Building and Construction Authority

ZEB Plus @ BCA Braddell Campus

From Zero Energy to Positive Energy Building

Green Buildings Innovation Cluster (GBIC) Programme

Best-in-Class Super Low Energy Building Series | Positive Energy Office Building (Existing Building)

Contents

Foreword

To support Singapore's commitment on climate change, BCA partnered the Singapore Green Building Council and other Built Environment (BE) stakeholders to roll out the Singapore Green Building Masterplan (SGBMP) in 2021. The SGBMP aims to deliver three key outcomes of '80-80-80 in 2030'.

When the BCA's Zero Energy Building (ZEB) at our Braddell Campus was unveiled in 2009, it was one of the first retrofitted net zero energy buildings in Asia, producing sufficient energy on its own to offset its consumption. Since then, we have continued to work with various partners to invest in research and innovation (R&I) to push the boundaries of energy consumption. Through collaboration with our local and international innovation community, ZEB is now 'ZEB Plus', a positive energy building producing at least 20% surplus energy than it consumes.

BCA, with the National Research Foundation's support, seeks to promote research and showcase advanced technological solutions to achieve net-zero and beyond, and also to connect BE technology partners with leading sustainable developers to pilot green building solutions. ZEB Plus will continue to offer itself as a living lab for both our local and international innovation community to develop and test innovative solutions.

Through ZEB Plus, we hope to inspire BE stakeholders to work towards decarbonisation and take charge of their sustainability journey.

Mr. Kelvin Wong
CEO
Building and Construction Authority

Foreword

Buildings contribute over 20% of Singapore's carbon emissions. Greening these buildings is hence crucial to our commitment to achieve net zero emissions by 2050. With global demand for green buildings on the rise, it is also a market opportunity for our companies in the built environment sector.

BCA and the National Research Foundation (NRF) introduced the Green Buildings Innovation Cluster (GBIC) programme in 2014, as an integrated research, development and demonstration programme to accelerate the development and deployment of promising energy efficient technologies in buildings. Funding for the GBIC was enhanced by $45 million under the Research Innovation and Enterprise 2025 plan, to accelerate the commercialisation of such technologies through industry partnerships and help grow the local ecosystem of firms with green building expertise.

While we have greened close to 55% of our buildings (by Gross Floor Area), a greater challenge is to green and enhance the energy efficiency of existing, older buildings that formed the majority of the built environment. To encourage this transformation, the existing Zero Energy Building (ZEB) was recently retrofitted and BCA partnered with researchers from SinBerBEST, a research programme under the NRF Campus for Research Excellence And Technological Enterprise to deliver the ZEB Plus.

Today we are pleased to announce that the ZEB Plus is on track to achieve a 20% improvement in energy efficiency and I would like to take this opportunity to congratulate BCA for taking a step closer to the Singapore Green Building Masterplan's targets and wish them success towards a greener and more sustainable built environment.

Mr. Beh Kian Teik
CEO
National Research Foundation

INTRODUCTION

Background

Singapore has committed to the goal of achieving net-zero emissions by 2050, as well as aiming to reduce emissions to 60 million tonnes of carbon dioxide equivalent (MtCO2e) by 2030 after peaking emissions earlier. Buildings account for more than 20% of the country's total carbon emissions, which plays a major role in reducing carbon footprint to mitigate climate change.

As the world looks towards an increasingly uncertain future disrupted by climate change, the need for sustainably designed buildings has never been greater. Although the pace of developing building technologies has accelerated, there is still a considerable need to retrofit sustainable solutions to existing buildings.

In 2009, Singapore launched the first Zero Energy Building (ZEB) at the BCA Braddell Campus. Retrofitted from an existing building, it is also the first of its kind in Southeast Asia.

The ZEB at BCA offers a glimpse into the buildings of tomorrow, today. Through the use of energy saving technologies, ZEB only consumes half the energy of a typical office of the same size. With the inclusion of on-site renewables produced by solar panels, ZEB has achieved net-zero energy for more than 10 years.

From a Zero to Positive Energy Building[1]

In the past decade, technological advances and intensified national efforts have been shaping the landscape of Singapore's built environment. Greater opportunities to develop, deploy and mainstream technological innovations to push the boundaries of energy efficiency in buildings have arisen.

These developments have been a powerful catalyst for realising BCA's aspirations of achieving net-zero and Super Low Energy buildings that are at least 60% more energy efficient compared to 2005 levels.

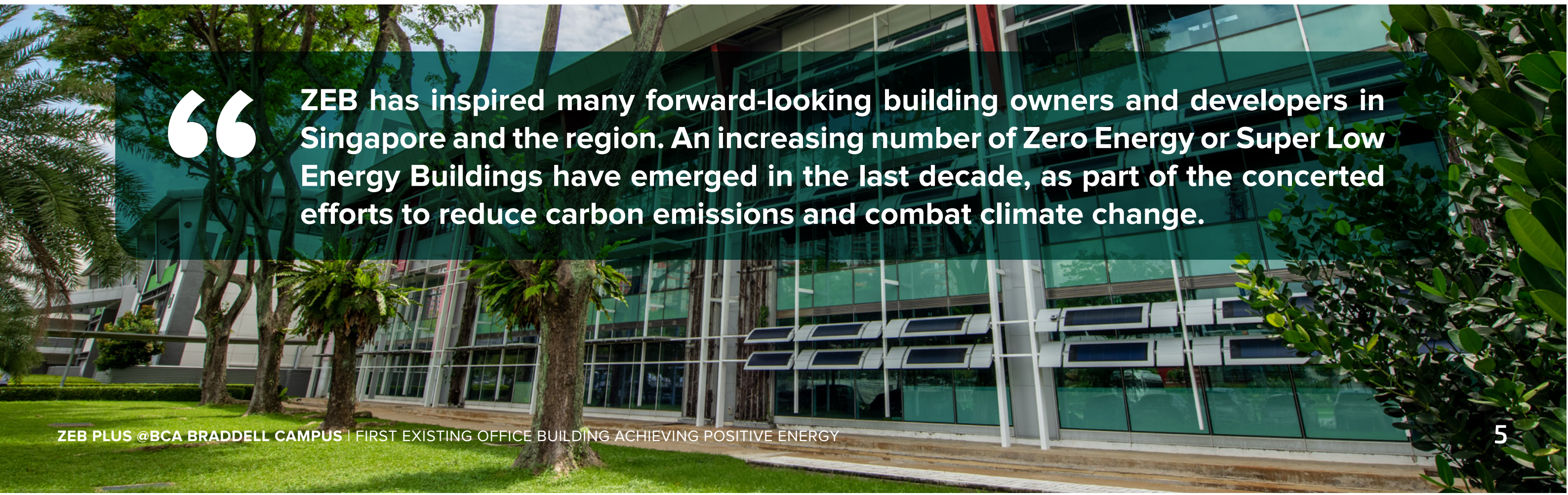
ZEB has inspired many forward-looking building owners and developers in Singapore and the region. An increasing number of Zero Energy or Super Low Energy Buildings have emerged in the last decade, as part of the concerted efforts to reduce carbon emissions and combat climate change.

Moving forward, in 2019, BCA partnered with the Singapore-Berkeley Building Efficiency and Sustainability in the Tropics (SinBerBEST), a research entity under the National Research Foundation CREATE Programme, to embark on a research collaboration to transform BCA's Zero Energy Building (ZEB) into a positive energy building, ZEB Plus, which serves as a unique living laboratory for smart building technologies. This transformation was completed in 2022, heralding the arrival of ZEB Plus. With the integration of green technologies into working spaces, the ZEB Plus, an "Office of the Future", provides insight into what tomorrow's office buildings could look like.

The ZEB was recognised as one of the most energy efficient buildings in Singapore with energy efficiency 50% better than a code-compliant building. Together with the upgrading of the existing solar PV system, the building has pushed its boundaries further and has achieved an overall energy surplus of more than 20%. ZEB Plus has also achieved about 77% improvement in energy efficiency as compare to 2005 baseline.

