Building and Construction Authority

KEPPEL BAY TOWER

Singapore's first Green Mark Platinum (Zero Energy) commercial building

Green Buildings Innovation Cluster (GBIC) Programme

Best-in-Class Super Low Energy Building Series | Commercial/Office Buildings (Existing Building)

Contents

Foreword

Keppel Bay Tower (KBT) marks a significant milestone in Singapore's green building journey. It is a prime example of how an existing high-rise commercial building could be upgraded to be net zero.

I applaud Keppel Land's commitment in this outstanding accomplishment demonstrating how innovation both technological and financial can make high rise zero energy commercial buildings a reality. I hope Keppel Land's efforts will spur more building owners to make the decisive shift towards super low energy buildings and contribute to a low-carbon Singapore in line with the Singapore Green Building Masterplan.

This project is supported under BCA's Green Building Innovation Cluster programme. In collaboration with the industry, we are developing a series of publications on High-Performance Super Low Energy Buildings. These publications will help to raise awareness and facilitate knowledge sharing on green building solutions.

We hope that this publication on KBT, together with the subsequent publications, will be a useful and valuable resource for all built environment stakeholders in Singapore and the region.

Mr. Kelvin Wong
CEO
Building and Construction Authority

Foreword

In line with Keppel's Vision 2030, Keppel Land places sustainability at the core of our strategy. We are committed to supporting the global fight against climate change as well as Singapore's sustainability efforts, including the Singapore Green Plan 2030.

Keppel Land has committed to halve our Scope 1 and 2 absolute greenhouse gas emissions by 2025 from 2020 levels, and achieve net zero by 2030. We are also contributing to greening the built environment with our suite of sustainable, smart urban space solutions.

With the support of BCA, we were able to test-bed and implement new emerging technologies under the GBIC programme, that were used to help transform the 20-year-old Keppel Bay Tower into Singapore's first BCA Green Mark Platinum (Zero Energy) commercial building. The initiatives implemented have enabled Keppel Bay Tower to be almost 50% more energy-efficient compared to typical office buildings in Singapore, and reduce over 2,400 tonnes of carbon emissions per year.

The transformation of Keppel Bay Tower is a showpiece of Keppel Land's Sustainable Urban Renewal initiative which aims to retrofit, future-proof and extend the lifespan of older commercial buildings. We believe that we have a scalable and innovative model through which Keppel Land can contribute solutions to advance sustainable development in Singapore as well as other key gateway cities in the Asia Pacific and beyond.

We will continue to push the envelope to redefine urban spaces for a sustainable future, harnessing the Keppel Group's diverse capabilities in energy and environment, connectivity and asset management to create greener and smarter solutions.

Mr. Louis Lim
CEO
Keppel Land

Introduction

Background

Keppel Land provides innovative and multi-faceted urban space solutions, including quality homes, offices, malls as well as large scale integrated developments, that enrich people and communities.

A prime showcase of Keppel Land's sustainability efforts is Keppel Bay Tower (KBT), which was completed in 2002. KBT was retrofitted and became the first commercial building in Singapore to be awarded with BCA's Green Mark Platinum (Zero Energy) certification in 2020. It exemplifies how companies can play a part to reduce the built environment's carbon footprint through the greening of brownfield assets and providing sustainability as a service to investors and like-minded asset owners.

While a new building can be designed with new energy-efficient technologies from the onset, there are more challenges in implementing these technologies for an existing operating building where the infrastructure is already in place. This includes the need to carry out the improvement works without disrupting the building's ongoing operations.

KBT is a good demonstration of the effective implementation of five emerging energy efficient technologies: a high-efficiency air distribution system, an innovative cooling tower water management system, fresh air intake control system, smart LED lighting solutions, and an intelligent building control system.

KBT's upgrading is the first time all five systems have been implemented in a development in Singapore, representing a milestone in the nation's history in its push towards sustainability. In addition, the installation of more than 400 square meters of solar panels at KBT allows the property to tap on renewable energy for its operations.

This publication captures KBT's unique journey in becoming a net zero building.

Timeline

Keppel Land has long been committed to running its business in a sustainable manner, and continually strives to create real estate solutions that mitigate climate change. KBT's upgrading journey began in 2017, when Keppel Land and the Building and Construction Authority of Singapore (BCA) jointly launched the BCA-Keppel Land Super Low Energy initiatives for KBT.

In 2018, Keppel received a grant from BCA's Green Buildings Innovation Cluster (GBIC) programme to pilot the aforementioned five systems at KBT, with a target annual 20% improvement in energy efficiency. In February 2020, with the completion of the pilot programme and the deployment of the five systems, KBT was able to achieve a 22.3% reduction in its annual energy consumption, exceeding its original goal.

After passing the pilot phase, some of the technologies under these five systems have been deployed to the rest of the building. A 400 square-meter solar panel installation, yielding 100,000 kilowatt-hours per annum, has been installed on the roof of the 18-storey Keppel Bay Tower, as well as its six-storey podium block.

KBT's annual energy consumption has been reduced by some 30%, or 2.2 million kilowatt-hours a year, compared to its 2017 Green Mark Platinum level. At this stage, KBT's annual energy consumption is half that of a typical office building in Singapore, resulting in electricity cost savings of around $400,000 annually. The remaining energy use is offset through the purchase of renewable energy certificates through Keppel Land's electricity retailer, Keppel Electric, which are generated from PV panels installed at Keppel Offshore & Marine's yards in Singapore.

