ACHIEVING ZERO CARBON FOR BUILDINGS IN A DENSELY POPULATED CITY AND A SUBTROPICAL CLIMATE

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Abstract

In Hong Kong, the buildings consume most of the energy and are the major contributor to the Green House Gas (GHG) emissions. GHG emission reduction requires rethink of the planning and design processes as well as behavioral changes. Construction Industry Council (CIC), as the construction industry coordination body in Hong Kong, has developed the ZCB, the first zero carbon building in Hong Kong. The main objective of the ZCB is to showcase the state-of-the-art eco-building design and technologies to the construction industry locally and internationally as well as to raise the awareness of low carbon living in Hong Kong. The ZCB integrates the state-of-the-art design and technologies within the context of a high density city and the sub-tropical climate. This paper presents the technologies, the energy strategy and the carbon strategies of the ZCB and highlights the importance of the behavioural changes as well as technologies in achieving the zero carbon emissions.

Keywords: *zero carbon building; zero energy building; passive design; active systems; renewal energy generation.*

1. INTRODUCTION

Buildings in HK account for 90% of electricity consumption and 60% of Green House Gas (GHG) emissions. Therefore, buildings are both a challenge and an opportunity for reducing GHG emissions, and the construction industry has a significant role to play in GHG emission reduction.

To this end, Construction Industry Council (CIC), as the construction industry coordination body, has undertaken a number of initiatives including the development of the ZCB (in collaboration with the Hong Kong Government), the first Zero Carbon Building in Hong Kong.

The ZCB aspires to showcase the latest eco-building design and technologies applicable to Hong Kong which is of a high population density in the subtropical climate, and to serve as an education centre to inspire positive behavioural changes towards low carbon living.

Completed in June 2012, it covers a total land area of 14,700 square metres surrounded by high rise office buildings. It is a 3-storey building with the following facilities and components:

- An indoor exhibition and education area to show case the latest zero/low carbon design and technologies
- An eco-home to promote low carbon living
- An eco-office for staff
- An eco-café to promote low carbon living
- A multi-purpose hall for conferences, seminars, exhibitions and corporate functions in a zero carbon environment
- A public green leisure space, which can also be used for outdoor exhibitions and events
- Hong Kong's first urban native woodland to promote biodiversity
- A ring path to demonstrate the concept and principles of "One-planet Living"

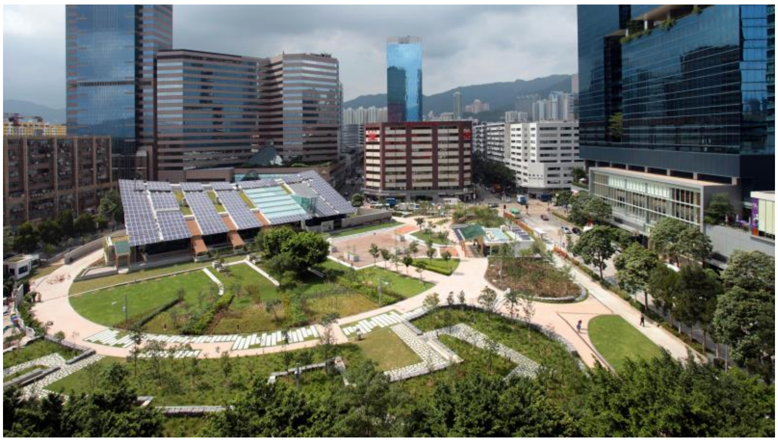

Figure 1 Perspective View of ZCB

2. KEY DESIGN PRINCIPLES

The main consideration in planning for the above components was to create a real use building blended with the environmental design and latest technologies.

Being in the subtropical area, Hong Kong's summer is long (May to October), hot and often humid. Afternoon temperatures frequently exceed 31 Degree C. The remaining months of the year are generally considered pleasant. As such building energy consumption peaks in summer due to air-conditioning. Keeping the buildings cool whilst minimising energy consumption in summer is the focus of the design consideration.

