Electrical and Mechanical Services Department

The Government of the Hong Kong Special Administrative Region

Agreement No. CE 36/2000

Study on the Potential Applications of Renewable Energy in Hong Kong

Stage 2 – BIPV Demonstration Project
Executive Summary (Final)

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consulting • engineering • construction • operations

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1 INTRODUCTION

1.1 BACKGROUND

CDM International, Inc. has been commissioned by the Electrical and Mechanical Services Department of the Government of Hong Kong Special Administrative Region to conduct this *Study on the Potential Applications of Renewable Energy in Hong Kong (*hereinafter referred to as the Study*)*.

The Study is structured into two stages, consisting of:

Stage 1

- ❑ Review the latest developments in renewable energy technologies world wide through a literature search and desktop study;
- ❑ Examine the potential for wide-scale adoptions of suitable renewable energy technologies in Hong Kong in the short and long term;
- ❑ Assess the feasibility and potential for wider application of new and renewable energy technologies as alternative forms of energy sources in Hong Kong; and
- ❑ Devise a strategy for implementation.

Stage 2

- ❑ Conduct a pilot project to demonstrate the applicability of Building Integrated Photovoltaic (BIPV) system.

1.2 OBJECTIVES OF STAGE 2 – BIPV DEMONSTRATION PROJECT

The Stage 2 – BIPV demonstration project is a grid-connected PV system in Hong Kong. Its primary objectives are:

- To gain experience with the operation and maintenance of a BIPV system under typical local conditions,
- To demonstrate the applicability of BIPV system to the general public the potential adoption of photovoltaic (PV) technologies as an integral part of building design and construction;
- To design suitable PV power systems integrating into an existing electricity supply system of a government building ;
- To design a electrical system allowing the BIPV system operating in parallel with the utility supply serving the building;
- To gain hands-on experience through the design and installation of the PV systems and associated electrical systems; and
- To monitor and analyse system performance over a 12-month period.

The findings of the analysis of the system performance over the monitoring period between 1 April 2003 and 31 March 2004 are summarised in the Stage 2 report. This Executive

Summary presents the key findings of Stage 2 – BIPV demonstration project. Separate reports have been prepared for the Stage 1 of the Study.

2 PROJECT DESCRIPTIONS

2.1 LOCATION OF INSTALLATION

The BIPV system is installed in the Wanchai Tower at 12 Harbour Road, Wanchai. The building is a 24-storey government office building and accommodates several government departments, as well as a coffee shop on the ground floor. The latitude and longitude values of the building are 22°16′50″N and 114°10′30″E respectively, and the south facing façade orientation is about 5° off south towards the east.

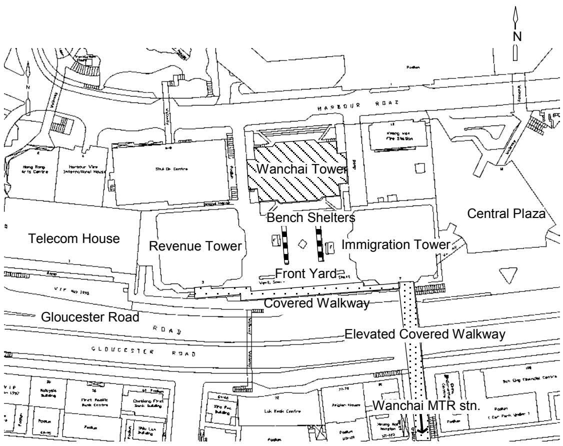

Figure 2-1: Location of Wanchai Tower

2.2 SYSTEM DETAILS

The system comprises three PV power systems including:

- Rack type PV system on the top roof (see **Figure 2-2**);
- Sunshade Screen type PV system on the south-facing façade from the 1st to 12th floor (see **Figure 2-3**); and
- Skylight type PV system at the south-facing glass entrance on the ground floor (see **Figure 2-4**).

