GREEN BUILDINGS INNOVATION CLUSTER (GBIC)

+ Experiment
+ Exhibit
+ Exchange

For more information, visit www.bca.gov.sg/ResearchInnovation/gbic.html
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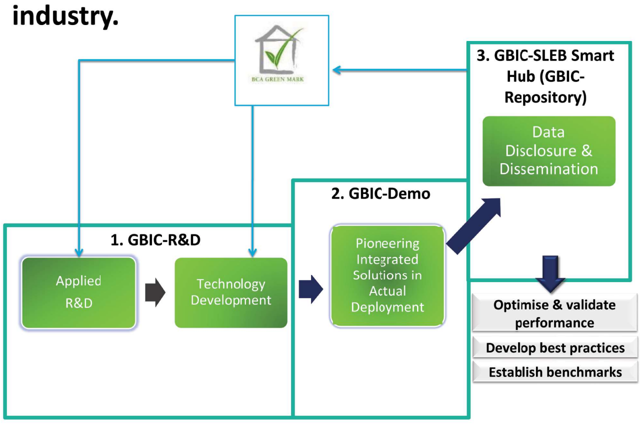
Content Page

Green Buildings Innovation Cluster (GBIC)
Overview

OBJECTIVES

- **One-stop integrated RD&D hub to experiment, exhibit, and exchange knowledge of promising building energy-efficient solutions with industry stakeholders.**
- **To accelerate market adoption of promising building energy-efficient technologies and solutions in the industry.**

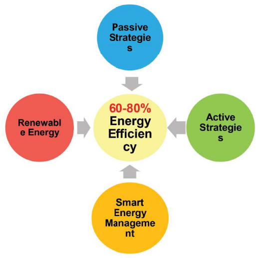


GBIC-R&D

The GBIC-Research & Development (GBIC-R&D) aims to collaborate with industry & R&D community, to develop innovative solutions with significant impact in building energy efficiency and with high market adoption potential.

Top-down Direct Collaboration Projects to Drive BCA Green Initiatives

Ground-up Grant Call Programmes to Push EE Boundaries to Advance Super Low Energy



GBIC-DEMO

The GBIC-Building Energy Efficient Demonstrations Scheme (GBIC—Demo) aims to link up building owners and technology providers in order to establish platforms where industry can test and showcase these technologies to generate local performance data for verification.

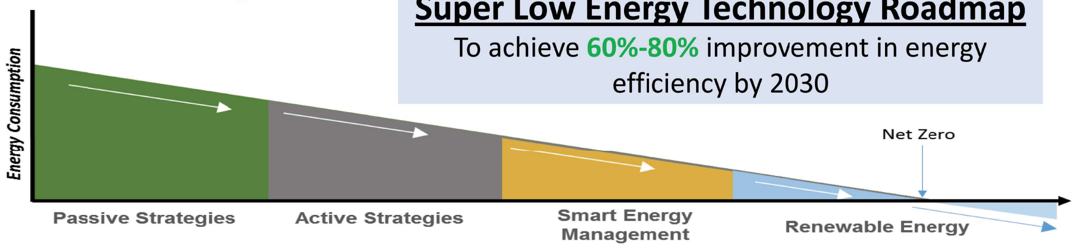
- Large-scale demonstrations of promising energy-efficient technologies in actual buildings
- Encourage building owners and developers to demonstrate innovative energy efficient technologies
- Demonstration projects to achieve performance at least 20% better than current best-in-class buildings

GBIC-SLEB SMART HUB (GBIC-REPOSITORY)

The GBIC-National Building Energy Efficiency Repository (GBIC-Repository), renamed to Super Low Energy Building (SLEB) Smart Hub, aims to collect and analyse essential data and information related building energy efficiency.

Super Low Energy Technology Roadmap

To achieve 60%-80% improvement in energy efficiency by 2030



> 60 Key Technologies in 4 Broad Strategies

Passive Strategies	Active Strategies	Smart Energy Management	Renewable Energy
Sunlight Shading & Daylighting	Air-conditioning	Building Automation	Site Optimisation
Natural Ventilation	Mechanical Ventilation	Smart Building	Solar PV
Dynamic Facade	Lighting Technologies	Plug Load Management	Buildings-to-Grid Integration

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Green Buildings Innovation Cluster (GBIC)
Partnership, Engagement & Outreach

Engagement

18 Workshops
>3,000 Participants


Smart Building Workshop Jun 15


Towards ZE Low-Rise & SLE High-Rise in the Tropics Jan 16


PE School Workshop Aug 16


ZEB/ SLEB Workshop Dec 16

Dedicated Design Workshop to guide industry to achieve Positive Energy/Zero Energy / Super Low Energy

ZEB Design Workshop (23-27 Apr 18)
- Supporting ongoing / upcoming pioneering ZEB projects
- 1-to-1 Design Charrettes with Project Teams

Workshop Trainers:
Dr. Wolfgang Kessling
Mr. Martin Engelhardt
(Transsolar, Germany)

- **20 Project Teams**
- **From 25 organizations**
- **>120 participants**


LED Lighting and Human Health Mar 17


ZEB Roundtable Discussion Workshop Sep 17


ZEB Design Workshop Apr 18


Innovation Challenge Workshop Jun 18


Samwoh Hub


Changi Airport Group (CAG) on Terminal 5


SIT Punggol Campus

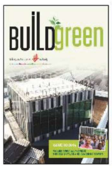

BCAA Phase 2


NParks JLD

Outreach

International Green Building Conference 2017 Singapore
URBAN SUSTAINABILITY R&D CONGRESS
ENERGY INNOVATION

Conferences / Events



BCA Build Green Magazine

BERII Publication

Emerging Tech Reviews


Site visit to pioneering proj

GBIC e-Newsletters

SLE Factsheet

>100 Industry players

- Evercomm Pte Ltd
- Huami
- Tsinglink
- Schneider Electric
- JC Kuhpi
- Power Automation
- Honeywell
- OSIsoft
- IESVE
- ABB Pte Ltd
- Lumani Pte Ltd
- Danfoss
- Innovative Polymers
- brIQs Pte Ltd

- G-Energy
- Kaer Co.
- Beca Carter
- Surbana Jurong
- BSD Pte Ltd
- Six Sigma Pte Ltd
- Meinhardt
- Webearth
- EM Services
- MKPL

- Racks Central
- SMU
- Khoo Teck Puat Hospital
- MOE
- Samwoh
- SIT
- Lend Lease
- DSTA
- Banyan Tree
- SAS
- Ascendas Singbridge
- JTC
- HDB
- MOHH
- CapitaLand
- CDL
- CAG
- Keppel Land
- UWCSEA

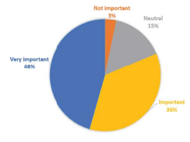
Legend:
- Technology Providers
- Consultants
- Building owners/ Developers

>10 Local Research Institutes

- NUS
- NTU
- SUTD
- ADSC
- ERI@N
- S'pore Poly
- Republic Poly
- S2Lab
- Ngee Ann Poly
- SERIS
- A*STAR-IHPC
- SIT

>6 Overseas Research Institutes

- LBNL
- UCB
- ETH
- NREL
- IEA
- MIT



82% agreed it is important for Singapore to have PE/ZE/SLEB polices or initiatives

Partnership Programme

In collaboration with Keppel Land Thinking Unboxed

GBIC Challenge Call
To achieve **overall energy savings** of at least **20%** better than the best-in-cass Green Mark Platinum buildings

KEPPEL BAY TOWER
[EEI* = 92 kWh/m2/yr]

* For demonstrated area


Industry Workshop


Site Visit to KBT


Sourcing & Shortlisting Technologies

Pro-active Approach to Promote
Super Low Energy High Rise
Demonstration

Industry-Joint Challenge Call

Linking up building owner, technology providers and researchers, to establish a platform where technologies can be pioneered

Successful technology providers to put up a joint proposal to seek GBIC funding to **demonstrate technologies** at actual building

Demonstrated technologies will be showcased with industry to **promote wider adoption** of emerging technologies

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GBIC – R&D

Toward Learning-based Thermal Comfort Models to Instill Behavioral Changes for Greener, Smarter and Healthier Buildings in the Topics via Pervasive Sensing

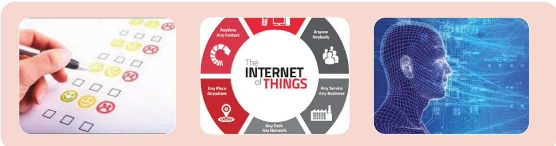
Prof. Wen Yonggang, Mr. Toh Kok Chuan, Mr. Wong Yew Wah, Prof. Georgios Christopoulos, Prof. Tseng King Jet, Prof. Tao Dacheng

1 Objective & Motivation

➢ Evolutions of Thermal Comfort Modelling Approaches & Technologies

Climate Chamber Study **Data Inadequacy**

- Small number of datasets
- Exhibition of psychological bias
- Lack of input from test subjects



Survey-Based
Costly
Error Prone
Limited Scope
Manual
[1,2]

IoT-Based
Automatic
Data Driven
Group Optimal
Static
[3,4]

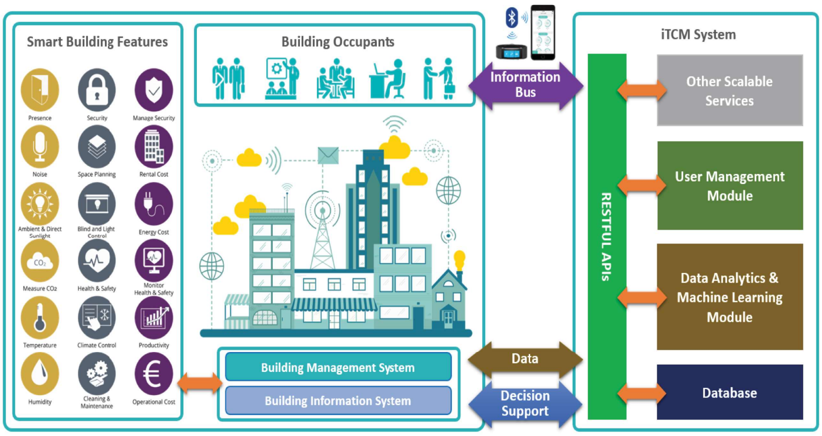
AI-Based
Intelligent
Personalized
Online
Smart
[*]

➢ Rapid Growth of the Global Smart Building Market

Our solution addresses a fast growing (with a CAGR of 34% [5]) smart building market with an estimated market size of $61.9 billion by 2024

2 Methodology

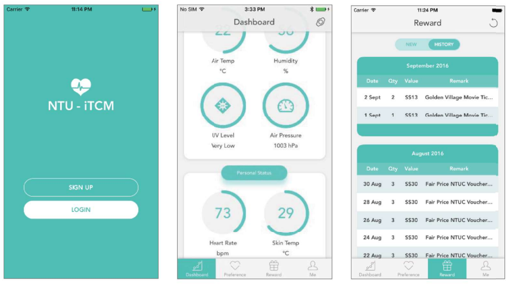
➢ iTCM: An Integrated Intelligent Thermal Comfort Management System



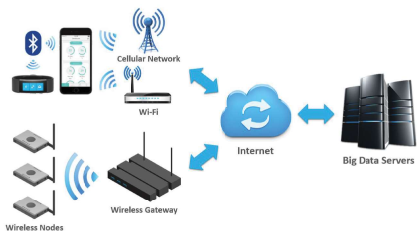
Our proposed iTCM system consists of the following three major modules:

1) Wireless Sensor Network (WSN);
2) iOS & Android Mobile App;
3) Big-Data Based Back-End Server.

