Hong Kong First Zero Carbon Building:
Design principles, features and technologies

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ABSTRACT: In Hong Kong, buildings consume most of the energy and are the major contributor to the greenhouse gas emissions. To combat consequent climate change, Hong Kong opened its first Zero Carbon Building for the public in 2012. Commissioned by Hong Kong's Construction Industry Council and designed by architects at Ronald Lu & Partners and engineers at Ove Arup & Partners HK Ltd, the 1,500 square meter, two storey buildings aspire to be the first zero carbon building even when taking the embodied energy of the building into account. The team firstly clarified the definition and set the goals of the building. It then investigated the micro-climate of the city site and designed the building passively to minimize energy needed. Various active devices were then added to balance the remaining energy loads. Monitoring systems were added for the day to day operation. In addition, despite the hot and humid climate of Hong Kong, the building occupants will be working in a mainly naturally ventilated building with appropriately designed work spaces. The building will serve the function not only as an office, it has a large exhibition space and a demonstration home for low energy living. It is set in a park that had been designed with bio-diversity in mind. The park will create a better micro-climate for the surroundings. Post occupancy studies will be conducted in the future as to evaluate how the building will perform. The building has just won the Grand Building Award 2012 organized by the Hong Kong Green Building Council. This paper elaborates the political and technical journey of the 18 months design and built process.
Keywords: zero carbon building, zero energy building; renewable energy; occupant behaviour; climate change

INTRODUCTION

Hong Kong's average carbon footprint was just lower than the most developed countries, such as USA, UK, and Singapore in the global share in 2008. Hong Kong building accounts for 89% of the total electricity consumption of which mostly is generated by burning fossil fuels. All generated electricity accounts for 68% of total GHG emissions in Hong Kong as by-product (HKEPD, 2012). And this emission of anthropogenic greenhouse gas is very likely accounted for the observed increase in globally averaged temperature since the mid-20th century (IPCC, 2007). In order to combat the climate change, the Government of Hong Kong has proposed a voluntary national target of carbon intensity reduction at about 50 - 60% by 2020 when compared to 2005 baseline (HKEB, 2010). Construction Industry Council (CIC) of Hong Kong, and the Government, collaborated on developing ZCB, the first Zero Carbon Building in Hong Kong, which is aimed to showcase state-of-the-art eco-building design and technologies to the construction industry internationally and locally and to raise public awareness of sustainable living in Hong Kong. The building is a visitor education centre, houses, an office of CIC, a demonstration home for low energy living, a multi-function room and other ancillary functions. It thus acts as a teaching tool and a living platform for sustainability. It is to set a world-class example in Hong Kong for low-carbon, highly energy-efficient buildings. The project requires an imminent need for actions to reduce GHG emissions addressing the high density, hot and humid context of Hong Kong.

Figure 1: First zero carbon building, completed in 2012.

BREIF REVIEW OF LITERATURE

To address the problem of global warming, we should reduce the greenhouse gas (GHG) emission by designing energy-efficient buildings since they are the major consumers for emission-producing energy around the world. The basic strategy is to minimise energy use or demand within the buildings, to which design guidelines or standards are applied and established by different countries and regions in the globe. As a result, the notion of zero carbon building (ZCB) is subject to be studied recently.

The term 'zero carbon', which meant a zero net emissions of carbon dioxide (CO_2) from all energy use, was originated from another term 'zero carbon home' in the Code for Sustainable Home (CSH) in the United Kingdom (DCLG, 2006). The CSH was intended to be a single national standard for construction industry to design and build a sustainable dwelling space by introducing a six-tiered sustainability rating system from level 1 to 6, with level 6 is the highest, based on nine code categories, such as energy, water, material and so on. A dwelling space is said to be completely zero carbon if it meets the level 6 standards, which is, however, unattainable for as many as 80% of new homes (ZCH, 2009). Therefore, the definition of zero carbon is revised in a three-tiered hierarchical approach based on energy efficiency, on-site low or zero carbon technologies and allowable solutions so as to achieve the level 6 sustainable homes in 2016 (ZCH, 2009).