Figure 2-2: Rack Type PV System

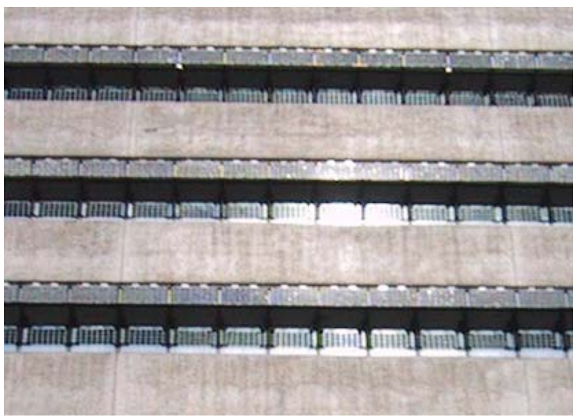

Figure 2-3: Sunshade Screen Type PV System

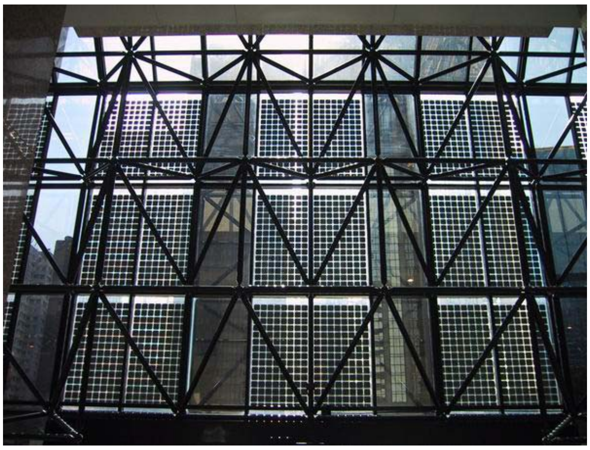

Figure 2-4: Skylight Type PV Modules

The total PV array area is about 493 m² with total installed capacity of 56 kW. The details of the BIPV system are summarised in **Table 2-1**.

Table 2-1: BIPV System Details

	Rack Type	Sunshade Screen Type	Skylight Type
Rated DC Peak Power	20.16 kW	25.80 kW	10.08 kW
PV Array Area	164.70 m²	231.84 m²	95.98 m²
PV module	252 × 80W module	336 × 76.8W module	35 × 288W module
Cell Type	Polycrystalline	Monocrystalline	Monocrystalline
Connection of PV modules	⑨ 2 arrays ⑨ Each array has 7 strings connected in parallel ⑨ Each string has 17 modules connected in series	⑨ 2 arrays ⑨ Each array has 8 strings connected in parallel ⑨ Each string has 21 modules connected in series	⑨ 1 array ⑨ Each array has 7 strings connected in parallel ⑨ Each string has 5 modules connected in series
Array Orientation	Tilted 10° towards South	Vertical and facing South	Vertical and facing South
Features	Mounted on the rooftop for electricity generation	Served as a functional architectural feature: ⑨ to generate electricity ⑨ to reduce solar heat gain through windows	Served as an integral part of the south facing glass entrance: ⑨ to generate electricity ⑨ to reduce solar heat gain through skylight
Power Conditioning Unit	2×10 kW	2×10 kW	1×10 kW

PV modules are connected in series to form strings and the outputs are connected directly to the power conditioning units (PCU) for converting into alternating current (AC) outputs. The strings are of nominal output of 300V direct current (DC) to match with the voltage rating of the PCUs and interconnections of strings are made via DC junction boxes. In the DC junction boxes, there are isolation switches, over-current and over-voltage protection devices and bypass diodes which are used to prevent the modules from damage caused by reverse voltage under shaded condition, in addition to interconnection terminals.

2.3 GRID-CONNECTION

The power generated by the three grid-connected BIPV systems is consumed at the time of generation and hence there is no battery storage required for the project. Instead the PCUs are needed to convert DC current generated by PV cells into AC current so that the energy can be consumed by the power equipment in the building. As all the generated energy will pass through the PCUs, it is important to have the PCUs working at high conversion efficiency. In this project, PCUs are specified to have a conversion efficiency of more than 91% at rated power output.

For this demonstration project, the PCUs' AC outputs are 3-phase 50 Hz at 380V compatible to the requirement of the Hongkong Electric Co., Ltd. (HEC) for power quality are fed directly to existing distribution boards in Wanchai Tower (see **Figure 2-5**). As the AC output of the PCU is connected in parallel with the utility grid, each PCU must comprise automatic protection features to prevent the PV power system, the building electrical systems, and the utility grid connection from any possible damages including fault conditions and variations in voltage or frequency. An isolation transformer has also been provided to prevent damages from DC current injection. All these features comply with *IEC 61727: Photovoltaic (PV) systems – Characteristics of the utility interface* and *Engineering Recommendations developed by the Electricity Association (UK)* and were demonstrated to HEC before connection to the grid.