➢ iTCM Mobile Application & Microsoft Band 2

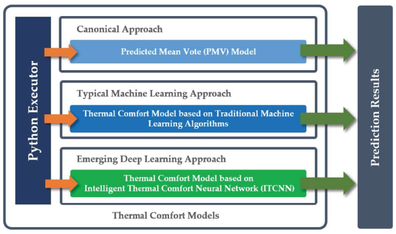


3 Research Achievements



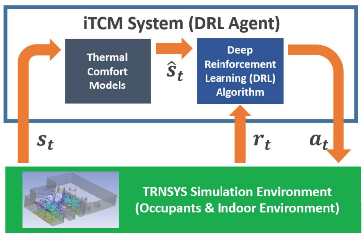
✓ System prototype is **ready to deploy**;

✓ Pressure tests show that the throughput of iTCM web service is 321 requests per second with **a single-core, 2GB memory instance**.



✓ Fine-tuned **learning-based algorithm** has been implemented in AI module;

✓ Experiment results show that our approach **outperforms PMV model by 51.6% on average**.



✓ **DRL-based HVAC control algorithm** is tested in the **TRNSYS simulation environment**;

✓ Our solution can achieve **5.2% and up to 8.6% cooling energy saving.**

4 Commercialization & Industry Collaboration

❖ Resource Providers

NVIDIA. amazon webservices

❖ System Integration Partners

huami intel

❖ POC Partners

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE SinBerBEST

❖ Potential Customers

JLL Jones Lang LaSalle CBRE CB RICHARD ELLIS

References

[1] P Ole Fanger (1970). *Thermal Comfort: Analysis and applications in environmental engineering*. McGraw-Hill.

[2] Richard de Dear and Gail Brager (1998). "*Developing an adaptive model of thermal comfort and preference*". *ASHRAE Transactions*, **104** (1): 145–67.

[3] H.-Y. Lam, Y. Yuan and D. Wang, "*An occupant-participatory approach for thermal comfort enhancement and energy conservation in buildings," the 5th international conference on Future energy systems*, New York, NY, USA, 133-143.

[4] T. Hamatani, A. Uchiyama and T. Higashino, "*Real-Time Calibration of a Human Thermal Model with Solar Radiation Using Wearable Sensors*," the 2015 workshop on Wearable Systems and Applications, New York, NY, USA, 45-50.

[5] Zion Market Research, "Global Smart Building Market Expected to Reach USD 61,900 million by 2024", 2018, URL=https://www.zionmarketresearch.com/news/smart-building-market, accessed on 16, July, 2018.

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GBIC – R&D

Intelligent Building Automation and Analytics Using Model-predictive Control

Assoc. Prof. Wan Man Pun (PI), Asst. Prof. Ng Bing Feng (Co-PI), Dr. Swapnil Dubey (Co-PI), Yang Shiyu, Rai Suleman Khalid, Zhai Deqing, Rajashree Sundaram Agatheswaran, Mr. Krishnamoorthy Baskaran (Collaborator), Dr. Gao Chunping (Collaborator), Mr. Kelvin ONG (Collaborator)

❶ Problem Statement and Objective

Problem:

- Building sector consumes around 40% of the world's final energy and accounts for 30% of the world's CO_2 emissions which drives high demand of energy efficient technologies.
- Current building control and automation (BAC) systems, composed of conventional reactive controllers, have several limitations, such as never reaching desired control set points and only suitable for single-input-single-output systems etc. Advanced control technologies are required to enhance current BAC systems.

Objective: To develop an integrated building automation system that is based on a novel model-predictive control (MPC) algorithm for building systems operation optimization and analytics.

❷ Methodology

Building information

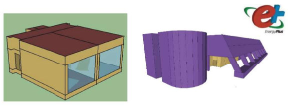
Floorplan
Building material data
Occupancy schedule


BCA SkyLab


NTU lecture theatre 3&4

Virtual test bed :

Non-linear full scale building model



Linear state-space model for controller development:

System states (x):
- Room air temp and humidity
- Wall temp

Disturbance variables (u):
- Internal heat gain
- Outdoor temp and humidity
- Solar radiation

Control variables (u):
- ACMV cooling power
- Shading level

System output (y):
- Room air and globe temp,
- Room humidity ratio
- Room thermal comfort index

MPC control algorithm

ACMV control

$$J = Minimize\left(\sum_{i=0}^{M}\sum_{k=0}^{N}\hat{Q}^2_{i,t+k|t} + \sum_{k=0}^{N}(W_{PMV}\overline{PMV}_{t+k|t})^2 + \sum_{k=0}^{N}W_{\epsilon}(\epsilon_{t+k|t})^2\right),$$

Cooling energy — Thermal comfort — Soft constraints

Subject to:

$$\dot{x} = Ax + Bu,\quad y = Cx + Du \qquad \text{Predictive model}$$

$$\hat{Q}_{ll} < \hat{Q} < \hat{Q}_{ul},\quad \overline{PMV}_{ll} - \epsilon \cdot ECR_{ll} < \overline{PMV} < \overline{PMV}_{ul} + \epsilon \cdot ECR_{ul} \qquad \text{Constraints}$$

Shading and lighting control

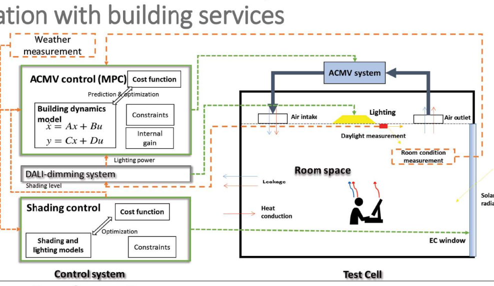
$$J = Minimize(P_{lig} + P_{lig}/COP + Q_{win}/COP)$$

Lighting — Corresponding cooling power due to lighting — Corresponding cooling power due to Heat gain from window

Subject to: $DGP \le 0.35$,

$500\ lux \le illuminance \le 2000\ lux;$

Integration with building services



❸ Experiment results

Compared to conventional reactive-based building management system (BMS), MPC maintains more comfortable and stable thermal environment (temp and PMV). MPC-controlled electrochromic (EC) window provides better visual environment than a typical Low-e glazing window.

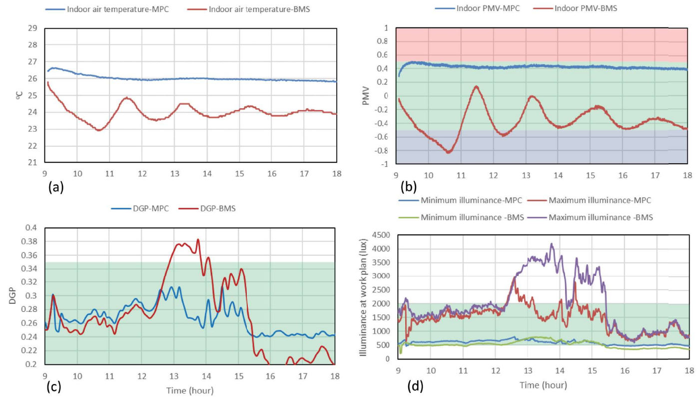


Figure 1. Indoor environment characteristic comparison of MPC and conventional BMS control. (a) indoor air temp, (b) PMV, (c) DGP, (4) illuminance at work plane

Better indoor thermal and visual environment were achieved by MPC for ACMV and shading control compared to conventional reactive-based BMS control.

Table 1. Human comfort performance comparison of MPC and conventional control. (a) PMV, (b) DGP

(a)

Rating	Acceptable	Warm/cool
Range	-0.5 - 0.5	>0.5 or <-0.5
Test Cell (MPC)	99.9%	0.1%
Ref. Cell (Conv)	95.5%	4.5%

(b)

Rating	Imperceptible	Perceptible or worse
Range	< 0.35	>0.35
Test Cell (MPC)	100.0%	0.0%
Ref. Cell (Conv)	93.6%	6.4%

MPC brings 9.3% - 24.3% energy saving compared to conventional reactive based BMS control, while providing the occupant comfort advantages shown above.

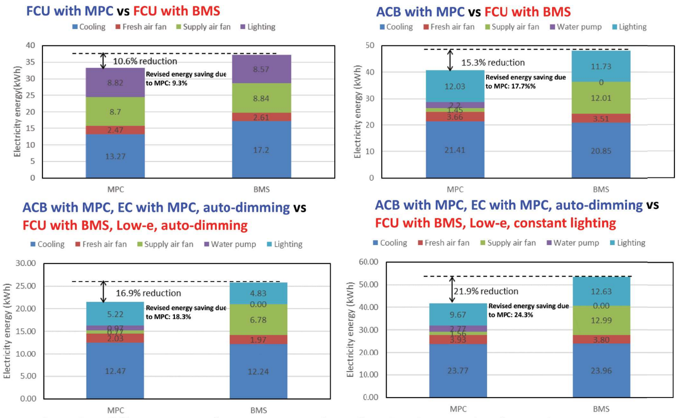


Figure 2. Building energy performance comparison of MPC and conventional control.

Conclusion

A novel model-predictive control (MPC) algorithm with a linear state-space model and multiple-objectives function is developed for real-time building control and optimization. The MPC system achieves 9.3%-24.3% building electricity energy reduction while indoor thermal and visual comfort are also improved.

Acknowledgments

This research is supported by the National Research Foundation (NRF) of Singapore through the Building and Construction Authority (BCA) under the Green Buildings Innovation Cluster (GBIC) grant nos. NRF2015ENC-GBICRD001-020.

