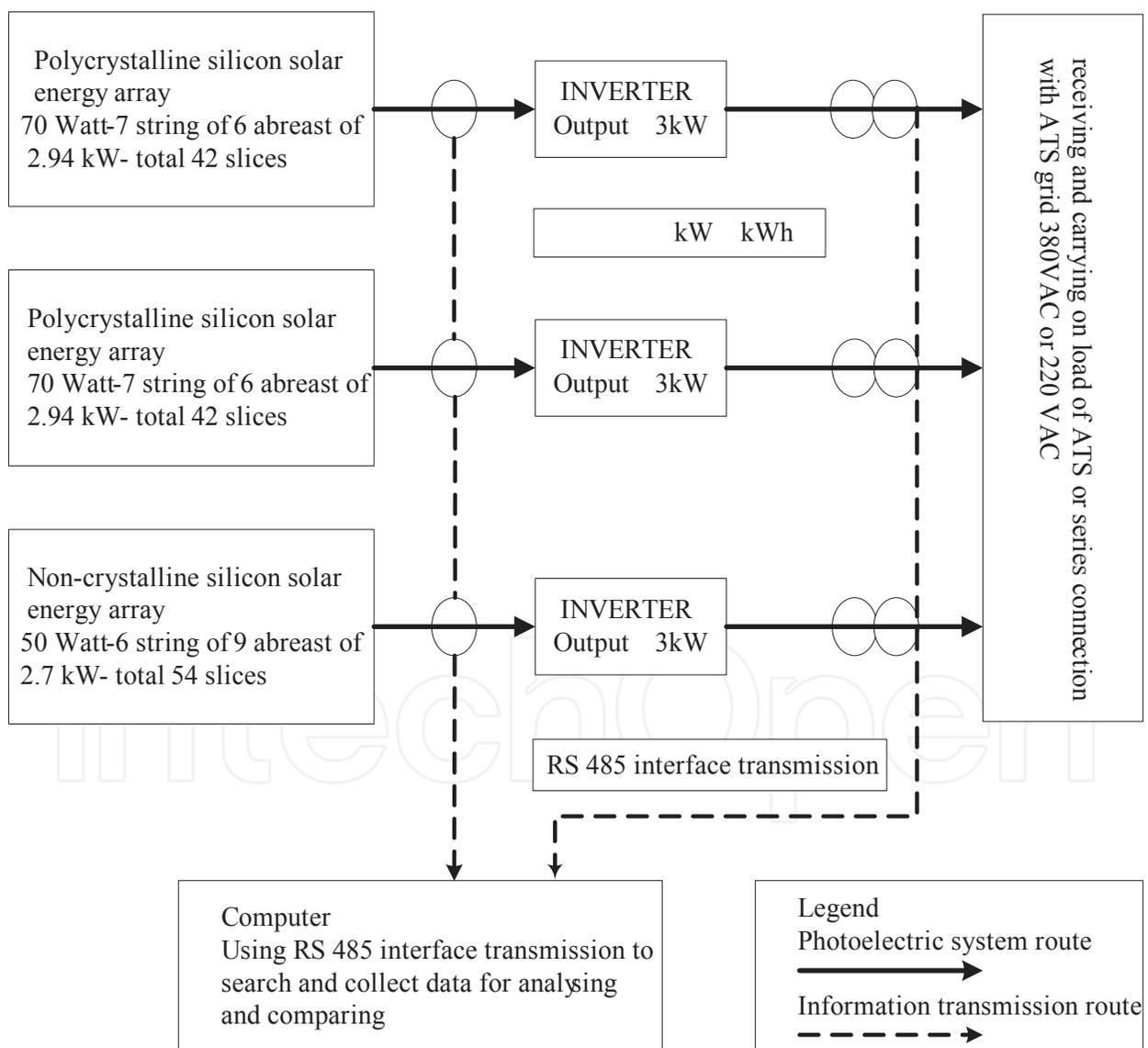


Figure 1. Integrated photoelectrical solar panel System I of 8.58kW

Figure 2 shows the system (System II) equipped with multiple silica and single silica solar energy photoelectrical panels.