In responding to the aspirations set for this project, the following 4 “E” principles were adopted:

“Experimental” – The ZCB shall be an experimental ground for the latest eco-building design technologies. Over 80 different environmental features and technologies are showcased in the ZCB. Most of the technologies are new. Some of them are used for the first time in Hong Kong such as the combined cooling, heating and power generation system running on the biofuel reprocessed from waste cooking oil. Whilst not all are essential to achieve the zero carbon emission target of the ZCB, they all serve the purpose of showcasing how the technologies work in practice.

“Evolving” – Technologies evolve fast. The ZCB is designed to have as much flexibility as possible for upgrade with the future technologies. Examples include the easy installation of the photovoltaic panels, easily upgradable eco-home and interactive displays in the mezzanine floor, and the adoption of a plenum floor system which houses all utility conduits and cables.

“Evaluation” – As not all technologies adopted have been proven in Hong Kong, evaluation of those design and technologies in terms of capital costs, operation costs, energy saving and carbon reduction would provide valuable information for promoting their wider application to the construction industry in Hong Kong. Accordingly, over 2800 sensors are installed throughout the building to record and monitor the key environmental performance parameters, such as CO_2, temperature, humidity, renewable energy generation, energy consumption, energy import from the city grid, surplus energy export and light level. That information is constantly fed into a Building Management System for recording, analysis, reporting and optimisation of building system performance.

“Education” – Even with the best design and all the latest technologies, it is still the people who use the buildings matter most in terms of energy saving and reducing carbon emissions. Much of the emphasis of the ZCB during the operation stage is education, particularly for the younger generation. Three sessions of guided tours are provided each day to the public with interactive displays to explain the design strategies, rationale and benefit of the key design features and technologies adopted.

3. Carbon Strategy

The ZCB has its mission in carbon neutrality. That is, the building has net zero consumption of energy generated from fossil fuel. The energy needed for its operation is provided by renewable sources on site. The building is connected to the city grid for exporting surplus renewable energy and when needed, for importing electricity from the city grid. Production of on-site renewable energy offsets the power consumed from the grid on an annual basis.

The ZCB also goes beyond the common definition of a Zero Carbon Building by exporting surplus renewable energy to the local grid to offset the embodied carbon of its construction process and major construction materials. Figure 2 illustrates the carbon strategy based on the life cycle analysis of the ZCB.

