Towards Low-Energy Factory Buildings (A Case Study)

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ABSTRACT

This paper presents a case study of a typically poor energy performing factory building singled out from nation-wide study on factory buildings for improving energy performance. Short term energy monitoring has shown that lighting system is the main energy consumer of landlord area energy usage in these naturally ventilated factory buildings. It aims to maximize significant energy performance upgrading opportunities in the lighting system and explore the use of photovoltaics to achieve low-energy factory buildings. This case study also serves as a platform for other poor energy performing factory buildings identified for low-energy retrofit.

KEYWORDS

Energy efficiency, low energy, industrial building, photovoltaics

INTRODUCTION

The success of high-rise industrial buildings housing light manufacturing processes is a hallmark of industrial developments in Singapore. This approach is now widely adopted by many Asian cities including China and India. This industrial building type is commonly known as the “flatted factory”. They are high-rise ready built multi-tenanted factories (typically 7-storeys high) designed for light industries. Frequently, they are developed in clusters owned and managed by the landlord or his agent, and tenanted to various small to medium size enterprises for light manufacturing, product processing and warehousing activities. Common spaces, shared amenities and services are maintained and operated by the landlord. In-depth study on energy performance of this building type is a step towards energy efficient development among industrial buildings.

Stemming from a previous energy benchmarking study on industrial buildings in Singapore (Chia & Lee, 2005), this paper presents a case study of a typically poor energy performing factory building singled out from the cohort of factory buildings for improving energy performance. It aims to maximize significant energy performance upgrading opportunities in the building systems and explore the use of photovoltaics to achieve low-energy factory buildings. The findings presented forms a part of a major study on Energy Performance of Industrial Buildings in Singapore funded by Jurong Town Corporation.

BACKGROUND

Extensive work around the world has been carried out to study the energy performance of office or commercial buildings. One of these includes a local energy survey carried out by Singapore Public Utilities Board in 1990 from end 1988 to end

1989 on 45 commercial buildings. In a recent study, Lee (2001) investigated 104 office buildings and developed a classification system to profile energy performance of office buildings in different performance levels. In the area of flatted factory buildings and with particular reference to the tropical context, there is no in-depth energy study conducted to date. Energy benchmarking studies conducted in the temperate region frequently focus on establishing process energy benchmarks by stage of production in the various industry sectors (NRCan, 2002; Industry, Science and Resources, 2000; Phylipsen et al, 2002), rather than examining the efficiency of the industrial building itself. In the case of flatted factories, the common spaces and amenities may be considered a major resource base similar to that of an industrial process or support services. It therefore requires careful study and benchmarking.

WHOLE BUILDING PERFORMANCE

The flatted factory building under study is first classified based on the "Energy Smart Tool" developed by Energy Sustainability Unit (ESU), a nation-wide statistical-based benchmarking tool which can be used to track energy performance of non-process load in industrial buildings in Singapore (Chia & Lee, 2005). Based on the previous energy study by Chia & Lee on industrial buildings, one of the poor energy performing factory buildings is identified for in-depth investigation and prioritized for significant energy performance upgrading and retrofitting. The energy efficiency standing of the building under study, as compared to a group of similar buildings, a Class III building with energy use intensity (EUI) of 12.94 kWh/m^3/year.

SYSTEM PERFORMANCE

To understand the detailed energy consumption breakdown by end uses, short-term energy monitoring is introduced for the twelve selected buildings across various energy classes. From the short-term energy monitoring, the main energy consuming system is determined. TEM-1, which stands for true energy meter-1, is specially developed for the measurements by Schafer Automation (Germany) and National University of Singapore (NUS) is used to monitor energy consumption for one week. TEM-1, with accuracy up to ±2.2%, measures true current and voltage, and output true energy consumption in real-time; power factor and form factor (for non-sinusoid curves) are automatically taken into account by this method. Short term energy monitoring has shown that the lighting system and vertical transportation system are the two main energy consumers in these naturally ventilated factory buildings. The major controllable energy consumer is the lighting system so more emphasis will be placed on the retrofit and recommendations analysis to improve the lighting system performance.

LIGHTING UPGRADES

The building under study currently uses T8 lamps conventional magnetic ballast. By replacing them with T5 lamps using electronic ballast, the energy savings of 17,082kWh can be achieved as demonstrated in Table 1. This works out to be an average reduction of 1,424kWh per month from the average monthly consumption of 15,389kWh, giving rise to about 10% energy savings. To attain low-energy factory buildings, other means needs to be explored. The following section presents the feasibility of harnessing solar energy to reduce the reliance on natural resources in a tropical city like Singapore.