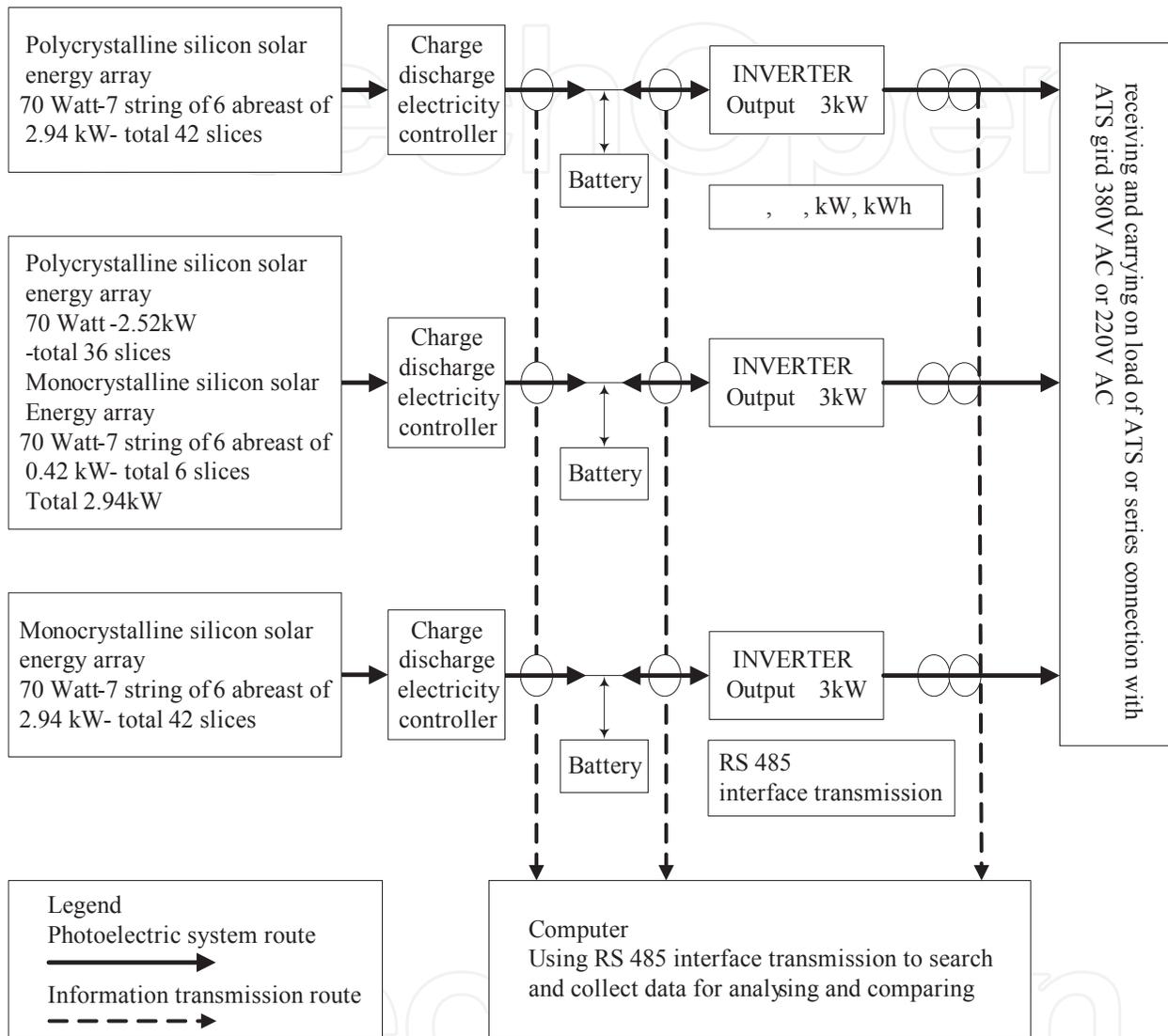


Figure 2. Integrated photoelectrical solar panel System II of 8.82kW

Figure 3 shows the system (System III) with single silica solar photoelectrical panels only installed.