Project Partners: Nanyang Technological University Singapore; Schneider Electric

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GBIC – R&D

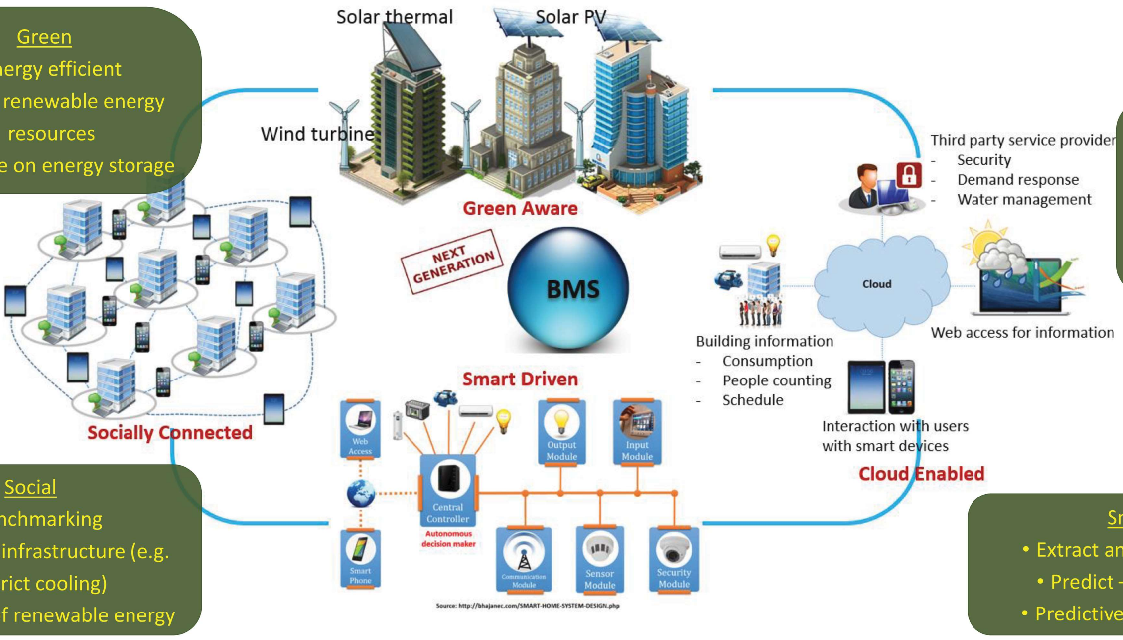
Green Building Management System – An Open IoT Platform Approach

Assoc. Prof. Yuen Chau (SUTD), JC-Kuphi, KTPH, BCA, BCAA

Next Generation Green Building Management System (BMS)

Green
- Energy efficient
- Tap on renewable energy resources
- Leverage on energy storage

Cloud
- New eco system
- Tap on booming IoT devices
- Third party to provide services



Social
- Benchmarking
- Sharing of infrastructure (e.g. district cooling)
- Exchange of renewable energy

Smart
- Extract and understand
- Predict – scheduling
- Predictive maintenance

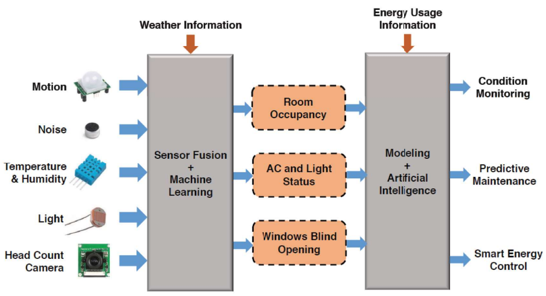
Global Trend and Our Objectives
- Cloud connected IoT for seamless integration and rapid deployment
- Attribution of energy usage to human activities
- Big data for insightful analysis
- Renewable energy and storage for increasing flow of green energy

IoT
- Affordable
- Scalable

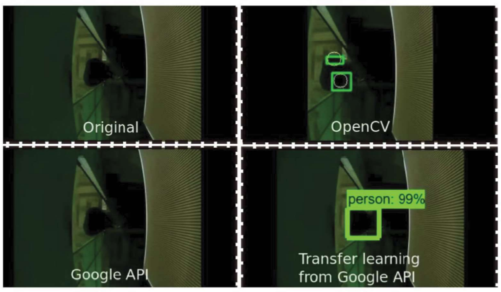
→ **Big Data**
- Modelling
- Prediction

→ **Energy**
- Abnormal detection
- Improve energy efficiency

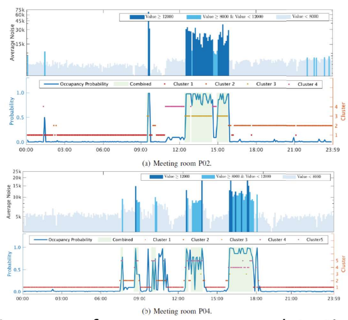
Methodology and Testbed
- Multi-model sensor fusion
- Smart IoT Device powered by artificial intelligence
- Modelling and benchmarking energy efficiency
- Testbedding at KTPH learning center and solar thermal hot water system



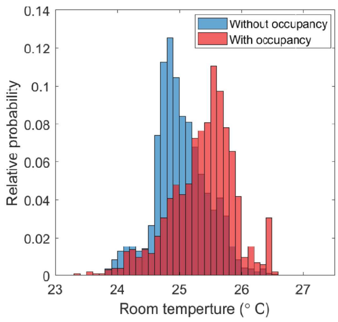
Overview for the testbed at learning center

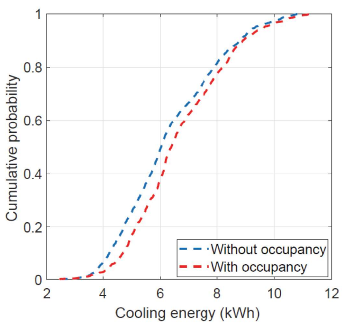


Low cost head count sensor powered by AI

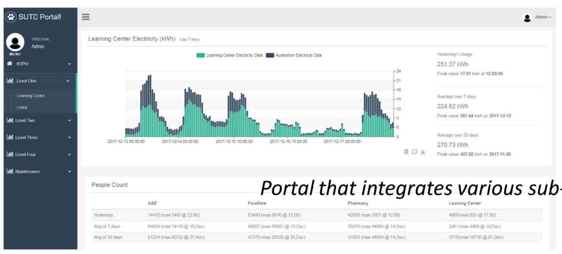


Noise sensor for room occupancy detection through unsupervised learning





Energy modelling



Portal that integrates various sub-systems

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GBIC – R&D

Wireless and Flexible Indoor Environmental Quality Monitoring

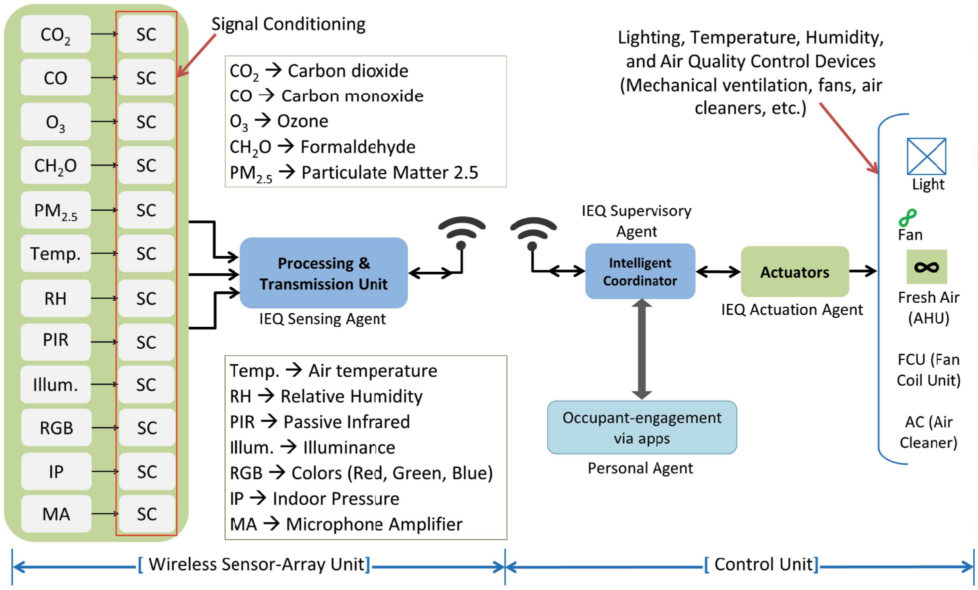
Dr. Krishnanand K.R. (RF), Dr. Hoang Duc Chinh (RF), Assoc. Prof. Sanjib Kumar Panda (PI), Assoc. Prof. Tham Kwok Wai (Co-PI)

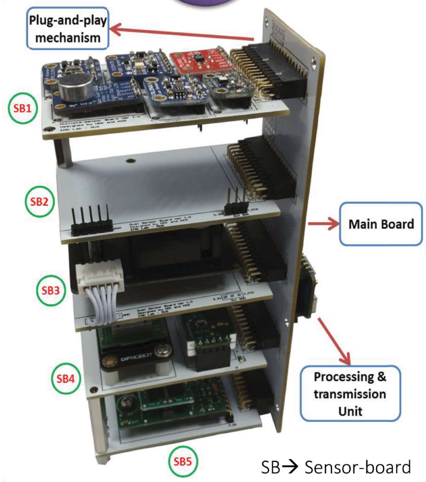
1 Background of Research & Development

In urbanized areas, most humans spend majority of their time indoors.

Indoor Environmental Quality (**IEQ**) implies the quality of the environment inside buildings, pertaining to factors such as – air quality, temperature, humidity, lighting, sounds, odors, and factors that influence human well-being and health. Maintaining IEQ consumes energy, and has to be managed.

