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Towards zero energy school building designs in Hong Kong

Siwei Lou*[a], Ernest K. W. Tsang[a], Danny H. W. Li[a], Eric W. M. Lee[a], Joseph C. Lam[a]

[a]*Building Energy Research Group, Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, China*

Abstract

The energy saving and electricity production schemes for a school building in hot and humid climate were studied by a building energy package eQUEST. High-performance building envelops, energy-efficient air-conditioning systems and lighting fixtures were employed to save energy consumption and building integrated photovoltaic (BIPV) panels were adopted to meet the energy needs. The annual electricity demand was 300 MWh, and 97.5% of it can be supplied by the vertical BIPV facades. Further PV installations on the roof can generate more electricity to balance the energy use. The results show that school block is possible to achieve the zero building energy consumption.

Keywords: Energy simulation; School Building; Zero energy building; Renewable energy

1. Introduction

Buildings account for 40% of worldwide energy consumption [1] and one-third of greenhouse gas emission [2]. Designing zero energy buildings (ZEB) has therefore become an international aim [3]. The general design strategies for a ZEB involve the minimization of energy use through energy-efficient measures and the renewable energy (RE) productions to meet the minimal energy needs. School buildings represent a significant part of building stock [4]. Currently, there are 572 primary schools and 506 secondary schools in Hong Kong (HK). With short school hours and long vacations periods, school buildings have potential to be ZEB with proper energy saving designs. To achieve zero energy, it is essential to accurately estimate the energy demands and PV energy production based on the readily accessible energy saving techniques and the available PV installation spaces on the building envelop.

Building-energy simulation programs are appropriate design tools to depict the trade-off between various design alternatives. The annual and monthly building energy requirements and renewable energy generations can be modeled by comprehensive computer simulations. Recently, the HK government has

*Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address:swlou2-c@my.cityu.edu.hk.

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issued several compulsory and voluntary building-energy codes [5] which accept computer simulations to illustrate compliance. This paper presents the energy saving designs of a school building, simulates the energy expenditures and discusses the findings and design implications.

2. Computer simulation approach

Energy performance of a building depends on the subtle interactions of many building features and building-services systems. Computer-based building-energy simulations are valuable design aid in giving a comprehensive picture of the building's energy-behavior and the trade-off alternatives in detail. The simulation tool employed in the study is the eQUEST building energy program [6] which builds on the well-validated DOE-2.2simulation program and contributes to various worldwide green building crediting schemes such as LEED and BEAM Plus.

The eQUEST package conducts hour-by-hour calculation, using 8,760 hourly records of measured weather data to analyze the heating and cooling loads, and calculates the energy consumptions. The meteorology, however, may vary year-by-year. The typical meteorological year (TMY) of Hong Kong developed using 30 years of reliable measured data [7] representing the typical year-round local climate was adopted for the building energy performance analysis.

3. Reference school building

The institutional building is a 6-story-school with total floor area of around 7,000 m². It has 30 classrooms in total, 2 computer rooms, 3 staff offices, a library, a lecture hall, a study room, a visual art room and several shops. Figure 1 presents the typical layout plan for the building. Table 1 lists out the occupant densities, fresh airflow rate and equipment densities for different areas according to the ASHRAE Standard 62.1-2007 [8], Hong Kong BEAM [9] and ASHRAE Handbook [10]. With an efficiency of 100 lm/m^2, the T5 fluorescent lamps can keep the power density of classroom (500 lux), staff office (300 lux) and assembly hall (200 lux) lower than the Standards [11]. High frequency daylight-linked dimming controls were used to reduce the lighting energy use [12, 13].

