Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 33 (2013) 288 – 301

Energy Procedia

PV Asia Pacific Conference 2012

Solar Capability Building Programme for Public Housing

Johnny L.H. Wong, P.S. Teh, Valerie X. Wang*, Lester M.H. Chia

HDB Building Research Institute, Housing & Development Board, HDB Hub, Singapore 310480

Abstract

Expanding the use of renewable energy such as solar photovoltaics (PV) is part of the Housing and Development Board's ongoing efforts to promote sustainable development and is in line with the second thrust of HDB's Roadmap for Better Living – to develop 'Sustainable Towns'. Recognising the unique resource constraints of Singapore, HDB has looked towards solar PV. The Solar Capability Building Programme for public housing involves a wide-scale solar PV test-bedding in both new and existing towns. This paper documents the unique challenges that HDB faced (and still faces) in its drive towards sustainability, a key feature of which is the introduction of solar PV to public housing. The main sections covered are:

- HDB's main objectives of starting the Solar Capability Building Programme,
- The journey since 2008 till now,
- HDB's vision of turning Punggol into a zero-energy (for common services) town,
- Various challenges faced and how they were overcome,
- Findings from the systems installed so far, and
- The future direction HDB is headed in.

The focus of the paper is on how HDB is working towards achieving its aims for the Solar Capability Building Programme despite the high solar PV system cost, small number of industry players and lack of grid parity or tariffs. It is an in-depth look into the ways in which HDB has chosen to push forward for solar PV despite the odds. Other governments and companies facing the same challenges can adopt similar methods to overcome them.

Selection and peer-review under responsibility of Solar Energy Research Institute of Singapore (SERIS) – National University of Singapore (NUS). The PV Asia Pacific Conference 2012 was jointly organised by SERIS and the Asian Photovoltaic Industry Association (APVIA)

Keywords: Photovoltaic; Singapore; public housing; government; solar leasing

* Corresponding author. Tel.: +65 64902665; fax number: +65 6490 2662
E-mail address: vw3@hdb.gov.sg (Valerie Wang).

Selection and peer-review under responsibility of Solar Energy Research Institute of Singapore (SERIS) – National University of Singapore (NUS). The PV Asia Pacific Conference 2012 was jointly organised by SERIS and the Asian Photovoltaic Industry Association (APVIA)
doi:10.1016/j.egypro.2013.05.070

1. Solar capability building programme objectives

The Association of Southeast Asian Nations (ASEAN) nations[a] receive a high daily solar radiation of an average of more than 4.5 $kWhm^{-2}$ [1], with Singapore's annual solar irradiation averaging at 1635 $kWhm^{-2}$ [2].

The Housing and Development Board (HDB) realised the potential of this resource and thus the Solar Capability Building Programme (SCBP) for public housing was started in 2009. It involves a wide-scale solar photovoltaic (PV) test-bedding in both new and existing towns. This programme enables HDB to achieve the following objectives:

- To study the system performance based on different block configurations, geographical locations and technologies in a tropical setting,
- To gather and learn from the design and development, and further enhance the organisation's overall sustainable building design strategy,
- To help the industry build technical expertise and capability, and
- To develop cost-effective solar PV systems.

Furthermore, the knowledge acquired through the solar PV test bedding can be used to deploy solar PV systems on a wider scale, and potentially share our experience and know-how to the region.

The solar energy generated is used to power the common services of residential blocks. The excess energy not consumed during the day will be exported back to the grid. Any additional energy required is then imported from the grid. This optimises the energy usage within the HDB estates with lower usage of power from the grid, helping to reduce peak demand of the grid. The electricity savings will help to optimise Town Council's operating and maintenance costs to mitigate rising energy costs.

HDB's research and test-bedding work on solar PV systems is carried out with funding support from other government bodies such as the Economic Development Board (EDB) and Ministry of National Development (MND), and in conjunction with the research and test-bedding that is carried out by the Building and Construction Authority (BCA) and Solar Energy Research Institute of Singapore (SERIS). This paper focuses on the work carried and unique challenges faced by the HDB in the test-bedding of solar PV systems on the roof tops of public housing blocks in Singapore.

2. Solar photovoltaic journey since 2008

Back in 2008, solar photovoltaic technology was very new in Singapore. The limited application of Solar PV in the region was largely due to the high costs involved, uncertainty pertaining to performance in the local climate, and maintenance involved. Despite that, HDB recognised the merit in harnessing the power from the sun through use of PV panels as part of its overall efforts to drive environmental sustainability in its estates.