2 Sensor Array – Real-time Subsystem for IEQ Multi-Agent System

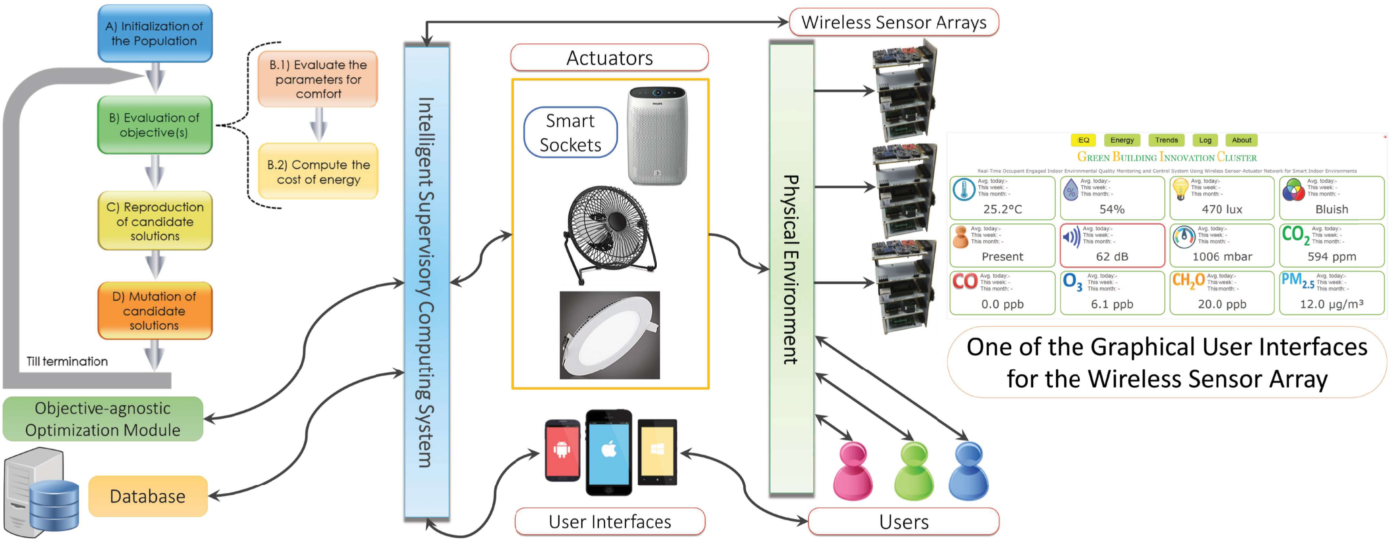




Prototype Implemented

❖ Features: Modular and displaceable, Wireless (operates using Wi-Fi communication), Flexible sensing (the sensor boards are plug-and-play), Edge-computing paradigm (data are stored and analyzed locally), Easily interoperable with other cyber-physical systems – these collectively lead to ***technologically self-sustaining buildings***.

3 System-Level Architecture for Energy Management



4 Conclusion and Future Work

- ✓ A wireless sensor array (WSA) for indoor environmental quality (IEQ) monitoring has been developed.
- ✓ It is a flexible and interoperable subsystem.
- ✓ This cyber-physical system uses edge-computing.
- ✓ Digitalized building services are its future.

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GBIC – R&D

Smart Solutions Promoting Behavior Driven Energy Efficiency: A Personality-based Energy Management System

Dr. Lu Yujie, Dr. Kua Harn Wei, Dr. Qingbin Cui, Dr. Shen Meng, Xu Qian, Liu Yiming

1. Problem Statement & Objectives

Problem statement

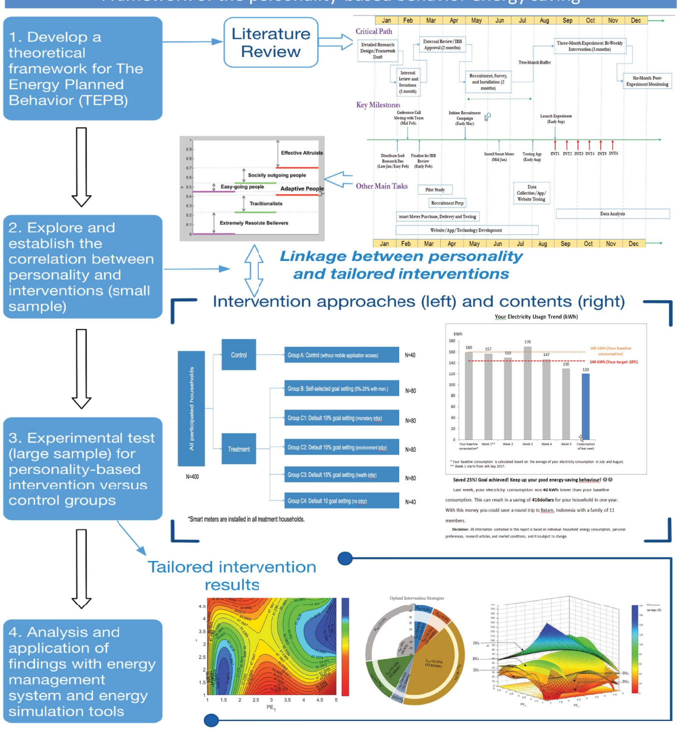
- Technologies can achieve over 30% of energy savings. ***Yet***, technology alone cannot obtain the full potential of energy savings (Jain et al. 2013).
- Behaviour-driven energy efficiency is cost-efficient and has great potentials.
- This proposed study aims to incorporate **personality traits** into behaviour-driven energy efficiency interventions to achieve the full potential of energy savings.
- The project develops a software platform that can track consumers' energy consumption, and deliver treatment messages to users.

Objectives

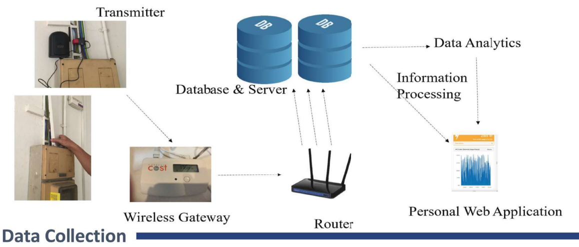
- **Investigate the impact of personal traits on energy conservation behavior;**
- **Establish the best-fit interventions;**
- **Develop a behavior-driven energy conservation algorithm**

2. Methodology

Framework of the personality-based behavior energy saving



3. Data Collection



Data Collection

Earn a **$10NTUC VOUCHER** just by filling a quick questionnaire!

You need to be:
- A Singapore Resident living in a HDB flat,
- At least 21 years of age &
- Have a refrigerator older than 5 years

We are a group of NUS students working on our final year project on the topic of Building Energy Efficiency. Your participation will be of utmost appreciation!!! :)

Want to participate? Text us! :)

Melissa 96424379 or Kiran 82871857

Note: Only 1 survey response is allowed per household.

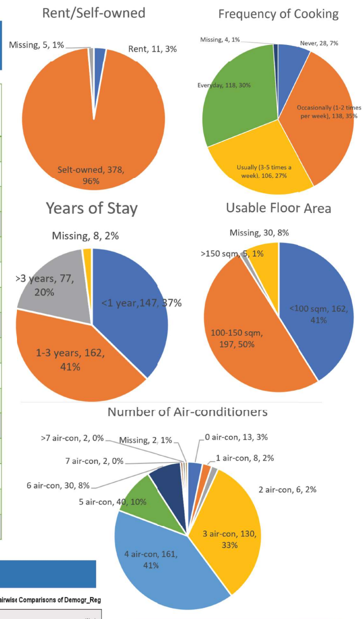
Real-time energy consumption data was captured by the smart meters and online and on-site questionnaires were used to collect behaviour information needed for the study.

4. Preliminary Results

- The two week recruitment received a total of **394 respondents**.
- Kruskal Wallis H test, correlation and regression analyses were carried out to examine differences in **energy behaviours across personality traits and demographics**.
- **Conscientiousness, Openness**, level of household **monthly income** and **highest education level** significantly impacted energy behaviour.
- The **consideration of future consequences** was found to be positively correlated to energy behaviours.
- Monthly income of the household was found to be negatively correlated to two of the **household energy behaviours**.

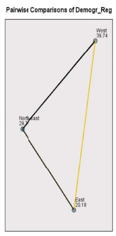
Unstandardised Regression Coefficients for the Frequency of Energy-saving Behaviour (EBQB)

Predictor Variables	Step 1	Step 2	Correlation with EBQB
Model A			
Conscientiousness	0.029*	0.029*	0.137*
Education		-0.140*	-0.117*
R squared	0.017*	0.031*	
Model B			
Conscientiousness	0.032*	0.031*	0.137*
Income		0.116**	0.152**
R squared	0.021*	0.044*	
Model C			
Openness	0.022*	0.020*	0.086
Education		-0.133**	0.152**
R squared	0.012*	0.025*	
Model D			
Openness	0.023*	0.022*	0.086
Income		0.116**	0.152**
R squared	0.013*	0.036*	



Pairwise Comparisons

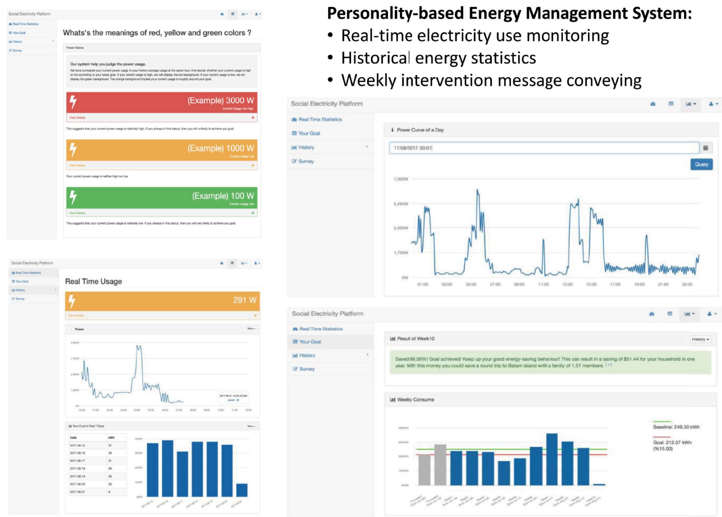
Sample1-Sample2	Test statistics	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.	Decision
East-Northeast	9.591	5.682	1.688	0.091	0.274	Retain null hypo
East-West	19.560	5.914	3.308	0.001	0.003	Reject null hypo
Northeast-West	9.969	5.029	1.982	0.047	0.142	Retain null hypo



Region and self-set goal

- Households at the East region shows a **lower level of energy saving goal** than the **West** region.
- If the East region is considered to be made up of **higher-end households**, they tend to demonstrate a **negative attitude towards their behaviour** and show little willingness in adopting energy conservation measures.

