YUDELSON ASSOCIATES

Building and Construction Authority Zero Energy Building Braddell Road Campus, Singapore

November 2011

In October 2009, Singapore's Building and Construction Authority (BCA), announced the opening of the Zero Energy Building (ZEB) located on BCA's campus. Formerly a workshop, the renovated 4,500-square-meter (48,438-sq.ft.) structure now houses corporate offices and academic classrooms and is a true zero net energy building. One of us (Yudelson) visited this building in 2010 and saw first-hand not only the measures taken to reduce energy use, but the continuous readout of energy supply/demand in the main lobby, making this one of the more transparently ZEB's in the world.

BCA is an agency under the Singapore Government's Ministry of National Development and is tasked with developing green technologies to meet the goal of making 80 percent of all Singapore's buildings green by 2030. ZEB is BCA's flagship project and the first net-zero energy building in Singapore.[1]

Zero energy refers to energy self sufficiency—a building that produces as much energy as it uses. In Singapore, an island country that is devoid of natural resources, "the success of ZEB in achieving this target is exciting and has tremendous implications on the way energy is used in Singapore for specific types of buildings," according to the BCA.[2]

ZEB was conceived with two primary objectives:

- To serve as a laboratory for the integration of green building technologies in existing buildings.
- To be a hub for the study of energy efficiency and green buildings.[3]

The technologies currently undergoing testing at ZEB will have potential applications for many of the existing buildings that will be retrofitted over the next 20 years to meet the national goal.

Strategically placed photovoltaic panels serve the dual purposes of energy generation and sun shading.

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A 300-millimeter gap between the solar panels and roof creates a negative pressure area which draws warm up from inside the office and out solar chimneys.

"Besides bringing our vision into fruition, it is something that we strongly believed in and set out to do, and for this reason that the ZEB has placed Singapore favorably on the world green building map," said Dr. John Keung, BCA's CEO.[4]

To meet the zero energy goal, the design team adopted an integrated design approach that focused on two general principles to reduce energy consumption: passive and active design. First step was to incorporate passive design solutions that take advantage of natural resources to minimize the amount power supplied from the grid. The next step was to incorporate active solutions: energy-efficient equipment and solar power systems.[5]

PASSIVE SOLUTIONS

Three passive design strategies informed the energy efficiency strategy at ZEB:

1) Minimize heat transmittance: Reducing the amount of heat entering the building in the summertime helps reduce the loads on the air conditioning system.

2) Daylighting: In many office buildings, the lights are on throughout the day even when sunlight is abundant. At ZEB, daylight enters deep into the space reducing the amount artificial lighting required.

3) Natural ventilation: Over 40 percent of energy consumed in a typical office can be attributed to air conditioning. Natural ventilation at ZEB helps reduce the air conditioning load.[6]

Glazing is the one of the primary strategies used to control heat transference. At ZEB, four different types of glazing were installed and researchers will analyze the performance of each.

- Electro-chromic glass is glazing that changes opacity depending on the amount of incoming sunlight. At ZEB, BCA is testing it for its light and heat control capacities.
- Photovoltaic glass has the dual functions of providing shading and generating power at the same time. Researchers are monitoring it to determine its efficiency, impact on views to the outdoors, shading, heat absorption and re-radiation.
- Double-glazed units (DGU) with internal operable glass are being studied for their impact on views, shading and heat absorption. DGUs are made up of a glazing system with blinds between the panes that adjust according to incoming sunlight.
- Clear DGU glass is being used as a reference for com-

parison. The air between the double panes is thoroughly dried and the space is sealed air-tight, providing superior insulating properties and eliminating possible condensation. Double-glazing surrounds all air-conditioned areas, with single glazing installed in the classrooms and school hall.[7]

Mirror ducts, light shelves and light pipes are three of the daylighting strategies in use at ZEB. Mirror ducts capture zenith daylight (which is brighter than lateral daylight) through external collectors. The light is channeled into horizontal reflective ducts within the false ceiling. The light harvested from mirror ducts is usually glare-free and the technology involves no mechanical parts and requires no power. At ZEB, three types of mirror ducts were installed to test their reflectivity and effectiveness.[8]

Light shelves are highly reflective surfaces that reflect daylight deeper into the building. Externally mounted on the façade, they also provide shading against direct sunlight. The efficiency of the light shelves at ZEB is enhanced using ceiling material that has a highly reflective coating.[9]

Light pipes are essentially pipes that stick out of a building's roof and direct sunlight into interior rooms. They are more energy efficient than skylights because less energy escapes owing to reduced surface area. Two types of light pipes are in use at ZEB—one that is equipped with rotating mirror and one without.[10]

The roof-mounted solar panels assist in ZEB's ventilation system. Heat builds up in the 300-millimeter (12-inch) gap between the solar panels and the metal roof creating a negative pressure area as warmed air rises. Due to the buoyancy effect, when heat is removed from the gap, warm air from inside the building is drawn up towards ceiling vents and out through the four solar chimneys.[11]

ACTIVE SOLUTIONS & SYSTEMS

Obviously it is not possible to eliminate the use of electricity entirely. To achieve the goal of net-zero energy on an annual basis, active solutions are required. Active solutions are mechanical devices that increase efficiency, collect energy and/or convert energy, for example fans, sensors and solar panels.