5 emerging energy efficient technologies:

- High efficiency air distribution system
- Innovative cooling tower water management system
- Fresh air intake control system
- Smart LED lighting solutions
- Intelligent building control system

Keppel Bay Tower

Singapore's first Green Mark Platinum (Zero Energy) commercial building

Energy Use Index (EUI) of <115 kWh/m² per year

Almost 50% more energy-efficient compared to typical office buildings in Singapore.

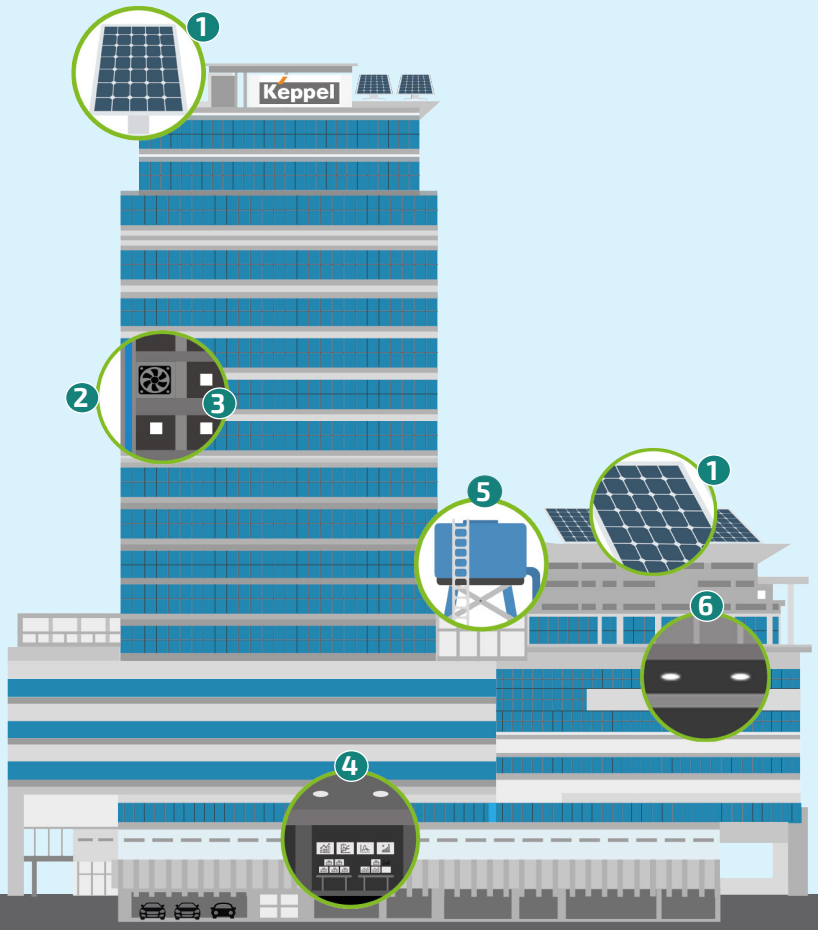
Overall energy savings of over 30% or 2.2 million kWh/year

Equivalent to the amount of energy required to power more than 400 five-room HDB flats in Singapore for a year.

Reduction of over 2,400 tonnes of carbon emissions per annum

The purchase of renewable energy certificates generated from PV panels installed in Keppel Offshore & Marine's yards in Singapore, together with the installation of onsite PV panels at Keppel Bay Tower, result in a reduction of over 2,400 tonnes of carbon emissions per annum. This amount would otherwise require about 12,000 trees to absorb over approximately 50 years.

Source: Keppel Land Limited



Smart Eco-Features of Keppel Bay Tower

1. **PV Panel System** will generate about 100,000 kWh of energy per annum
2. **Energy-Efficient Air Distribution System** with air handling unit fans that are about 45% more energy-efficient than other best-in-class technologies
3. **Demand Control Fresh Air Intake System** utilises integrated sensors to regulate fresh air intake according to indoor activities, optmising energy usage for better thermal comfort and indoor environmental quality
4. **Intelligent Building Control System** employs a high precision physics-based simulation engine to improve data analytics and control
5. **Cooling Tower Water Management System** utilises a patented solution that reduces cooling tower water usage and eliminates the need for chemical water treatment
6. **Smart Lighting System** utilises occupancy sensors which allow seamless transition in lighting levels according to building occupancy

Keppel Land

Keppel Bay Tower is conveniently located at HarbourFront and within five minutes' drive from CBD. It offers excellent connectivity via the HarbourFront MRT station, major roads and expressways. Tenants enjoy a wide array of dining and lifestyle choices with the building in close proximity to VivoCity and Resorts World Sentosa. The 18-storey office building has approximately **394,000 square feet of overall floor area**.

G-ENERGY

G-Energy offers a wide array of integrated energy and project management services, acting as the System Integrator in the Keppel Bay Tower project.

IES INTEGRATED ENVIRONMENTAL SOLUTIONS

IES are leading global innovators in integrated performance based analytics, and home to the largest building analytics team in the world.

Innovative Polymers Pte Ltd

Innovative Polymers Pte Ltd specialises in providing advanced technological chemical free cooling water management system for air-conditioning and mechanical ventilation system (ACMV).

Lumani

Lumani uses its expertise to reduce energy consumption with intelligent algorithms that contribute to sustainability.