[a] ASEAN Nations: Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam.

2.1. Solar test bedding

The first solar test-bedding projects were conducted at two existing precincts at Serangoon (Fig. 1a) and Wellington (Fig. 1b) in 2008. Each precinct, comprising of 7 residential blocks and a multi-storey car park (MSCP), was installed with a 73 kW_p solar PV system.

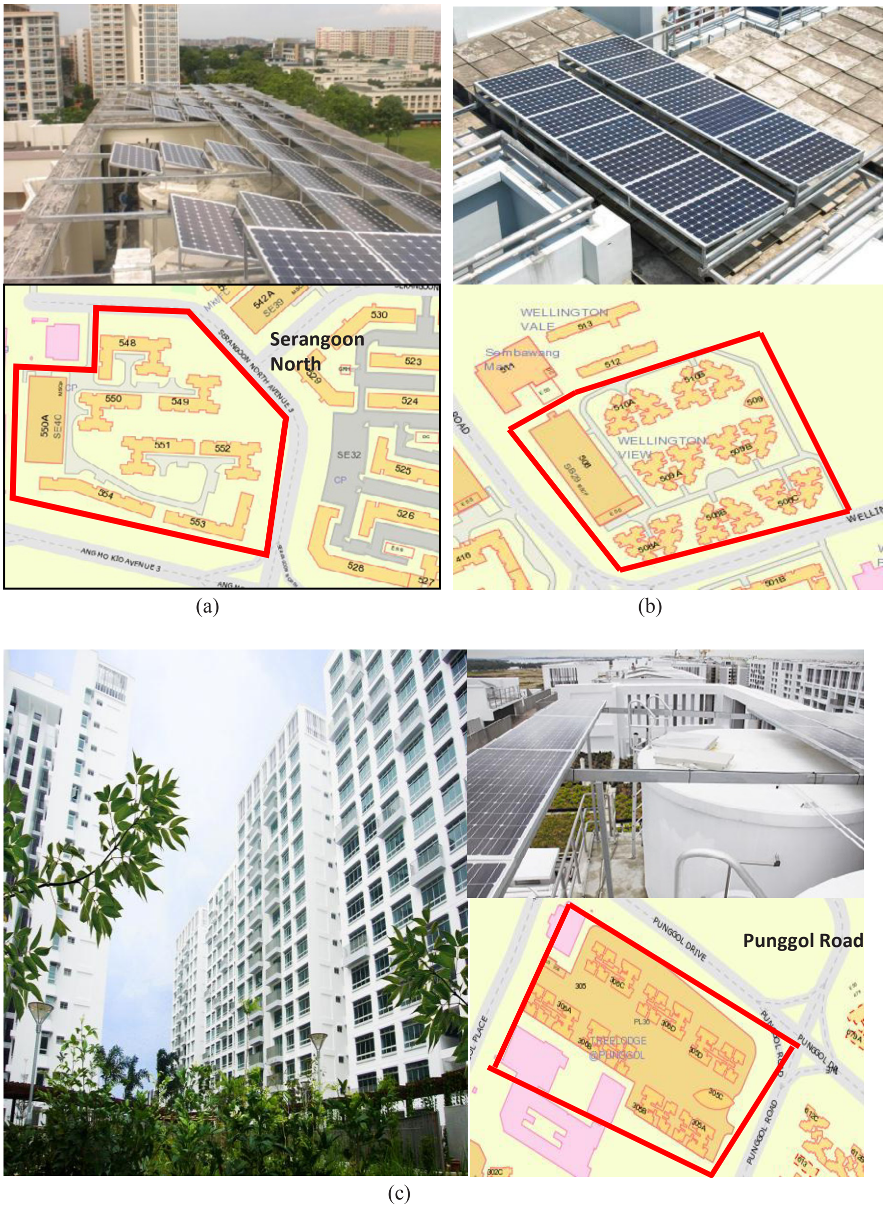

Fig. 1. (a) Solar PV test-bedding at Serangoon; (b) Solar PV test-bedding at Wellington; (c) Treelodge@Punggol. The three precincts were installed with monocrystalline panels.

Following the successful installation of solar PV at existing blocks, HDB proceeded to incorporate solar PV into its first eco-precinct new development, i.e. Treelodge@Punggol. This would be HDB's first solar integrated development project. The extensive solar installation at Treelodge@Punggol was (Fig. 1c) to generate sufficient green energy to meet the energy demand for its common services, i.e. targeting to achieve zero energy consumption for common services. The services in common areas that are powered by the solar energy generated include the corridor and staircase lighting, lifts and water pumps.