Another term 'zero energy building' is similarly developed in U.S. Torcellini, P. *et al*. (2006) systematically defined a term net 'zero-energy building' (ZEB) as either a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. Based on this idea and different concerns, he further developed four definitions of ZEB, namely net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions, which respectively concerned, the site energy usage, source energy, energy costs of building, and emission of pollutants, such as carbon dioxide. For example, the definition of 'net zero energy emissions' means that a net zero emission building which can produce at least as much emissions-free renewable energy to offset its usage of emissions-producing energy. By this definition, zero energy building is more or less the same as zero carbon building.

DESIGN AND TECHNOLOGY OF ZCB

Apart from theory, in practice, there are several ZCBs or ZEBs have been built within these years in the worldwide, such as UK's both the Beddington Zero Energy Development (BedZED, Arup) and The Barratt Green House in Watford (Barratt), Singapore's Building and Construction Authority Academy (BCAA), Seoul's Samsung C&T (Arup), Hong Kong' Zero Carbon Building (ZCB, Arup) and etc. These show that real application and different experiments of ZCBs reflect raised awareness of sustainability around the globe. As for Hong Kong, its first Zero Carbon Building (ZCB) is not only of Zero Carbon, but also of Energy Positive. This section briefly describes the key design principles, features and technologies of ZCB that enables its zero carbon and energy positive operation.

Being 'energy positive', ZCB goes beyond the common definition of zero energy building. It produces its on-site renewable energy that not only to offset its site energy consumption supplied by the grid, but also export surplus renewable energy to the grid in turn to offset its embodied energy due to its own construction process and major structural materials. Low embodied emission design is adopted with minimized use of materials and recycled / regionally manufactured materials, such as eco-pavers, concrete mix with high percentages (25 to 35%) of pulverized fuel ash (PFA) and recycled aggregates, and use of C&D waste salvaged on-site.

Adhered to zero carbon hierarchy, ZCB gives priority to energy conservation by passive design reducing its reliance on mechanical systems in reference to the best current practice building energy codes. Systems of the highest efficiency are selected if mechanical means are required. Finally, unavoidable energy consumption is met through on-site renewable means.

High sustainability and low impact on environment are targeted. To minimize carbon footprint from construction, the site is formed in a balanced cut and fill manner creating higher planting zones along its perimeters and a lower multi-purpose open space at its centre. Any concrete debris salvaged from the demolition works was used in the gabion wall construction in the landscaped areas. Thus, a concrete slab laid on its raised platform screening off environmental nuisances such as heavy traffic.
Greenery coverage with about 370 trees occupies more than half of the site providing shaded amenity for inhabitant. It serves not only as 'carbon' sink' absorbing 23 kg of carbon dioxide per year for each tree, but also as a 'heat sink' cooling prevailing winds against heat island effect. To minimize ecological footprint, other sustainable measures have been implemented, such as storm water harvesting, grey and black water recycling.

To optimise potential solar and wind resources, the sitting, form and orientation of the building were determined after rigorously investigating the microclimate of its site. Located at the North West corner, the building and its open space receive better south easterly prevailing wind throughout the year. The location also allows the building staying away from the shadows of surrounding buildings so as to harvest more renewable solar energy by PV. The elongated and tapered built form helps to maximize its solar capture for PV panels with its sloping roof of 17 to 20 degrees.

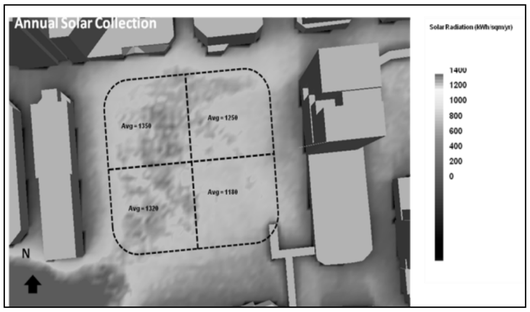

Figure 2: Solar irradiance study.