5. Deliverables for the Project



Personality-based Energy Management System:

- Real-time electricity use monitoring
- Historical energy statistics
- Weekly intervention message conveying

Brought to you by:

Building and Construction Authority

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Prime Minister's Office
Singapore

GBIC – R&D

Lifecycle BIM Integration with Energy MM&V for Net Zero Energy Building:

Adrian Chong[a,*] (PI), Cheong Kok Wai, David[a] (Co-PI), Khee Poh Lam[a](Co-PI), Bertrand Lasternas[a], Chandra Sekhar[a]

[a]NUS, School of Design and Environment, Department of Building

1. Project Overview

Objectives of Project:

- Develop knowledge framework for guiding building information modeling (BIM) and building energy modeling (BEM) integration
- Automate BIM and BEM integration process
- Bridge the gap between simulation predictions and measured data

Deliverables for the Project:

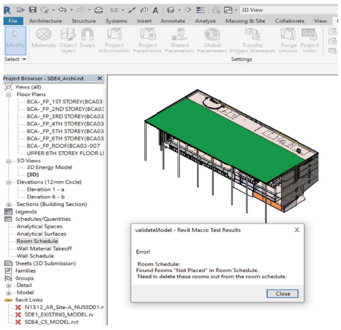
- Automated translation of BIM (gbXML) to BEM (EnergyPlus) tested on 2 actual case study buildings.
- Framework for automated calibration of BEM

2. BIM to BEM

Method

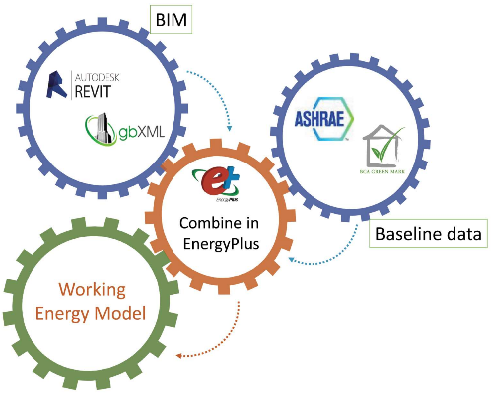
Preprocessing

- BIM model created often not suitable for translation
- Created Revit macro to detect these errors and prompt users to rectify errors before running translator to convert BIM to BEM

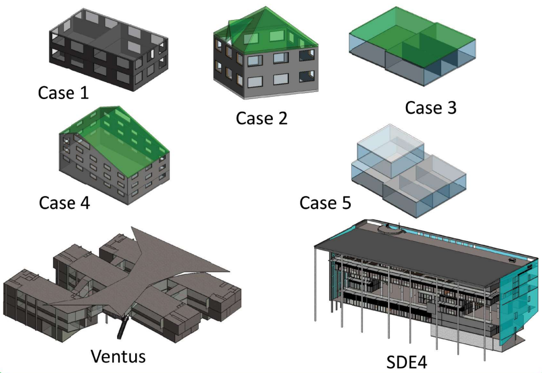


BIM to BEM Translation

- Includes mapping of geometry, construction layers, material properties and internal loads
- If gbXML exported does not contain the required information, baseline data is assumed



Testing: 5 simple test cases and 2 actual test buildings

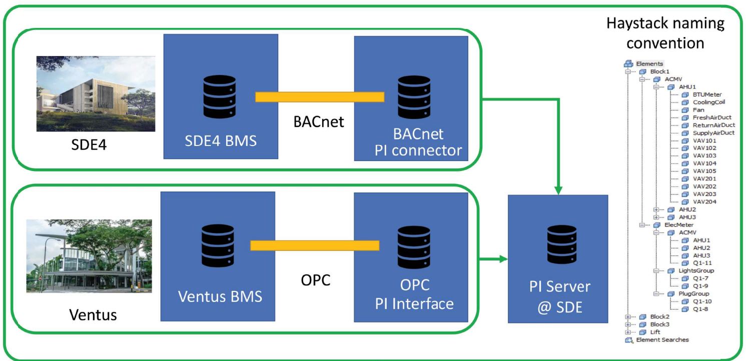


* Corresponding author.
E-mail address: bdgczma@nus.edu.sg (Adrian CHONG)

Contribution & Impact:

- Practical approach for the automated translation of BIM to BEM
- Framework for continuous calibration using real time data collected from a building's BMS system

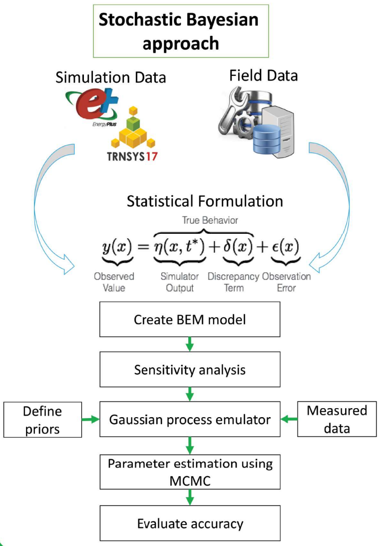
3. Data Collection

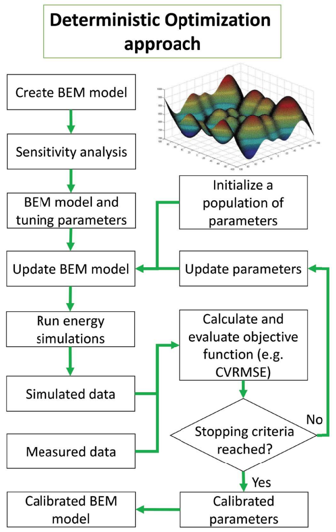


4. BEM calibration

Method

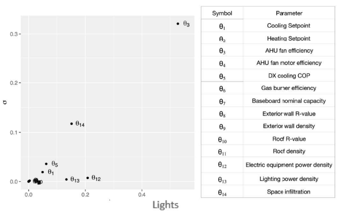
Tested 2 Automated calibration methods

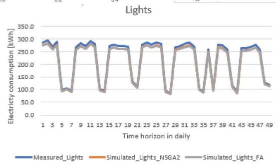




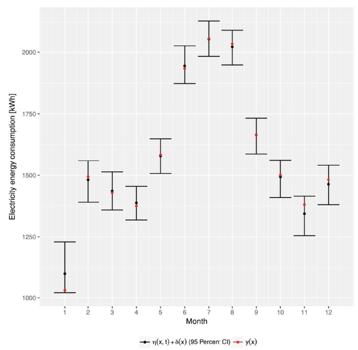
5. Calibration Results

Sensitivity Analysis (Morris Method)





Daily lighting energy consumption



Monthly electricity consumption

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GBIC – R&D

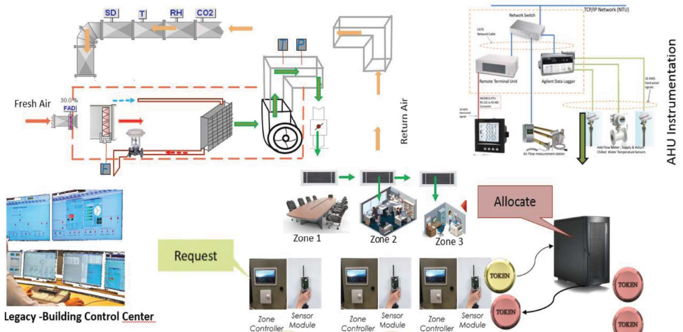
Scalable and Smart Building Energy Management Systems

Rong Su (PI), Kameshwar Poolla (Co-PI), Irene Yong (Co-PI), Jia Mein Wong (Collaborator), Korkut Bekirogulu (RF), Ethan Png (RA), Chaoyang Jiang (RF)

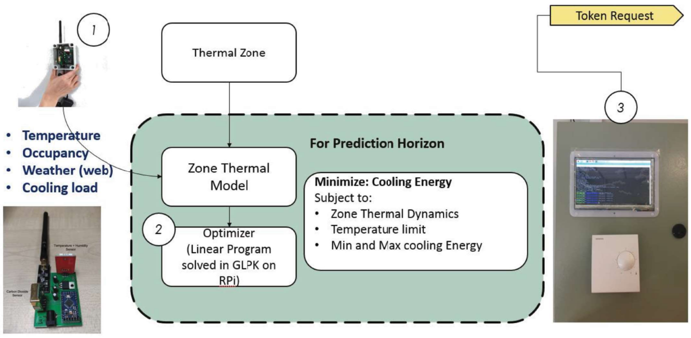
1 Problem Statement & Motivation

- ❑ **To minimize HVAC energy consumption**
  - ❑ To be scalable, smart, and adaptable.
  - ❑ To be aware of human thermal comfort.
  - ❑ To have a low retrofit cost.
  - ❑ IoT-based realization over a legacy system.
  - ❑ Web-accessible data collection & visualzation.
  - ❑ Demonstration in a pilot system at NTU.

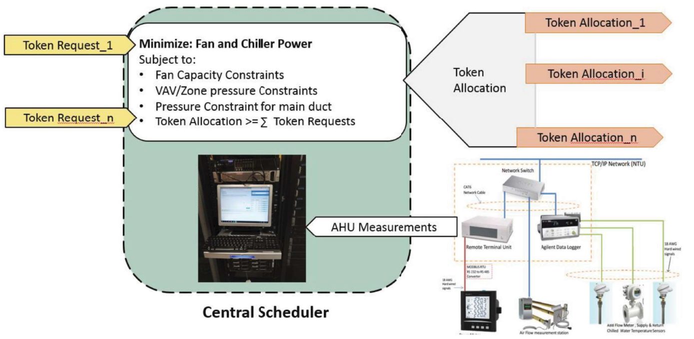
2 Token-based Scheduling Algorithm



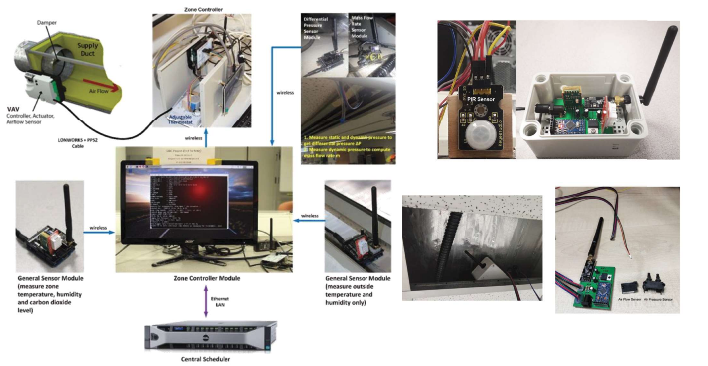
Zone Controller: Model Predictive Control



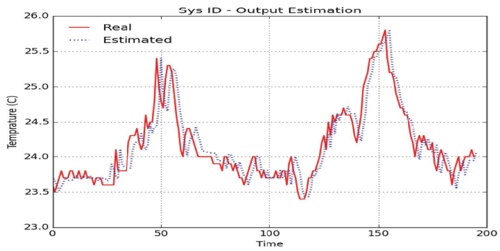
Central Scheduler: Tokens Allocation Algorithm