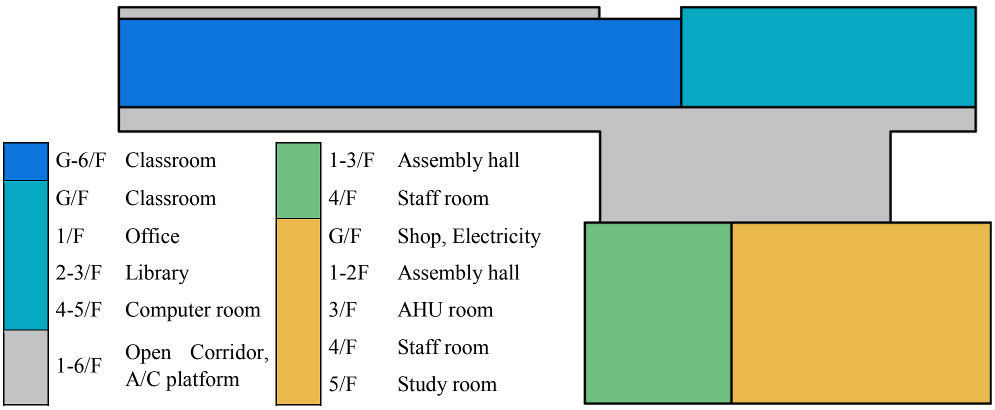

Fig. 1. The layout plan of building

Table 1. Areas of the building

Area	Area (m^2)	Space cooling?	Occupancy (m^2 $person^{-1}$) [8]	Equipment (W m^{-2}) [10]	Lighting (W m^{-2}) [10]	Fresh air (m^3 h^{-1}) [8]	Dimming?
School classroom	2,578	Yes	2.8	-	6.7	25	Yes
Computer classroom	363	Yes	3.7	21.5	6.7	25	Yes
Assembly hall	849	Yes	2.8	-	4	20	Yes
Staff office	644	Yes	9.3 [9]	10.8	4	29	Yes
Library	199	Yes	9.3	5.4	6.7	29	Yes
Stage	104	No	-	5.4	28	20	N
Shop	106	Yes	7.0	2.7	12	27	No
Changing	56	Yes	2.8	-	5	25	No
Corridor/Staircase	1,222	No	-	-	5	-	No
Toilet	563	No	-	-	8	-	No
Mechanical/Electrical	575	No	-	-	16	-	AHU room
Total	7,259		-	-	-	-	-

The floor-to-floor height is 3.6 m (5.4 m for G/F). The window-to-wall ratio (WWR) in north, east, south and west are 21.3%, 11.5%, 15.2% and 19.1%, respectively. Properties of the building envelop were assumed according to a previous study [14] and manufacturer catalogs [15] shown in Table 2.

Table 2. Parameters of building envelop

	U-factor (W m^{-2} K^{-1})	Reflectivity	Shading coefficient	Visible transmittance
Roof [14]	0.8625	0.5	-	-
Wall [14]	4.925	0.7	-	-
Window [15]	5.2	0.86	0.3	0.6
Window (coated by a-PV) [15]	5.2	0.74	0.18	0.27

Table 3. Description of HVAC system

Inputs	Specifications
Air-conditioner type	Split, Variable Refrigerant Volume (VRV)
Air-conditioner Coefficient of performance (COP)	3.70
Fan power	0. 1177 (W m^{-3} h)
Fan control	Constant volume
Zone set air temperature	25.5 (℃)
Zone entering minimum temperature	14.5 (℃)
Zone minimum air flow	9 (m^3 h^{-1})
Maximum outside air temperature for free-cooling	18.33 (℃)
Maximum outside air enthalpy for free-cooling	69.78 (kJ kg^{-1})

Table 3 specifies the settings of the air-conditioning. The split, direct expansion variable refrigerant volume (VRV) air-conditioners were installed in all classrooms as they are flexible to control in individual rooms. The VRV has no cooling tower and it can save space and avoid legionnaire disease. The assumed COP of 3.7 was slightly greater than the ASHRAE Standard 90.1 [11]. The zone air temperature was 25.5 °C based on the local recommendations [9] and the zone entering minimum temperature was 14.5 °C to keep an 11 °C difference from the zone air temperature [11]. Other settings followed the default of the software. During transitional and winter seasons, the outdoor air was introduced to cover the internal loads as free cooling for energy conservation.

The daily occupancy, lighting, and HVAC schedules were in accordance to the specifications in ASHRAE Standard 90.1 User's Manual [16]. Table 4 shows the local school holidays when there is no occupancy, no air-conditioning and minimum lighting in the building. The ASHRAE schedule assumes certain school occupancy after 17:00 and on Saturday, which is not common for primary and secondary schools in Hong Kong. Such setting may overestimate electricity uses for the local issues though represent a general condition.

Table 4. Holidays of the school

Month	Jan.	Feb.	Mar.	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Date	1	4 to 17	24 to 31	1, 4	2, 13	9, 27	1, 14 to 31	1 to 31	3, 28	1, 21	None	21 to 31

To meet the building power needs by renewable energy, photovoltaic (PV) panels were installed on the building facades and the roof. The PV systems were modeled using an in-built module of the eQUEST software. The produced electricity feeds to the grid over the entire year. Table 5 specifies the installed PV modules from the manufacturer catalogs [15, 17]. The crystalline Silicon PV (cS-PV) has larger efficiency than the amorphous PV (a-PV), while the latter is semi-transparent and applicable to assembly hall as fenestrations. Table 6 gives the area for PV installations, which accounts for 90% of the available areas. The areas of rooftop playground and green roof were not used for PV installation. The tilted PVs on the other roof areas can be elevated to save the roof space for other uses. The largest vertical PV areas are in south and north orientations.