In ZEB, lighting sensors represent a key active solution. Occupancy sensors control the amount of artificial lighting used. Lights are activated only when someone enters a room; additionally, light intensity is adjusted according to daylight-

Courtesy of the Building and Construction Authority of Singapore

About 1,540 square meters of roof- and façade-mounted photovoltaic panels are connected to grid power supply and generate about 207,000 kWh a year.

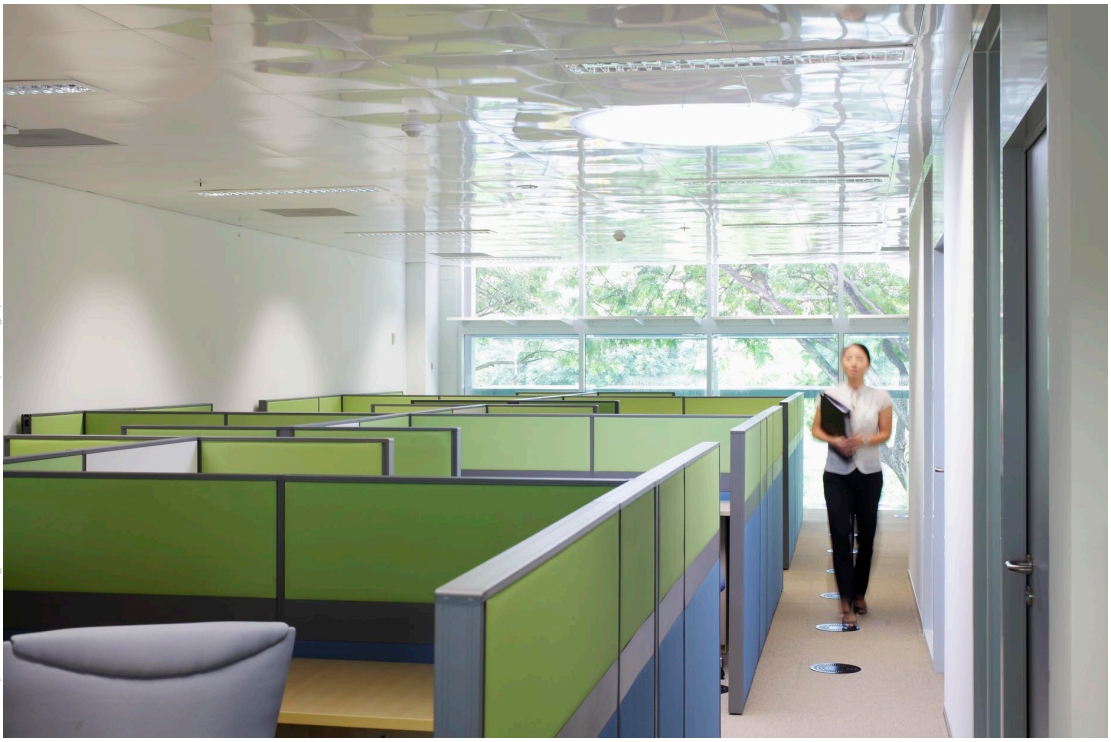
ing levels. When there is abundant daylight, artificial lights are automatically dimmed. Temperature and ventilation rates are also adjusted with occupancy sensors, according to the number of people using the space.[12]

To achieve net-zero energy power consumption, the building produces electricity. About 1,540 square meters of roof- and façade-mounted photovoltaic panels are connected to grid power supply and generate about 207,000 kWh a year. After supplying ZEB, surplus power generated by the panels is distributed to other BCA Academy buildings and the excess is supplied to the grid. If insufficient power is produced by the solar panels, the grid supply provides the balance. Ultimately of the course of a year, the solar panels generate more than the amount of energy required by ZEB. Additional non-grid-tied photovoltaic panels supply power for specific functions such as the visitor center's solar-charging kiosk.[13]

"The main target of the project was to demonstrate that the concept of a zero-energy building is possible even in the tropics, where high air-conditioning loads make up more than 50 percent of the electricity consumption of buildings," said Stephen Wittkopf, associate professor and director at the Solar Energy Research Institute of Singapore. "After almost one year of analytical energy monitoring we are happy to confirm that we have achieved this target. The building-integrated photovoltaic systems have generated a surplus of electricity which is fed back into the BCA premises grid."[14]

Other features that contribute to net-zero energy include:[15]

- Floor diffusers: These supply cool air, which, once warm, will rise toward vents in the ceiling and exit the building.
- Energy-efficient air-conditioning: The system detects carbon dioxide levels and lowers fan speed (and thereby ventilation rates) when fewer people are around.
- Personalized ventilation: Air-conditioning around each desk is adjustable according to individual needs.
- Efficient lighting: Use of fluorescent lamps cut power usage by 26 percent.
- Green roof and green wall: These features cut heat transmission into the building.
- Shading devices: These work with the greenery system to cut heat transmission.