In each system, the panel faces south, and is 25° inclined that can be manually adjusted 10° up and down. These systems were used to investigate the influence of solar panel material, angle of inclination, ambient temperature and panel clarity on the effectiveness of solar energy generation.

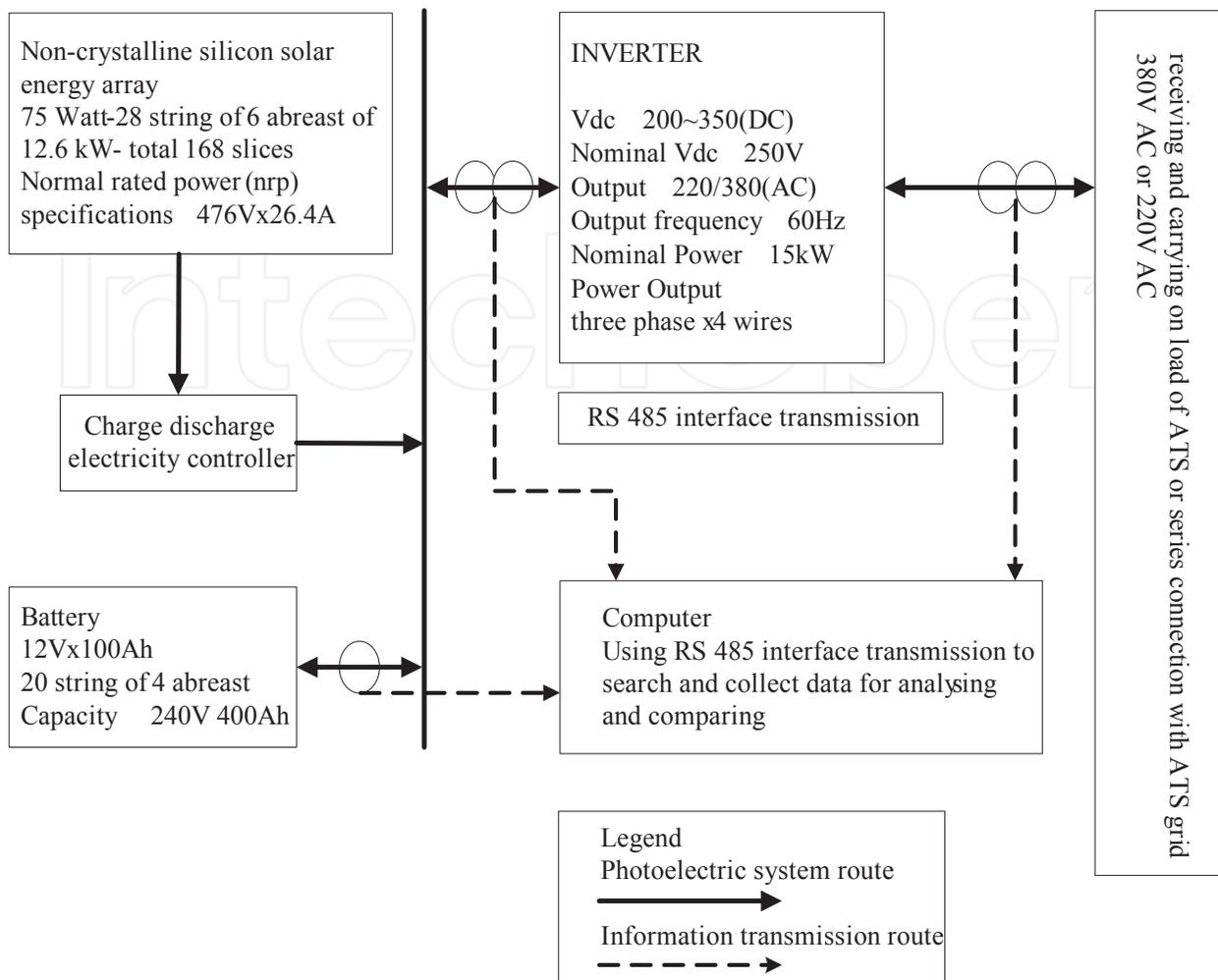


Figure 3. Integrated photoelectrical solar panel System III of 12.6kW

### 3. Installation of experimentalequipment

The integrated solar energy panel proposed in this research consists of shielding and solar panels. Initially, the experimental room is only equipped with the proposed shielding panels for comparing variations of the room temperature, humidity, and energy consumption of air conditioning before and after installing the shield panels. Solar energy panels are then installed for studying the performance and efficiency of solar photocells made of different materials under various environmental conditions, comparing the effectiveness of solar photoelectrical systems equipped with or without the battery module, analysing the various methods to connect the current converters, studying the influence of solar panel installation angles on the efficiency under direct sunshine or solar radiation.