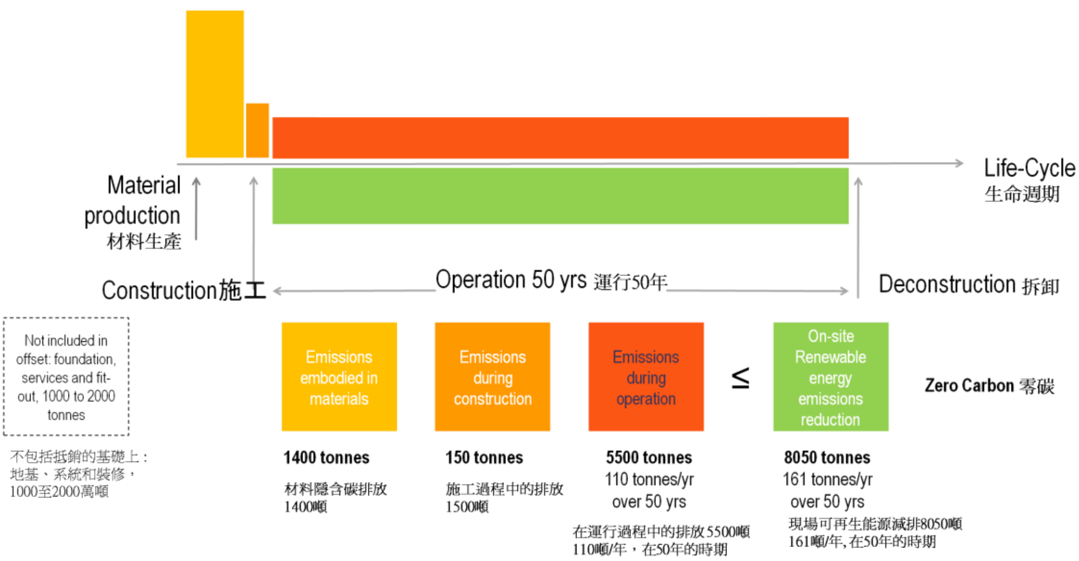

Figure 2 Illustration of Carbon Strategy

In order to minimize the embodied carbon, much effort went to the selection of the low carbon construction material and the low carbon construction method. Examples include the opting out for the reinforced concrete structure rather than the steel structure for the building, use of the timber and bamboo for the floor, fair faced external concrete wall and balanced cut and fill in the site formation. Table 1 summarises the comparison of the embodied carbon of the ZCB as compared to the scenario of the current standard practice.

Table 1 Reduction of the Embodied Carbon as Compared to the Current Standard Practice

	Benchmark Embodied CO_2 (tonnes)	**Embodied CO_2 of ZCB (tonnes)**	**Reduction**
Construction Process	2200	150	30%
Material Use		1400	

4. ENERGY STRATEGY

The design process of the ZCB adhered to an energy hierarchy as illustrated in Figure 3. The corresponding key passive design features and active systems of the ZCB are illustrated in Figure 4.

The current best practice - Code of Practice for Energy Efficiency of Building Services Installation, also referred to as Building Energy Codes, was used as a starting point.

Passive design opportunities for reducing the reliance on mechanical systems were then explored. The most noticeable passive design features in the ZCB are the maximal use of the natural ventilation and natural lighting and the optimal use of thermal insulation. The maximal use of the passive design measures leads to a reduction in energy needs by about 20%, compared to the benchmark of the Building Energy Code.

The electrical and mechanical systems of the highest efficiency (also referred to as active systems) were selected. Main examples are the floor cooling system combined with radiant cooling from the ceiling, high volume low speed ventilation fans, separate cooling and humidity removal systems, active skylights and light tubes. The adoption of those active systems lead to another 25% energy saving compared to the benchmark of the Building Energy Code.

Finally, the essential energy need is met through the on-site generation of electricity from the renewable sources. At the ZCB, 60% of the energy need is met by the electricity generated from the solar panels. A tri-generation system provides another 110% of the energy needs, using waste cooking oil. As such, about 100 MWh/year surplus electricity is expected to be exported to the city grid, which is used to offset the embodied carbon over a period of 50 years.