Danfoss NOVENCO

Danfoss and **Novenco** provide engineering solutions that utilise resources to drive sustainable transformation of tomorrow.

依图 YITU

YITU integrates state-of-the-art AI technologies with industrial applications for a safer, healthier and faster world.

(A video feature: https://www.youtube.com/watch?v=f0Tz2ON6ECY)

Design Strategies & Features of Emerging Technologies

All five technologies exhibit positive returns in energy savings as compared to their pre-retrofit energy usage

Technologies	Test-Bed Area	Pre-Retrofit Energy Consumption (MWh per year)	Measured Energy Savings	Achieved Energy Saving (kWh per year)
Danfoss AHU Fans	Level 12	43.8	46.8%	20,500
DeCalon Cooling Towers Management	Whole building (2 running chillers)	1,679	7.0%	117,500
Yitu Integrated Sensors	Level 12	62.5	12.0%	7,500
IES Intelligent Building Control	Whole building	5,102	7.0%	357,200
Lumani Smart Lighting	Level 2, 5, 6, 10, 11, 12 & 18	17 (from LED)	13.4%	2,300 (level 12 only)

Keppel Bay Tower -
Design & Innovation

High Efficiency Air Distribution System

Technology Introduction

The solution combined highly efficient and easily integrable components such as the Novenco's axial fans especially designed for air handling unit (AHU) applications, Danfoss's motor independent variable frequency drives (VFD) with ACMV intelligence and IE5 permanent magnet motors to the existing AHU. The fan technology employs an optimised design of blade profiles, taking inspiration from the aircraft jet engines, and delivers high performance of aerodynamics. It is 25% more efficient than the standard belt driven fans used for building applications. The Danfoss VFD utilises motor independent technology that makes integration to the high efficiency permanent magnet motor (IE5 motors) an easy task and delivers highest levels of Motor-VFD efficiency. By integrating these technologies together, the solution resulted in the "wire to air efficiency" (Fan + Motor + VFD) of 80-85%. This is significantly higher than the belt driven conventional centrifugal fans and the direct driven plug fans or the EC (electronically commutated) fans that typically have "wire to air efficiency" of 60-68%.

Project Implementation

A Novenco ZerAx® axial flow fan, Danfoss VLT®-HVAC-FC102 VFD and Domel IE5 motor were installed in an existing air handling unit over a 12-month period and achieved energy savings of 46.8%, compared to the pre-retrofitted system comprising a conventional belt driven centrifugal fan. In addition, the new fan operates at 3-17% lower noise levels, noticeably reducing noise within the building.

46.8%
Achieved Energy Savings

3% - 17%
Lower noise levels

Outcomes

The success of this fan retrofit can easily be replicated with new or existing ACMV systems, to reduce power consumption and greenhouse gas emissions.

Following the successful pilot, KBT retrofitted its remaining 21 AHUs to Danfoss low-power systems in a similar fashion, minimising energy usage throughout the whole building.

Websites:
https://www.danfoss.coWm/en/markets/buildings-commercial/dds/drives-for-fans/#tab-overview
https://www.novenco-building.com/solutions/ecplus-concept/

Before Improvement	After Improvement	Achieved Savings
0.533 W/CMH 13.53 kW	0.230 W/CMH 6.96 kW (Jan-Dec 2019)	46.8%

Cooling Tower Water Management System

Technology Introduction

A typical cooling tower requires significant amounts of water, energy and chemical treatments to function.

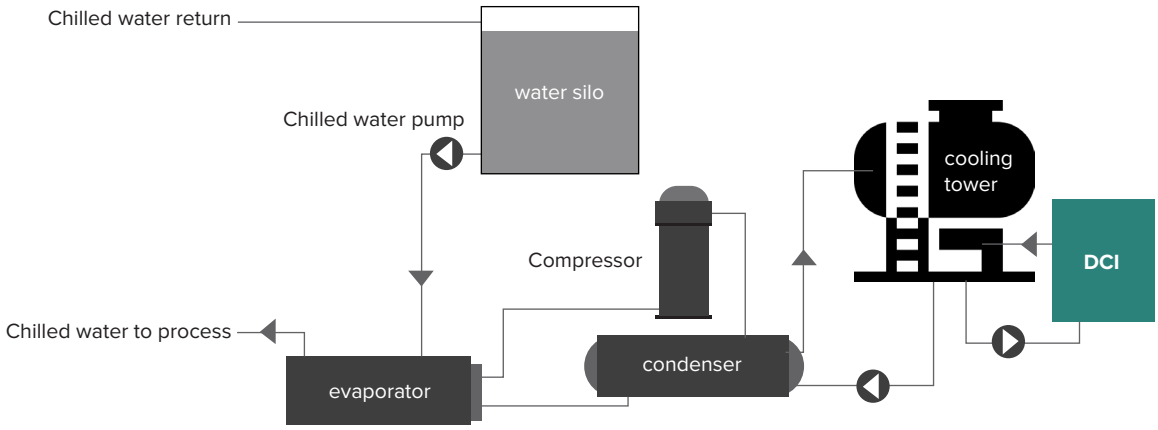
Innovative Polymers' Decalon (DCI) system represents a significant breakthrough in improving the efficiency of cooling energy. Its worldwide patented technology is able to remove and prevent scale formation and greatly slow corrosion by removing dissolved oxygen from the water. The DCI system also disinfects water through its proprietary CataGreen technology, removing the need for complex chemical treatments to deal with algae and bacteria build-up in KBT's cooling towers more efficiently than some other Non-Chemical Device (NCD) technologies available in the market. Unlike other NCD, such as magnetic, electronic, hydrodynamic and catalytic, DCI uses scientifically proven electrochemical technology to remove the existing scales, to prevent future scaling, to reduce the corrosion rate and to disinfect the cooling water.