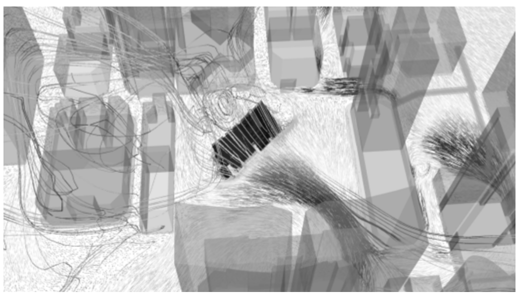

Figure 3: Computational fluid dynamics study.

ZCB features a large open-plan and cross-ventilated layout, for example a large void deck at the entrance hallway and temporary exhibition area, so that to minimize cooling load during peak summer periods, and not to request any air-conditioning. For non-summer periods, High-Volume-Low-Speed (HVLS) fans are associated with the layout to promote gentle and uniform air-velocity inside building effectively encountering humid weather. To further optimize prevailing wind, ZCB with a tapered sectional form helps itself to create higher negative pressure on leeward façade drawing natural wind through itself. Second, daylight is harvested from the double-height north windows, and interior brightness is then amplified by sloped ceiling through reflection so as to reduce the usage of artificial lighting, which is also adjusted by dimming system minimizing further energy consumption. Besides, recess spaces are introduced along southeast façade enhancing both air and light penetration. Third, high performance building envelope with low-e insulated glass units, deep overhangs, minimized glazing areas on east and west facades and shaded roof by PV is used. It reduces the cooling load during peak summer periods and minimizes solar heat gain (with an OTTV of 11W/m^2 which is about 80% lower than the current statutory threshold).

ZCB is subject to comprehensive monitoring by more than 2800 sensing points in order to report and optimize every aspect of its performance. Real time results are displayed interactively on a 3-D model of the building. For instance, air quality within occupied spaces is monitored by CO_2 sensor so that required fresh air is ensured. Also, four microclimate monitoring stations are installed on and around building to understand better building performance and hence to optimize operation of windows with both surrounding environment and air-conditioning systems. Desired room conditions of 26 °C, 55% RH is then achieved by adopting an advanced high supply air temperature air-condition system, which consists of under floor air-supply, radiant cooling system and desiccant dehumidification. In such design, humid fresh-air is pre-treated through a desiccant dehumidification process and supply air is diffused directly to inhabitants. Thus, air and coil temperature is significantly higher to minimize load on the chillers, rather than that by conventional system is overcooled (10 to 14°C). For the lighting, occupancy sensors are adopted to switch-off the lightings of office areas, divided in zones, when there is no occupant over a default period. Daylight sensors are also provided at the perimeter of office areas to monitor and ensure a desired daylight level according to the pre-set program of dimmer rack system. More importantly, most of the building areas will be illuminated to about 200 lux (appropriate for circulation), while task-lighting is provided at areas where fine work occurs, instead of uniformly lighting areas to a high-level of brightness conventionally. Other active systems include an active skylight (a controllable skylight that allows users to actively adjust the natural daylight level through control of louver blades) and low energy office equipment for office occupants.

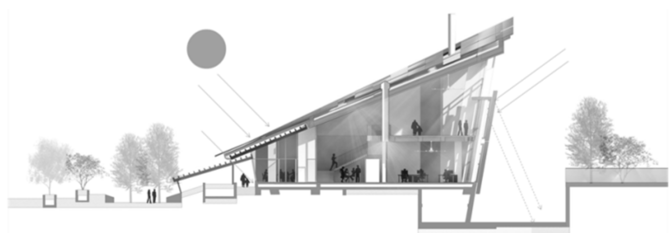

Figure 4: Architectural Section.

Figure 5: ZCB interior.

Energy Cascade is adopted to capture 70% of the fuel energy from combustion of biodiesel by firstly utilizing the highest grade heat for electricity generation rather than 40% from the conventional system.

Surplus electricity energy from renewable energy systems will feed to utility grid on an annual basis. An estimated net CO_2 reduction is 7,100 tonnes for over 50 years with the following on-site renewable energy systems and technologies.