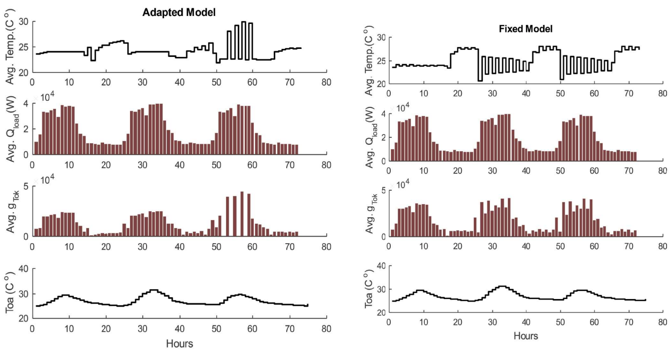
3 IoT-based Implementation



4 Results & Conclusions

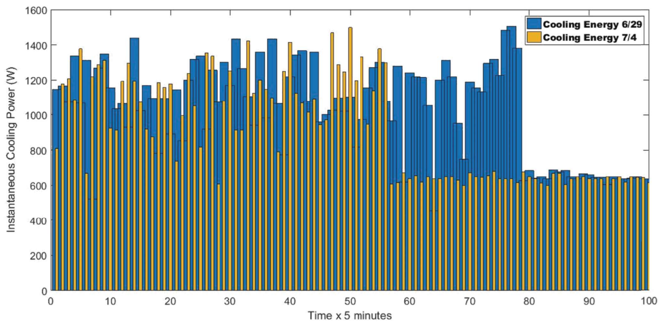


Model Adaption



Energy Savings per AHU

Zone Controller Implementation Snapshot



Energy Savings at NTU S1B1 building

- Token Based Scheduling: **20-24%**
- Token Based Scheduling with Model Adaptation: **25-30%**

Project Partners: Nanyang Technological University, University of California Berkeley, Beca, ABB

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GBIC – R&D

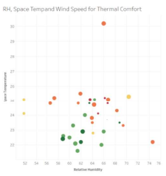
Data-Driven Modelling and Real-time Optimisation for Diversify Chiller Plants

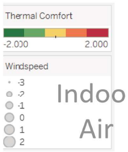
Chai Kok Soon and Jose Vu (Kaer Pte Ltd) in Collaboration with Zhenjie Zhang (ADSC)

❶ Problem Statement

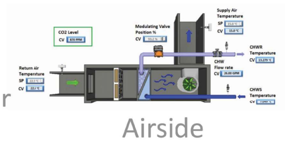
- In Asia, ACMV equipment accounts for 20%-50% of a building's energy consumption
- To deliver an energy efficient ACMV system, engineers must constantly adjust control variables to accommodate changes in external conditions
- These systems are dependent on a large number of variables that provides too much complexity for humans to understand so many systems are not optimised and therefore waste huge amounts of energy.

Occupancy, weather

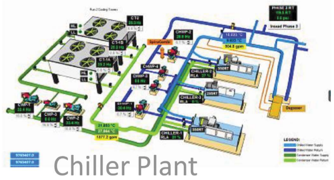




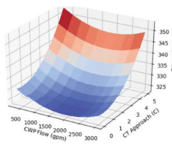
Indoor Air Quality



Airside Equipment



Chiller Plant



Optimisation

❷ Motivation

- Develop inferring engines using machine learning
- Automate optimisation of ACMV system efficiency (chiller plant and air-side)

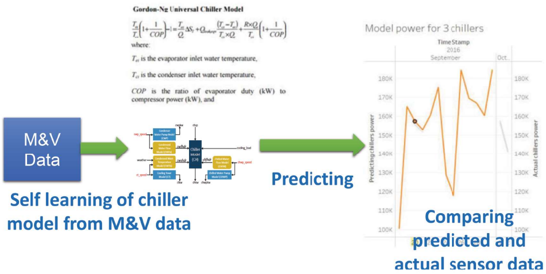
Flow rates, temperatures, power, weather, occupancy, relative humidity and indoor air quality

=

	Power (kW)	Load (RT)	Efficiency (kW/RT)
AHU's	18.96 kW	105.17 RT	0.180 kW/RT
CH Plant System	144.64 kW	240.30 RT	0.602 kW/RT
Overall System			0.782 kW/RT

End-to-end optimization – From air to chiller plant, and equipment test and commissioning to maintenance

An example of building a data driven chiller predictor using flow and temperature sensor data

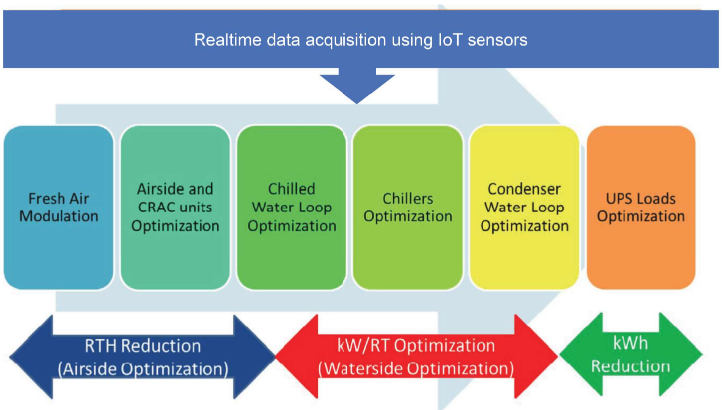


❸ Data Driven Model Development

1	2	3	4
Fresh air intake = {CO2}	Thermal comfort and Indoor Air Quality = {supply air, space temperature and RH, indoor air pollutant}	Chilled water loop = {set point, chilled water flow rate to various airside units}	Condenser water loop = {cooling tower approach temperature, condenser water flow rate}

Cool Air Demand (1–2) — Chilled Water Supply (3–4)

❹ Experiment of End-To-End Optimisation



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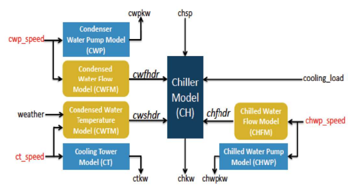
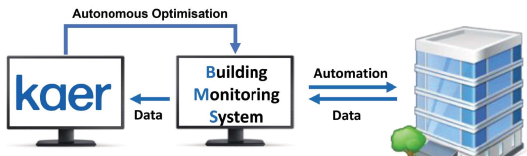
❺ Deployment of End-to-End Optimisation

5.1 Data driven predictors



5.2 Integration with BMS



Kaer's software is capable of machine learning, optimisation and interfacing with the existing BMS to update set-points and control variables in real-time

5.3 Data driven and end-to-end optimisation

Actual data

	cwp kwr/rt	chiller kw/rt	(cwp + chiller) kw/rt
actual	0.04	0.477128601	0.517128601

Predicted data

	cwp kwr/rt	chiller kw/rt	(cwp + chiller) kw/rt
predicted	0.055	0.471083132	0.526083132
predicted	0.05	0.473078826	0.523078826
predicted	0.045	0.475093982	0.520093982
actual	0.04	0.477128601	0.517128601
predicted	0.035	0.479182682	0.514182682
predicted	0.03	0.481256226	0.511256226
predicted	0.025	0.483349232	0.508349232

- Equipment T&C
- Equipment maintenance
- Energy optimization
- IAQ optimization

GBIC – R&D (DCP)

Test Bedding Research for Innovative Technologies in BCA SkyLab

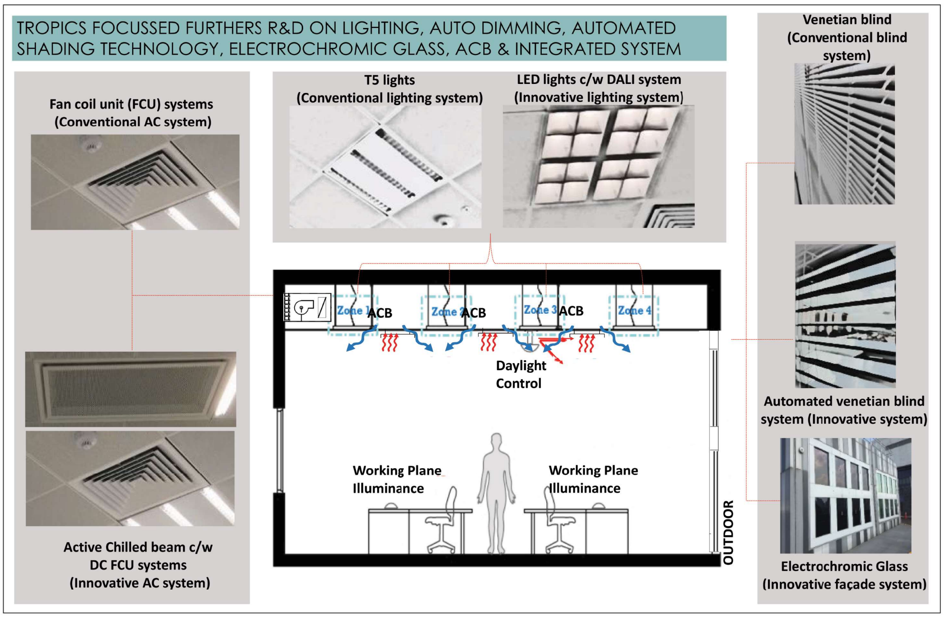
Assoc. Prof. Man Pun Wan, Sushanth Babu, Adrian S. Lamano, Jatin N. Sarvaiya, Zhe Zhang, D.E.V.S. Kiran Kumar, Krithika Krishnasayee
Dr Chun Ping Gao, Selvam Valliappan, Alice Goh, Alvin Seoh

1 Problem Statement and Motivation

Problem
- Concerns about gaps between the energy-efficiency claims by the manufacturers and the actual implemented performance of some building technologies.
- It is important to have un-biased performance evaluation by neutral party to support wide-scale implementation of such technologies.
- Some energy-efficient building technologies may compromise on occupant comfort and well-being. Tropical focussed R&D on this subject is limited.