The experimental site is located in Tainan City, Taiwan; the experimental installations are shown in Figures 4 and 5. The solar panel system is mounted on an existing building in order to evaluate on-site the system's efficiency under natural solar illumination conditions. The evaluation is also carried out using a system facing east, south, and west so that annual performance and efficiency of the solar system proposed in this research can be assessed.



**Figure 4.** Final Photo of experimental installations in test filed



**Figure 5.** Final Photo of experimental installations with Integrated Photovoltaic and Sunshading Board

## **4. Results and discussions**

### **4.1. Advantages of sunshading board for energy-saving of building**

Temperature differences of the experimental building before and after installing sunshading board and then the solar panel were recorded. The actual effectiveness of shading board

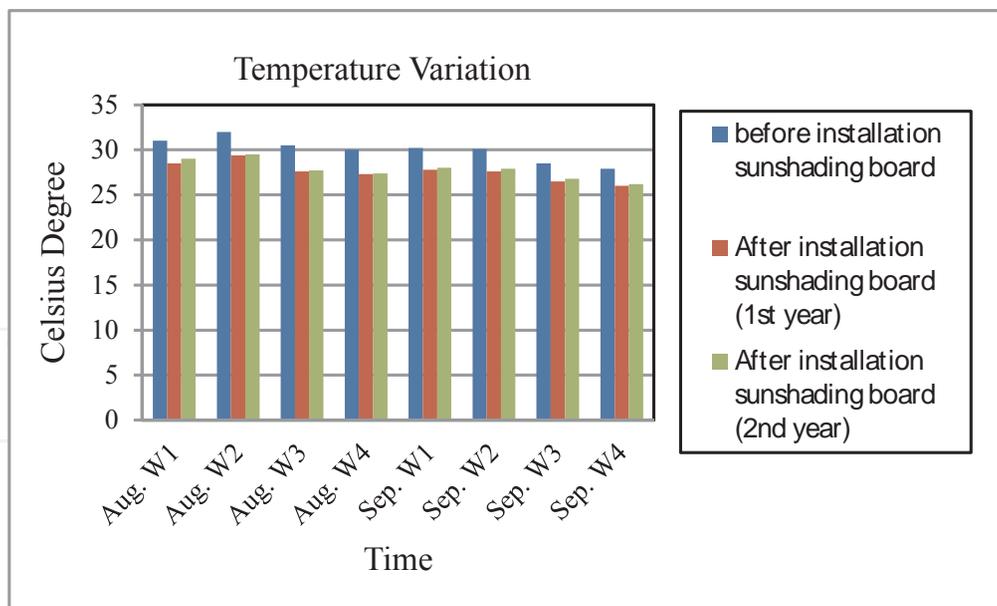
was evaluated by comparing the indoor room temperature and the shaded spot temperature with the outside temperature in order to monitor the savings on air conditioning energy consumption.