DCI is SGBC certified with "Excellent" status, certified by ISO 9001, bizSAFE 3, TUV Rheinland and CE too.

Project Implementation

This system was implemented throughout the entire building in December 2018. Average chiller plant system efficiency over a 12-month period in 2019 improved by 7%. The system also enjoys an 80% reduction in cooling tower blowdown water usage.

How It Works



Source: Innovative Polymers Pte Ltd

Outcomes

The system replaces the environmentally unfriendly chemical treatment method that is commonly used in the cooling water process. It does not dose any toxic chemicals into the cooling tower water, typically used to prevent scaling, corrosion and reduce bacteria buildup. As a result, water drained from the system can be safely be discharged into the environment without treatment.

Before Improvement	After Improvement	Achieved Savings
0.620 kW/RT	0.575 kW/RT (Dec 18 - Feb 20)	7%

Website:
http://innovativepolymers.com/sub_decaion.html

After 12-month pilot period

7%
improvement in chiller plant system efficiency

80%
reduction in cooling tower's blowdown water consumption

Photo: Keppel Land Limited

Fresh Air Intake Control System

Technology Introduction

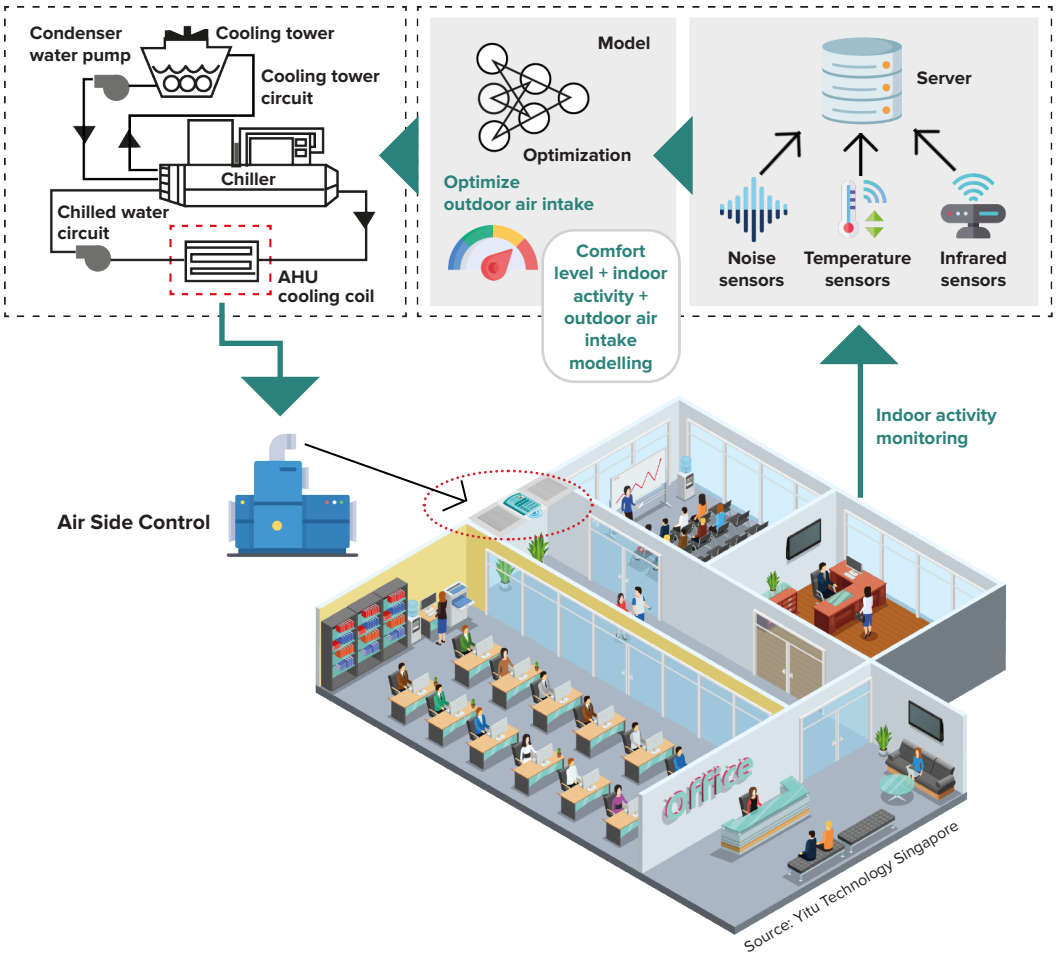
The constant flow of outdoor fresh air is vital to maintaining a healthy, pleasant indoor working environment. However, cooling demands are constantly changing every day, throughout the day, and there is a need to find a solution to minimise cooling energy usage without compromising indoor comfort and air quality.

This air system utilises integrated sensors to optimise fresh air intake based on indoor activities through a data driven demand control fresh air optimisation method. The aim is to reduce cooling load by optimising fresh air intake based on demand analysis via indoor activity modelling, while maintaining acceptable indoor air quality. This is through a regression model based on both independent variables (fresh air quality, indoor activity modeling and thermal comfort), and dependent variable (energy usage) that were developed as part of this project. These data driven models allow us to optimise the energy consumption dependent variable by fine-tuning the independent variables while meeting indoor air quality constraints.