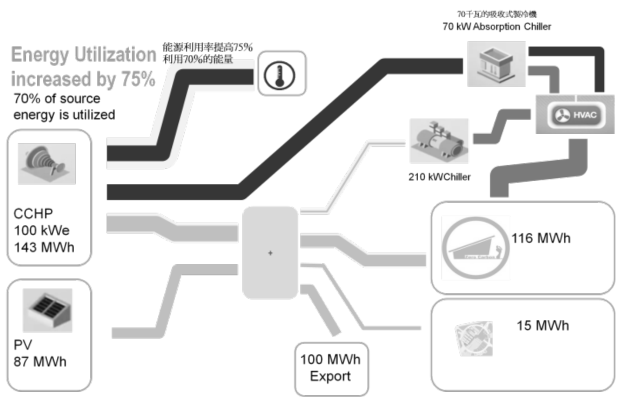

Figure 6: Energy cascade for ZCB.

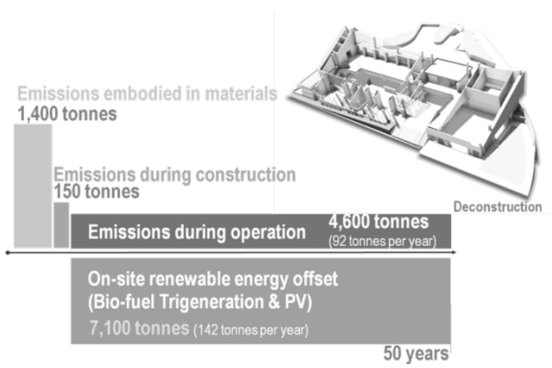

Figure 7: Carbon Reduction Estimation over 50-year life cycle.

Biodiesel Tri-generation – In a large-scale usage of biodiesel, to EN 14214 Standard, as a renewable fuel for tri-generation, carbon dioxide emitted from combustion of biodiesel will be absorbed via photosynthesis by plants producing feedstock for making biodiesel. In Hong Kong, the feedstock for producing biodiesel locally is waste cooking oil, which is typically sent to landfill. Thus, emission factor is very low since it avoids combustion of fossil fuel and generation of methane gas at landfills.

PV Panels – ZCB features 1,015sqm of crystalline panels producing a high output. Building-integrated photovoltaic (BIPV) is used as fabric in areas where natural light is desirable through the roof. The design also showcases the new ultra-light-weight cylindrical CIGS technology. Solar Thermal System is also adopted to generate hot-water for eco-cafe. Building Loading Profile which is the typical daily loading profiles estimate (summer and winter) are as in figure 8.

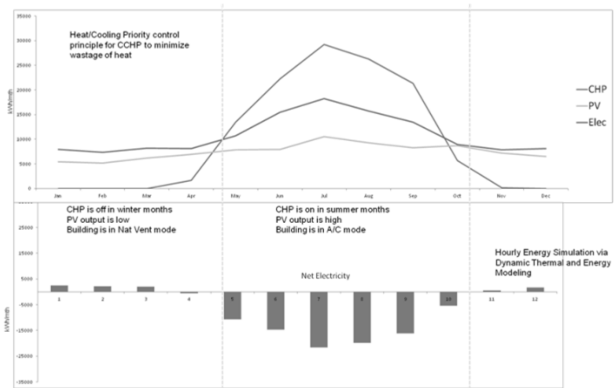

Figure 8: Building loading profile.

IMPORTANCE OF OCCUPANT BEHAVIOUR

Apart from the sustainable design and technology, individual participation is of prime importance in reducing GHG emissions and conserving the energy. According to United Nations Environment Programme publication (UNEP, 2008), individual is the main contributor of indirect greenhouse gas (GHG) emissions. For a typical European's GHG emissions to individual shares, more than 50 per cent are indirect emission. Among them, 20 per cent arise when we produce, consume and displace products; 25 per cent account for powering our workplaces, and 10 per cent come from the maintenance of our public infrastructure. In contrast, only less than 50 per cent, the rest, contributes to the direct GHG emissions, for example, driving a car or turning on a heater, which we might think the major contributor at first sight. This might imply that we are unaware of our individual responsibility, habits and lifestyle, and thus overlook the consequent great indirect emission of GHG.