The temperature monitoring programme started one year before the installation of shading boards and lasted for three years; the results obtained during the hottest August and September were used for evaluating the cooling effectiveness. The temperature sensors were installed on the balcony of the building so that the temperature measurement was not affected by direct sunshine or precipitation.

Energy consumption for cooling was recorded with three digital wattmeters from 8:00 am till 5:00 pm. The daily energy consumption was accumulated to yield the monthly consumption, and the following formula was used to estimate the energy savings:

$$\text{Percent of Energy Savings} = \frac{\text{Reduction of Watts}}{\text{Yearly Watts}} \% \quad (1)$$

The on-site experimental results obtained with three experimental rooms are shown in Figure 6. The room equipped with a shading board shows lower temperature of 2.6°C to 2.7 °C in August and 1.8° C to 2.1 °C in September.



**Figure 6.** The temperature variation of various test rooms before and after they were equipped with a shading board

Figure 7 shows the analyses on energy consumption in August and September for the three rooms. Savings on air conditioning energy air consumptions for the two-year study period were 9.17% to 31.95% in August and 18.30% to 29.05% in September.

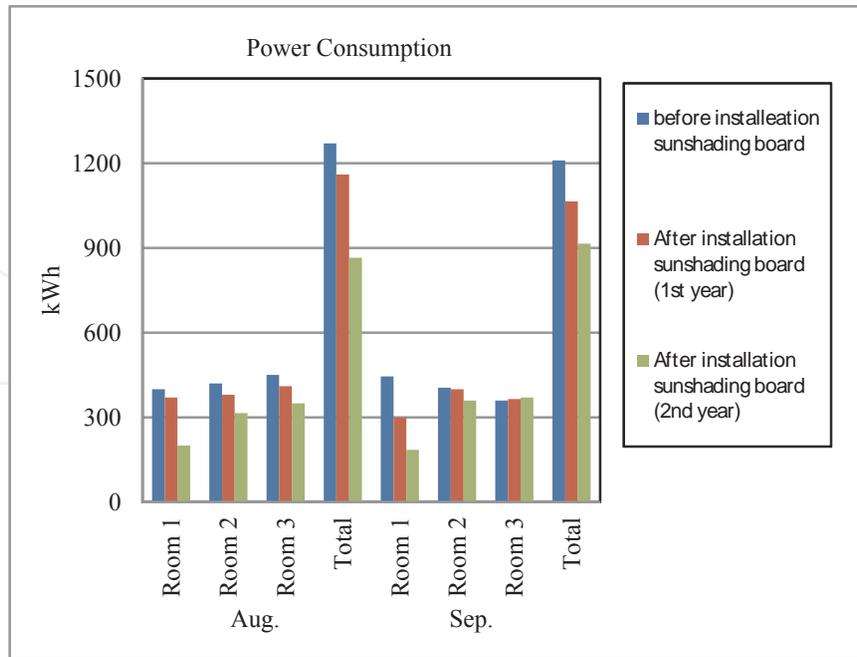


Figure 7. The power consumption in August and September for the three rooms before and after they were equipped with a shading board

#### 4.2. Energy efficiency for solar panels installed at various angles

The efficiency of solar panels installed at various angles – 15°, 25° and 30°, – was carried out using the polycrystalline silicon and monocrystalline silicon panels in Systems I and III. These panels have different output rated values, so that the results are normalized by dividing the data by the output rated value of individual solar panels. As shown by the results in Figure 8, the solar panel with a 25° inclination has better energy output efficiencies than those 15° and 30° inclinations. Additionally, the performance of monocrystalline silicon panel is not significantly influenced by the angle of installation.