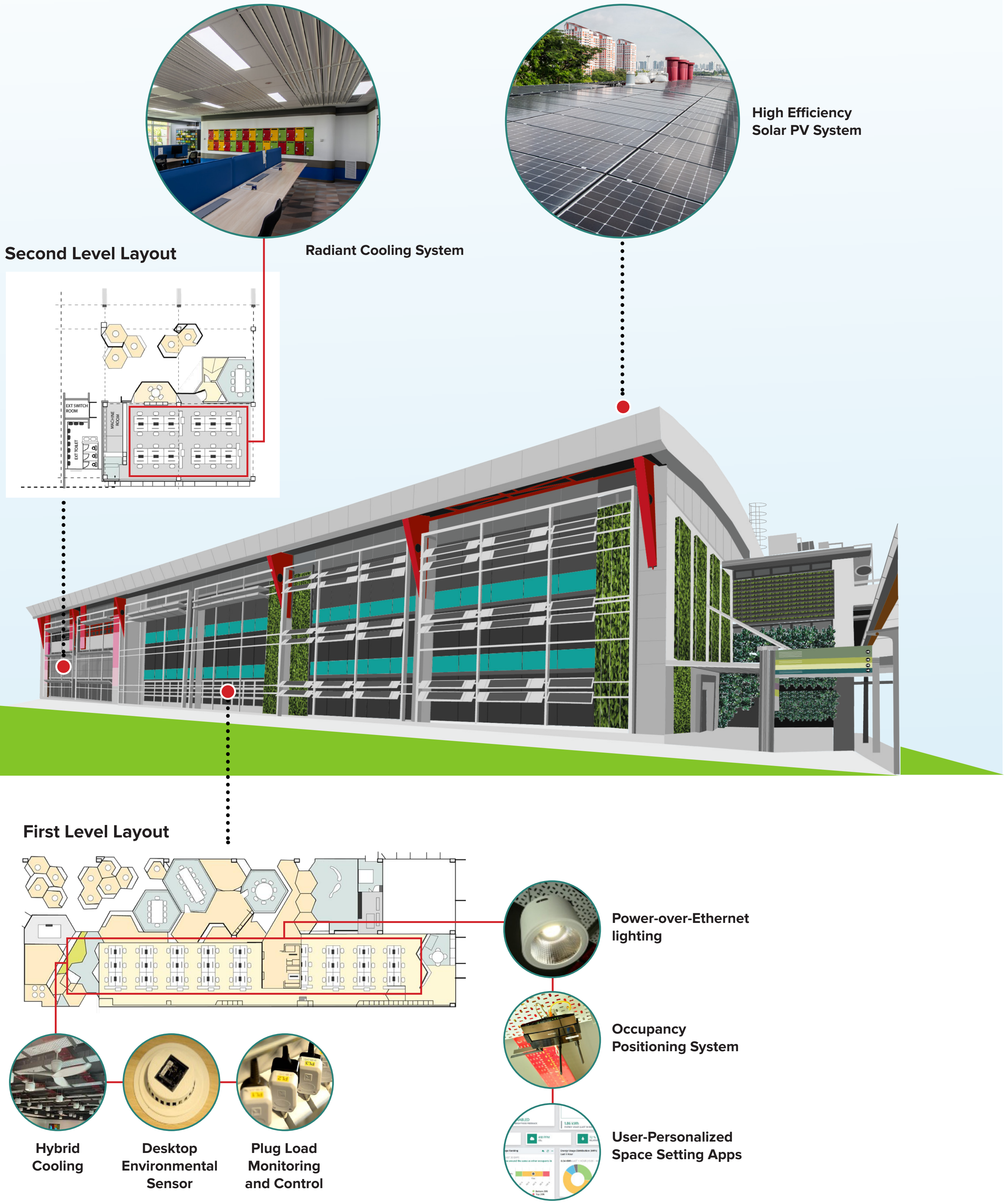
This was made possible by leveraging the latest green building technologies and integrating them into ZEB Plus's various building systems, such as air-conditioning, lighting, building management system and solar panels. More than 1,000 sensors feed data back to a centralised AI engine, which enables the building to continuously adjust itself to deliver the most optimum energy performance.

[1] *A positive energy building refers to a building that produces at least 15% energy surplus with energy supplied by onsite renewable energy sources.*



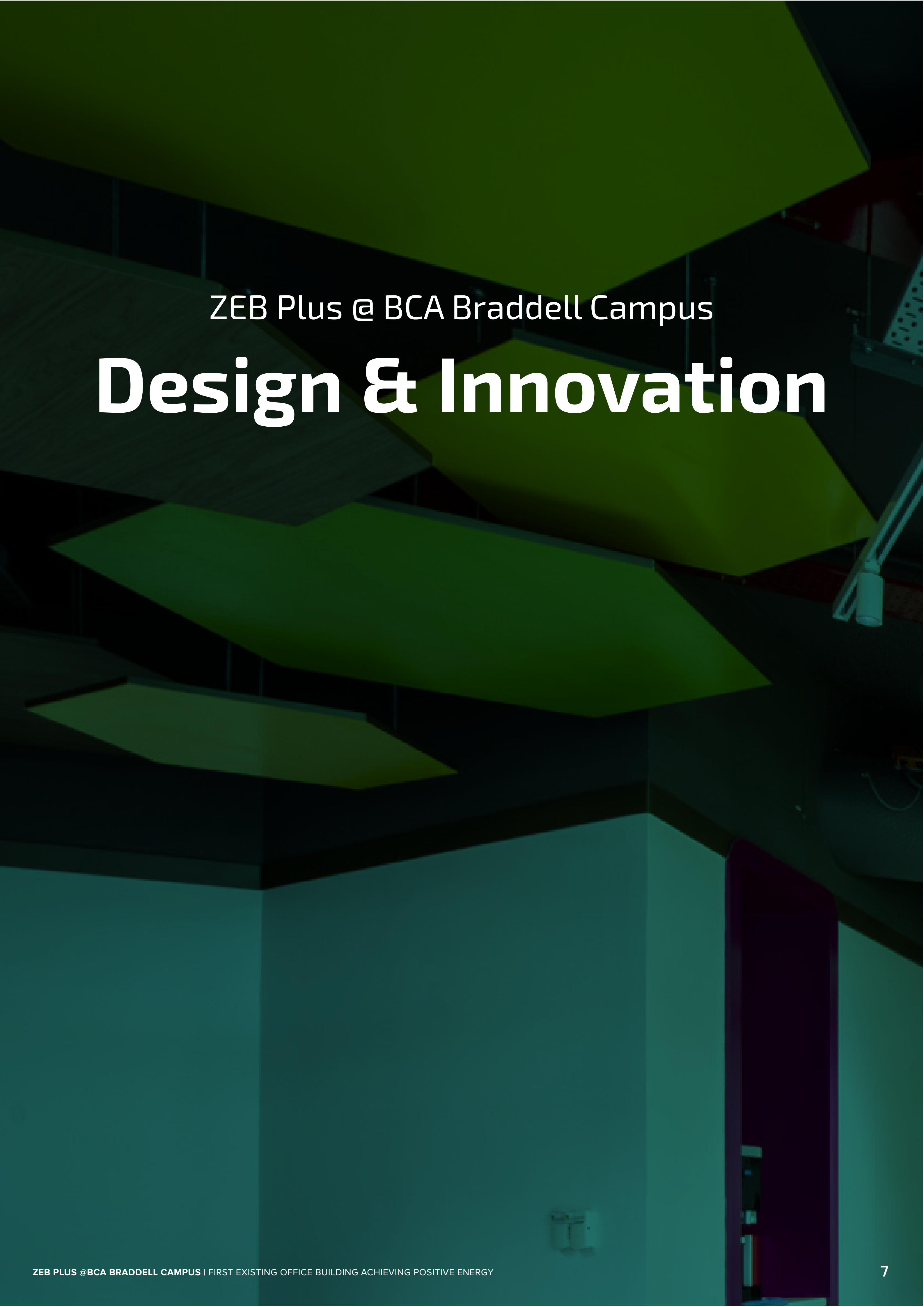
"ZEB has inspired many forward-looking building owners and developers in Singapore and the region. An increasing number of Zero Energy or Super Low Energy Buildings have emerged in the last decade, as part of the concerted efforts to reduce carbon emissions and combat climate change.

