CONSTRUCTING A ZERO ENERGY BUILDING

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ABSTRACT

In 2006, the Singapore government revealed its 1st Green Building Master Plan outlining its plan to promote environmental sustainability. The Building and Construction Authority is tasked to lead the construction industry towards this goal. Apart from setting up the framework to encourage the local players to construct sustainable buildings, BCA also took the initiative to construct the first Zero Energy Building in Singapore as a showcase for the local construction industry to learn and study. Besides consuming zero energy, this building also incorporates the latest state of the art technologies, e.g. stacked assisted solar chimney system and personalised ventilation system, into the building for further test-bedding purpose. Hence, given its technical complexity and as a first in Singapore, the process of realising this project has its challenges. This paper highlights these challenges and some of the lessons learnt from the construction of this Zero Energy Building.

Keywords: Environment, Singapore, Sustainability, Zero energy building.

INTRODUCTION

The Building and Construction Authority (BCA) introduced the Green Mark Scheme, a green building rating tool, in January 2005 to encourage the construction industry to construct environmental friendly buildings (BCA, 2009). The scheme provides the framework for Singapore's 1st Green Building Masterplan which was launched in 2006 to promote environmental sustainability in buildings based on the following strategies (BCA, 2009):-

1. Incentives for the Private Sector
   A $20 million Green Mark Incentives Scheme to encourage the private sector to construct above Green Mark Certified Buildings.

2. Promoting Research and Development (R&D) in Environmental Sustainability
   A $50 million Ministry of National Development (MND) Research Fund for the Built Environment to spur and promote research into developing more viable and cost-effective green building technologies and energy efficiency solutions.

3. Imposing Minimum Standards on Environmental Sustainability for Buildings
   The Singapore Building Control Act was amended to meet Green Mark Certified standard.

4. Building up Industry Capability
   The BCA Academy (BCAA) to offer Green Mark Manager and Green Mark Professional Course to train the professional to design and operate green buildings.

In response to the Green Building Masterplan and to promote R&D in environmental sustainability, BCA and the National University of Singapore (NUS) took the initiative to construct a Zero Energy Building (ZEB) as a showcase project for the local construction industry to learn and study.

DEFINITION OF ZERO ENERGY BUILDING

Torcellini et al. (2006) commented that the key principle of a ZEB model is that the 'buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, (and) renewable sources'. This implies that a ZEB should be able to generate adequate renewable energy on site to match or surpass its annual energy use (Torcellini et al., 2006) to achieve net zero energy consumption and/or zero carbon emission.

However, Torcellini et al. (2006) also stated that an efficient ZEB design 'should first encourage energy efficiency, and then use renewable energy resources available on site'.

ZERO ENERGY BUILDING @ BCA ACADEMY

Project Description

Zero Energy Building @ BCA Academy is part of BCA's initiative to promote sustainable construction. The joint BCA-NUS research project involves retrofitting an existing 3-storey building at BCA Academy to become a zero energy building and to test-bed the following Green Building Technologies (GBTs):-

- Photovoltaic (PV) System;
- Light Pipes;
- Mirror Duct System;
- Light Shelves;
- Vertical Greening;
- Roof Garden;
- Personalized Ventilation System;
- High Performance Glazing;
- Solar Assisted Stack Effect Ventilation System; and
- Building Management System (BMS).

