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Feasibility study of developing a zero-carbon-emission Green Deck in Hong Kong

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Abstract

This study examines the feasibility of utilizing renewable energy power generation technology to developing a zero-carbon-emission Green Deck. The power consumption of the deck, including lighting, ventilation and air-conditioning, is firstly estimated. Then the potential of solar photovoltaic (PV) module installation in roof and vertical façade is evaluated through simulation and theoretical calculation, demonstrating that it is highly possible to achieve the target of net-zero-energy consumption and zero carbon emission. Furthermore, the economic feasibility of the proposed PV system on the Green Deck has been studied.

Keywords: Green Deck; Feasibility study; Photovoltaic power generation

1. Main text

Currently, about 120,000 vehicles per day go through Hung Hom Cross-Harbour Tunnel, causing severe air pollution. The footbridge linking Hung Hom MTR station and PolyU is overloaded with people. Moreover, several main roads have divided the area into many small regions, making the pavements meander [1]. Therefore, The Hong Kong Polytechnic University (PolyU) proposed to construct a Green Deck over the Cross Harbour Tunnel plaza to provide recreational, cultural and sports facilities while tackling these problems, such as poor air quality, overloaded footbridge and poor connectivity problems in the vicinity. To support the development of a 'green' deck, this study aims to investigating the feasibility

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of developing a zero-energy consumption/zero-carbon emission Green Deck by integrating feasible renewable energy technologies

2. Estimation of energy consumption

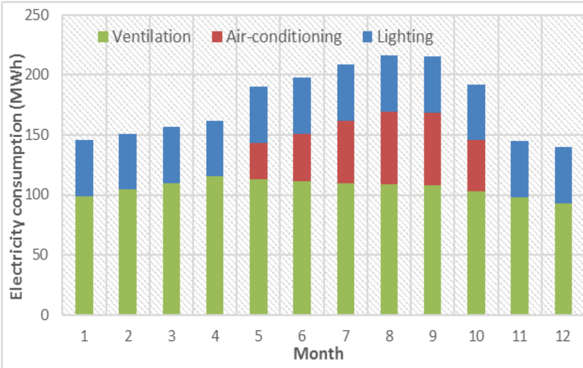

Figure 1 Annual energy consumption

In this deck, electricity will be mainly used for ventilation, air-conditioning and lighting of the midlevel walkways/bus waiting lobbies and ground-level bus stations. The natural ventilation strategy for the Green Deck proposed in [2] is considered for this study, while it is not enough to dilute all pollutions below the deck through natural ventilation. Hybrid natural and mechanical ventilation, therefore, is employed in this study. The handbook for Design of Ventilation and Lighting of Highway Tunnel in China [3] is used to as reference to estimate the energy consumption of mechanical ventilation.

Table 1 Summary of energy consumptions

	Air conditioning	**Mechanical ventilation**	**Lighting**
Estimated serving area (m^2)	14,500	15,000	15,000
Estimated energy consumption density (W/m^2)	Jul-14	9.8-16.9	2.5-5.0
Operation hour	7:00am-24:00pm	7:00am-22:00pm	7:00am-23:00pm full-opening
	May-October	All year	0:00am-6:00am half-opening
Estimated energy consumption (kW)	100-203	147-253	43-86
Remarks	Two air conditioners are required for a waiting lobby, and one air conditioner is required for a bus station.	Mechanical ventilation is required for the waiting lobbies and pedestrian in the midlevel	Lighting is required for the waiting lobbies and pedestrian in the midlevel

The annual energy consumption of the proposed deck is shown in Figure 1. It is found that most energy is consumed for mechanical ventilation. The highest consumption occurs in August, and lower in winter. A summary of energy consumption is presented in Table 2, which shows that about 5,800 kWh of electricity, would be consumed every day for the proposed Green Deck. The total cost of the electrical consumption from utility grid could be about HK$2 million in a year. Therefore, solar energy is proposed to supply renewable electric power for the deck in the future.

3. Evaluation of solar power generation

In this study, solar photovoltaic modules are proposed to be installed on possible building areas on the deck, e.g. on the roof and vertical façade of the nearby buildings (office buildings, hotels, and apartments), the covers of walkways and other constructions (sports complex, art gallery) in the deck. Power generation from solar photovoltaic could be estimated using the following equation [4]:

$$E = G \cdot \eta \cdot A \cdot \gamma \tag{1}$$

where G is the solar radiation received per square meter (W/m2); η is the energy conversion efficiency of PV systems, A is the installation area of the proposed PV modules (m^2) and γ=0.85 is the performance ratio of the PV system [5].