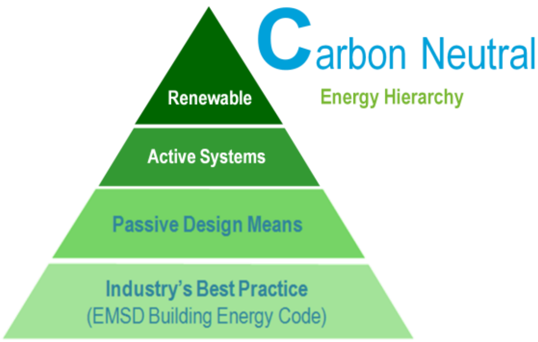

Figure 3 Illustration of Energy Strategy

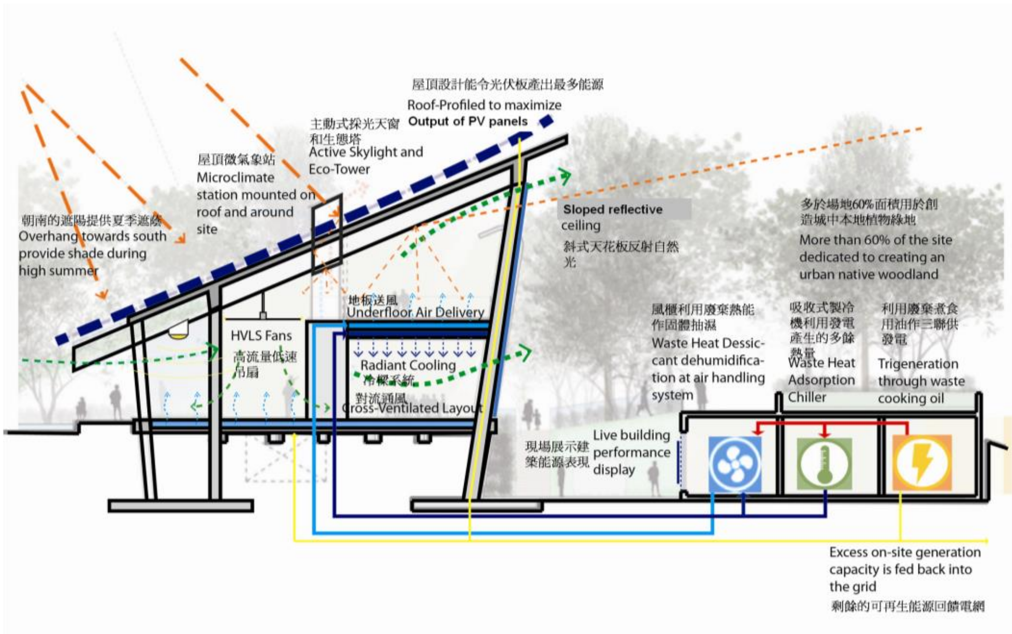

Figure 4 Key Passive Design Features and Active Systems of ZCB

5. KEY PASSIVE DESIGN FEATURES

Passive design refers to a design approach that uses natural elements to heat, cool, or light a building. The key passive design features of the ZCB are illustrated through the optimal use of natural ventilation, natural lighting, solar shading and thermal insulation, which are further described in the following.

Optimization of Building Orientation and Form

The orientation and shape of the building represents an optimised shape according to the local microclimate.

(i) *Natural Ventilation:* The main southeast facing facade presents ample opportunities for capturing wind flow, in particular for summer wind for natural ventilation. The built form of the ZCB also works with the prevailing wind, creating larger negative pressure on the leeward facade and helping draw natural ventilation air through the building.

(ii) *Chimney / Stack Effect*: The exhibition spaces and multi-functional room feature high ceilings. By integrating the ceiling height with the overall shape of the building, these spaces can be largely ventilated through stack effect.

(iii) *Shading*: Angling the building with a sloping sectional profile reduces the south façade and increases the north facade. This reduces solar heat gain to the south. The southeast facade has deep overhang (about 45 degree) to shade the summer sun.

(iv) *Daylighting:* The sloping sectional profile encourages natural lighting by introducing diffuse daylight through the clerestorey of the north facing façade.

(v) *Capturing Solar Irradiance*: The gradually sloping roof (17 to 20 degrees) maximizes solar capture for the PV panels.

Building Permeability

To enhance cross ventilation, a permeable built form with large void deck at the reception hallway is employed to effectively ventilate the space. This will also benefit the local urban climate in terms of air ventilation. The ZCB runs for 30% of the year in the natural ventilation mode, including solar assisted stack ventilation. Ceiling mounted fans are also provided to delay air conditioning usage by more than 2^0C when mechanical cooling is needed in the summer season.

Hybrid Ventilation Mode

Hybrid ventilation system is adopted, making use of natural ventilation when the outdoor climate is comfortable.

Façade Thermal Performance

Direct solar gain through windows is reduced by the use of external solar shading and high performance glass. Window to wall ratios (WWR) for respective facades are optimised for daylighting and view without excessive ingress of heat. Relatively higher glazing ratio for transparency is used for the north facing façade. Deep overhang of the southeast façade provides shading while allowing good views towards the landscape area. The high performance glazing with fritted pattern controls the opacity of the two facades to avoid heat gain.

Envelope Air-Tightness

This is particularly important for reducing energy demand in Hong Kong's climate because dehumidification of high humidity infiltration has a disproportionally large impact on the capacity of mechanical cooling plant and its energy use. Good air tightness also eliminates the risk of condensation.