ZEB Plus @ BCA Braddell Campus



ZEB Plus @ BCA Braddell Campus

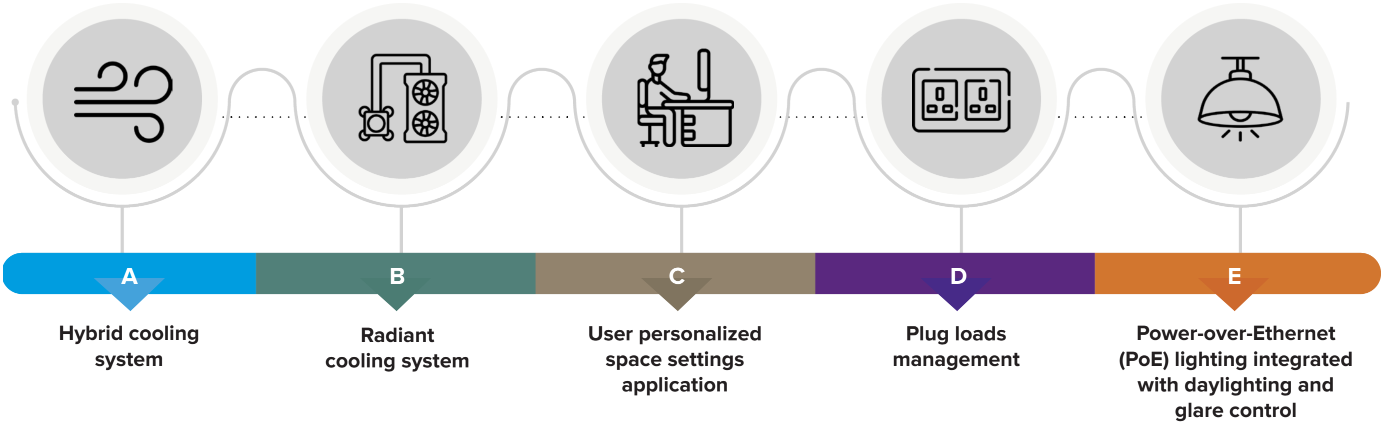
Design & Innovation



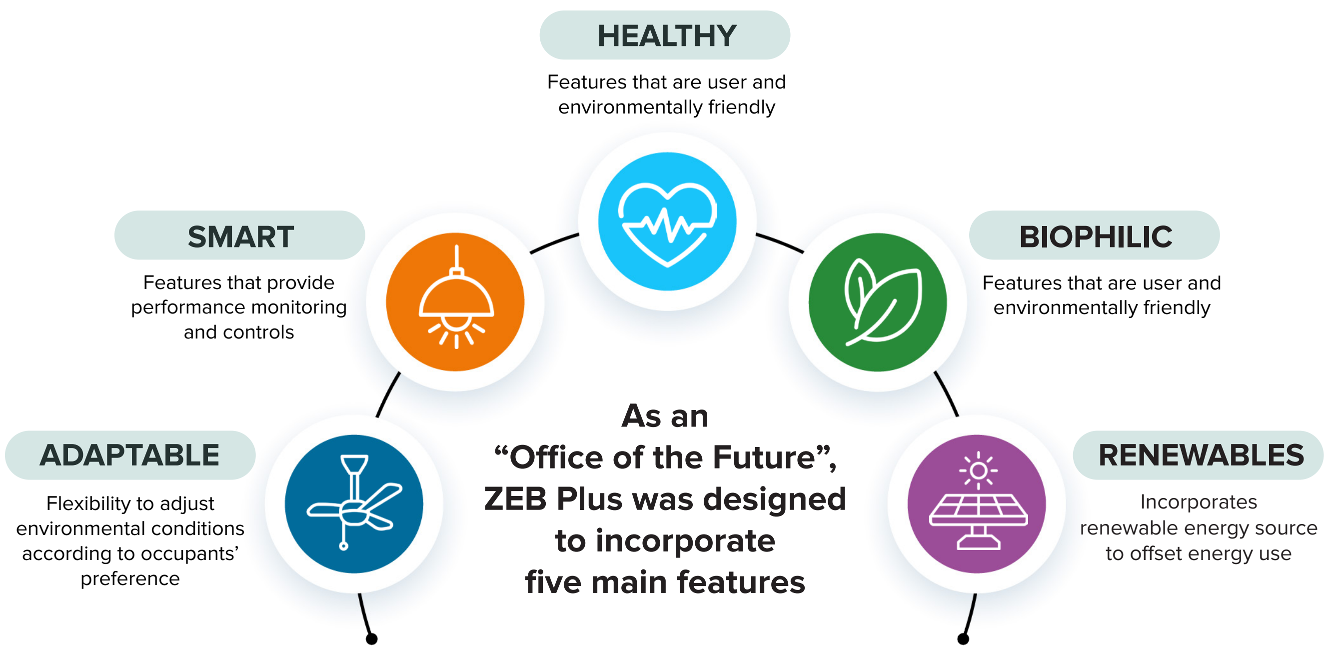
Overview

ZEB Plus is a co-innovation project with the research community that translates research and innovation into practical applications. The technologies demonstrated at ZEB Plus provide practical use cases where building owners and industry stakeholders can refer to and apply in their own Super Low Energy (SLE) journeys.

As a living laboratory that test-beds new and innovative green building technologies, the ZEB Plus showcases state-of-the-art solutions that seek to push the boundary of SLE buildings and improve energy efficiency for best-in-class buildings.



Key Features



ADAPTABLE

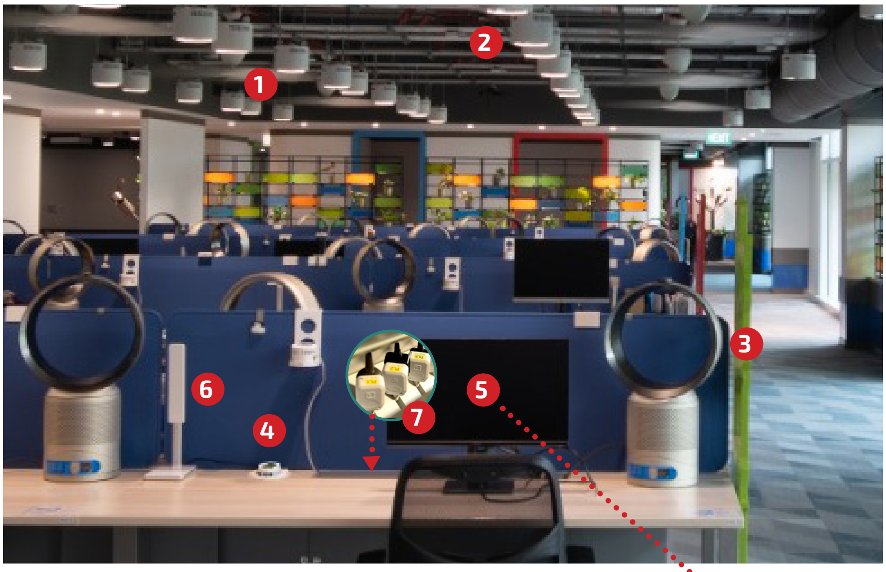
Hybrid Cooling System - Elevated Air Movement and Increased Temperature Setpoint Air-Conditioning System

Many commercial buildings in tropical climates are overcooled, causing energy waste and occupant dissatisfaction. As the population in tropical countries grows, it becomes increasingly crucial to reduce the reliance on air conditioning (AC). The Hybrid Cooling System allows indoor air temperature to be increased and provides greater air movement with ceiling fans as needed. Through an app, occupants have direct control of their environment which can enhance their thermal satisfaction. Each desk has a desktop sensor that measures and monitors indoor environmental conditions, such as relative humidity and lighting level.