Project Implementation

The deployment of demand control fresh air optimisation system was carried out on Level 12 in KBT over a six-month period, in which sensor arrays were positioned to monitor air temperature, noise, carbon dioxide and infrared levels.

Live data was fed into a smart machine learning model, trained to derive the optimal balance between thermal comfort, air quality and energy consumption. As time progressed, this model was able to learn from a growing base of sensor data. This further refined its understanding of factors affecting indoor air quality trends, improving the model's performance.



Outcomes

After a six-month period, the deployed solution was able to achieve a 12% reduction in air-con energy consumption. The system was also able to improve thermal comfort and indoor air quality, creating a more conducive work environment for occupants.

Before Improvement	After Improvement	Achieved Savings
38.46 RTh	33.87 RTh (Jul - Dec 2019)	12%

After 6-month period

12%
reduction in air-con energy consumption

Smart Lighting System

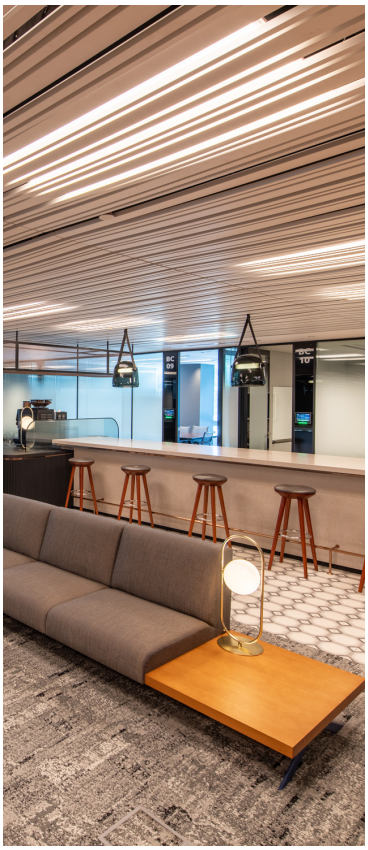
Technology Introduction

This lighting system is a fully autonomous solution that utilises occupancy sensors to allow seamless transition (dimming) in lighting levels according to building occupants' activities level. The system uses the Passive InfraRed (PIR) motion sensors as the counter of activities rather than a relay switch similar to lighting systems in a typical office building set-up. Lighting controllers collect the activities and then send the data to the cloud to decide the mode to operate the light:

Busy Mode:
Switches to the upper dimming level when high activity level is detected

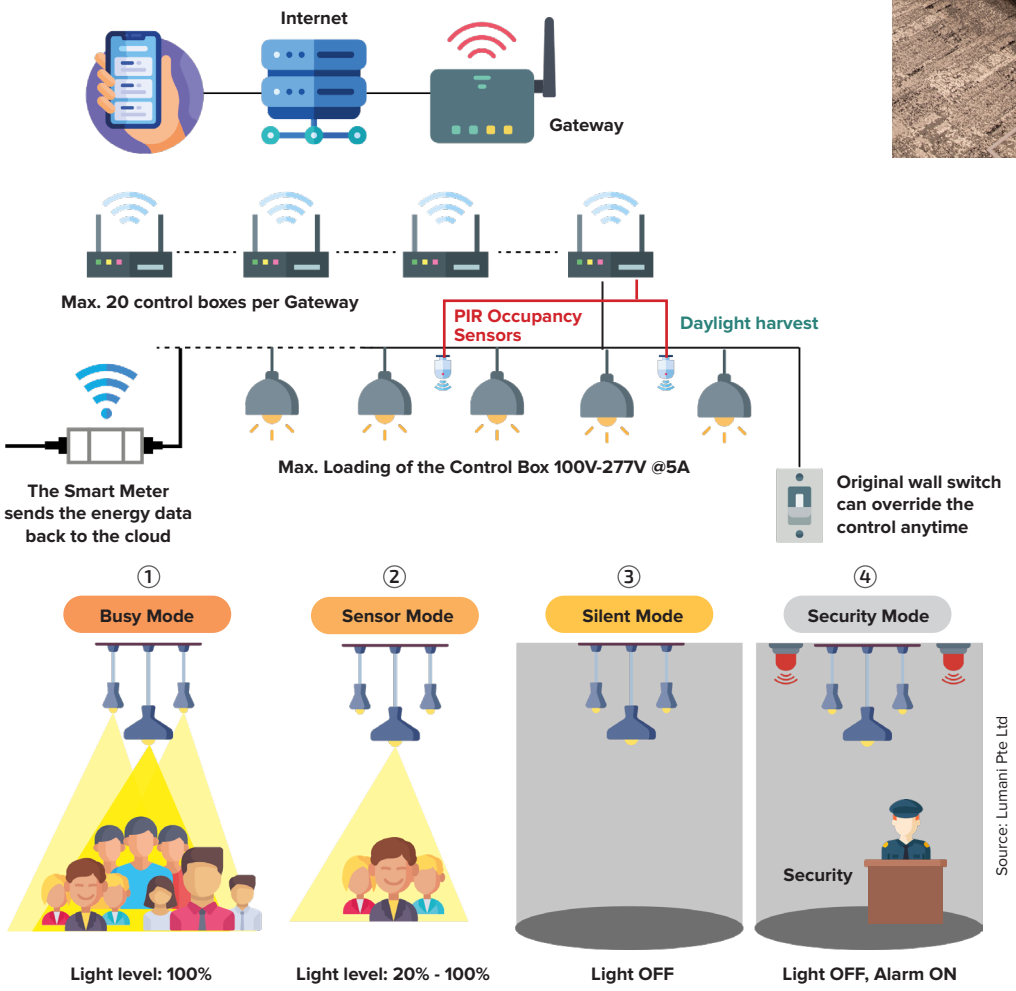
Sensor Mode:
The dimming level fluctuates between upper and lower levels in response to the triggers of the PIR sensors

Silent Mode:
When there is no activity detected for a while, the lights are switched off



Project Implementation

The lighting system was installed across 270 localised zones in seven floors of KBT.



