香港天文台
HONG KONG OBSERVATORY

Reprint 965

Potential of wind and solar energy in Hong Kong

B.Y. Lee & H.Y. Mok

Symposium on E-Management - Challenges and Opportunities,
Hong Kong, 28 May 2010

Potential of wind and solar energy in Hong Kong

B.Y. Lee and H.Y. Mok
Hong Kong Observatory, Hong Kong, China
E-mail: bylee@hko.gov.hk

ABSTRACT

Located at the coast of south China, Hong Kong has sub-tropical climate. Analysis of winds and direct solar radiation levels measured by the Hong Kong Observatory provides information on the potential of wind and solar energy resources in Hong Kong. It was found that a high wind energy potential is possible in such exposed places as hilltops and offshore waters. In respect of solar energy, large open space for its capture is hard to come by and is costly if it is available. However, given the abundance of solar energy in Hong Kong, there is plenty of room for creative solutions if consideration is given to the capture of solar energy by buildings and other structures.

Introduction

Currently, a majority of energy resources in the world are derived from fossil fuels which scientists believe to have very likely led to global climate change as a result of release of greenhouse gases into the atmosphere. The World Meteorological Organization's Greenhouse Gas Bulletin 2008 released in November 2009 reminds us once again the imminent carbon dioxide issue --- the latest concentration is 385 ppm (parts per million), up 2 ppm from the previous year and 100 ppm from the pre-industrial era.

It has been pointed out that at any given moment the world requires a maximum of about 12.5 TW (T is tera, i.e. 12 zeros), and this is expected to increase to some 16.9 TW by 2030. The rise in energy demand will exacerbate the impact of global warming. To combat this threat, it is apparent that renewable energy should be widely encouraged through the use of appropriate technologies to capture it. It is estimated that excluding places such as oceans, mountains and other inaccessible areas, the potential for wind and solar power is about 60 TW and 600 TW respectively, giving a total of 660 TW (Jacobson *et al*, 2009). Taking a conservative approach, if just 5% is extracted, i.e. 30 TW, the world would even end up with surplus energy. There is a plan to install a large number of solar thermal collectors in the Sahara with a view to supporting 15% of Europe's electricity needs by 2050 (BBC, 2009).

Located at the coast of south China, Hong Kong has sub-tropical climate with abundance of sunlight as well as monsoon and tropical cyclone winds. According to the climate records of the Hong Kong Observatory, the average daily global solar radiation is about 13.23 MJm^{-2} and the mean wind speed at Waglan Island, an off-shore island lying at the southeast corner of Hong Kong, is about 6.6 ms^{-1} (Lee *et al*, 2006). This paper assesses the resource potential and discusses the possibility of wider application of wind and solar energy in Hong Kong from the climatological point of view.

Wind energy resources in Hong Kong

The wind speed data measured over a 10-year period at 16 weather stations operated by the Hong Kong Observatory were used to assess the wind energy potential at various places in Hong Kong. They are located on hilltops (Ngong Ping, Tai Mo Shan and Tate’s Cairn), at offshore islands (Waglan Island, Cheung Chau and Tap Mun), in the harbour (Kai Tak, Star Ferry, Shell Depot and Green Island), sub-urban areas (Sha Tin, Lau Fau Shan and Sai Kung), and rural areas (Ta Kwu Ling, Plover Cove and Sha Lo Wan). Except for Ngong Ping in which the period of 2002-2009 was used, the data period for all the station run from 2000 to 2009. The anemometer (i.e. wind sensor) heights range from 16 m above the mean sea level at Shatin to 966 m at Tai Mo Shan (HKO, 2009). An averaging period of 10 minutes instead of 60 minutes for the mean wind speed was used in the present study because according to Jensen *et al* (1984), a longer averaging period (such as 60 minutes) would under-estimate the corresponding wind energy.

The wind energy resource available at a potential site is expressed in terms of the mean wind power density (*WPD*) which is defined as the average wind power available per unit area swept by a wind turbine blade over a certain period (Janardan and Nelson, 1994):

$$WPD = (0.5)(\rho)(\overline{u^3}) \qquad (1)$$

where ρ = the air density, and

$\overline{u^3}$ = the average of cube of the mean wind speed.