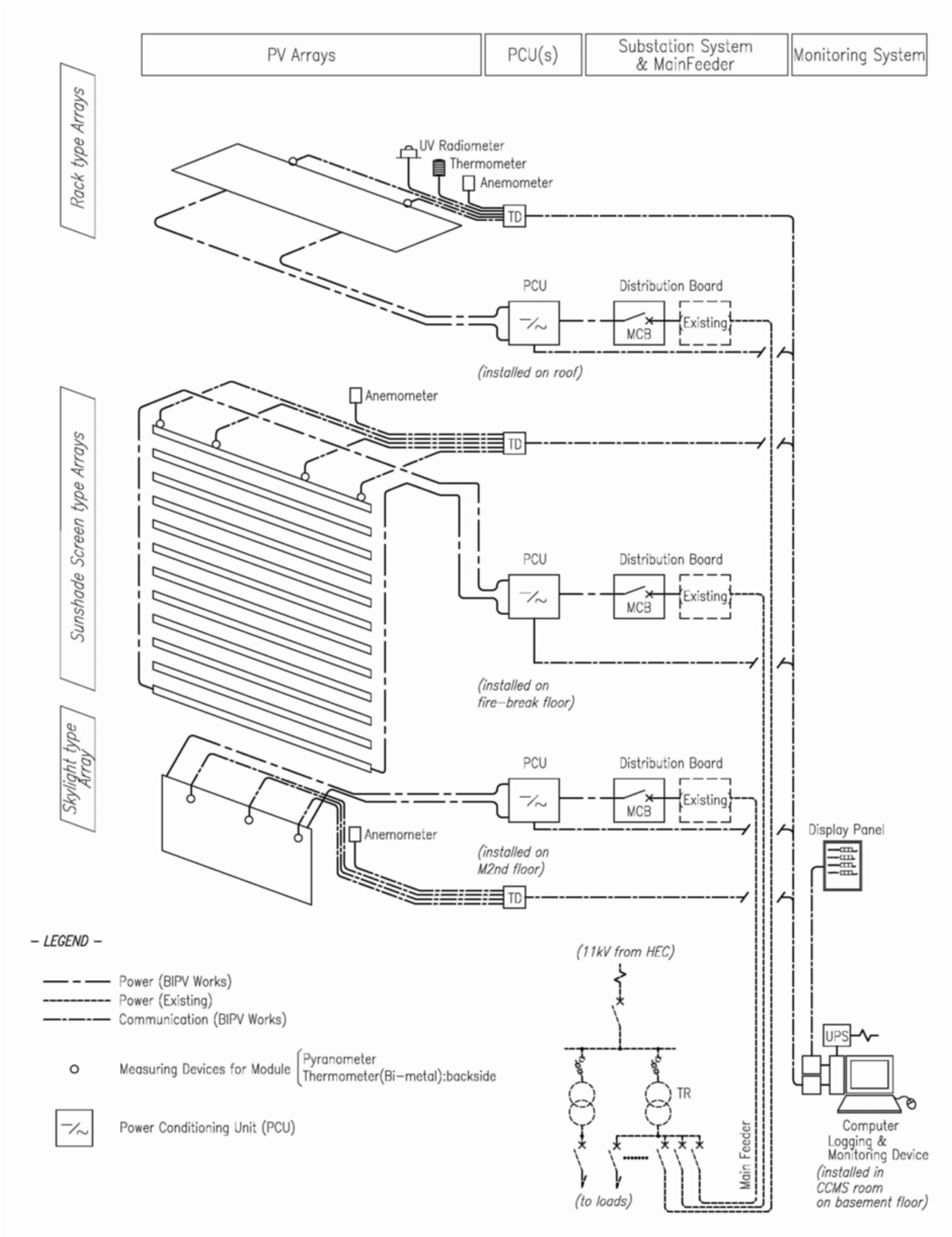

Figure 2-5: System Diagram

3 OPERATING EXPERIENCE

The BIPV system has been operating since January 2003 and the 12-month monitoring period started from April 2003 to March 2004. All three PV power systems showed excellent reliability without any component failures and grid connection problems during monitoring period. Over the 12-month monitoring period, the BIPV system generated over 21,900 kWh which was consumed directly within the building.