Table 1: Energy savings for replacing T8 lamps using conventional magnetic ballast with T5 lamps using electronic ballast for 1 x 18W fluorescent fitting

s/n	Point of comparison	Calculation formula	Unit	Lighting System	
				Conventional Ballast	Electronic Ballast
A	No. of Luminaires		pcs	600	600
B	Configuration		W	*1 x 18W*	*1 x 14W*
C	Circuit wattage per luminaire		W	24	17.5
D	Annual hours burned		hrs	4380	4380
E	Total circuit wattage	A x C / 1000	kW	14.40	10.50
F	Annual energy consumed	D x E	KWh	63,072	45,990
G	Average electricity tariff		S$/kWh	0.21	0.21
H	Economic lamp life		hrs	5000	16000
I	Lamp replacement cost i/c lamp		S$	12	20
J	Annual energy costs	F x G	S$	13,245.12	9,657.90
K	Annual lamp costs	A x D x I/H	S$	6,307.20	3,285.00
L	Annual operating costs	J + K	S$	19,552.32	12,942.90
M	Annual savings		S$	0	6,609.42
	Saving as % of conventional ballast operation		%	0	34

APPLICABILITY OF PHOTOVOLTAICS IN SINGAPORE

Solar Radiation in Singapore

All of Singapore's electricity is produced with imported fossil fuels. Thus, in order to move a step forward towards a more self sufficient or sustainable city, a need to tap into the inexhaustible source of energy would seem to be a reasonable option.

As stated earlier that Singapore is located near to the Equator, the sunlight over the island can be considered vertical on a horizontal surface sometimes. Besides having a mean annual global radiation of 1627.9kWh/ m^2 more than 300 days of a year have their mean annual daily solar radiation greater than 3kWh/m^2 which allows for efficient use of photovoltaics (Rao, 1987). However, one problem exists, that is, Singapore has a rather high percentage of cloud cover. On the other hand, this does not deny the fact that Singapore has a number of favourable conditions for the application of building- integrated photovoltaics.

The paramount consideration in photovoltaic design is the knowledge about the solar irradiance on a specific site. Therefore, hourly data will be necessary so as to consider the maximum and minimum radiation of a day, and also on a monthly basis. Data of more than 10 years will be used for this purpose.

Table 2 shows the mean daily global and diffuse solar radiation for clear and average days in Singapore; this is based on 10 years averages and is in MJ/m^2/d (the original unit taken from the data by Rao, 1987). As shown, on clear days, the annual mean value of daily diffuse radiation is 4.31MJ/m^2/d. The diffuse component accounts for about 18% and 43% of the global radiation for clear days and average days respectively. Clear days are days with more than 9 hours of sunshine and those less than 3 hours of sunshine are considered overcast.

Table 2: The mean daily global and diffuse solar radiation on a horizontal surface for clear and average days in Singapore (Rao, 1987)

Month	Clear days			Average days		
	Global MJ/m^2/d	Diffuse MJ/m^2/d	Ratio of diffuse to global	Global MJ/m^2/d	Diffuse MJ/m^2/d	Ratio of diffuse to global
Jan	23.71	4.18	0.176	16.08	6.85	0.426
Feb	25.09	4.38	0.175	17.5	7.11	0.406
Mar	25.54	4.48	0.176	17.85	7.18	0.402
Apr	24.69	4.42	0.179	16.85	7.16	0.425
May	23.26	4.28	0.184	15.74	6.77	0.43
Jun	22.53	4.2	0.186	15.62	6.5	0.416
Jul	23.07	4.25	0.184	16.24	6.58	0.405
Aug	24.41	4.39	0.18	16.06	6.91	0.43
Sept	25.25	4.47	0.177	16.31	7.14	0.438
Oct	24.83	4.38	0.177	16.12	7.25	0.45
Nov	23.62	4.22	0.179	14.69	7.17	0.488
Dec	22.93	4.1	0.179	13.72	7	0.51
Annual Mean	24.08	4.31	0.179	16.06	6.97	0.434

To achieve the total solar radiation on a horizontal surface for a chosen day of a month, the unit MJ is converted into kWh (1kWh=3.6MJ) and only global solar radiation is considered. Refer Table 3 for total solar radiation on a horizontal surface in kWh/m^2 for clear and average days in Singapore.