2.2. Testing different solar PV panel types

The development of the SCBP was structured around testing the various types of solar photovoltaic technologies – monocrystalline panels, polycrystalline panels and amorphous thin film. The aim was to build on the interest and attention from the industry due to the initial test-beds mentioned in Section 2.1, and to test out the performance and efficiency of these solar PV systems in our local cloudy conditions.

2.2.1. Phase 1 – Monocrystalline panels

Setting the bar higher, a tender was called for 500 kW_p of monocrystalline solar PV panels. Capitalising on the quantity, HDB hoped to keep costs reasonable. Phase 1 of the SCBP began in January 2010 with the installation of a total of 500 kW_p solar PV panels at three precincts - Bukit Panjang (West), Marine Parade and Tampines (both in the East). The locations were selected with the intention of testing out the impact of the micro-climate on the generation performance of the solar PV systems. 230 W_p monocrystalline PV panels with a stated efficiency of 14.1% were chosen for the first phase of works.

2.2.2. Phase 2 – Polycrystalline panels

With Phase 1 installation works on-going, researchers at HDB continued to look into new solar PV technologies and came across polycrystalline panels. Polycrystalline panels are generally of a lower efficiency than monocrystalline panels, but also come at a lower cost. HDB researchers were also keen to test out the use of polycrystalline PV panels under diffused sunlight – similar to conditions faced in often-cloudy Singapore. Polycrystalline panels were chosen for Phase 2 of the SCBP, with the intention of testing this theory. The team pushed for a higher roll-out of 1 MW_p of panels to be installed at seven precincts - Ang Mo Kio, Bishan, Bukit Merah, Hougang, Jurong East, Kallang Bahru, and Telok Blangah Heights. 230 W_p polycrystalline PV panels with a stated efficiency of 13.9% were chosen for the second phase of works.

2.2.3. Phase 3 – Amorphous thin film

Over 2010, developers around the world started looking into the aesthetic potential of solar PV systems – including flexible amorphous thin film panels that would enable the creation of artistic architectural detailing for roofs and facades.

Amorphous thin film solar PV panels have a much lower efficiency than crystalline solar PV panels, and thus require about twice as much roof space. It is much more challenging to install this large amount of amorphous thin film solar PV panels given HDB blocks' limited roof space. However, HDB also realised that this flexibility can also allow for more creativity in integrating the amorphous PV panels to the roof surface, which can provide more possibilities of a streamlined layout (Fig. 2).

Deciding to focus on this architectural potential while still testing a new solar PV technology, Phase 3 of the SCBP was kept to the procurement of 150 kW_p each of rigid and flexible amorphous thin film solar PV panels for the precincts of Simei and Woodlands respectively in August 2011.

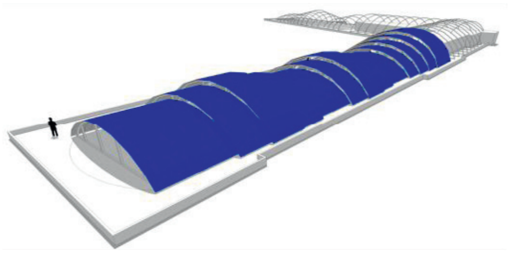

Fig. 2. Possibilities of a streamlined layout of flexible amorphous thin film installation

The first three phases of the SCBP were fully funded in the efforts to test-bed and roll-out solar PV systems. HDB would procure and install the systems, while the Town Councils were responsible for the maintenance. However, HDB realised that for solar PV take-up to be sustainable, a robust business model would have to be developed. With the initial investment and efforts of HDB, the local solar PV industry was prepared and ready to take up the challenge and opportunity offered to the private sector by the solar leasing model.

2.3. Solar leasing model

This new model involves leasing solar PV systems from private companies. Under the solar leasing model, private solar PV system developers will design, finance, install, operate and maintain the entire system. As an incentive, HDB may provide a percentage of the initial start-up costs whilst the remaining costs will be recovered from the solar energy sold to Town Councils (Fig. 3).