Thermal Storage / Inertia

The operation of the exhibition and the multi-purpose hall means the building will experience fluctuating loads. Exposed concrete slabs and cladding act as thermal storage to regulate temperatures in these spaces, to absorb temporarily intensive loads (from tour groups) and purges the excess heat during the occupation time through natural ventilation.

6. KEY ACTIVE SYSTEMS

Active systems refer to the electrical and mechanical systems of the building. The key active systems of the ZCB include cooling, dehumidification, ventilation, lighting, solar control and comprehensive monitoring systems.

Cross-ventilation and High-Volume-Low-Speed Fans

This building is designed to address specific environmental challenges in the climatic conditions of Hong Kong. It features an open-plan cross-ventilated layout and is equipped with High-Volume-Low-Speed (HVLS) ceiling mounted fans, which promotes a gentle and uniform air flow throughout the building that can effectively counter the effects of the often humid weather (effective for approximately 30 to 40% of the year).

Under Floor and Radiant Cooling Systems

Under the air-conditioning mode, the building uses an advanced concept: high temperature system consisting of under floor air-supply, radiant cooling system and desiccant dehumidification. To achieve the desired room conditions of 26°C, 55% relative humidity, conventional system tends to overcool the supply air (10 to 14°C) to achieve dehumidification. In the ZCB, the humid fresh-air is pre-treated through a desiccant dehumidification process; hence the air and coil temperature can be significantly higher, thus reducing the cooling load on the chillers.

Energy Cascade

The design also addresses the shortcoming of the conventional electricity supply which is inherently inefficient due to the high-rate of waste heat rejection: normally only 40% of the source energy is captured. In the ZCB, the thermal energy from the combustion of biofuel is captured in an energy cascade that first utilises the highest grade heat for electricity generation, then adsorption cooling, and then desiccant dehumidification. As a result, 70% of the fuel energy can be captured.

Comprehensive Monitoring

There are over 2,800 sensors throughout the building to monitor and report on every aspect of the building performance. The results are displayed interactively in real-time and are used to optimise the building performance.

Microclimate Monitoring

Four microclimate monitoring stations are placed on and around the building to enhance the understanding of how the building performs and interacts with its surroundings. This is particularly important in the high-density context of Hong Kong.

Automatic Windows and User Control

A number of high-level windows are centrally controlled by coordinating their operation with the air conditioning strategy. At the same time, there are a number of low-level windows that can be controlled by the user to tailor the amount of ventilation and wind speeds at the occupied level.

Task-Lighting

Rather than uniformly lighting the building to a high-level of brightness, most of the building is illuminated to approximately 200 lux (appropriate for people circulation), while task-lighting is provided in areas where fine work occurs (office desk, display etc).

Active Skylights

The skylights are used to optimise the daylighting and solar control. The shading fins are controlled by a computer and sunlight sensors and their shading angles are constantly adjusted to cut out direct sunlight as the sun passes over the sky.

7. RENEWABLE ENERGY GENERATION

Renewable energy is generated on-site from 1,015m^2 photovoltaic panels and a 100kWe tri-generation system using biofuel reprocessed from the waste cooking oil.

The renewable energy generation at the ZCB is more than its operation needs. The tri-generation (Combined Cooling, Heating and Power) system and the PV system generate approximately 230MWh/year. The ZCB itself is designed to consume less than 130 MWh/year of electricity. Surplus energy is exported to the city grid to offset embodied energy of its construction process and major structural materials.

Tri-Generation System

The tri-generation system is a combined cooling, heating and power generation system using biofuel. The waste heat from the power generation is harvested for cooling and dehumidification. The large-scale use of biofuel extracted from waste cooking oil is for the first time in Hong Kong. In a conventional power generation system, the combustion of fossil fuel releases carbon dioxide into the atmosphere that will otherwise have remained in the ground undisturbed. Biofuel is a form of renewable energy. Typically, waste cooking oil in Hong Kong is sent to landfill where further decomposition will lead to the generation of methane gas. Hence the emission factor for the use of biofuel from waste cooking oil is very low since it not only displaces the combustion of fossil fuel, but also avoids the generation of methane gas at landfills.