The Hybrid Cooling System can provide substantial energy savings. Energy analysis for tropical buildings has shown that up to 45% in cooling energy savings can be achieved by increasing the cooling temperature setpoint from 24 °C to 27°C.

Through test bedding at ZEB Plus , changing the setpoint temperature from 24°C to 27°C with the introduction of ceiling fans has increased occupant satisfaction from 60% to 90%. Also, the best cognitive performance (as indicated by task speed) was obtained at 26°C. In this smart building, 27 ceiling fans has been installed while the air temperature is set at a minimum of 26°C. Additionally, each work desk has a desk fan for personalised comfort.

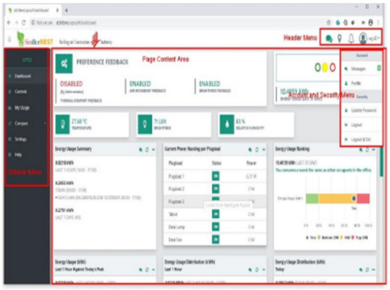
Technology on Workstation Desk



Closed-loop control over PoE lighting and roller blinds utilizing desktop sensor maximizing daylight while providing individual task lighting.

1. Elevated Air Movement
2. High-Performance PoE (Power Over Ethernet) Based Dimmable Ceiling Luminaire
3. Personal Desk Fan
4. Desktop Sensor
5. User Personalized Space Settings Application
6. Dimmable Desk Lamp
7. Monitored Plug Lead (inset)

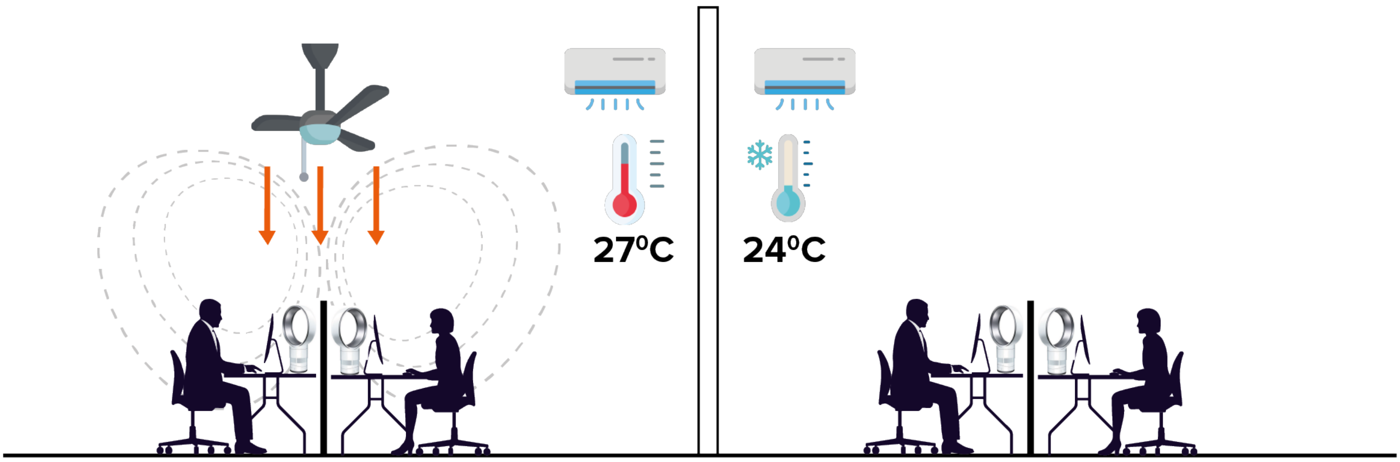
Data is harvested, processed and displayed through UPSS



Most importantly, occupant feedback provided to the User-Personalized Space Settings (UPSS) application informs the system whether an increase or decrease in air movement or temperature is preferred.

Hybrid cooling allows indoor air temperature to be increased and provides greater air movement with ceiling fans as needed. This provides up to 45% in cooling energy savings and enhances thermal comfort.

Elevated Air Temperature and Movement



Radiant Cooling System

Radiant cooling refers to the use of cooled surfaces to remove sensible heat (heat from people, lights, computers etc.) emitted through radiation. In a radiant cooling system, radiant panels cooled by chilled water remove sensible heat while humidity is removed with a Dedicated Outdoor Air System (DOAS) which provides cool and dry air to the space.

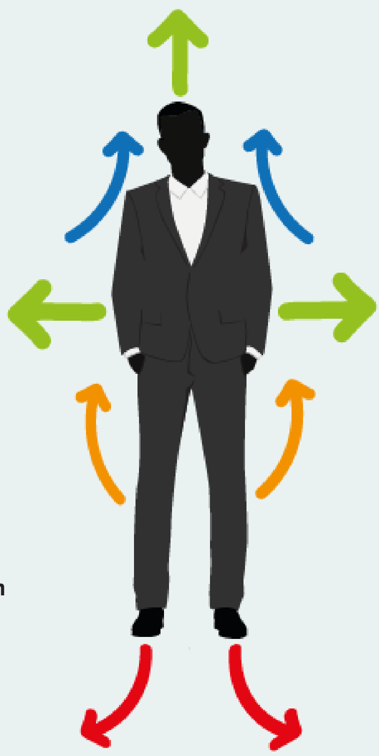
In a typical air-conditioning system, both sensible heat and humidity are removed by providing cool and dry air to the space. The radiant cooling system uses water as a heat transfer medium to remove heat, which is more energy efficient than air.

The radiant cooling system uses water as a heat transfer medium to remove heat, which is more energy efficient than air.

Thermal Comfort of Radiant Cooling

Heat is lost from the human body mainly through radiation

The temperature distribution in the room is more uniform because there are fewer sources of air flow



Radiation
The emission or transmission of energy in the form of waves or particles through space.

Convection
The process by which heat is transferred by movement of a heated fluid such as air or water.

Conduction
The process by which heat is directly transmitted through the material of a substance when there is a difference of temperature without movement of the material.

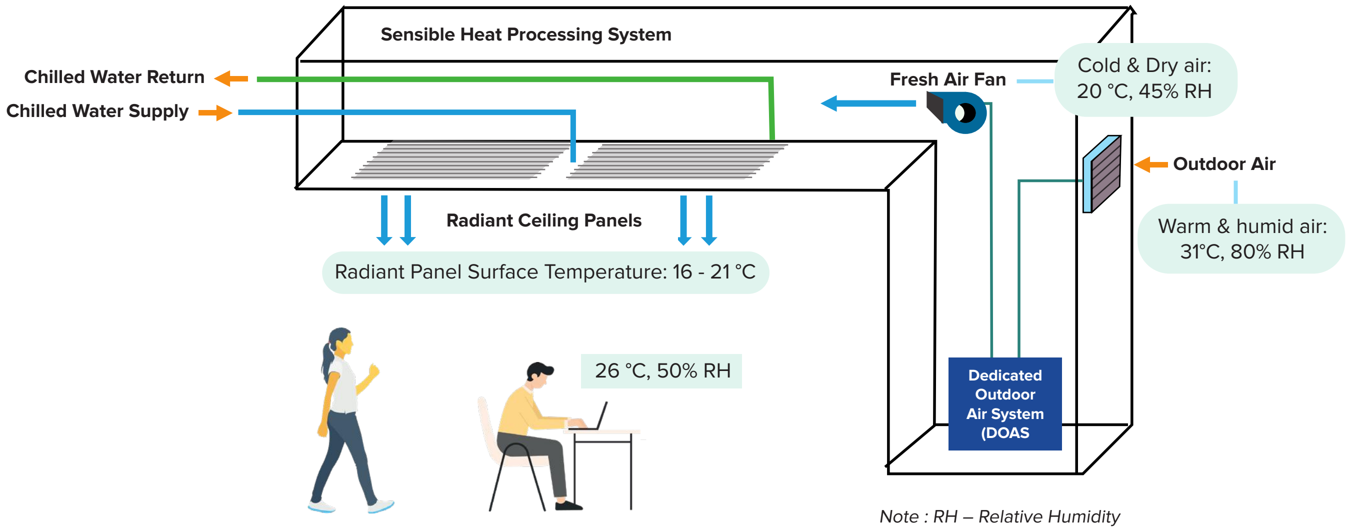
Evaporation
The process of turning from liquid into vapour.