3.1 BIPV SYSTEM PERFORMANCE

Performance monitoring of the BIPV system was conducted in accordance with the International Standard, *IEC 61724: Photovoltaic System Performance Monitoring – Guidelines for Measurement, data exchange and analysis*. A monitoring system has been installed to collect performance data including ambient temperature, PV panel temperature, sun irradiation, DC outputs from the PV arrays and AC outputs from the PCUs. The system is controlled by a dedicated personal computer which is also used to log the data collected from the sensors. A summary of monthly values for several key performance indicators is provided as follows.

3.1.1 Solar Irradiation

The electrical output of the BIPV system is directly proportional to the solar irradiation. To evaluate the performance of the PV systems, a set of pyranometers has been installed to measure the in-plane irradiation on the PV arrays. Measurement results of total monthly irradiation on plane tilted at 10° (Rack) and vertical plane (Sunshade Screen and Skylight) are shown in **Figure 3-1**.

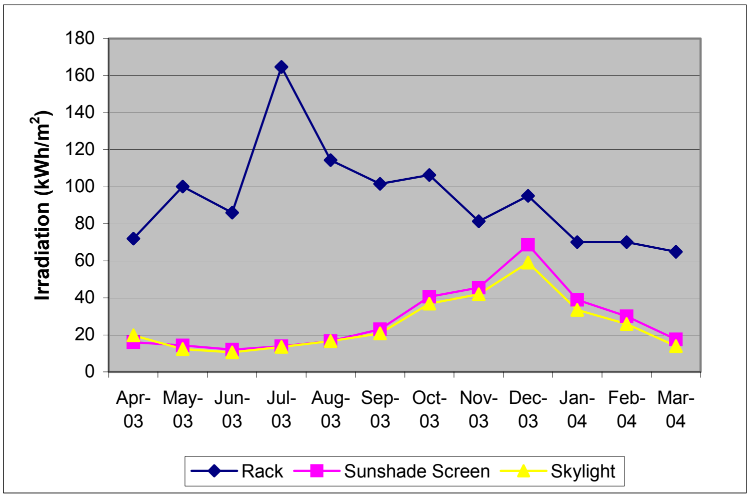

Figure 3-1: Monthly In-plane Irradiation on PV Arrays (April 2003 to March 2004)

The figure indicates that the monthly total irradiation on the Rack PV arrays was ranging from 65 to 165 kWh/m² with an annual total of 1,127 kWh/m². The Sunshade Screen and the Skylight arrays had lower annual totals (303 and 338 kWh/m² respectively). It also shows that the tilted surface had greater solar resource during summer and the south-facing facade had a reverse trend.

Comparing the annual total irradiation on two different surfaces, the south-facing facade is significantly less than that on the slightly tilted surface. This indicates that the rooftop PV arrays have better solar resource than the PV arrays installed on the façade towards south. For the reference, the measured long-term average global solar irradiation at King's Park by the Hong Kong Observatory (HKO) for 30 years is 1,472 kWh/m²/year. It is expected that the annual solar irradiation at Wanchai Tower would vary around this long-term reference figure.

3.1.2 Electricity Output

The total net energy to the grid[1] from the system between April 2003 and March 2004 is measured at 21,935 kWh comprising 15,759 kWh produced from the Rack PV system, 4,540 kWh from the Sunshade Screen and 1,636 kWh from the Skylight. It is estimated that a total of 14,000 kg of CO_2 emissions has been offset from burning of fossil fuels for electricity generation.

To determine the long-term average energy output of the PV systems at Wanchai Tower, the Measure-Correlate-Predict (MCP) approach was adopted for this estimation. The long-term historical irradiation data recorded at King's Park was also used to establish the correlation between the solar irradiation levels at the two locations. The results of the analysis suggest that the long-term average output of the BIPV system would be about 24,098 kWh/year.

In addition to the total net energy output of the PV systems, several normalised indicators of performance are also used to compare the PV systems of different size and design. The most commonly used indicators are *final yield* and *performance ratio*.