Outcomes

The system was implemented from December 2018 and after a 12-month period, the system significantly achieved a 13.4% energy reduction, from best-in-class (LED) levels.

To define lighting parameters across such a large number of zones, innovations in software allowed for the creation of lighting 'templates' to be set for each zone, greatly speeding up current deployment and future expansions of the system. Further optimisations relating to the day of the week - weekday, weekend and holiday modes - were also deployed to further reduce energy use.

The system also holds much potential for the future expansion of its capabilities. With the addition of new sensors, such as CO_2 monitoring, the system can also potentially be used to warn occupants in the event that hazardous working conditions arise. Various ambient inputs can be used to further improve and dynamically alter system behaviour, to keep lighting energy consumption to an absolute minimum, and possibly add new features into the system.

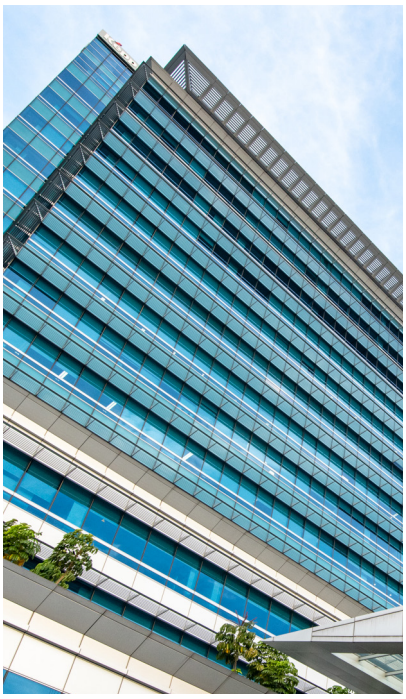
After 12-month period

13.4%
reduction in lighting energy consumption

Website:
http://www.lumazones.com/index.html#msg-box

Before Improvement	After Improvement	Achieved Savings
11.15 W/m² (T8)	3.31 W/m² (Jul - Dec 2019)	70%
3.89 W/m² (LED)	Ave 3.37 W/m² (Jan-Dec 2019)	13.4%

Intelligent Building Control System



Technology Introduction

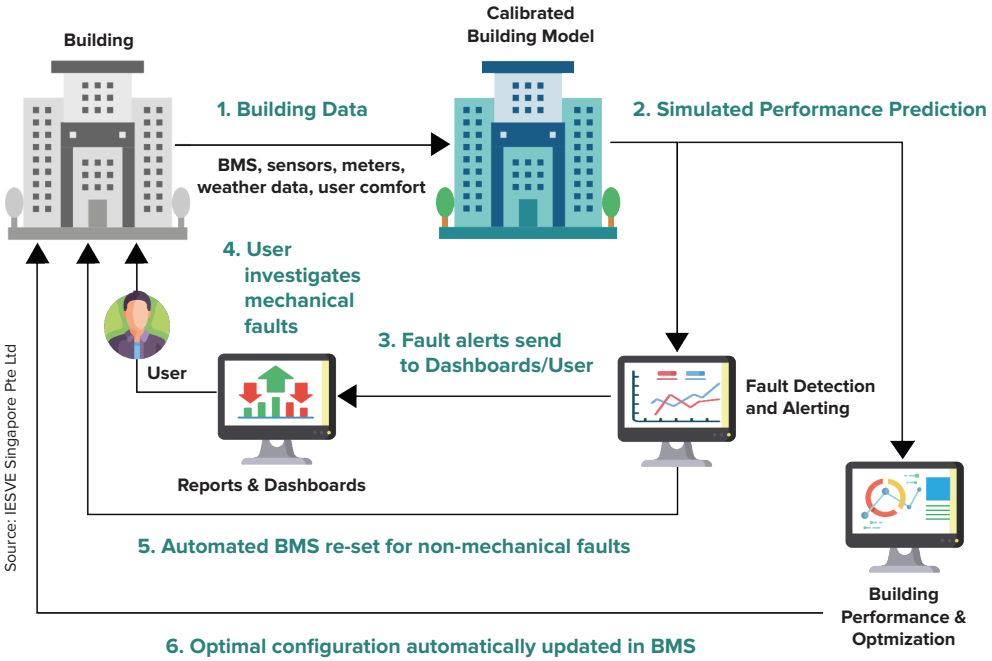
The Intelligent Building Control (IBC) system developed for this project uses a combination of building simulation modelling and real-time building data (digital twin approach) to provide cloud-based advanced building performance prediction, optimisation and diagnosis. This IBC prototype integrates proprietary software tools (The IES Virtual Environment, IES SCAN and the IES model calibration toolset) along with intelligent control algorithms, to create a flexible and robust web-based operational building analysis and optimisation tool.