PV Panels

Over 80% of the roof is covered with crystalline PV panels. BIPV (building integrated PV) panels and thin film PV panels of new ultra-light-weight cylindrical CIGS (copper indium gallium diselenide) technology are also showcased. The PV panels produce 87 MWh of electricity per year, providing about 70% of the energy needs of the ZCB

8. LANDSCAPE AREA

The greenery area covers over 50% of the total ZCB site and is planted with a total of 280 trees. The greening ratio is over 33%, equivalent to 215 trees per hectare. Each mature tree is estimated to be able to absorb around 23kg of carbon dioxide a year. The greenery serves as “carbon sink” (although not counted in the ZCB carbon budget) and a “heat sink” to cool the local air.

The landscape design improves the cooling effect and is estimated to be able to lower the air temperature by up to 1°C, leading to a positive impact on the local microclimate.

A key feature of the landscape area is the planted urban native woodland, which contains some 220 trees of over 40 different native species. The variety of native trees and native shrubs provide food and shelter to attract native wildlife into the city, creating a high quality ecosystem embedded in a built-up area of the city. The planting pattern is random to emulate the natural woodland, with small trees interspersed amongst the medium and large trees aiming at the formation of a dense tree canopy in due course. Some trees with ornamental traits have been selected to improve visual amenity. It offers pleasant natural aroma and fresh oxygen and helps remove gaseous and particulate air pollutants to improve air quality.

9. CHALLENGES AND LESSONS

With many new technologies adopted and that some are adopted for the first time in Hong Kong, ensuring all technologies perform collectively has taken an extensive testing and commissioning process.

The ZCB is designed to operate on the natural cooling mode for about one third of a year. In its first year operation from June 2012 to June 2013, the ZCB was actually operated on the natural cooling mode for 40% of the time. Under the natural cooling mode however, the indoor air quality (IAQ) can only be as good as the ambient air quality.

The cost of electricity generation from biofuel is about HK$3.5/KWh as compared to the current electricity cost of about HK$1/KWh from the city grid. To promote the wider use of the renewable energy, the environmental cost of the electricity generated from fossil fuel should be taken into account and perhaps reflected in the electricity tariff; or the renewable energy generation should be supported through public finance.

The ZCB attracted a total of 22,000 visitors in its first year operation. They were made of 50% school students, 25% professional institutions and 25% general public. Those figures are encouraging and show that the public is interested in new ideas to reduce carbon emissions. The most interest showed to the Eco-home within the ZCB indicates that the environmental education tends be most effective when it is close to one's daily life.

Achieving the zero carbon emission objectives means that the building performs to the design standards and that the occupier exercises strict discipline in energy use whilst without comprising the comfort level. The latter will have to be matched by behavioural changes and even mindset adaptation, which, based on the first year operation, can be more challenging than getting all the hardware installed and performing.

10. SUMMARY

A variety of green design features and technologies are featured in the ZCB although not all are essential to achieving the zero carbon emission objectives. The purpose is to showcase how those green design features and technologies work in practice and how they can contribute to energy saving and therefore carbon emission reduction.

To achieve the zero carbon emission over the whole life cycle of the building, the key considerations were:

- selection of the low carbon construction material and lean or low carbon; construction method to minimise the embodied carbon;
- optimal use of the passive design measures;
- selection of the most energy efficient electrical and mechanical systems; and
- selection of the most appropriate renewable energy sources.

Whilst it is not expected to have many zero carbon buildings in Hong Kong in the foreseeable future due to the technology and land constraints, most of the technologies showcased in the ZCB are applicable to the high density cities in the subtropical climate such as Hong Kong, for energy saving and carbon reductions.

The importance of behavioural changes, culture shift and education towards low carbon living cannot be emphasised more.