The *final yield* is the total net energy output of the PV array normalised to the rated power of the PV array. This normalised indicator is given to compare energy output of different PV power systems regardless the size of the systems. **Figure 3-2** shows that the variation in output of the three PV systems closely follows the seasonal variation in in-plane irradiation as shown in **Figure 3-1**.

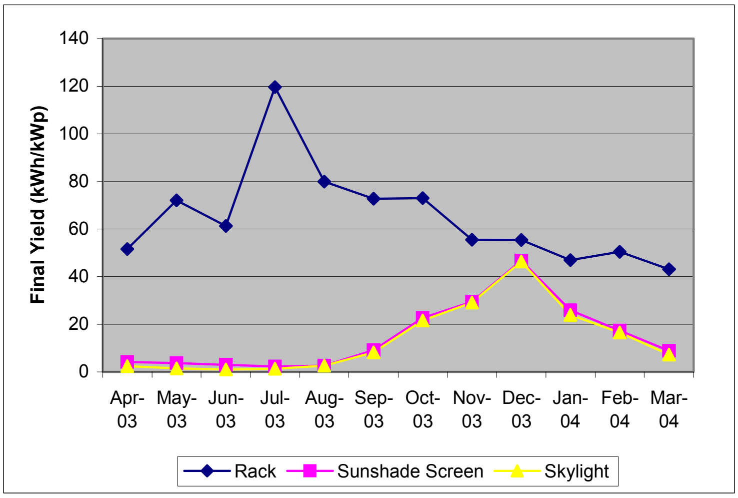

Figure 3-2: Monthly Final Yield from PV Systems

[1] The total net energy to the grid is defined as the useful output electricity from PCUs connected to the building's electricity supply system.

The analysis of the performance also provide that the annual values of final yield for the Rack, Sunshade Screen and Skylight systems are 782, 176 and 162 kWh/kW_p respectively. Comparing the slightly tilted rooftop installation and the vertically orientated arrays, the energy output from the former was four times greater than the vertical systems.

3.1.3 Performance Ratio

The *performance ratio* (PR) is also widely used in comparing PV system performance and is defined as the ratio of the *final yield* to the *reference yield* which is based on the in-plane irradiation and presents the theoretically available energy per rated power of the array. It provides an indication the overall effect of losses on the PV array's rated output due to array temperature, incomplete utilisation of the irradiation (e.g. loss of irradiation due to dirt), and system components/wirings inefficiencies or failure (down time)

Figure 3-3 shows the monthly performance ratios of the three PV systems. The figure indicates that the monthly PR values for the Rack system was typically ranging from 58 to 72%. In contrast, it is observed significant variations of monthly PR for the Sunshade Screen and Skylight systems ranging from 10 to 78%. The lower monthly PR between April and September 2003 (below 50% PR) reflects the effects of poor solar irradiation conditions, an increase in shading losses and reduced PCU efficiencies at low irradiation[2] in that months. The results of performance analysis provide that the annual PR for Rack, Sunshade Screen and Skylight are 69%, 52% and 53% respectively.

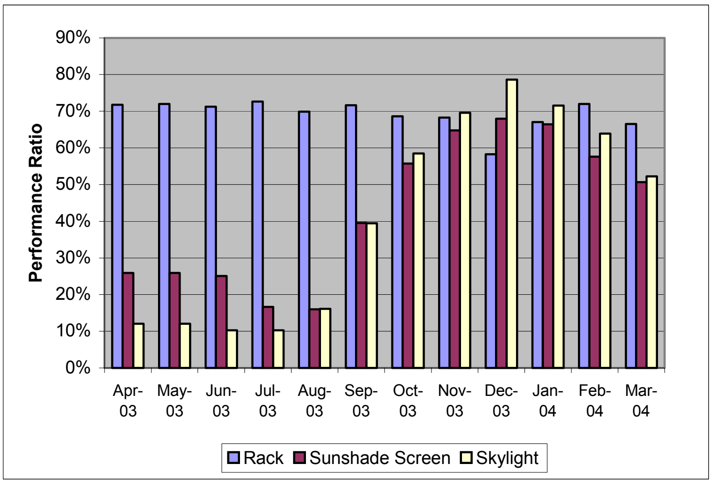

Figure 3-3: Monthly Variation in Performance Ratio

From the performance analysis of 170 overseas grid-connected PV systems, it indicated that the annual PR of the PV systems ranges between 25% and 90% with an average value of 66%. The analysis also highlighted the annual performance ratio ranging from 60 to 80% can be expected for grid-connected PV systems[3]. It is considered that the Rack system which has an annual PR of 69% is comparable to overseas experience.