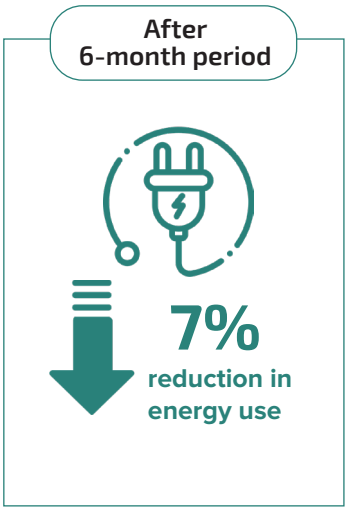
Project Implementation

The IBC system was implemented in September 2019 and different energy conservation measures (ECMs) were carried out. Comparisons were made between simulation results and actual energy data to verify the achievable savings.

In addition, the IBC system can provide performance prediction and suggestions for further optimisation. It also uses novel data analysis techniques, 'virtual sensors' built upon live data and complex calculations, and the ability to consider real-time weather data to simulate key parameters. Running in the cloud, the IBC system can be accessed remotely with minimal downtime, providing a robust total control solution to KBT.

IES Intelligent Building Control (IBC) cloud-based solution





Outcomes

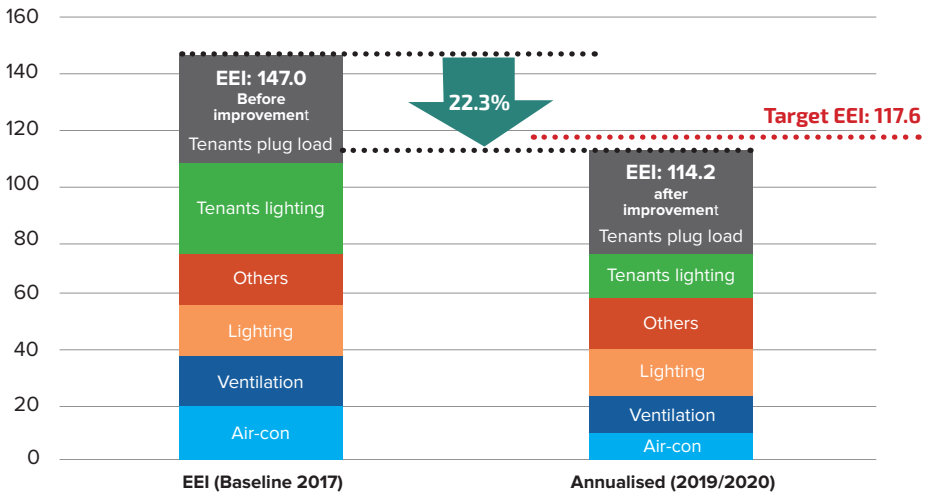
Based on KBT's 'digital twin', an energy saving of about 10% over a six-month period was predicted. When the ECMs were implemented, the IBC system achieved a 7% measured reduction in energy use, a hugely convincing performance for a new, experimental technology.

Before Improvement	After Improvement	Achieved Savings
EEI = 122.8 (Jan - Aug 2019)	EEI =114.2 (Sep 19 - Feb 20)	7%

Overall Building Performance Outcomes

The overall project was successfully completed in November 2019. Based on annualised measured electricity consumption, the total building EEI is at 114.2 kWh/m²/yr. Comparing with baseline EEI of 147 kWh/m²/yr, KBT's annual energy usage has been reduced by 22.3%. At level 12, where all the five emerging energy efficient technologies have been implemented, the resultant EEI is 72.5 kWh/m²/yr which is an energy improvement of about 50% as compared to a pre-retrofit baseline. When comparing with the 2005 baseline, KBT's level 12 is about 70.3% more energy efficient, making it effectively a super low energy floor.

Achieved EEI - Annual Energy Consumption (kWh/m²/year)



After 12-month period

1 mil kWh/year

Measured savings

Challenges Faced by KBT

All test-bedding of technologies must be carried out without affecting the ongoing operations of the tenants. This is challenging especially when establishing baseline measurements and quantifying energy savings.

During the retrofitting of KBT, several challenges were faced.

1

The first was identifying game-changing technologies that would maximise the benefits of such a retrofitting, both to the environment and in reducing costs.

2

The second challenge involved addressing the added complexity required in retrofitting these technologies to existing infrastructure. Installing and optimising these new technologies within the existing design constraints proved to be a complex task.

3

The third challenge faced was avoiding disruptions to existing tenants and building operations during the installation of these new technologies. Minimising downtime during KBT's retrofitting was crucial in managing stakeholder relationships and improving the building's operations.

4

The final challenge involved integrating and deploying multiple systems together. With the interdependency of some systems upon others, synergising many new technologies together for the first time required careful planning and ingenuity.

For the KBT project, Keppel Land was able to overcome the challenges with the management's strong commitment and support, and by having an experienced team that was focused on achieving the goals.

The team adopted a comprehensive project management and planning process to ensure that the deployment was carried out in phases so that energy savings for each technology and overall building could be properly measured and verified.

Taking The Next Steps

Powering KBT Through Renewables

In January 2020, Keppel Bay Tower became Singapore's first commercial development to be completely powered by renewable energy. This was achieved through the installation of over 400 square meters of solar panels on KBT's roof and its adjacent podium block, and offsetting all its remaining energy use through the purchase of renewable energy certificates from Keppel Electric.