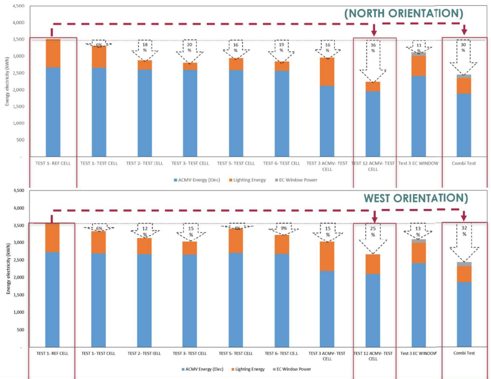
Motivation
- An experimental investigation of energy and comfort performance under the tropical climate of Singapore utilizing a well-controlled rotatable test bed set up.
- The results shall provide new insights into the operational characteristics, energy savings potentials and occupant comfort performance for a wider-scale implementation in Singapore.

2 Methodology



3 Results: Energy savings potential

The testing results provide high energy saving potential in comparison with non-dimmable T5 fluorescent lamps (baseline). The integrated system could save up to 32% compared to baseline case.



T5	LED	T5	LED	T5	LED	T5	LED	T5	LED
No Dimming	No Dimming	Auto Dimming	Auto Dimming	Auto Dimming	Auto Dimming	No Dimming	Auto Dimming	Auto Dimming	Auto Dimming
Retracted blinds	Retracted blinds	Retracted blinds	Retracted blinds	Auto Blinds	Auto Blinds	Retracted blinds	Auto Blinds	No blinds	No blinds
DGU Facade	DGU Facade	DGU Facade	DGU Facade	DGU Facade	DGU Facade	DGU Facade	DGU Facade	EC Facade	EC Facade
FCU	FCU	FCU	FCU	FCU	FCU	ACB	ACB	FCU	ACB

*Chiller plant efficiency assumption: 0.6 kW/RT

3 Results: Occupant comfort

Automated Blinds c/w Auto Dimming System

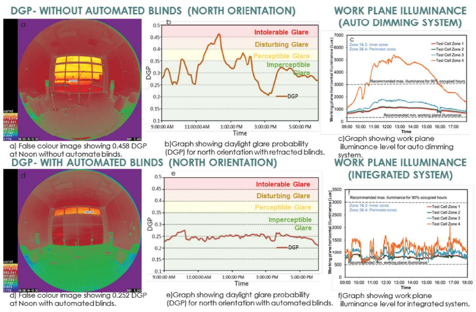
Good visual comfort was maintained at all time as DGP (Daylight Glare Probability) was kept below 0.35 and working plane illuminance was maintained between the recommended 500 to 3000 lux.

Electrochromic Glass (EC) Facade

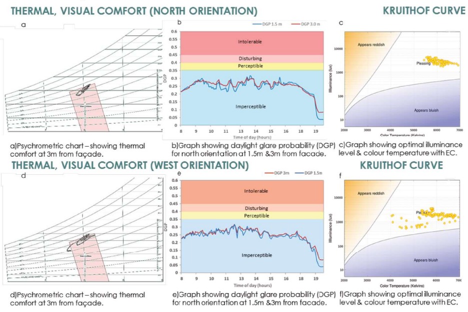
EC could provide both thermal and visual comfort with unobstructed view. It provided a better thermal environment falling in category A for PMV and maintained good visual comfort (DGP below 0.35) without the need for internal shades when compared to a typical building using a low emissivity (Low-e) double-glazing unit (DGU) and blinds system.

Active Chilled Beam (ACB)

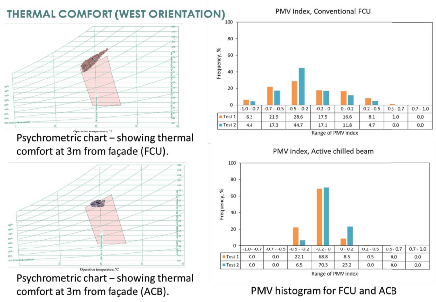
With proper design, ACB system can provide satisfactory thermal environment, with much lower air discharge compared to FCU. However, ACB system is not recommended when the total cooling load density is high (112 W/sqm) due to high Air Diffusion Parameter Index (ADPI) and more occupant discomfort closer to window as opposed to conventional FCU.



a) False colour image showing 0.458 DGP at Noon without automated blinds.
b) Graph showing daylight glare probability (DGP) for north orientation with retracted blinds.
c) Graph showing work plane illuminance level for auto dimming system.
d) False colour image showing 0.252 DGP at Noon with automated blinds.
e) Graph showing daylight glare probability (DGP) for north orientation with automated blinds.
f) Graph showing work plane illuminance level for integrated system.



a) Psychrometric chart – showing thermal comfort at 3m from façade.
b) Graph showing daylight glare probability (DGP) for north orientation at 1.5m & 3m from facade.
c) Graph showing optimal illuminance level & colour temperature with EC.
d) Psychrometric chart – showing thermal comfort at 3m from façade.
e) Graph showing daylight glare probability (DGP) for north orientation at 1.5m & 3m from facade.
f) Graph showing optimal illuminance level & colour temperature with EC.



Psychrometric chart – showing thermal comfort at 3m from façade (FCU).

Psychrometric chart – showing thermal comfort at 3m from façade (ACB).

PMV histogram for FCU and AC3

In Singapore's tropical climate, the integrated system exhibits capability to achieving significant annual energy savings while providing both thermal and visual comfort.

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BCA SkyLab
Nanyang Technological University Singapore
Berkeley Lab
Lawrence Berkeley National Laboratory

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Singapore

GBIC – R&D (DCP)

Energy Efficient Building Facades for Thermal Comfort Environment

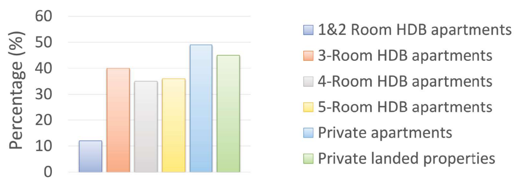
Department of Building, National University of Singapore PI: Prof. Wong Nyuk Hien, Team members: Dr. Tong Shanshan, Ms. Erna Tan, Ms. Wen Jianxiu

1 Problem Statement & Objectives

Problem

- Façade design with full-height window is gaining popularity
- Substantial amount of energy is used by air conditioner for indoor comfort

Electricity bill proportion by air-conditioner for each housing type in Singapore [1]



Objectives

- Understand impact of façade design on indoor environment
- Evaluate façade design under existing RETV regulations
- Develop façade design guidelines to promote passive design

2 Methodology

Survey on Façade Design

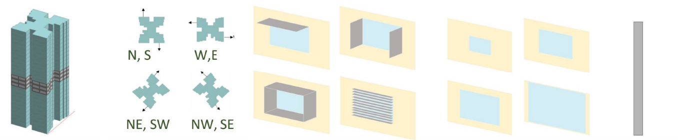
Façade survey | Developer survey | Collect drawings | Thermal comfort survey

Field Measurement

Measurements in both new and old, occupied and vacant HDBs and condominiums

Parametric Study

- Impact of façade parameter on air temperature (Energy simulation)
- Impact of façade parameter on indoor air flow (CFD simulation)



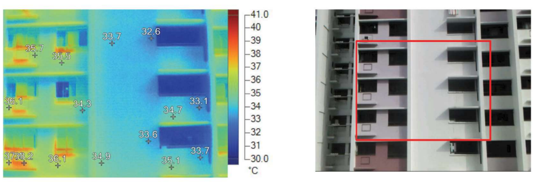
Parameters | 8 Orientation | Shading device | Window-to-wall ratio | U-value

Development of guidelines

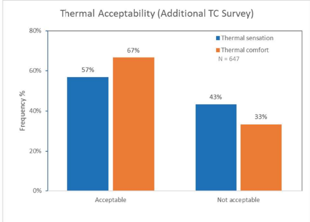
- Proposals of design guidelines to enhance and/or supplement existing residential building envelope regulations (e.g. RETV)

3 Preliminary results and analysis

Façade survey using thermal image

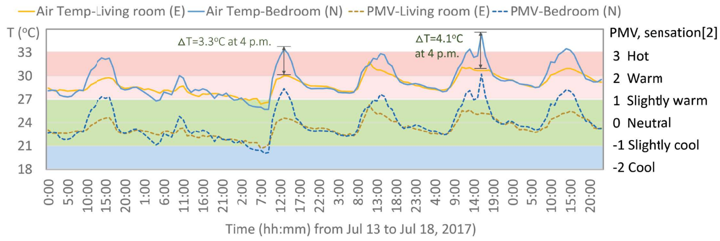


Residents' thermal comfort survey



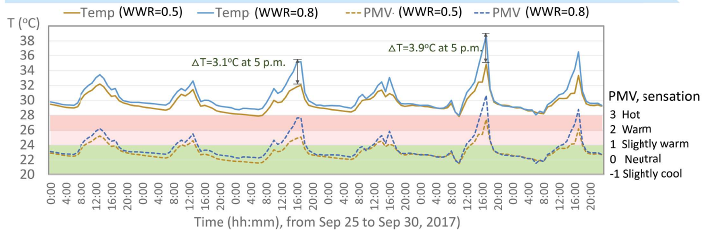
Indoor environment measurement	Minimum	Maximum	Median	Interquartile Range
Temperature (°C)	27	32.4	30.2	25.4 - 30.6
Wind Speed (m/s)	0	1.94	0.34	0.2 - 0.5
Mean Radiant Temp (°C)	26.6	36.6	31.7	30.2 - 32.6

Impact of orientation on temperature and thermal comfort

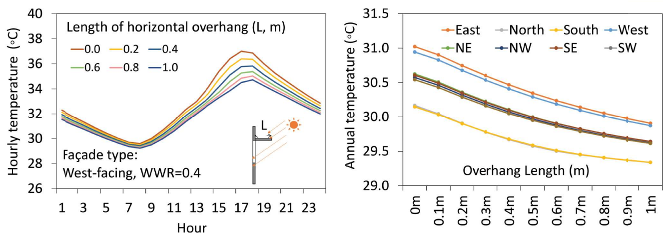


- Predicted mean vote (PMV) index predicts the mean thermal response of a large group of people;
- PMV= -11.7853+0.4232T-0.57889V [2], T- air temperature, V- wind velocity

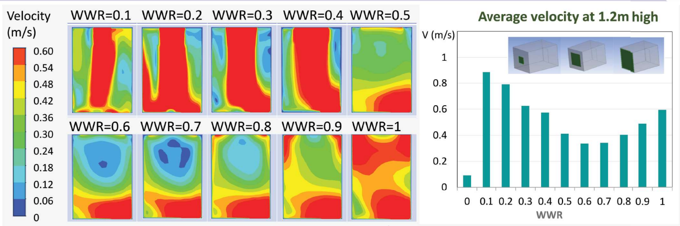
Impact of WWR on temperature and thermal comfort



Impact of shading on indoor temperature (Energy simulation)

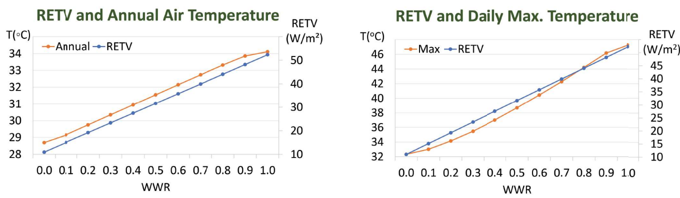


Impact of WWR on indoor wind flow (CFD simulation)



Outdoor wind scenario: North wind at 2.8 m/s.
Room layout: north-facing window and south-facing door (size: 0.9m*2m)

Relationship between RETV and indoor air temperature



- The correlation between façade parameters and RETV, indoor air temperature, wind speed and thermal comfort are analysed.