Project Team

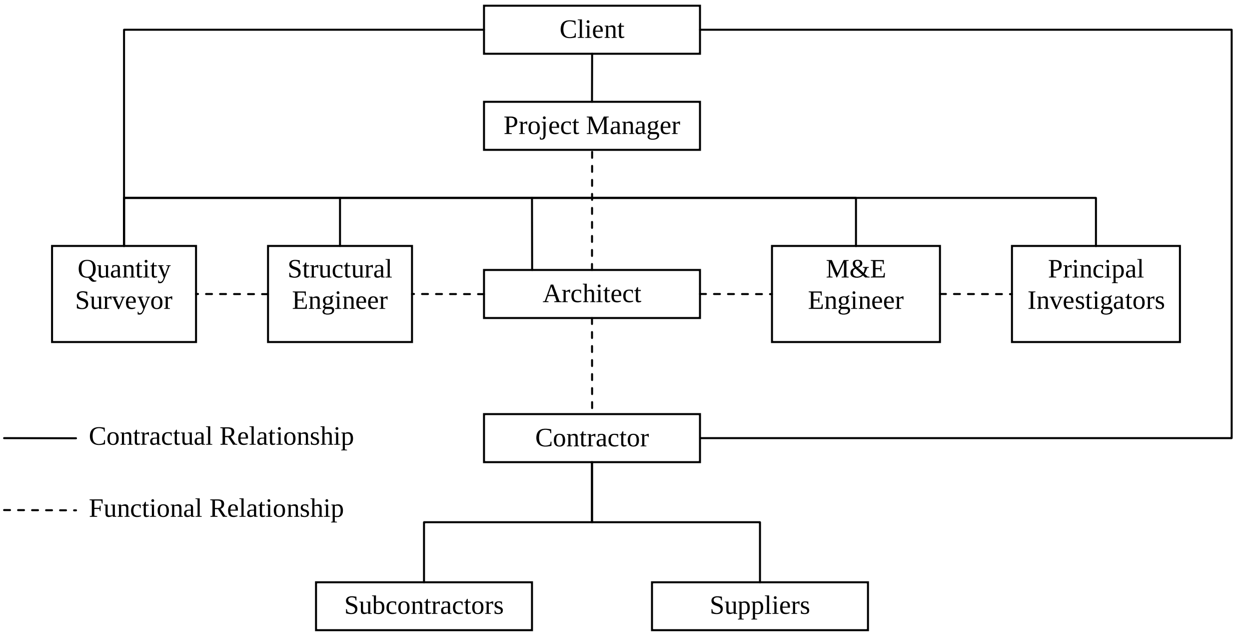
The project team consists of the following parties:-

Client	:	Building and Construction Authority (BCA)
Principal Investigators	:	National University of Singapore (NUS) • Solar Energy Research Institute of Singapore (SERIS) • Centre of Total Building Performance
Project Manager	:	Beca Carter Hollings & Ferner (Southeast Asia) Pte Ltd

Architect	:	DP Architects Pte Ltd
Structural Engineer	:	Beca Carter Hollings & Ferner (Southeast Asia) Pte Ltd
Mechanical and Electrical Engineer	:	Beca Carter Hollings & Ferner (Southeast Asia) Pte Ltd
Quantity Surveyor	:	Davis Langdon & Seah Singapore Pte Ltd
Contractor	:	ACP Construction Pte Ltd

The structure of the project team is as illustrated in Figure 1: Project Team Structure. As shown, the project manager acts on behalf of the client to manage and coordinate the project team.

Figure 1: Project Team Structure



The Principal Investigators (PIs), the experts in the field of sustainability, lead the architects and the engineers to design a zero energy building. The framework of the Works is determined through a series of workshops and technical meetings.

The quantity surveyor appraises and monitors the cost of the project.

The contractor constructs the building.

Procurement

The Zero Energy Building @ BCA Academy is the first of its kind in Singapore. Besides being a zero energy building, BCA and NUS are conducting research and test-bedding state of the art technologies.

Given its unique status and the project requirements, the project team decided to procure the building based on design-bid-build. This is to ensure that the project team is able to control the quality of the building and the contractor is able to construct the building according to the specifications.

This procurement method also facilitates the transfer of knowledge on sustainability design and concepts from the PIs to the consultants and the contractors.

Features

As a net zero energy building, this building generates its own source of energy onsite via the photovoltaic system. The energy generated will be used to power the building and excess energy will be supplied back to the grid. As a showcase project, other GBTs are also installed onsite for research purpose. The GBTs are:-

Photovoltaic (PV) System

Photovoltaic (PV) is a form of clean renewable energy that generates electric power by using solar cells or photovoltaic cells. These cells are joined to form photovoltaic modules and arranged into arrays to convert the sunlight into electricity (Solar Energy Technologies Program, 2005).