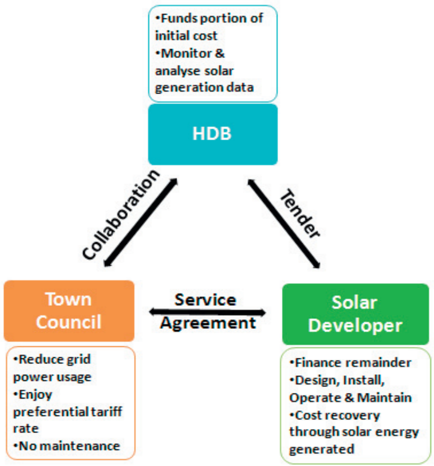

Fig. 3. Solar leasing business model

The initial start-up cost provided to the contractors is necessary while the current payback period for solar remains long (about 20 years). It helps to bridge the grid parity gap, and prevents the Town Councils from having to pay higher electricity tariff rates compared to current retail tariff rate. Solar Leasing also helps bring about greater involvement from the private companies as there would be greater appeal for them to optimise the solar PV systems to maximise solar generation. This will fuel existing research on solar power generation for the tropics, and support the programme's objective to further develop the solar industry.

The solar leasing model allowed HDB to achieve significant cost reduction in the procurement of solar PV systems. The model also provided opportunities for both HDB and the private sectors to test out a new business model for a fast ramp-up of the solar building capability programme. The projected large-scale ramp-up of solar PV capacity to be installed on HDB buildings meant that a suitable location was crucial. The beginning of the development of Punggol Eco-Town provided the perfect starting-point for the new solar leasing model.

3. Solar Leasing in Punggol Eco-Town

As the youngest HDB town currently under development, Punggol town presents a very good opportunity to demonstrate sustainable urban planning and design, green technology adoption and active community partnership. As such, HDB is developing Punggol town into Singapore's first Eco-Town, encompassing environmental, social and economic sustainability. Punggol will serve as a 'living laboratory' to test new ideas and technologies in sustainable development, integrating urban solutions to create a green living environment.

As part of HDB's sustainable efforts for Punggol Eco-Town, solar PV panels are to be installed for most blocks in Punggol Eco-Town by the solar leasing business model to meet the energy demands for common services such as corridor lightings, lift and pump operations. The solar leasing project will contribute to HDB's overall target of reducing energy consumption in Punggol Eco-Town by 20%. This is in support of Singapore's overall aim to achieve a 35% improvement in energy efficiency from 2005 levels by 2030, which is outlined in the Sustainable Singapore Blueprint.

A 2 MW_p PV system tender was awarded on 1 August 2011, kick-starting the first solar leasing project in Singapore. The PV system has been installed in 40 residential blocks in Punggol. Completed in October 2012, the solar PV system will provide power for the common services in the blocks. The services in common areas that are powered by solar energy generated include the corridor and staircase lighting, lifts and water pumps. Following the success of the first solar leasing tender, HDB will be calling more solar leasing tenders for solar PV installation in Punggol.

4. Challenges

With the net-zero common services energy consumption for Punggol Eco-Town, one of the main challenges was to accurately size the capacity of the solar PV panels to be installed at the blocks. Another challenge was whether there was enough roof space to allow an adequate number of panels to be deployed to achieve net-zero energy consumption for common services for the blocks. Moreover, an added constraint on the selection of the blocks was that it may also be shaded at some areas of the roof which reduce potential useful area for solar PV.

The challenge was overcome by conducting site inspections for all possible blocks to be installed with solar PV installation and identifying blocks which were not suitable. The selected blocks which may meet net-zero energy consumption for common services can then be verified using a software simulation programme which computed the amount of solar PV panels to be installed for the block and amount of shading the block will face.

Another challenge faced was the collection of solar data for analysis once the block has been installed with solar PV panels. Manual collection of solar data was time consuming and labour intensive, consequently translating into higher operation costs for solar PV systems. Data collected will also be hard to break down and analyse given the large volume and complexity.

HDB managed to overcome this by installing a centralised remote monitoring system. Data read from solar inverters for every block was transmitted wirelessly back to HDB's master server through a 3G network. A data collection and analysing software developed in-house allows HDB to collect and analyse the data without the need for manual collection of data. Data collected can then be studied and analysed to yield useful information.

5. Solar data analysis

After the implementation of the PV systems, it is necessary to evaluate the performance to determine whether any further improvements are needed, or whether or not to roll out the programme on an even wider scale. The three parameters of analysis are:

- To compare the different types of solar PV panels,
- To determine the impact of microclimatic conditions of the different areas of Singapore, and
- To determine the impact of the roof configuration on the solar PV panel output.

To ensure the significance of the data, only precincts which have a minimum of 6 months data are used for data analysis as shown in Table 1.