- **Radiation: 40 - 50%**
- **Convection: 20 - 25%**
- **Evaporation: 20 -35%**
- **Conduction: 3 - 5%**

Copyright: K Thompson College of Louisiana at 25°C

The radiant panels which remove sensible heat (heat from people, lights, computers etc.) are operated in combination with the Dedicated Outdoor Air System (DOAS) which removes humidity by supplying cool and dry fresh air.

Radiant Cooling System Schematic



Note : RH – Relative Humidity

The radiant panel uses a higher chilled water temperature of 15 - 18°C for cooling rather than the typical 6 - 8°C for a conventional air distribution system. At this higher water temperature, the chiller plant efficiency can significantly be improved, hence reducing energy use for cooling.

This particular system results in 30 to 35% energy savings for cooling as compared to a conventional air distribution system. It also enhances occupant thermal comfort by ensuring more uniform temperature distribution within the space, a low noise level and absence of draft.

30 to 35%

expected energy savings for cooling as compared to a conventional air distribution system

SMART

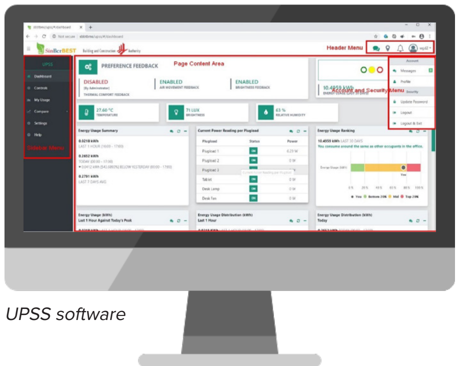
Smart Office Desk Plug Load Monitoring & Control and User-Personalised Space Setting (UPSS) Application

To reduce plug load or energy consumption by plugged devices, smart plugs to control and monitor energy consumption were introduced at the ZEB Plus office. In this building, each desk is fitted with six power sockets equipped with energy metering capabilities.

Occupants can keep track of their own energy utilisation behaviour and schedule when to turn on or off their devices through the UPSS application. Facility managers can also analyse energy consumption patterns across occupants and encourage behaviours to reduce energy consumption through the application without affecting their day to day work and productivity.

Presently, many buildings do not take into consideration the desired environmental conditions by occupants. Despite low levels of satisfaction from occupants, they often receive the same levels of thermal conditions, air quality and lighting. In this building, the UPSS software is able to solicit occupant's preferences in terms of air temperature, air movement and lighting. The control algorithms will then tweak the system to adapt to their needs, thus leading to better satisfaction while simultaneously minimizing energy use.

Plug load



UPSS software

PoE Lighting and Active Use of Daylight

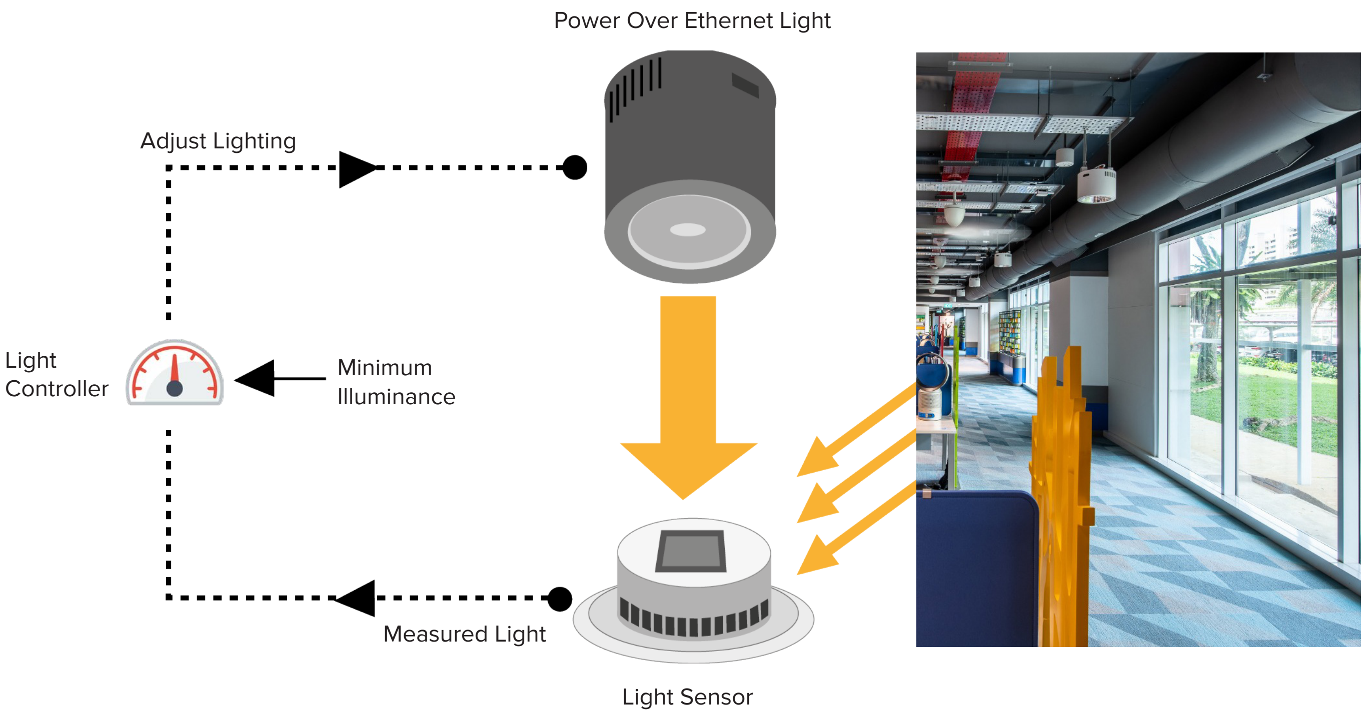
The central lighting system utilises ultra-low power LEDs powered by Ethernet (PoE) instead of normal power cables, which is expected to save up to 30% of lighting energy. A total of 53 PoE lights were installed in a closed-loop design configuration to ensure light is delivered into the space such that a minimum level of light is uniformly distributed on desks.

The lighting that occupants receive can originate from either artificial or natural sources of illumination. When there is sufficient daylight in the space, the central lighting system reduces reliance on electrically powered lights and thus saves more energy. Should the incoming daylight excessively exceed the target light level, a feedback signal will be sent to the roller blinds to reduce the light received on the surface. These controls are also programmed so that when the light is below the target level, the roller blinds will be retracted.

Because of the high degree of control over many important lighting parameters, the SinBerBEST team has been able to develop and test the lighting controls under a wide range of conditions in a relatively short period of time. Additionally, should occupants prefer a more personalized lighting level on their desks, they can control lighting level directly through the User Personalised Space Settings (UPSS) application.

> **“**
>
> **The central lighting system utilizes ultra-low power LEDs by Ethernet, which is expected to save**
> **up to 30%**
> **of lighting energy.**

Central Lighting System utilising PoE Lighting and Daylighting to Optimise Lighting Level



HEALTHY

Demand Controlled Ventilation (DCV)

Essentially, the smart ventilation system automatically adjusts the air flow of outdoor air into the office space according to the occupancy level , saving up to 20% of AC energy. Using carbon dioxide sensors in the indoor environment, the control algorithm modulates the volume of outdoor air flow into the entire office via the air-conditioning mechanical ventilation equipment.

The new innovation in this design involves the occupancy positioning system (see below) within the zones that detect the actual number of occupants to provide accurate outdoor airflow in compliance with ASHRAE Standard 62.1 and Singapore Standard SS554.