For this project, the 1st Generation monocrystalline / polycrystalline / multicrystalline PV modules, the most efficient solar technology at present, are installed on the roof to generate 90% of the required electricity for the building. Concurrently, the PIs also installed 2nd Generation amorphous thin-film laminate PV panel and 3rd Generation dye-sensitized thin-film solar cells on other parts of the facade to study the feasibility of integrating these thin-film PV panels into part of the façade.

The performances of these cells are currently being monitored real-time on ZEB site.

Advanced day lighting system

As part of the energy efficiency strategy, the design team has proposed the following daylight systems to be incorporated into the design of the building:-

- Light Pipes

  Two types of light pipes, i.e. with and without solar tracking device, are installed on the roof of ZEB. Apart from testing the effectiveness of vertical light pipes in transporting natural daylight into the building, the team is also testing the effectiveness of the solar tracking device, a device that tracks the position of the sun to adjust the angle of the reflective mirror panels to reflect the maximum amount of sunlight throughout daytime (Solar Tracking Skylights, Inc., 2010).

  It is projected that with daylight being transported deeper into the building, there will be lesser dependence on artificial lightings which could translate into considerable energy consumption saving.

- Mirror Duct System

  The mirror duct system works based on same principal as the light pipes albeit via horizontal means. The PIs have also taken the opportunity to test out three different types of reflective materials i.e. aluminium alloy, mirrored acrylic and mirrored polycarbonate.

- High Performance Glazing

  As part of an efficient passive solar building design, the selection of the glazing is essential to maintain the balance of daylight and solar heat gain permissible into the building. Four types of high performance glazing, i.e. low-emissivity (low-e) glass, electrochromic glass, BIPV glass and glass with internal blinds, are installed on the 1st storey west façade to test effectiveness of these glazing in reducing solar heat gain and transmitting daylight into the building in local climate.

- Light Shelves System

  Light shelf, an architectural element with mirror finish panel, is installed on the west façade to reflect the daylight deeper into the building. A sunshade is added to the system to reduce emission of glares into the building.

Roof Garden and Vertical Greenery System

The concept of integrating greenery with the façade is not novel. Studies by Wong et al. (2007) and Wong et al. (2010) have shown that rooftop / vertical greenery systems are able to reduce thermal heat transfer into the building which in turn reduces energy consumption. As part of the passive design study, three types of vertical greenery system, i.e. unit panel system, unit system and panel with support frame system, are installed. Different species of plants are also planted to study the suitability of the plant to be planted on the façade.

Personalized Ventilation System

The objective of personalised ventilation is to improve the quality of inhaled air and the thermal comfort of each occupant (Schiavon, et al., 2009). This can be achieved by allowing the occupants to control the air distribution rate and temperature within their working zone through a personal air supply devices installed on their working desks. The efficiency and the potential cost and energy saving benefits of the systems are currently being studied in ZEB.

Solar Assisted Stack Effect Ventilation System

The design of the solar assisted stack effect ventilation system consists of solar chimneys installed on the roof of ZEB with vertical ducts that are connected to the indoor air space via louvered openings. This is an innovation passive design solution proposed by the PIs to enhance natural air movement inside the building 'utilising buoyancy principle' (Wong and Heryanto, 2004) to remove warm air from the building to reduce demand for mechanical ventilation.

Building Management System (BMS)

A building management system is installed onsite to monitor and control the performance of the building. Sensors are mounted at various locations to collect data on energy consumption, indoor environment quality, management control and special systems. The data collected will be used to assess the performance of the GBTs installed onsite.

Challenges

The Zero Energy Building @ BCA Academy is the first net zero energy building in Singapore. Without prior example to inspect, the project team has to deal with the uncertainties and challenges brought on by the never-been-tested technologies.

Complexity of project

As a test-bedding project, the structure of the project team has been expanded to include the PIs. The PIs, the champions of the project, have to convey their ideas and requirements to the project team.

To bridge the gaps between the PIs and the consultants, the project manager therefore plays a vital role in managing the team to ensure that effective communication network is established. This is to promote the exchange of information among the team members and to minimize confusion over roles and duties of the respective parties. This is of essence to the success of the project when new products, e.g. mirror ducts, solar assisted stack effect ventilation system and personalised ventilation system, are to be incorporated into the design of the building.