Table 3: Total solar radiation on a horizontal surface in kWh/m2 for clear and average days in Singapore (Author's own)

Month	Total For Clear days kWh/m2	Total For Average days kWh/m^2
Jan	6.59	4.47
Feb	6.97	4.86
Mar	7.09	4.96
Apr	6.86	4.68
May	6.46	4.37
Jun	6.26	4.34
Jul	6.41	4.51
Aug	6.78	4.46
Sept	7.01	4.53
Oct	6.90	4.48
Nov	6.56	4.08
Dec	6.37	3.81
Average daily solar radiation	**6.69**	**4.46**

Integrating Photovoltaics in Industrial Buildings

By performing energy-efficient lighting upgrades, energy consumption for the lighting system is reduced. To adequately meet the industrial landlord's low energy target, further reduction of energy consumption can be achieved by incorporating the use of photovoltaics (PV). Coupled with the gradual fall in the cost of photovoltaic panels, it is most promising to harness solar power in a tropical country with constant overhead sunlight all year round like Singapore. The feasibility of implementing PV systems in buildings in Singapore is examined from two aspects, (1) energy savings and (2) the economics (life-cycle costing) of introducing the photovoltaic system into the factory building.

Life Cycle Cost (LCC) is defined as the sum of the Present Worths (PWs) of all components in the PV system. LCC takes into account all costs associated with the PV system over its lifetime. LCC helps to determine if the choice is economical. To calculate the LCC, the following assumptions must be made.

Assumptions

- PV modules mounted horizontally on a roof to maximize solar radiation
- No self-shading/shading by surrounding buildings.
- 75W crystalline silicon modules, efficiency of 13% with area of 0.6324m^2 is used
- Life span of PV system is 30 years
- Annual inflation rate (i) is 1% & Discount rate (d) is 10% in Singapore
- Roof space of 800 m^2
- A conservative value for average daily solar radiation of 4.46 kWh/ m^2 is used
- Cost of 75W PV module is S$750 (price provided by local company)

Energy Generated by PV system

Energy produced by PV systems per day
= surface area x 13% x average daily solar radiation   Eqn 1
= 800 m^2 x 13% x 4.46 kWh/m^2 = 463.84 kW

Life Cycle Costing (LCC) of PV system

Cost of PV modules = Number of modules on roof x S$750   Eqn 2
= (800 m^2/0.6324m^2) x S$750 = S$948,767

Table 3: Life Cycle Costing of PV system

LCC of PV System			
Component	**Initial Cost (C_o)**	**Present Worth Factor (Pr)**	**Present Worth (PW)**
PV Modules	S$948,767	1	S$948,767
Inverter	S$4,000	1	S$4,000
Inverter 5 yr	S$4,000	0.652594551	S$2,610
Inverter 10 yr	S$4,000	0.425879648	S$1,704
Inverter 15 yr	S$4,000	0.277926737	S$1,112
Inverter 20 yr	S$4,000	0.181373474	S$725
Inverter 25 yr	S$4,000	0.118363341	S$473
Annual Maintenance	S$100	10.35538107	S$1,036
LCC			**S$960,427**

Annualized Life Cycle Cost (ALCC)

This is the total LCC expressed in terms of cost in a year. However, the LCC cannot be simply divided by the number of years as this takes no account of the change in value of money due to inflation and interest rates.

ALCC = LCC / Cumulative Present Worth Factor   Eqn 3
= S$960,427 / 10.355 = S$92,750

Unit cost of electricity

Elec. Cost (S$/kWh)= ALCC (S$/year) / Energy supplied (kWh/year)   Eqn 4
= S$92,750 / (463.84 kW x 365) = S$0.55 per kWh

CONCLUSION

In comparison with similar building types, the flatted factory building under study is found to be a Class III building that warrants attention to identify retrofit potential. As such, detailed energy monitoring building systems is conducted to further understand the energy performance of industrial buildings. Lighting and lift systems are found to dominate the energy consumption in flatted factory buildings. It should be noted that lift energy management is largely left to the lift vendors who are the only people experienced enough with their own products to tune the lifts to their most efficient operating levels. Lift codes also prohibit building owner intervention in the existing lift control systems. Thus, lighting system has the highest potential for energy savings. By performing a upgrade from T8 lamps with conventional ballasts to T5 lamps with electronic ballasts, energy savings of 10% can be achieved. With an aim to build a low-energy building, most of the electric energy, if not all, can be produced by photovoltaic installation, as illustrated above. The reasonably acceptable payback period of about 20-30years and highly favourable climatic conditions that can maximize the use of photovoltaics, integrating PV systems into a building becomes a viable solution towards environmentally friendly building with little or no energy bill.

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