Table 1. Precincts used for data analysis. Colours denote region; North – Orange; South - Blue; East – Green; West – Purple.

Monocrystalline Panels	Polycrystalline Panels
Bukit Panjang	Ang Mo Kio
Marine Parade	Hougang
Tampines	Bukit Merah
	Kallang Bahru

5.1. Solar PV panel types

The Performance Ratio (PR) will be used in this paper to determine any differences between the solar PV panel types. It gives the actual output of a system as a percentage of the computed potential output (Eq. 1) in accordance with the guidelines of the IEC Standard 61724 [3]. The equations are shown below for reference purposes.

Performance Ratio = (System Yield (h)) / (Reference Yield (h))
System Yield (h) = (Energy Output (kWh)) / (System Installed Capacity (kW_p))

$$Reference\ Yield\ (h) = (Total\ In\text{-}Place\ Radiance\ (Wh/m^2)) / (Reference\ Irradiance(W/m^2)) \quad (1)$$

The significance of the PR is that it allows for a quick understanding of the performance of a PV system, and was also used in a paper analysing the performance of a 142.5 kW_p grid-connected rooftop BIPV system in Singapore [4]. The PR will be used as a method of comparison between the different solar PV panel types. Monocrystalline PV modules recorded a higher efficiency than polycrystalline PV modules. However, polycrystalline PV modules worked better in diffused sunlight, which is common in cloudy conditions that Singapore faces. The PR comparison will determine if the PV panel type has an impact on the power generation capability.

5.1.1. Monocrystalline PV panels

Bukit Panjang, Marine Parade and Tampines were the first three precincts to implement monocrystalline panels as part of the SCBP. As can be observed from Fig. 4, the average PR of the monocrystalline panels is 78.95%.

5.1.2. Polycrystalline PV panels

Ten precincts were installed with polycrystalline solar PV panels over 2011 totalling more than 1 MW_p. Of these, four precincts with at least six months of data were used for comparison – Ang Mo Kio, Bukit Merah, Hougang and Kallang Bahru (Fig. 5).

While the system and capture losses are different for the all the systems due to different components and system integrators, the average PR of the polycrystalline PV precincts still averages out at 5.6% lower than those of the monocrystalline PV precincts. This is indicative that the higher efficiency of monocrystalline PV modules allows it to generate more power than polycrystalline PV panels.