To achieve 'zero energy community' (ZEC), it is crucial to set individual behavioural changes on par with the environmental technologies (Carlisle, N. et al, 2009). One example to show behaviour can impact energy use is that there was an environmental competition held at Harvard University among 13 buildings resulting in a $72, 472 energy dollar savings through both operational and maintenance practices (Bradt, 2008). That meant to save 229 metric tons of carbon dioxide which was equivalent to either taking 42 cars off the road for one whole year, or carbon dioxide output of around 20 typical homes in U.S. per year. At the end, the coordinator of the energy reduction program pointed out that being green is not just about building design; it is also about occupant behaviour.

The most important thing is that the GHG reduction goal shall also be achieved by tangible behavioural change in Hong Kong. Aligning with the proposed GHG reduction goal, the Government of Hong Kong proposed the electricity consumption shall be aimed at a 58% reduction when compared to the projected electricity consumption in 2030. Among the nearly 60% of reduction, about 12% of the reduction target is going to be attained by behavioural change (HKGBC, 2012).

Last but not least, to promote zero energy community, it is important to educate citizens and occupants, as individual, to raise their awareness of ‘green’ behaviour and to take action in their living so as to reduce energy demand and usage, such as to use natural light and wind if possible, to turn off the light when there is no occupant, and to dress lightly rather than to use air-conditioning, and etc. That is why Hong Kong ZCB itself is open for public visits or tours targeting over 40, 000 visitors yearly providing an opportunity to educate people a green lifestyle through real experience.

CONCLUSION

In summary, there are four Ps key steps from zero carbon building to living, namely, Process, Place, Performance, and People which are as follows:

PROCESS: With clearly defined vision and targets, stakeholders engaged both early and continuously in an integrated teamwork playing a pivotal role in the fast-track delivery of this pioneering project from July 2011 for site formation to June 2012 for completion. To cater for the fast-evolving zero / low carbon technologies and changing needs, ZCB is designed with high spatial, structural and building system adaptability with allowance for plug and unplug of building systems. On-going monitoring and evaluation of the building performance shall be shared for stakeholders.

PLACE: ZCB is specifically designed for its context and microclimate with flexibility to switch from a tightly sealed air-conditioned environment to a highly porous cross-ventilated mode with low thermal storage capacity. The objective is to create a gentle but uniform air-movement throughout the building to encounter the often high humidity of Hong Kong. In contrast to many zero carbon buildings in relatively cool or mild climates are typically designed to be tightly sealed spaces with little energy exchange with the exterior.

PERFORMANCE: To achieve better zero carbon and higher building performance, other renewable fuel sources of higher energy density must also be taken into consideration if they provide the flexibility in using space with diversified commercial functions. Although using biodiesel tri-generation as a zero carbon renewable energy source is a topic of much debate, it is justified that biodiesel can be reproduced locally in Hong Kong providing that feedstock is waste cooking oil, which is typically sent to landfill. Thus, emission factor is very low as it avoids combustion of fossil fuel and generation of methane gas at landfills.

PEOPLE: ZCB not only showcases low/zero-carbon design and technologies, but also enlightens people about how to live in a low-carbon lifestyle. Open to the public, ZCB and its landscaped area is expected to cater for 40,000 visitors per year, for a wide range of functions: zero carbon exhibition tours, seminars and conferences, eco-wedding and so on. The designed number of inhabitants is higher than most of the other existing overseas ZCBs. It is because that human behaviour is a very critical factor to achieve carbon neutrality. Visitors can learn about the “One Planet Living” principles illustrated by on-site sustainable design features like, ZCB carbon footprint indicator, and constructed wetland, etc. To this end, ZCB is the first building in Hong Kong that requires compliance of “Cool Biz Dress Code” to foster cultural shift towards sustainable way of living. Continuous post occupancy studies will also be conducted in the future to gain research data on building performance.

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This section, if included, appears right after the main body of the text and is headed “Acknowledgments.” This section includes acknowledgments of help received from associates and colleagues, credits to sponsoring agencies, financial support, and permission to publish. Please try to limit acknowledgments to no more than three sentences. This document has been updated from previous PLEA Conferences.

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