103.4 mWh/year
onsite renewable energy generated

Offset energy consumption of about 22 4-room HDB flats per year

4,834.5 mWh/year
offsite renewable energy certificates (REC)

97 kWp
Installed capacity

Envision Energy Management

To further minimise energy consumption from air-conditioning, KBT partnered with Envision Digital International Pte Ltd, a global leader in energy management, to introduce additional smart building control systems. These systems helped to further decrease KBT's energy consumption.

The energy management system is powered by EnOS, Envision's leading AIoT operating system that comes with a complete suite of connectivity and device management tools, along with pre-built applications for decarbonisation and digitalisation.

Reduced air-con energy consumption by 10%

LED light installation

KBT also partnered Signify Singapore to enable tenants to replace fluorescent lights with energy-efficient LED lights without any upfront capital investment. This helped to reduce tenants' electricity bills by 30% and reduced KBT's total energy consumption by 5%.

Philips LED lights at 14.5W/tube
compared with existing T8 lights at 44W/tube

About
344,000 kWh/year
energy savings

Improves lighting power density of average
12 W/m² to 4 W/m²

Green Leases

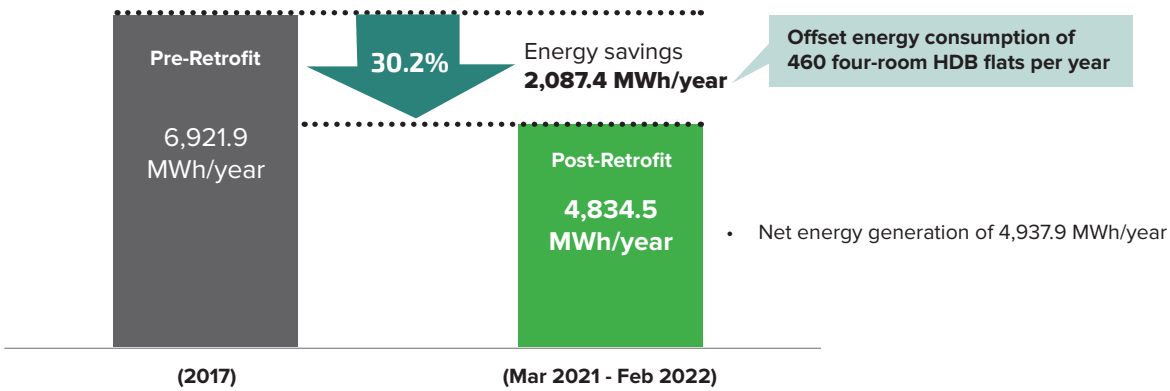
Reducing energy consumption and maintaining a healthy working environment are shared goals of both Keppel Land and its tenants in KBT. In 2019, Keppel Land began offering green leases to its tenants, incorporating requirements such as a minimum Green Mark certification standard for the building and set energy reduction targets for tenants. These green leases reflect Keppel Land's commitment to both environmental sustainability and tenant well-being. Keppel Land was able to achieve a 100% participation from tenants in signing green leases in the same year, an encouraging move towards synergising tenant needs with a sustainable future.

Through the green leases, all tenants have committed to allocate necessary resources to manage operations effectively to maintain high standards of environmental protection as well as to enhance the health and wellness of employees, including to reduce energy use by 5%.

Conclusion

Upon completion of the pilot projects and additional measures, Keppel Bay Tower received the Green Mark Platinum (Zero Energy) accolade in December 2020, the first commercial building in Singapore ever to do so. This accolade recognises Keppel Bay Tower for pioneering all five pilot technologies highlighted above, as well as for having its energy consumption completely supplied from renewable sources.

In the 12 months of March 2021 to February 2022, a 30.2% improvement in energy savings was achieved as compared to pre-retrofit conditions.



- Net energy generation of 4,937.9 MWh/year

Highlights

Keppel Bay Tower
Singapore's first Green Mark Platinum (Zero Energy) commercial building

50% reduction in Energy Use Index: <115 kWh per square meter per year
KBT consumes 50% less energy per square meter than most office buildings in Singapore

30% reduction in energy consumption: Over 2 million kWh per year
KBT's energy reduction from its new technologies offsets the energy consumption of 400 five-room HDB flats every year

CO_2 emissions reduction: 2,400 tonnes per year
KBT's use of solar panels, together with its purchase of renewable energy certificates from Keppel Electric, reduces 2,400 tonnes of CO_2 emissions every year

Sustainable Technologies Powering Keppel Bay Tower

Solar Panel Arrays
Generate 100,000 kWh of clean energy from the sun every year

Danfoss-Novenco Air Distribution System
Implements cutting-edge air distribution system, consuming 45% less energy than existing units

Demand-Control Fresh Air Intake System
Uses smart sensor arrays to optimise energy consumption, while preserving indoor air quality and thermal comfort

Smart Building Control System
Deploys a precise physics simulation model of KBT to predict, monitor and minimise energy use

Cooling Tower Water Management System
Leverages breakthrough innovations to greatly reduce water use and avoid chemical treatment

Smart Lighting System
Seamlessly varies lighting conditions in response to live occupancy levels, reducing energy use

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Lumani Pte Ltd

Yitu Technology Singapore

IESVE Singapore Pte Ltd

Energy Research Institute @ NTU (ERI@N)

Ngee Ann Polytechnic - EWT Centre of Innovation

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