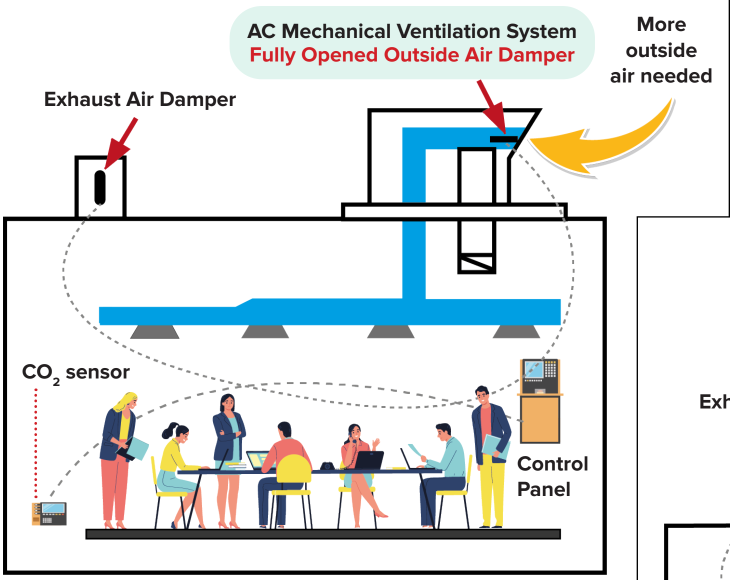
This ensures that the carbon dioxide levels are kept at an acceptable level within the enclosed space, thus enhancing the indoor environmental quality and the occupants' health.

The smart ventilation system automatically adjust the space ventilation requirements according to the occupancy level of the office, saving up to

20% of AC energy

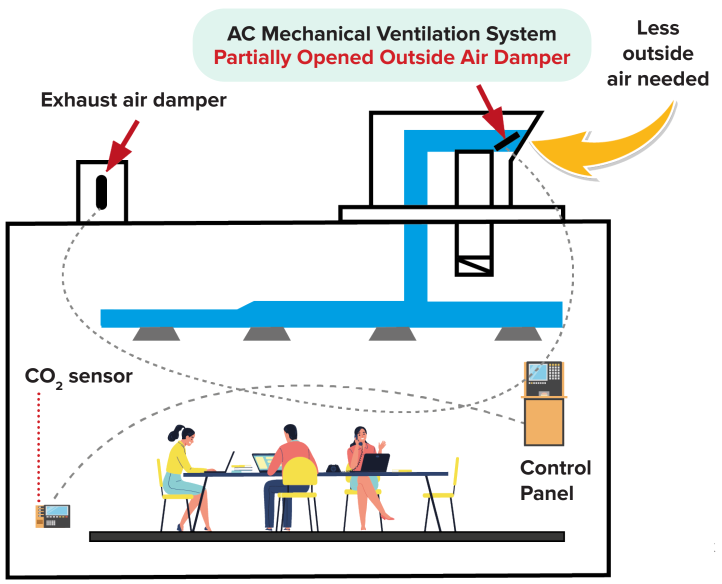
and enhancing the indoor environmental quality and occupants' health.

DCV System at Full Occupancy



Source: Yorkland Controls

DCV System at Partial Occupancy



Source: Yorkland Controls

BIOPHILIC

Direct and Indirect Features

To encourage a collaborative and healthier workplace, the office was designed to incorporate biophilic features. Biophilic designs and features are important because of their positive effects on mental and physical health. In 2020, the World Health Organisation (WHO) stated that more than 264 million people of all ages around the world suffer from depression. As such, the ZEB Plus office aims to have a positive impact on well-being.

One biophilic feature is the presence of indoor plants in the office, which were carefully selected during the design stage. Dedicated LED lights were installed to promote their growth.

In terms of interior space features, the ceiling panels were designed to look like a "honeycomb" to emulate nature. They also function as "acoustic panels" to reduce sound level within the space.

Biophilic designs and features are important because of their **positive effects on mental and physical health.**

Direct features: "Super Tree" and indoor plants

Indirect features: "Honeycomb" design

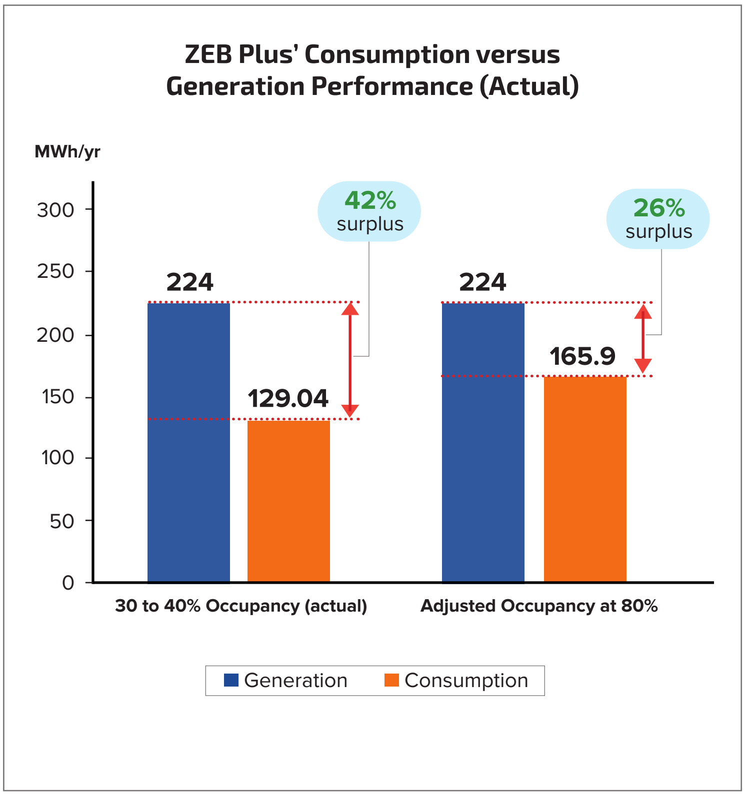
RENEWABLES

High Efficiency Solar PV System

While cutting down on energy consumption is one critical requirement for achieving zero energy, it is not enough. Inevitably, energy would be required to power equipment and systems throughout a building; hence, the building must be able to generate at least sufficient energy to meet such needs.

Prior to the retrofit, an energy surplus of between 7 and 9 percent had been achieved through the adoption of solar PV systems over a 10-year period. As part of the retrofit to achieve its positive energy building target, the existing solar PV system for the main roof was replaced with more efficient panels (22.3% @ 395 Wp/panel) as compared to the original one of about 13%.

Based on actual data and occupancy of the space, ZEB Plus has achieved an average 42% energy surplus for the last 2 years. With full occupancy, it is expected that the surplus will be about 20%, which would still make it a positive energy building.



SunPower MAXEON 3

Total Installed Capacity: 195.13 kWp

Panel Power: 395 Wp

Panel Efficiency: 22.3%

Total No. of Modules: 494 nos.