Courtesy of the Building and Construction Authority of Singapore

Light shelves and light pipes reduce the amount of artificial light required.

ZEB was awarded a Platinum rating, the highest possible, from Green Mark, Singapore's third-party green building rating scheme. Administered by BCA, Green Mark "is a benchmarking scheme which aims to achieve a sustainable built environment by incorporating best practices in environmental design and construction, and the adoption of green building technologies."[16]

The BCA Green Mark Scheme rates buildings according to five key criteria. They are:

- Energy efficiency
- Water efficiency
- Environmental protection
- Indoor environmental quality, and
- Other green and innovative features that contribute to better building performance.[17]

Because an important goal of ZEB is to serve as a test bed for green building technologies, the building's performance is carefully monitored, and it is performing better than predicted! Initial modeling estimated energy usage to be 206.6 MWh, whereas the building's annual actual usage is 183 MWh. In terms of emissions, estimates say that ZEB's CO_2 emissions reductions are close to 200 tons (88,000-kg CO_2 equivalent) annually.[18] In all, the building will save S$84,000 (based on electricity rate of 21.69 Singapore cents/kWh) a year in energy cost compared to typical office in Singapore.[19]

TABLE 1: ANNUAL ENERGY USE

	Total	Intensity
Electricity Consumption	183 MWh	41 kWh/sq.m.
Renewable Energy Production	203 MWh	45 kWh/sq.m
Carbon Emissions from Imported Energy, 2009	0.48 kg CO_2/kWh	N/A

TABLE 2: ENERGY END-USE REQUIREMENTS

Air Conditioning	104 MWhr
Building Internal Lighting	24 MWhr
Building Internal Plug Loads	25 MWhr
Common Area Lighting and Power	30 MWhr

TABLE 3: ANNUAL WATER USE

Indoor Potable Water	194.5 cu.m.
Outdoor Potable Water	159 cu.m.
Cooling Tower Potable Water	88.5 cu.m.
Total	442 cu.m./117,000 gal

AT A GLANCE

Name: Zero Energy Building
Location: Braddell Road Campus, Singapore
Size: 4,500 sq.m. (48,438 sq.ft.)
Completed: October 2009
Cost: S$11 million, S$227/sq.ft. (US$7.86 million; $162/sq.ft.)
Program: Government office and academic facilities

TEAM

Owner: Singapore Building & Construction Authority (BCA)
Architect: DP Architects Pte. Ltd.
Project manager: Beca Carter Hollings & Ferner SEA Pte. Ltd.
Mechanical/electrical engineer: Beca Carter Hollings & Ferner SEA Pte. Ltd.
Civil/Structural engineer: Beca Carter Hollings & Ferner SEA Pte. Ltd.
Quantity Surveyor: Davis Langdon & Seah Singapore Pte. Ltd.
Principal Investigators for green building technologies: Associate Professor LEE Siew Eang (Energy efficiency), Associate Professor WONG Nyuk Hien (Greenery and natural ventilation), Associate Professor Stephen Wittkopf (Building integrated photovoltaic and daylighting)
Contractor: ACP Construction Pte. Ltd.

(ENDNOTES)

1 Juniper Foo, "Singapore showcases its first Zero Energy Building," October 27, 2009, http://asia.cnet.com/crave/singapore-showcases-its-first-zero-energy-building-62109198.htm, accessed September 2, 2011.

2 Building and Construction Authority, www.bca.gov.sg/zeb/whatiszeb.html, accessed September 10, 2011.

3 Green Mark, www.greenmark.sg/about_proj_zero.html, accessed September 2, 2011.

4 Eugene Tay, "Singapore's Zero Energy Building (ZEB) On-Track to Meet Net Zero Power Consumption," September 15, 2010, GreenBusinessTimes.com, www.greenbusinesstimes.com/2010/09/15/singapores-zero-energy-building-zeb-on-track-to-meet-net-zero-power-consumption/, accessed September 2, 2011.

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7 Building & Construction Authority, www.bca.gov.sg/zeb/daylightsystems.html, accessed September 10, 2011.

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16 Building & Construction Authority, www.bca.gov.sg/greenmark/green_mark_buildings.html, accessed September 10, 2011.

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