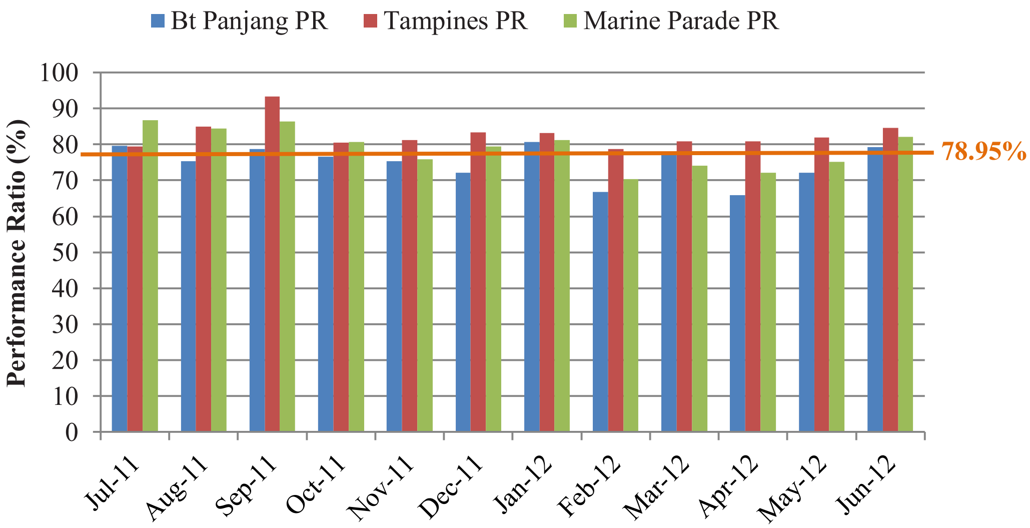

Fig. 4. PR of the monocrystalline PV panel precincts

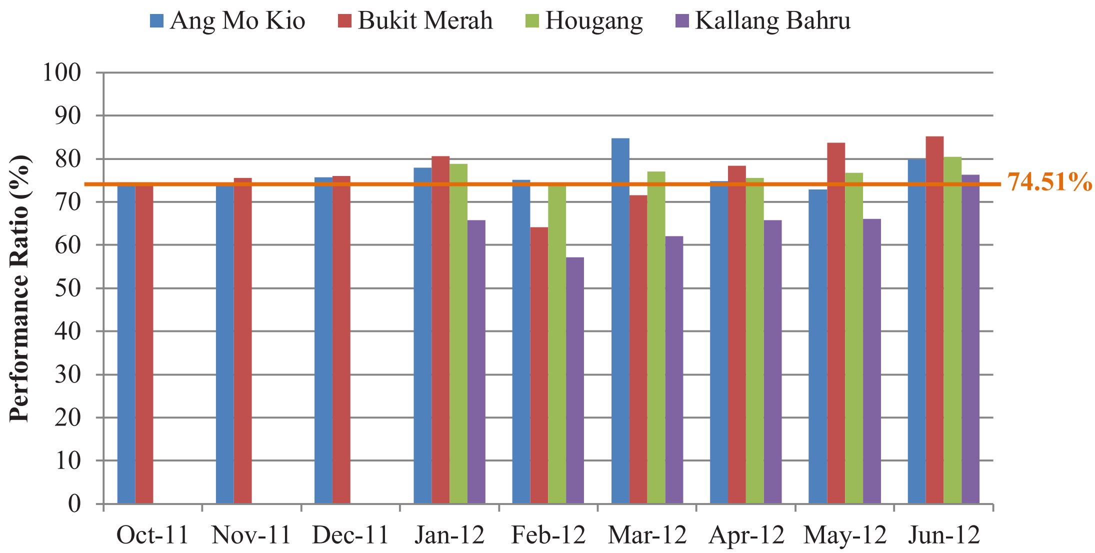

Fig. 5. PR of the polycrystalline PV precincts

5.1.3. Learning points

The variances in the PR of the seven systems can be attributed to maintenance capabilities of the different contractors, site location (further explained in Section 5.2), as well as proper use and maintenance of solar PV system equipment such as the inverters and pyranometers.

Through this, the importance of calibrating all measurement equipment, as well as specifying clearly the requirements of inverters and pyranometers, was shown. Measuring equipment that is not calibrated cannot show accurate results, making data analysis more difficult. This problem can be overcome by ensuring that data is monitored consistently to discover any faults, as well as highlighting the need to maintain and regularly calibrate the equipment to the maintenance teams.

5.2. Microclimatic conditions

Among the different solar PV system installations, a comparison of output and performance can be made between the various locations to determine the impact of the microclimate on PV system output and performance. The regions are classified as shown earlier in Table 1. Micro-climatic conditions can also be affected by the surrounding buildings, any potential shading (which will reduce output), and any other specific environmental characteristics of the various precincts.

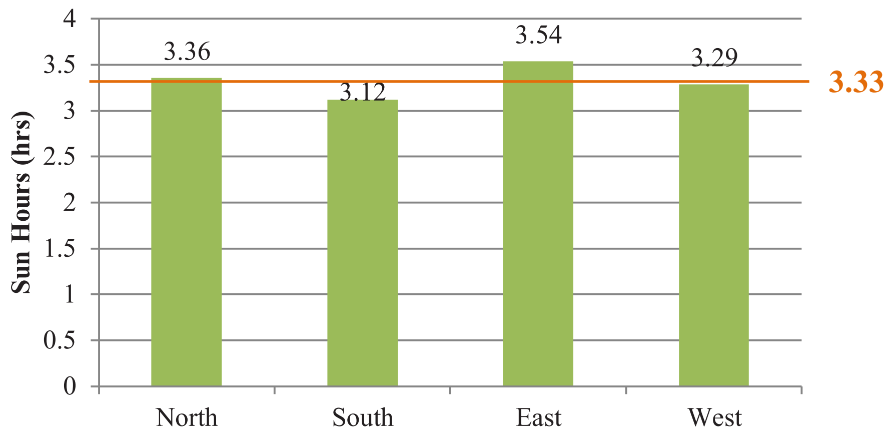

Fig. 6. Average sun hours of the four regions

The average sun hour value is 3.33 hours. While the sun hour values of the North and West region are average, the East region appears to record a sun hour value of 3.54 hours, 6.6% higher than the average. In contrast, the sun hour value for the South region is 6% lower than the average.

5.3. Roof configuration

The position of the building and the solar PV panels on it can affect the output and performance of the PV system greatly. The configuration of the panels on the roof includes the orientation of the panels and the buildings, as well as the tilt angle of the panels.