For simplicity, the air density ρ at a given station is assumed to be constant throughout the study period and is estimated by the Gas Law:

$$\rho = (P_o / RT)\, e^{(-gz/RT)} \qquad (2)$$

where P_o = standard atmospheric pressure at mean sea level
R = specific gas constant
T = average air temperature measured at the station or nearby station from 2000 to 2009 (2004 to 2009 for Ngong Ping)
g = the gravitational constant; and
z = the anemometer height above mean sea level

Since wind turbines typically do not operate below the cut-in wind speed of about 3 ms^{-1} and above the cut-out wind speed of about 25 ms^{-1} (Environment, Quality, Health and Safety Report 2005), the *WPD* for those mean wind speeds less than 3 ms^{-1} and exceeding 25 ms^{-1} is set at zero.

Table 1 shows the annual mean wind speed, the percentage of time with usable wind speeds and the mean *WPD* for the period from 2000 to 2009 (2002 to 2009 for Ngong Ping) for the 16 automatic weather stations. It can be seen that availability of wind energy at Ngong Ping, Tai Mo Shan, Tate's Cairn, Waglan Island, Cheung Chau and Green Island ranged from 76% to 88% with a mean wind power density between 204 and 495 Wm^{-2}. In comparison, the availability of wind energy and the mean wind power density at other stations were much lower.

Application potential of wind energy in Hong Kong

According to Elliott *et al* (1991), *WPD* is divided into 7 classes (Table 2). It is considered that sites with *WPD* of Class 3 or higher are suitable for utility-scale wind power applications, whereas Class 4 or higher is preferred for large-scale wind farms (AWEA, 1995). Figure 1 shows the mean *WPD* and the corresponding classes at the sites of the 16 automatic weather stations. According to the classification, areas with potential for large-scale wind farms in Hong Kong can be located on hilltops and offshore waters. On the other hand, the potential for utility-scale wind power generation in urban, sub-urban and rural areas is generally low.

Solar energy resources in Hong Kong

Direct solar radiation is measured at the King's Park Meteorological Station by means of a pyrheliometer mounted onto a solar tracker which keeps the former consistently pointing to the sun and aligned with the incident sunbeam.

Because their measurement commenced in mid-2008, a complete year of direct solar radiation levels, from January to December 2009, were used in the study. The average monthly figures for this period are shown in Figure 2 (blue line). In general, the direct solar radiation level was higher in the cooler months than in the warmer months. This is believed to be partly due the amount and type of clouds at different times of the year in Hong Kong. (With the accumulation of more direct solar radiation data in time, the above figures may need to be fine-tuned. However, this is not expected to significantly affect the overall conclusion of this paper.)

Although a sun tracking design will maximize the solar radiation energy collected, it is more practicable for small-scale installation of solar radiation collectors to be fixed at an optimal orientation and tilting angle. In this respect, the annual total amount of direct solar radiation reaching a plane surface of area 1 m^2 under various orientations and tilting angles were computed and analysed. Results showed that the optimum combination of orientation and tilting angle for a fixed plane surface for receiving maximum direct solar radiation in a year is 120° (from true north, i.e. approximately facing southwest) and 40° (from the horizon) respectively. The monthly total direct solar radiation levels falling on a fixed solar panel of size 1 m^2 with this optimum orientation and tilting angle are shown in Figure 2 (red line). With this orientation and tilting angle, the annual total direct solar radiation received was about 1570 MJm^{-2}, or on average, 4.3 MJm^{-2} per day.

Application potential of solar energy in Hong Kong

There are two main ways to turn solar radiation into useful energy: (a) conversion into electrical energy and stored in batteries by means of photovoltaic (PV) devices; or (b) conversion into thermal energy by means of solar-thermal collectors. The efficiencies of state-of-art commercially available PV type solar panels and solar-thermal collectors are about 20% and 40% respectively. Thermal energy originating from solar energy can further be converted to electricity, with an overall efficiency (from solar to electricity) of roughly 25%.

Based on the data from the Census and Statistics Department, the electricity consumption in Hong Kong in 2009 was about 446 TJ per day (CSD, 2010). To meet 10% of such consumption, it requires a surface area of about 42 km^2 (about 8,400 football fields of size 100 m x 50 m) for a solar-thermal set-up with a solar-to-electricity efficiency of 25% efficiency. The surface area required for PV devices is even larger. As open surface areas in Hong Kong are limited, it may not be feasible to operate large-scale solar energy plants in the territory. In respect of near-shore or offshore solar plants, there are policy and other constraints such as aesthetic issues, fish culture zones, seabed utilities, near-shore infrastructures, marine shipping channels and exposure to typhoons. However, consideration could be given to integrating solar-thermal converters and/or PV devices into buildings making use of otherwise alienated space, and this may be more practical for Hong Kong's circumstances. Three examples were quoted below to illustrate the potential for wider use of solar energy in Hong Kong:

(a) According to the Stage 1 Study Report of "Study on the Potential Applications of Renewable Energy in Hong Kong", the total surface areas of residential, public rental housing, commercial and industrial buildings and government, institution and community facilities in Hong Kong is about 93 km^2 (Electrical and Mechanical Services Department, 2002). Assuming that 30% of this area (about 28 km^2), mainly on the rooftop of the buildings, can be used for installing PV-type solar panels of 20% efficiency at the optimal orientation and tilting angle, the annual total solar thermal energy that can be collected will be about 24 TJ per day, or 5.4% of total electricity consumption in Hong Kong.

(b) Taking 42 ^{o}C as the 'comfortable' temperature for showers and assuming that the monthly mean fresh water temperatures are the same as the monthly mean sea surface temperatures measured at North Point, the amount of such warm water produced daily by three 40% efficiency solar thermal collectors of size 1 m^2 each are calculated for January to December and shown in Table 3. It can be seen that on average about 80 litres of warm water can be produced each day during the cooler months of January to March and October to December (even up to 110 litres in some individual months). As another example, for a house with a rooftop of 100 m^2 (typical house in the rural areas and villages in the New Territories, normally 3-storey high), about 530 litres of warm water can be produced per day in the cool months if 20% of the rooftop surface area is used for installing solar-thermal collectors. This amount of water is sufficient for 13 persons assuming that each of them consumes about 40 litres of water in a shower. The savings in electricity amounts to about HK$390 per month during the cooler months.

(c) As more and more buildings with a high proportion of glass windows in their external walls have been built in the last couple of decades for better view and natural light, window-based thin-film solar cells will become more popular. State-of-art of this type of solar cell has a solar-to-electricity efficiency of about 10%. For a vertical window of size 1 m^2 installed with window-based thin-film solar cells facing south without obstruction, it has been calculated that the annual total electricity generated from direct solar radiation is about 99 MJ, or about 0.27 MJ per day (Table 4). For a household with a floor to ceiling window of 3 m x 3 m facing south without obstruction, about 2.4 MJ per day or 20 kWh per month of electricity can be generated. This reduces the household electricity bill by about HK$20 a month.

An added advantage to all these is a reduction in indoor temperature, as incoming solar radiation has been diverted to become useful energy.

Conclusion

The potential of wind and solar energy in Hong Kong was assessed using wind and direct solar radiation data measured at a number of weather stations operated by the Hong Kong Observatory over the territory. Results show that both wind and solar energy are abundant in Hong Kong. For wind energy, a high wind energy potential is possible in such exposed places as hilltops and offshore waters from the climatological point of view. However, there are policy and other constraints. On the other hand, solar energy has the potential for widespread application in buildings in Hong Kong through the use of devices such as PV panels and solar thermal collectors.

References

1. BBC, 2009: Sahara Sun ‘to help power Europe’, BBC News, 2 Nov. 2009 (available online at: http://news.bbc.co.uk/2/hi/8337735.stm)
2. American Wind Energy Associations (AWEA), 1995: The most frequently asked questions about wind energy (available online at: http://www.awea.org/faq/basicwr.html)
3. Census and Statistics Department, the government of the HKSAR, 2010: Hong

Kong Statistics Table 127, Electricity Consumption (available online at: http://www.censtatd.gov.hk/hong_kong_statistics/statistical_tables/index.jsp?subjectID=11&tableID=127)
4. Electrical & Mechanical Services Department, 2002: Study on the Potential Applications of Renewable Energy in Hong Kong, Stage 1 Study Report, p.5-17.
5. Elliott D.L., C.G. Holladay, W.R. Barchet, H.P. Foote and W.F. Sandusky, 1991: Wind Energy Resource Atlas of the United States, Solar Technical Information Programme, Solar Energy Research Institute, Golden Colorado
6. Environment, Quality, Health and Safety Report 2005: Pioneering Hong Kong's First Wind Turbine, Hong Kong Electric (available online at http://www.heh.com/NR/rdonlyres/CA62344F-38AE-41B3-BAED-5BD311C9C5EB/0/06bPioneeringHongKongsFirstWindTurbine.pdf)
7. Jacobson M.Z. and Delucchi M.A., 2009: A Path to Sustainable Energy by 2030, Scientific American, Nov. 2009, 58-65
8. Janardan S. Rohatgi and V. Nelson, 1994: "Wind characteristics: an analysis for the generation of wind power", Alternative Energy Institute, West Texas A&M University, Canyon, Texas.
9. Jensen N.O., E.L. Petersen and I. Troen, 1984: Extrapolation of mean wind statistics with special regard to wind energy applications, WMO WCP 86.
10. Lee, T.C., W.M. Leung and K.W. Chan, 2006: Climatological Normals for Hong Kong 1971- 2000, Hong Kong Observatory Technical Notes (Local) No.83
11. Wong, M.S., and W. K. Kwan, 2002: Wind Statistics in Hong Kong in relation to Wind Power, Hong Kong Observatory Technical Note (Local) No. 77,29pp
12. World Meteorological Organization, Geneva, 2008: World Meteorological Organization Greenhouse Gas Bulletin 2008 (available online at: http://www.wmo.int/pages/prog/arep/gaw/ghg/ghg5-online.html)