Product uniqueness

The GBTs featured in ZEB are state-of-the-art technologies in local context. Prior to ZEB, there are no or very few tried and tested examples in Singapore for the project team to review. Some of the proposed GBTs are so novel that that the contractor has to either procure the products, e.g. solar tracking light pipes and electrochromic glass, from overseas suppliers or to fabricate the products, e.g. light shelves and solar assisted stack effect ventilation system.

The project manager has to take into consideration of the above factors in planning the schedule of the project as the absence of the products in local market will imply longer lead time to procure the items. In some instances, the contractor also required longer time to review and develop the details of the proposed GBTs which might not be available at the tender stage.

Further to the above, the project team also has to take into consideration that the overseas suppliers might not be able to provide warranties and indemnities for their products and the contractor might not be able to warrant or indemnify the performance of the customised GBTs.

Cost

During the design development stage, the quantity surveyor faced the challenge of allocating sufficient budget for the proposed GBTs as there were no or limited cost information available in local context. The quantity surveyor has to contact specialists or overseas suppliers for cost advice. The accuracy of the cost will depend on the adequacy and availability of information. For quotations that are in foreign currencies, the quantity surveyor has to exercise extra care to account for the differences in exchange rates and to include the shipping and training cost related to the products. Proposals that are too expensive were removed from this project.

Concurrently, the PIs and the quantity surveyors also checked on the products' procurement period and the suppliers' track records and ensured the products comply with local codes.

Specifications

At the tender stage, the PIs and the consultants faced challenges while preparing the specifications for the proposed GBTs. Very often, the PIs and the consultants would have to liaise closely with the suppliers to obtain adequate information to draft the specifications. In some instances, the PIs may have to draft the specifications based on performance requirements e.g. solar assisted stack effect ventilation system and task lightings.

Bearing in mind that some of the proposed GBTs have never been tested locally, the PIs and the consultants have to ensure that their specifications are able to reflect the design intent and to integrate with the other systems. The project team would also have to ensure the adequacy of the indemnities and warranties for the performance of the proposed GBTs, not withstanding the fact that the GBTs are meant for research purpose.

Construction

The proposal for ZEB @ BCA Academy is to retrofit one of the existing blocks to be zero energy building. During construction, the other blocks are in operation. The contractor has to work within restricted hours and to take extra care to minimize noise pollution. As a showcase project, BCA also demonstrated its commitment to sustainable construction by stipulating environmental friendly site management clauses in the contract.

Time is critical in the planning of the programme. The Contractor has to schedule for the timely delivery of the overseas products and the customised products to ensure the building is completed within the contract period.

However, the most critical task for the project team to accomplish is to achieve net zero energy consumption. During the construction, the contractor has to work very closely with the subcontractors, the suppliers and the consultants to fine-tune the designs of the proposed GBTs to derive the best solutions to meet the objective of balancing onsite energy consumption with onsite energy generation.

CONSTRUCTION COST

The contract is awarded based on $10,468,213.08. The photovoltaic system accounts for 18.42% of the contract sum. The other GBTs accounts for 14.54% of the contract sum.

Incremental Cost

In total, there is 33% increase in the construction cost due to the GBTs (including the PV system). However, it should be noted that this is test-bedding project. The higher cost is attributed by the following factors:-

- Economic of scale

  The scope of work is too small to achieve economic of scale.

- R&D elements

  Some of proposed GBTs are not readily available in the market. The suppliers and the subcontractors have to fabricate the products, e.g. light shelves and mirror ducts, for this project. There is a premium attached to this service.

- Risks and uncertainties

  The contractor bears the risks to ensure the constructed and installed GBTs are able to perform as per specified, notwithstanding the fact that the design responsibilities lies with the consultants. Subject to the above understanding, the contractor is likely to have priced in the risk factors in the tender price.

The unit costs of the GBTs installed in ZEB @ BCA Academy are shown in Table 1.