Based on Singapore's location, the theoretical ideal tilt angle should be zero degrees [4], which would negate any significance that the orientation of the panels might have. However, to allow some self-cleansing for the PV panels, a slight tilt angle of 3 to 15 degrees has been recommended although this may possibly have some impact on solar irradiance capture [5].

Most of the solar PV installations are angled in two opposing directions (per array per inverter) as shown in Fig. 7a. Therefore, the orientations will be classified as North-South and East-West facing.

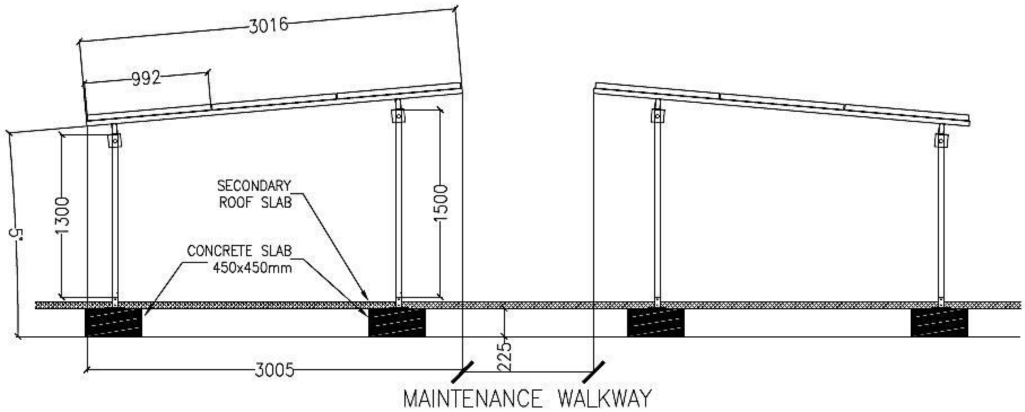

Fig. 7(a). Side view of panel tilt - 5 degrees

Fig. 7(b). Blocks with different panel layouts

Similar to Section 5.2, the sun hour values will be used to compare the outputs for the different layouts. Blocks 239 and 240 in Bukit Panjang precinct will be used as a case study as they have two different panel layouts with the same installed capacity (Fig. 7b). Figure 8 shows the sun hour values of blocks 239 and 240 over a year.

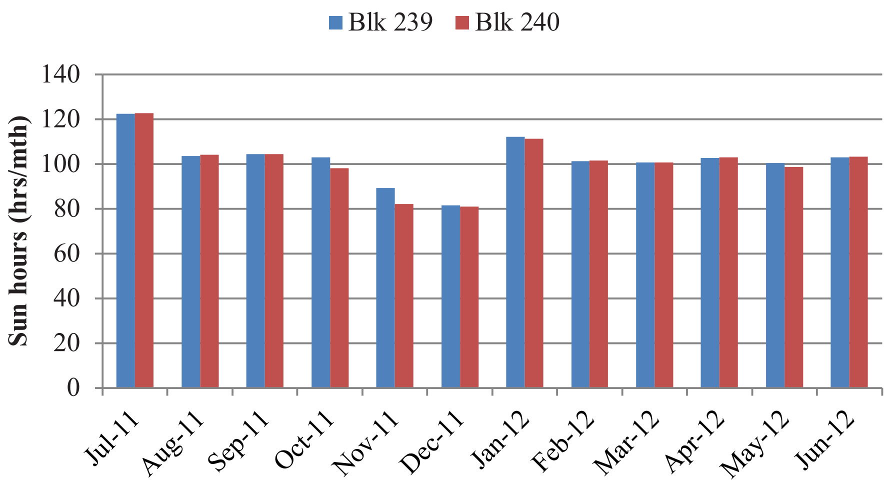

Fig. 8. Sun hour values of Blk 239 and Blk 240 (Bukit Panjang)

The sun hour values of Blk 239 are higher than those of Blk 240 for seven out of the twelve months, averaging at 0.5% higher over the year[b] . However, there is insufficient difference between the sun hour values of the two blocks over the analysed year to prove that the North-South layout and East-West layout have an impact on the solar PV output. Another study that analysed tilt angle dependency also found it had no significant impact on the final yield of the solar PV system [4].

6. HDB's achievements and future direction

From the start of small scale test-bed projects in various precincts to the solar leasing business model for large scale implementation under the SCBP, HDB has garnered much knowledge and expertise on the application of solar PV technology. HDB is headed towards wider scale implementation of solar PV with more towns targeted island-wide to embark on the solar leasing business model for solar PV implementation.