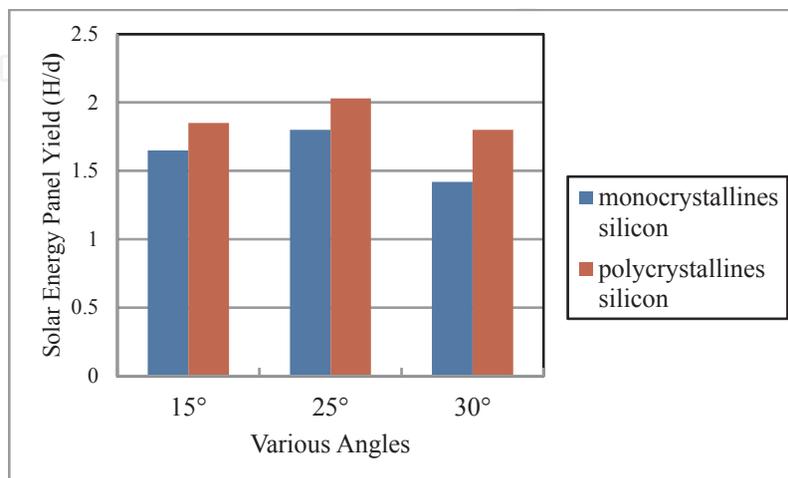
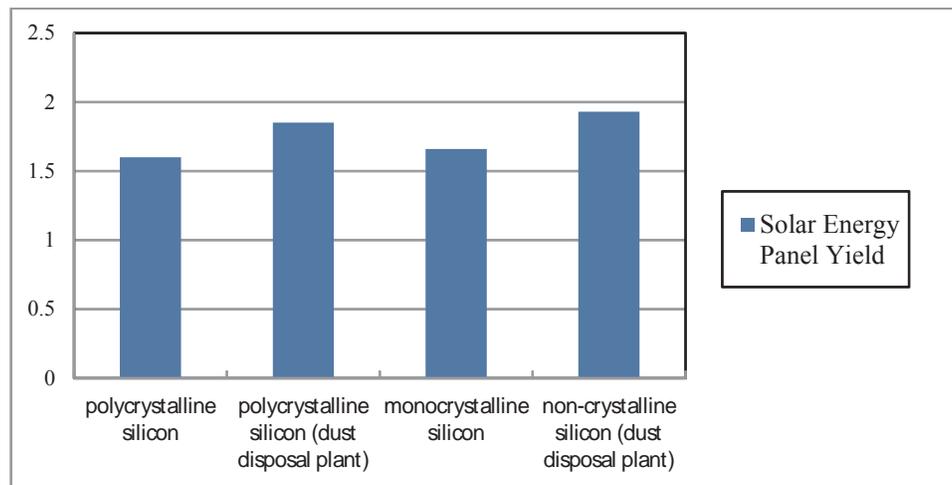


Figure 8. The comparison of the rated output efficiency of polycrystalline silicon and monocrystalline silicon panels

### 4.3. Solar panel surface clarity and energy efficiency

Improving the solar panel energy efficiency by cleaning the solar panel was undertaken to study the energy output efficiency for the non-crystalline, monocrystalline, and polycrystalline solar panel with and without the emulated rainfall. The weather in Taiwan is rather humid; the dust in the air is thus easily moistened, adhered to and accumulated on the solar panel's surface to interfere with the solar panel's energy efficiency. On-site observations reveals that raindrops were somewhat effective in cleaning the solar panel surface. Hence, a water spraying system was installed above the solar panel and operated once every week to study the effectiveness of cleaning by rainwater. The results are shown in Figure 9.