Table 5. Electrical data under standard test condition

Parameters	Open circuit voltage V_{oc} (V)	Short circuit current I_{sc}(A)	Max power voltage V_{mp} (V)	Max power Current I_{mp} (A)	V_{oc} temperature coefficient (V/°C)	I_{sc} temperature coefficient (A/°C)	Area (m^2)
cS-PV	47.3	9.35	37.9	8.97	-0.32	0.05	1.94
a-PV	47	0.74	32	0.63	-0.28	0.09	0.72

Table 6. Area of the PV in different directions

Direction	North	East	South	West	22.3° due South (on the roof)	Windows in hall	Total
Total area (m^2)	1,272	501	1,309	276	660	156	4,174

4. Results and data analysis

Figure 2 gives the annual energy consumption and electricity production for the school building. The simulated annual energy use was 296.5 MWh. The energy for space cooling, lighting, equipment, and fans accounted for 47%, 32%, 11% and 10% of the total building energy consumption. The high lighting and low equipment power consumptions are because of the significant lighting needs and low office equipment use in school. The annual energy consumption per area was 40.8 kWh/m^2, which is less than the current benchmarks of 52 and 59 kWh/m^2 for primary and secondary schools [18].

The annual electricity generation was 407.9 MWh. The electricity production by PV panels installed in north and south directions and the titled PV in 22.3° due south represent 20.7%, 31.8%, and 29.1%, respectively. The power generated by the vertically installed PV panels was 289.2 MWh, which is 97.5% of the annual building electricity demand.

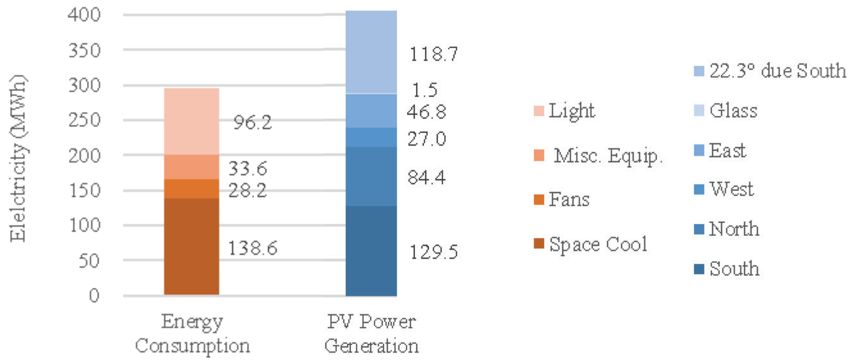

Fig. 2 the annual power consumption by building and generation by PV

Figure 3 shows the monthly electricity consumption by different energy consuming components of the school building. The largest energy consumption in June was due to the hot and humid summer in Hong Kong. The relative low energy needs in July and August were because of the summer holidays. The monthly fan, lighting, and equipment energy uses are in consistent with the monthly occupancy, which varies according to the holidays in different months. The minor variations of fan energy consumption were because of the similar monthly schedule and constant airflow volume.

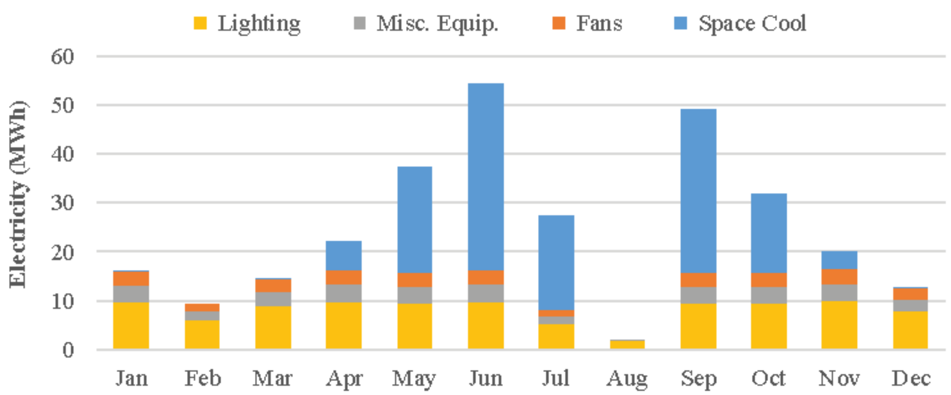

Fig 3. Monthly electricity consumption of different energy users in the building

5. Conclusions

The energy saving techniques are readily accessible from the present markets and can be implemented. The energy simulation shows that the annual energy consumption of a primary school is less than 300 MWh representing 41 kWh/m^2. The annual energy generated by vertically installed PVs can cover 97.5%

of the total building electricity use and more PV panel installations on the roof can balance the energy needs. The results could represent the primary and secondary schools with similar plans, occupant, lighting and equipment load densities and schedules. The findings show that the zero energy school building in the hot and humid climate is achievable by the high performance building envelop, efficient air-conditioning and lighting fixtures, and building integrated photovoltaic panels. Future works involving the analysis of life cycle cost, carbon savings and environmental benefits of the PV installations will be conducted.

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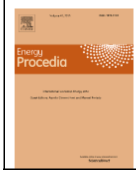

Biography

Siwei Lou is currently a Ph.D. candidate in Department of Architecture and Civil Engineering, City University of Hong Kong. His research areas include building energy conservation and solar radiation assessment.