To maximize the energy output of PV systems in limited PV-suitable roof areas, the high-efficiency mono-crystalline PV module (STP260S) made by Suntech of China is used in the study. According to the [6], the installation area for the selected PV module is 2.35 m^2. For the PV panels instated on vertical facade, the installation area can be equal to its original size, i.e. 1.64 m^2.

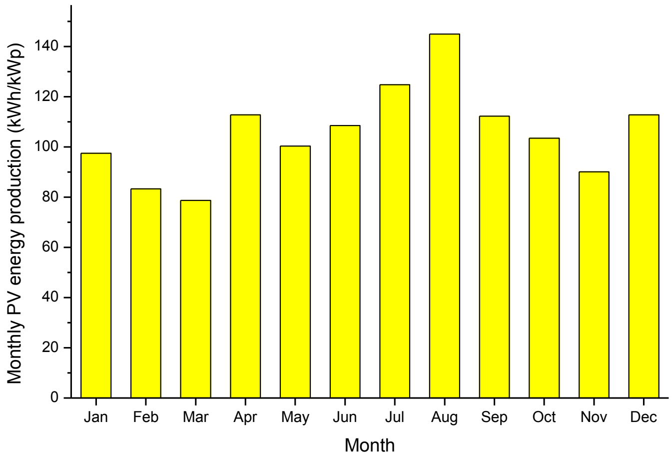

Figure 2 Power generation of 1 kWp PV panel in different months

Based on Eq. (1) and our previous experimental test [7], the electricity generated from 1 kWp PV panel is 1,545 kWh/year if installed on the roof with optimum angle and 778 kWh/year if installed in vertical facades. The simulated power production from 1 kW*p* PV on the roof in different months is presented in Figure 2.

As presented in Figure 3, therefore, the roof and vertical façade of the office buildings, hotels, and apartments in the extended deck should be used for PV panel integration. In addition, the walkways above the deck can be covered with solar panels, to make as 'solar covered walkways system'. Table 2 shows the available roof and vertical facade areas for PV installation, after considering the architectural and solar application suitability. The total roof area is 11,020m^2 and vertical facade area is 2,290 m^2. It means that totally 1.58 MWp PV system can be installed, which can generate 2,168,572 kWh electricity per year, which is sufficient to cover all the energy demand of the proposed deck.

Figure 3 Possible PV installations on the buildings above the Green Deck

Table 2 Summary of PV installation on the Green Deck

Building	Potential area (m2)		System capacity (kWp)		Annual energy production (kWh/year)	
	Roof	Vertical facade	Roof	Vertical facade	Roof	Vertical facade
A	5,500	-	608.5	-	940,148.9	-
B	1,650	800	182.6	126.8	282,044.7	98,669.2
C	870	900	96.3	142.7	148,714.5	111,028.5
D	1,000	197	110.6	31.2	170,936.2	24,278.2
E	1,000	197	110.6	31.2	170,936.2	24,278.2
F	1,000	197	110.6	31.2	170,936.2	24,278.2
Sum	11,020	2290	1219.2	363.1	1,885,261	283,310.5
	13,310 m^2		1,582.3 kWp		2,168,572 kWh/year	

4. Economic evaluation of the PV application

The economic feasibility of the proposed photovoltaic application on the Green Deck has been evaluated using the levelized cost of energy (LCOE). The LCOE of a PV system can be calculated according to the following equation [8]:

$$LCOE = TAC / E_{load} \tag{2}$$

where TAC is the total annualized cost ($/year), which is the sum of the annualized cost of individual system components; E_{Load} is the total amount of electrical load that the system serves per year (kWh).

Therefore, the calculated LCOE of the PV installation on the Green Deck is 0.217US$/kWh, i.e. 1.681HK$/kWh. Currently, the general service tariff in Hong Kong is 0.973-1.206 HK$/kWh depending on the amount of electricity consumption and actual fuel cost of the power supply company [9]. However, with rising price of fossil fuels, the tariff would increase for about 5% annually. Therefore, the LCOE of the PV systems on the Green Deck is probably lower than the retail electricity price 5-10 years later, based on the fact of energy shortage and increasing price of fossil fuels. In addition, if considering the environmental cost (penalty associated with pollutant), the economic benefit of the PV systems would be much more significant.

5. Conclusions

In this study, energy consumption of the proposed Green Deck and potential of solar photovoltaic power generation has been investigated. To develop a real "green" deck, it is proposed to install solar PV modules on the future roofs and vertical façade of the buildings on the Green Deck and nearby PolyU's buildings for power generation. Based on our simulation, the grid connected solar PV system on the building roof and facade will cover 100% electricity demand on an annual average basis. In addition, this proposal of using renewable energy on the deck is evaluated to be economically feasible after considering future tariff increase and environmental factors.

6. Copyright

Acknowledgements

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