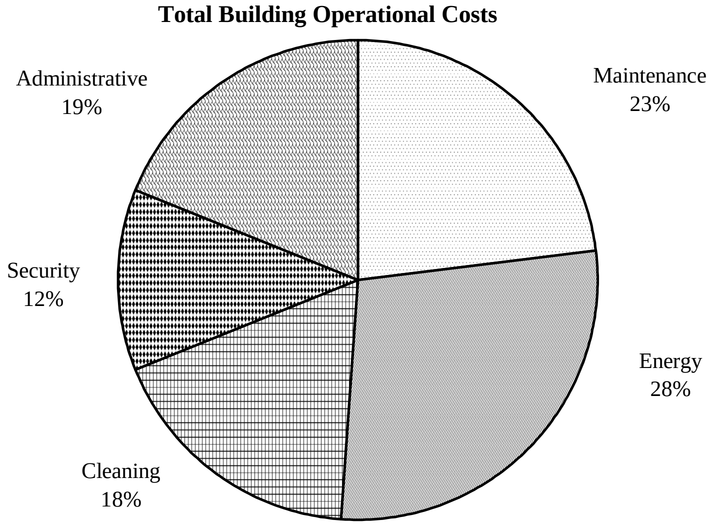
Table 1: GBTs Unit Cost

GBTs	Cost / unit ($)
Photovoltaic (PV) System (inclusive of Balance of System)	1,500 /m2
Solar Assisted Stack Effect Ventilation System (3m high solar chimney with 32m long ventilation ducts)	48,845 /set
Light pipes (inclusive of extension tube) • Solar Tracking Skylights (1000mm dia) • Solatube (530mm dia)	 15,000 /unit 7,500 /unit
Mirror duct system (1500 x 615 x 10900mm)	27,500 /unit
Light shelves system including frame and accessories (1200 x 890mm internal light shelf and 1200 x 1050mm external light shelf)	15,000 /set
Vertical greening	1,500 /m2
Roof garden	900 /m2
Personalized ventilation system	1,750 /set
Electrochromic glass	10,000 /m2
PV glass	1,500 /m2
Glass with internal blinds	2,700 /m2
Low emissivity glass	180 - 200 /m2
Underfloor displacement system	Depend on model and specification
BMS	250 /m2
WC with integrated basin	230 /set
Waterless urinal	700 /set

Life Cycle Costing / Projected Savings

In a typical commercial building, almost 30% of the operating costs are spent on energy (Knox, 2008) as illustrated in Graph 1:

Graph 1: Total Building Operating Expense



Payback Period for Photovoltaic System

An analysis of the payback period for the photovoltaic system is shown in Table 2. We have discounted the 2nd and 3rd Generation PV system from the analysis as these PV modules are meant for research purpose.

Table 2: Payback period for PV system

Parameter	**ZEB**
Capital Cost	
● PV Modules*	S$867,233.00
● Balance of System	S$738,104.00
Projected annual energy generation	190MWh/Yr
Projected cost saving based on the proposed PV system (based on 19.29 cents/kwh)	S$100 / day
	S$36,651 / year
Payback Period	44 years (without government subsidy)
	20 years (with government subsidy)

* The PV modules are funded by Economic Development Board of Singapore

As shown, the payback period for the whole system can take up to 44 years without government subsidy. This is due to the high cost associated with the production of the PV modules with current technology. In the future, the PV modules could be manufactured as Building Integrated Photovoltaic (BIPV) which can replace the traditional materials for façade. The PV manufacturers are also researching on possible means to lower production cost and to enhance module efficiency of the non-crystalline silicon PV modules.

Impact of PV System on Energy Cost

The PV system installed on ZEB @ BCA Academy is suffice to power the whole building without the need to tap onto any electricity form the utility power grid. This could translate to 30% of the operation cost. However, it should be noted that the potential saving generated by the PV will depend on the size of the PV system designed for the proposed building.

CONCLUSION

After 10 months of construction, the ZEB @ BCA Academy was launched to the public on 26 October 2009 which coincided with the International Green Building Conference 2009.

The success of ZEB @ BCA Academy is attributed to the project team's willingness to cooperate and embrace new technologies. With positive attitude, the project team is able overcome the challenges posed by the GBTs and the pressure to achieve net zero energy consumption. In the long run, this spirit could be spread to the industry and promotes the growth of innovative green construction.

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