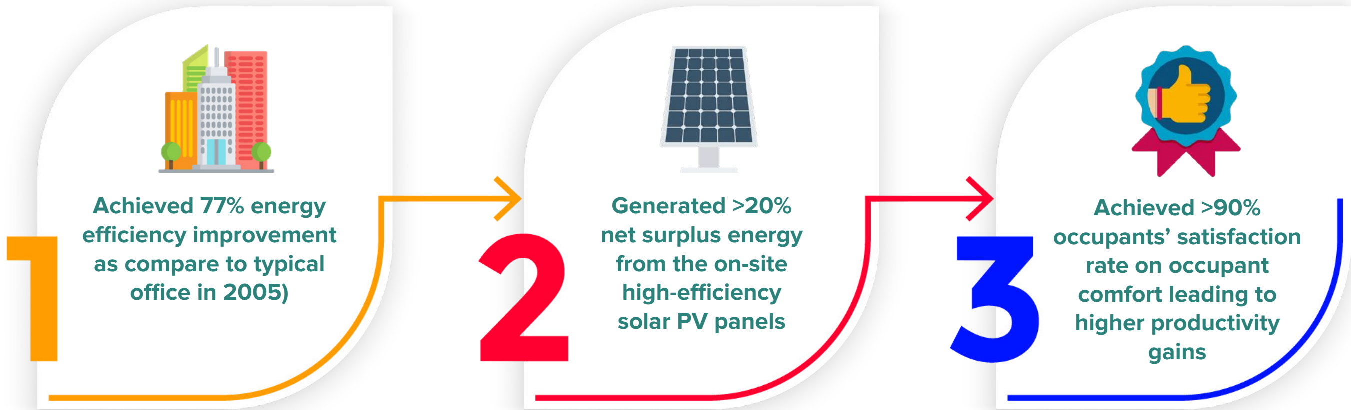
Conclusion

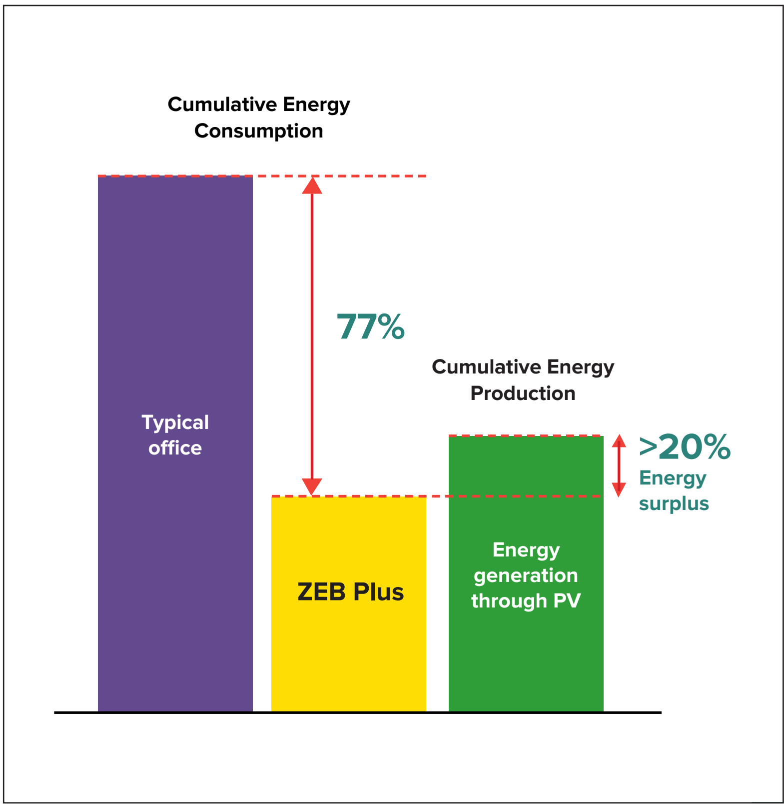
Technologies demonstrated at ZEB Plus provides best practices and strategies for practical Super Low Energy (SLE) uses cases where industry (building owners/developers) can refer to and apply in their own SLE's journeys.

The project also highlighted the public sector's commitment to sustainable low-carbon buildings in support of the Singapore Green Building Masterplan (SGBMP). By leveraging research and innovation, through close collaboration with industry players and research institutions, the project hopes to inspire the industry to replicate these to mainstream SLE buildings towards a low-carbon built environment.

Highlights

ZEB Plus's Overall Performance Indicators





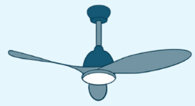
"Leveraging research and innovation, the public sector is leading the way for Singapore to mainstream SLE buildings towards a low carbon-built environment.

Lower Energy Use, Higher Comfort Acceptability and Better Satisfaction Results

Based on a study which surveyed a total of 35 occupants on thermal comfort and satisfaction over a 11-week period, setting a higher air conditioning temperature with elevated air-movement produced by ceiling fans does not compromise thermal satisfaction. In fact, the results show an improvement in comfort acceptability from 55% to 77% by raising the set-point temperature from 24 °C to 26.5 °C.

By increasing the temperature set point and supplementing this with elevated air-movement, a cooling energy savings of 32% was also achieved.

Increase in set-point temperature of ceiling fans from 24 °C to 26.5 °C with fans added

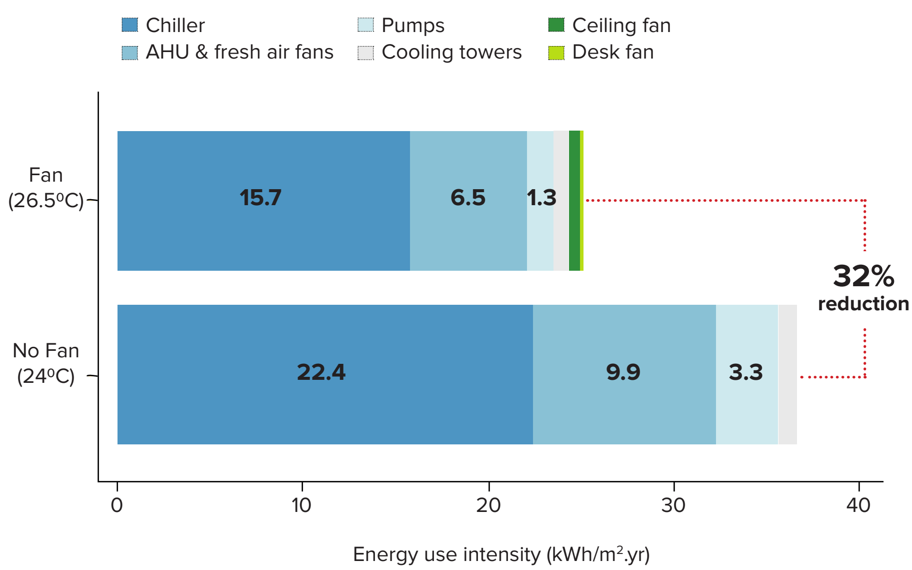


Improvement in occupants' comfort acceptability

to 77%

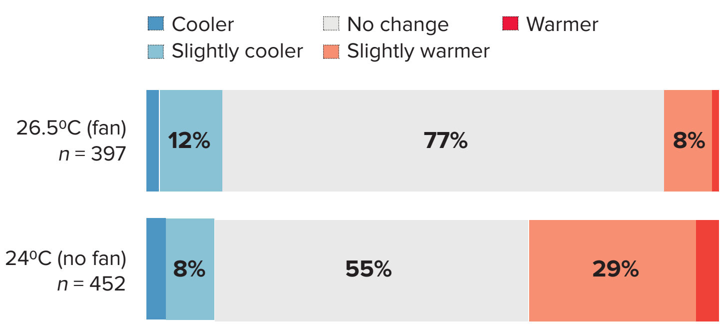
from **55%**

Cooling Energy Saving Results



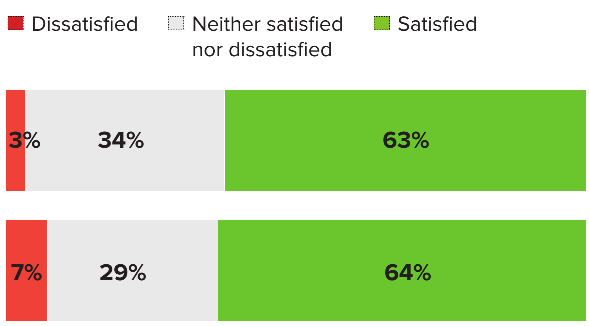
Comfort Acceptability and Satisfaction Results

Right now, would you prefer to be...



Improved acceptability at higher set-point temperature with ceiling fans

Right now, how satisfied are you?



Better thermal satisfaction was established

ZEB Plus @ BCA Braddell Campus

Reflections

SinBerBEST is honoured to have played a major role in transforming the first floor of BCA ZEB Plus to a living laboratory.

Our paradigm of looking at buildings as a factory or assembly line which manufactures the indoor conditions for occupants meant that our design for the living lab took a holistic approach.