**Figure 9.** The comparison of the energy output efficiency for the non-crystalline, monocrystalline, and polycrystalline solar panel

Without the water spray cleaning system, the polycrystalline solar panel produces 3.7% more energy than the monocrystalline solar panel. Providing the water spray cleaning system, however, causes the solar panels to produce more energy: 17.72% for the polycrystalline solar panel, and 5.38% for the non-crystalline solar panel.

A BIPV building will lower the indoor temperature by 1.8-2.7 °C during summer to save 9.17% to 31.95% of energy in cooling the building. The solar panel used in the BIPV building is made of monocrystalline silicon with a 25° inclination oriented westerly in order to obtain the maximum energy generating efficiency. The variation of ambient temperature may cause the electricity generation to vary by 0.07–4.5%; clear ambient air will assist in elevating the power generation by 3.7% to 29%. The overall experimental results revealed that the order of improved energy efficiency using water spray cleaning is monocrystalline solar panel, non-crystalline solar panel, then polycrystalline solar panel.

The energy output for solar panels before and after cleaning at various ambient temperatures are listed in Tables 1 and 2. The results in each table indicated that the clarity of solar panels affects the efficiency of solar panels made of different materials; dirty solar panels will lower the efficiency of producing electricity by 3.7% (Table 1) to 29.29% (Table 2).

Item System	Generated power output (kW)					
	Before cleaning (44 °C)	During cleaning	After cleaning		Clear degree (%)	Real temperature variation (%)
			Earlier stage (30 °C)	Later stage (44 °C)		
Polycrystalline silicon	1.31	1.59	1.64	1.48	12.98	1.44
Non-crystalline silicon	1.08	1.13	1.09	1.12	3.70	0.07

**Table 1.** Solar panel energy output for panel before and after cleaning.

Item System	Generated power output (kW)					
	Before cleaning (38 °C)	During cleaning	After cleaning		Clear degree (%)	Real temperature variation (%)
			Earlier stage (34 °C)	Later stage (38 °C)		
Polycrystalline silicon	1.40	1.63	1.71	1.81	29.29	4.53
Non-crystalline silicon	1.20	1.21	1.29	1.29	7.17	1.74

**Table 2.** Solar panel surface clarify and temperature before and after cleaning.

Hence, maintaining a clear solar panel surface by washing with natural raindrops or artificial water spraying system will assist in promoting the energy efficiency of the solar panel. The cleaning will lower the surface temperature of solar panels; but the temperature variation caused by cleaning the solar panel will result in decreasing energy efficiency slightly of only 0.07% (Table 1) to 4.53% (Table 2).

## 5. Conclusions

Various factors such as the solar panel's material, inclination angle, natural cleaning by rainwater and climatic conditions, among many others, may affect the solar panel's energy efficiency. Additionally, how the solar panel can be integrated with the shell of a building so that the combination will become a reliable source for cheap energy to provide air conditioning for the building is also the ultimate goal of this research.

The research results confirm that installing solar heat shading boards will lower the indoor temperature by 1.8°C to 2.7°C, save about 9.17% to 31.95% of energy consumption. As far as

the solar panel's material is concerned, the monocrystalline panel is better than non-crystalline solar panel, which is better than polycrystalline panel. The order of magnitude for the panel installing angles is  $25^{\circ} > 20^{\circ} > 30^{\circ}$  with west-orientation being the most favorable for energy production, followed by south-orientation and east-orientation.

Maintaining a clean solar panel surface by washing will reduce the panel surface temperature to lower the energy output by 0.07% to 4.57%; however, this action will improve the energy output by 3.7% to 29%. In summary, installing the shading board will reduce the energy consumption for air conditioning. Raising the energy efficiency of solar panels, and developing new solar panel technology and implementation methods will effectively alleviate the peak power demand, improve the balance of power consumption, and promote the development and reuse of renewable energy sources.

## Acknowledgements

This work was partially supported by CPAMI of R.O.C. The authors wish to thank Professor Chen Jiann-Fuh from NCKU for many helpful suggestions during the course of this work.

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