Table 1. Average annual mean wind speed, percentage of time with usable wind speed and mean wind power density at the 16 automatic weather stations

Automatic Weather Station	**Average annual mean wind speed (ms^{-1})**	**Percentage of time with usable wind speed**	**Mean wind power density (Wm^{-2})**
Tai Mo Shan	6.7	83	397
Waglan Island	6.2	84	339
Tate's Carin	6.1	85	283
Ngong Ping	7.4	88	495
Green Island	5.8	81	293
Cheung Chau	5.0	76	204
Kai Tak	3.4	58	73
Sha Lo Wan	3.4	49	119
Lau Fau Shan	3.4	56	80
Tai Mei Tuk	3.5	55	118
Star Ferry	3.2	52	80
Tap Mun	2.7	45	69
Sai Kung	2.8	43	106
Ta Kwu Ling	2.0	26	41
Shatin	2.3	31	39
Tun Mun	2.4	34	47
Tsing Yi	2.3	32	48

Table 2. Classification of wind power density (Extracted from Elliott *et al* (1991) at 10 m above ground level)

Wind power class	**Wind power density (Wm^{-2})**
1	0-100
2	100-150
3	150-200
4	200-250
5	250-300
6	300-400
7	400-1000

Table 3. Daily amount of water at a comfortable temperature of 42 ^oC produced by three 40% efficiency solar-thermal collectors each of size 1 m^2

Month	Direct solar radiation (MJ)	Monthly mean sea surface temperature at North Point (^oC)	Daily volume of water at comfortable temperature produced by 3 x 1 m^2 40% efficiency solar thermal converters (litre)
January	294.1	17.6	111
February	158.8	16.9	65
March	50.7	18.1	20
April	56.1	21.1	26
May	102.6	24.8	55
June	28.9	26.7	18
July	87.6	26.9	53
August	106.6	26.8	65
September	149.9	27.3	97
October	191.9	26.5	114
November	213.9	23.5	110
December	134.7	19.9	56
Monthly average	131.3	23.0	66

Table 4. Daily amount of electricity generated by a vertical window of size 1 m^2 facing south without obstruction and installed with 10% efficiency window-based solar cells

Month	Electricity generated daily (MJ)
January	0.87
February	0.41
March	0.09
April	0.06
May	0.03
June	0.00
July	0.01
August	0.09
September	0.23
October	0.45
November	0.60
December	0.43
Monthly average	0.27