The SinBerBeST technologies deployed at the living lab span the breadth of building systems: a lighting control system for daylight harvesting and visual comfort, a hybrid cooling system in which air conditioning works in tandem with ceiling fans, sensor network for IAQ monitoring, a granular Energy Metering System for plug load management, occupancy positioning system for demand-based ventilation, and User Personalised Space Settings Application for real-time user feedback.

A Testbed Building Management System ties all the technologies together by taking the real-time feedback from occupants and adjusting the SinBerBEST systems to meet their demands.

SinBerBEST
Building Efficiency and Sustainability in the Tropics

This project was a good opportunity to share our state-of-the-art net zero energy solutions for buildings in the Southeast Asia region. These solutions include a radiant ceiling panel for sensible cooling and decoupled latent cooling system.

The challenge was how to bring a proven HVAC technology in Japan to a different climate region such as Singapore's hot and humid climate. A simulation tool has been utilized to develop the optimized layout of the radiant ceiling panel and dew point temperature monitoring. We also installed a water leakage sensor to prevent condensation.

Another challenge was to reduce the energy consumption by implementing operative temperature control with radiant cooling system. Convective enhanced radiant ceiling panels have been also used to increase the cooling capacities in this project.

SANKEN
ENVIRONMENTAL ENGINEERING

We were able to work through various issues as a team because BCA (building owner) and SBB (collaborating researchers) are open minded and adaptable project partners. Working with these respective stakeholders of the project team to integrate the latest technologies into modern building systems and bring their ideas into reality was a challenging and enriching experience.

Being a member of this project offers wealth of knowledge, such as the interfacing with technologies which are typically not a part of a conventional building/construction project. Furthermore, the fact that ZEB was an existing building presented another challenge where designers needed to work with an operating building.

CCAPartners
CCA & Partners Pte Ltd
Consulting Engineers





ZEB Plus' Design Approach and Solutions

Specifically for ZEB Plus, the main challenge faced was catering to different user needs and preferences, especially on aspects such as office layout and cooling provision in the building.

While working towards reducing energy use, we also had to keep in mind the thermal comfort for occupants. Their opinions were also sought for matters pertaining to personal spaces, such as cubicle design.

To overcome this challenge, an integrated design approach was adopted, where all stakeholders (management, project team, occupants, and consultant team) were brought together and provided suggestions and feedback on their ideas for the new space.

Constant updates were provided by the project team to stakeholders on the progress of the project.

At ZEB Plus, it is our belief that buildings are for people and therefore, building occupants in turn have a part to play in sustainability practices. Building occupants therefore are given better control over their workspace through a smart mobile app. The app allows them to not just review their daily energy usage but also benchmark their usage against their colleagues.

Building occupants can also use the app to control the speed of the ceiling fans, adjust the lighting intensity, and manage the smart plugs which power up their electrical devices.

ZEB Plus @ BCA Braddell Campus

Taking The Next Steps

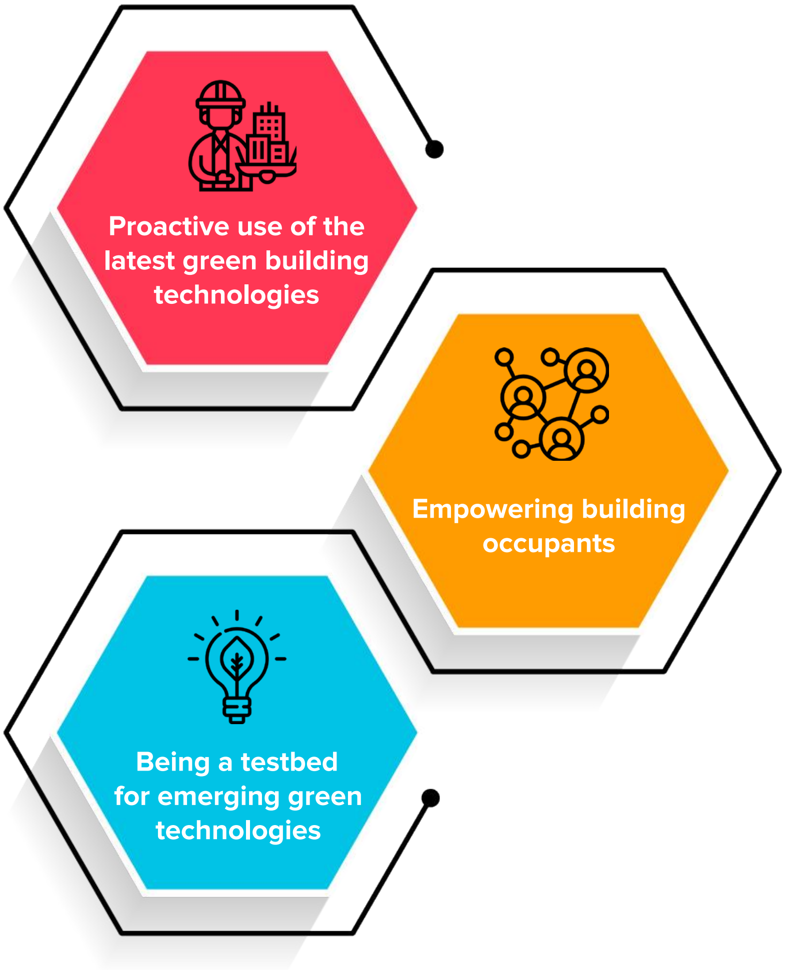
Looking beyond the present, ZEB Plus serves as a Living Lab for many innovative and emerging green building solutions. Through collaborations with research and industry partners, ZEB Plus has been the hub for research activities that push energy efficiency further. This includes testing LED lights powered by internet cables, Indoor Air Quality sensor network, and radiant cooling systems with heat recovery to validate the performance and interest industry partners to adopt these technologies.

Through the proactive use of the latest green building technologies, empowering building occupants and being a testbed for emerging green technologies, this three-pronged approach allowed ZEB Plus to achieve an energy surplus of more than 20%, which is then returned to the grid as clean energy stock.

The empowerment of occupants encourages them to be more aware of their energy usage and motivates them to take positive steps to reduce their energy consumption, hence contributing to lower energy usage at ZEB Plus.

ZEB Plus will continue to serve as a live demonstration for future high-performing buildings and environmental sustainability in Singapore.

ZEB Plus' Three-Pronged Approach



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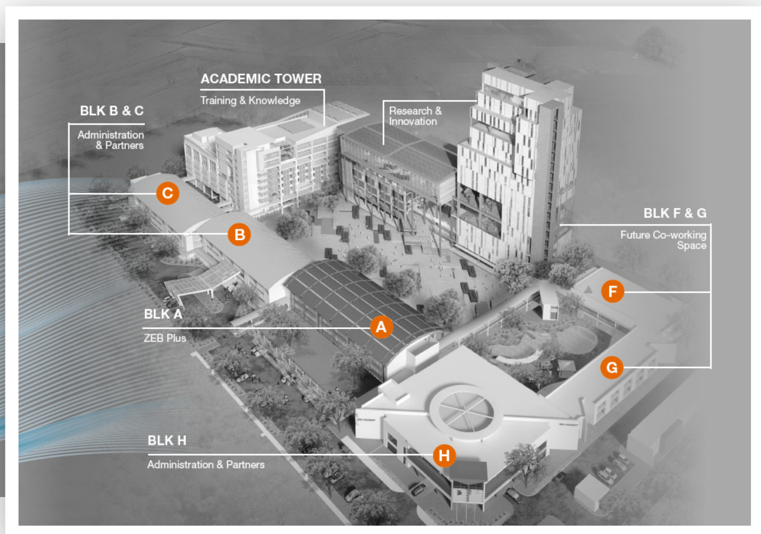
A living lab for research, innovation and training



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Editorial team

Ang Kian Seng | Group Director, Environmental Sustainability Group

Wong Ngian Chung | Principal Manager, Green Building Policy and Technology Department

Majid Sapar | Senior Manager, Green Building Policy and Technology Department

Cheng Yui Seeng | Executive Communications Manager, Corporate Communications Department

Design by: Kudos Graphics | https://kudosgraphics.com | Photos by: Glen Goh