[2] Where irradiation levels are poor, the PCU (inverter) is typically operating in the lower efficiency range and the monthly PR is reduced.

[3] U. Jahn et al, Analysis of the Operational Performance of the IEA Database PV Systems, *Proceedings of the 16th European Photovoltaic Solar Energy Conference and Exhibition*, May 2000.

3.2 MAINTENANCE

With the experience gained in this one year operation of the BIPV system, there was no component failure at all. Furthermore, there occurred no grid connection problems or non-scheduled outage since commissioning. The whole PV system was basically maintenance free, with the exception of regular cleaning of the PV panels similar to those used for existing windows with no extra equipment requirement. Cleaning of the PV modules can be carried out by building's estate management as part of their regular façade cleaning programme.

3.3 COSTS AND BENEFITS

The cost per unit energy generated from the BIPV system depends on a number of parameters, with the most important elements being the capital cost and long-term energy yield. The results indicate that the cost of generation from the Rack Type PV system in Wanchai Tower is about $3.4/kWh at 4% discount rate over a lifetime of 25 years. Generation costs for the other 2 systems are expected to be much higher due to less energy output.

The long-term average output of the BIPV system is estimated to be 24,098 kWh/year. Assuming an electricity tariff of $1.1/kWh[4], this results in saving of an estimated $26,500 each year. The reduction in peak power demand and air-conditioning cooling load requirement due to the installation of BIPV systems further add value to the systems.

[4] Hongkong Electric's block rate tariff for consumption from 1,501 units or above.

4 CONCLUSIONS & RECOMMNEDATIONS

In conclusion, the Wanchai Tower BIPV system has exhibited excellent reliability without any component failures and grid connection problems since commissioning. This grid-connected system has successfully demonstrated its applicability in Hong Kong under local typical conditions and the adoption of PV technologies as an integral part of building design and construction.

The total net energy generate to the grid from the system between April 2003 and March 2004 was measured at 21,935 kWh comprising 15,759 kWh produced from the Rack PV system, 4,540 kWh from the Sunshade Screen and 1,636 kWh from the Skylight. It is estimated that a total of 14,000 kg of CO_2 emissions had been offset from burning of fossil fuels for electricity generation. Its performance appeared to closely follow the solar irradiation conditions. However, the performance analysis clearly demonstrates that significant shading losses has been experienced by the vertically-orientated PV arrays (Sunshade Screen and Skylight). It can be concluded that horizontal and slightly-tilted surfaces have far better solar energy availability than vertical surfaces in the densely populated environment of Hong Kong.

This project has demonstrated a successful PV power system integrating into an office building located in an urban site. It has also proved that BIPV systems can be architecturally designed to harmonise with typical office buildings. Since commissioning, over a dozen of technical visits to the BIPV system were organised for various organisations such as legislative council, government's advisory committees, government departments, professional institutions, industry, etc. This project has also provided valuable experiences for future development of BIPV applications in Hong Kong.

In view of the reduced PCU efficiencies at low irradiation, it is recommended that a modification scheme could be considered to channel DC output from Skylight PV array into the PCU for the Sunshade Screen arrays. This would increase the total DC input into the PCU, which hence will be operating in higher efficiency range.

The whole system consumes lots of energy from Grid when the solar irradiation is too low to give sufficient output to maintain the system to operate in its standby mode. It is recommended that everyday the whole system should be automatically disconnected from grid through proper control system just shortly before sunset and be restored automatically shortly after sunrise. Seasonal timer control may be good enough to serve this purpose.

As the DC/AC electrical conversion efficiency is a very important parameter for grid-connected power generation, upgrading the PCUs could also be considered whenever a more advanced technology related to DC/AC conversion is available.

Since this is the first BIPV demonstration project in Hong Kong and has incorporated a sophisticated monitoring system to collect a full range of operational performance data for grid-connected PV power system, it is recommended that a long term monitoring and research programme should be developed to address other technical issues such as long-term degradation of PV module efficiency, shading loss analysis etc.