The solar leasing business model helps to increase the installed solar capacity of HDB blocks with the same amount of funds with the mutually beneficial partnership with the Town Councils and private sector. Through expanding the solar PV installations, energy usage can be optimised with lower usage of power from the grid, in turn reducing the carbon emissions in the long term.

The development of the local solar industry can also be seen through the increased level of participation from companies in the second solar leasing tender, which was called in 2012, a year after the first. Compared to just three companies who put in a bid for the first solar leasing tender, a total of 13 bidders participated in the second tender. This shows the increased competency and confidence of the solar industry.

[b]Excluding November 2011 as Blk 240 had a faulty inverter which recorded no input for 15 days.

The cost of solar PV installation for HDB has decreased significantly since the first solar PV installation project in Serangoon and Wellington (Fig. 9). In 2008, the cost of solar PV installation for HDB blocks was \$8.25 per W_p. In 2009, HDB began calling bulk procurement of solar PV panels for installation to conduct a wider scale test-bed of solar PV technology covering more precincts. The cost of solar PV installed subsequently decreased by almost 50% to about \$4.35 per W_p. With the introduction of the solar leasing model, HDB paid only a fraction of the total solar PV installation cost, which was \$1.64 per W_p for the first solar leasing project.

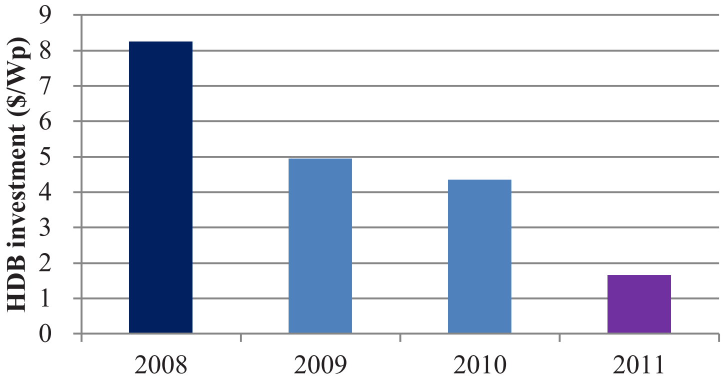

Fig. 9. HDB's investment in Solar PV installations

The trend of decreasing costs of solar PV panels is very encouraging. Should this continues, we could be looking at grid parity soon. When grid parity is reached, Town Councils will have the essential knowledge and skills to install solar PV on their own, with technical advice from HDB as a support to the Town Councils. This will further encourage a greater roll out of solar PV technology for HDB blocks in Singapore.

With the successful implementation of solar PV in Singapore, HDB has also managed to build up relevant expertise and knowledge for Singapore's local industry in solar PV technology. A new classification, ME03, has been added under the BCA work-head for contractors who want to participate in solar PV installations projects in Singapore. The addition of the work-head to regulate solar PV installers is a confirmation of the growing solar PV industry in Singapore.

The expansion of solar PV roll-out by adopting the solar leasing model allows HDB to help local solar PV developers to gradually build up their expertise and experience in financing and implementing larger scale projects. As HDB only funds a small start up cost to kick start the project, local PV developers have to seek funding from financial institutions to cover the remaining installation costs. This helps local PV developers to develop capabilities in seeking funding, and financial institutions to explore opportunities and build confidence in financing renewable projects.

References

[1] Lidula NWA, Mithulananthan, Ongsakul W, Widjaya C, Henson R. ASEAN towards clean and sustainable energy: Potentials, utilization and barriers. *Renewable Energy* 2007; **32**:1441-52.

[2] Kannan R, Leong KC, Osman R, Ho HK. Life cycle energy, emissions and cost inventory of power generation technologies in Singapore. *Renewable and Sustainable Energy Reviews* 2007; **11**:702-15.
[3] International Electrotechnical Commission. IEC 61724, photovoltaic system performance monitoring – guidelines for measurement, data exchange and analysis. 1st ed. Geneva, IEC: International Electrotechnical Commission; 1998.
[4] Wittkopf S, Valliappan S, Liu L, Ang KS, and Cheng SCJ. Analytical performance monitoring of a 142.5 kW_p grid-connected rooftop BIPV system in Singapore. *Renewable Energy* 2012; **47**:9-20.
[5] Energy Market Authority. *Handbook for Solar Photovoltaic (PV) Systems*. Singapore: EMA; 2009.