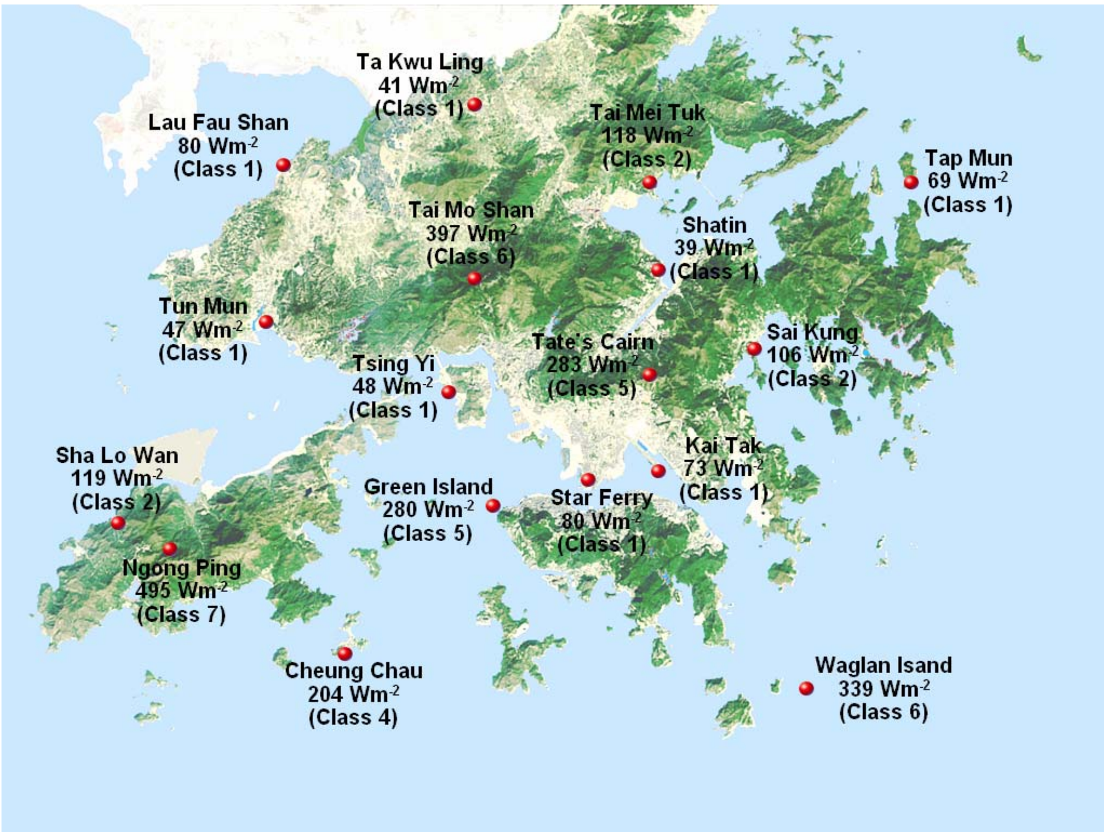

Figure 1. Distribution of mean wind power density in Hong Kong (Wind power class in brackets).

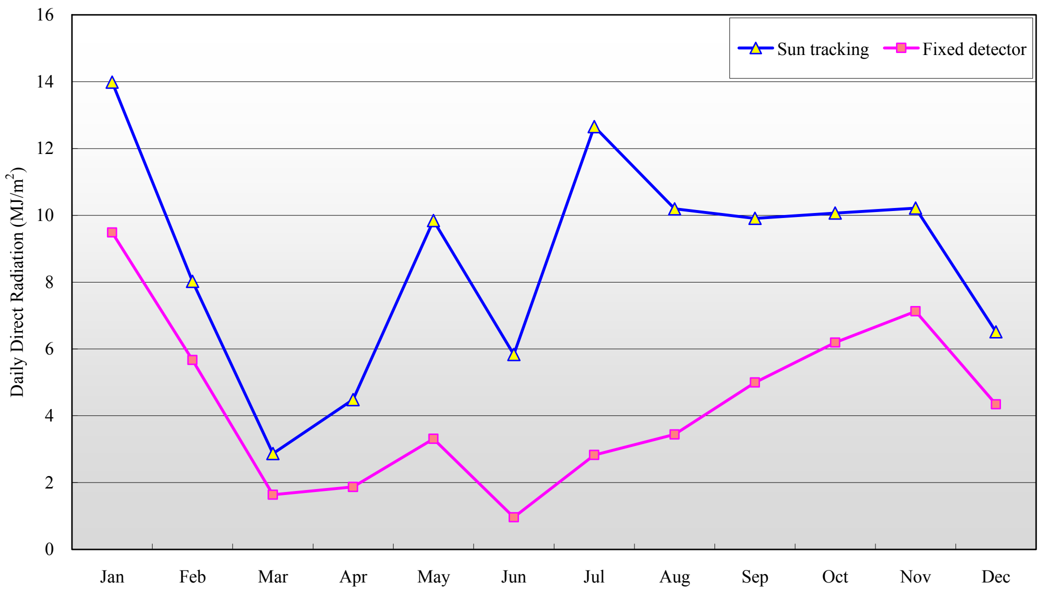

Figure 2. Average daily direct solar radiation levels measured at King's Park Meteorological Station by a sun-tracking pyrheliometer in 2009 (blue line), and the calculated average daily direct solar radiation levels to be received by a surface mounted at an orientation of 120^{o} and tilting angle of 40^{o} (red line).