Brought to you by: Building and Construction Authority

Funded by: National Research Foundation
Prime Minister's Office
Singapore

[1] Energy Market Authority. Average monthly electricity consumption of a HDB apartment. Singapore; 2002.
[2] BCA Green Mark for Residential Buildings Criteria GM RB: 2016.

GBIC - R&D

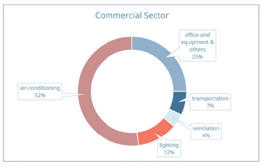
Enhanced ETTV and RETV Formulations for Energy Efficient Building Envelopes

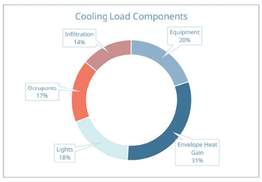
Team: Prof. S.K. Chou (PI), Ms. Maggie Low, Ms. Alice Goh, Mr. Amos Seah, Dr. Victor Nian, Mr. He Zhiyuan

01 Background & Challenges

- Buildings are energy intensive, accounting for 1/3 of total energy consumption in Singapore
- 52% of the energy consumption of a building is consumed by HVAC (Air-conditioning), with more than 30% of the cooling load contributed by the building envelope
- The Envelope Thermal Transfer Value (ETTV) and the Residential Envelope Transmittance Value (RETV) calculations formulations were last reviewed in 2008

Energy Consumption in Buildings





Code of Envelope Thermal Performance for Buildings

$$ETTV = 12(1-WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC)$$

$$RETV = 3.4(1-WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$$

where

ETTV	:	envelope thermal transfer value (W/m²)
RETV	:	residential envelope transmittance value (W/m²)
WWR	:	window-to-wall ratio (fenestration area/gross area of exterior wall)
U_w	:	thermal transmittance of opaque wall (W/m²K)
U_f	:	thermal transmittance of fenestration (W/m²K)
CF	:	correction factor for solar heat gain through fenestration
SC	:	shading coefficients of fenestration

Challenges

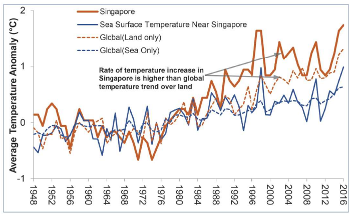
- There is a need to enhance the existing ETTV and RETV formulations in order to reflect a more accurate calculation of building performance and to account for current industry capabilities/ technologies
- Due to the changing climate, there is a need to update the Singapore weather file used to derive the ETTV and RETV formulations
- The current ETTV and RETV formulations do not consider the heat gain through fenestration frames

02 Singapore Typical Meteorological Year (STMY)

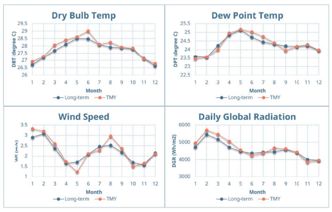
Global warming has caused a perceptible change in Singapore's weather conditions over the last decades. A new weather file, name "Singapore Typical Meteorological Year (STMY)" has been developed to address this change. The STMY file has been used to derive the enhanced ETTV and RETV equations.

Raw Data — 1986 - 2017; Changi Airport Station; National Environment Agency (NEA) → Data Pre-processing → **26 complete years** — Dry bulb temperature; Dew point temperature; Wind speed; Radiation → Modified Sandia Method → **STMY** — Compiled to .bin/.epw file for use in simulation programs; - representative of 8760 hourly data

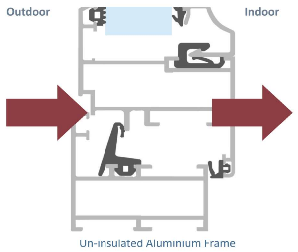
Global vs. Singapore Temperature Anomalies

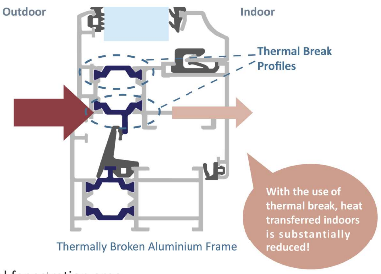


TMY vs. Long-term Monthly Mean Values



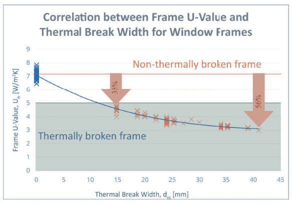
03 Impact of Fenestration Frame & Thermal Break

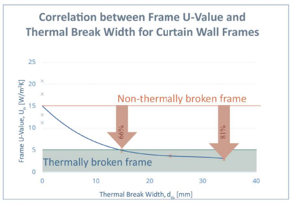




- **Fenestration frames** represent **10% – 30%** of total fenestration area
- **Aluminium**, a widely used material for fenestration frames, is a **good conductor of heat** with a material thermal conductivity of 160W/mK (160 times more conductive than glass)
- **Thermal break** can be used to separate the interior and exterior aluminium sections, **substantially reducing the heat gain** through fenestration frames
- Thermal break is made of **glass-fibre reinforced polyamide**, an engineering plastic with low thermal conductivity and excellent mechanical properties

Effectiveness of Thermal Breaks in Fenestration Frames



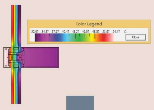


Note: Frame U-Value is also influenced by other factors, such as shape of thermal break, which are not considered here

Energy Saving Potential of Thermally Broken Frame

Methodology

Modelling & Simulations

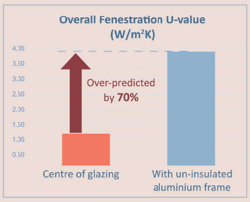


Guarded Hot Box (GHB) Test

BCA SkyLab Test (Outdoor Test)

Results Analysis & Conclusion

Underestimation of Fenestration Heat Gain

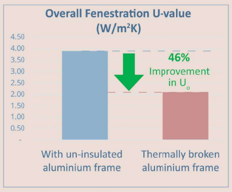


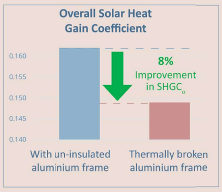
Glazing properties are commonly used to represent overall fenestration properties in today's practice.

By doing so, it is found that the overall fenestration properties are over-predicted.

Note: Simulation results have been validated by Guarded Hot Box Test

Improvement of Fenestration Performance with Thermal Break

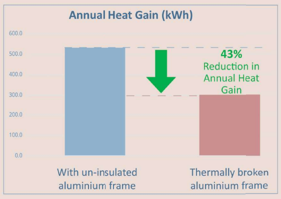




Note: Simulation results have been validated by Guarded Hot Box Test

BCA SkyLab Test

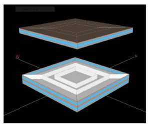
- On-site monitoring of frame thermal performance
- **Reference cell:** Un-insulated aluminium frames (without thermal break)
- **Test cell:** Thermally broken aluminium frames (with basic thermal break solution)

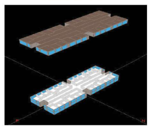


04 Enhancement of ETTV and RETV

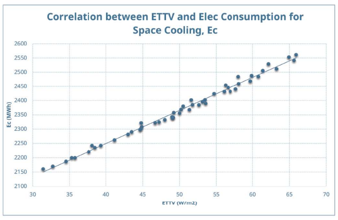
Methodology

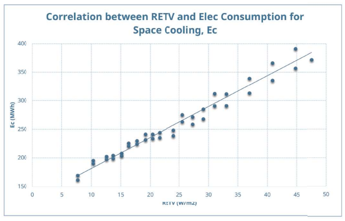
eQUEST: Create a building system → Input: Fenestration system → Input: TMY weather file (STMY) → Building energy performance report → Derive the ETTV & RETV formulations → Analysis of results → Enhancement of BCA ETTV and RETV code & updates to input tables and examples





ETTV & RETV Value and Building Cooling Energy Consumption





Enhanced ETTV and RETV Formulations

$$ETTV = 16.1(1-WWR)U_w + 5.6(WWR)U_o + 251.9(WWR)(CF)(SHGC_o)$$

$$RETV = 4.5(1-WWR)U_w + 1.6(WWR)U_o + 72.1(WWR)(CF)(SHGC_o)$$

where

U_o : Overall thermal transmittance of fenestration (W/m²K)

$SHGC_o$: Overall solar heat gain coefficient of fenestration

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In collaboration with:

NUS National University of Singapore — Department of Mechanical Engineering, Faculty of Engineering

TECHNOFORM

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GBIC – R&D (DCP)

Development of an Innovative Energy Modelling Framework for Design and Operation of Building Clusters in the Tropics

Darren Jordan, Catherine Conaghan, Ruggiero Guida, Rohan Rawte (Integrated Environmental Solutions IES)
Majid Sapar (Building and Construction Authority BCA)

Project Aim

This project is a collaboration between IES and BCA that demonstrated an innovative energy modelling framework for clusters of buildings in Building Construction Authority Academy campus (BCAA). This framework looked at how building(s) design, compliance, and building data management & analytics can be improved.

KEY FACTS

- Oct 2016-May 2017
- 5-ha site, building area of 25,000 m²
- 2009 Zero-Energy Building (ZEB 1.0) acts as live test-bed for green building technologies
- Exceptional operational model calibration with 1.1% MBE variation for existing ZEB 1.0
- Up to 21% Enhancement/Retrofit Savings found for existing ZEB 1.0
- 57% Energy Savings achieved for Proposed New Super Low Energy High Rise Building (SLEB)
- 67% Energy Savings achieved for Proposed New Zero Energy Mid Rise Building (ZEB 2.0)
- Existing ZEB 1.0 P.V solar generation preserved

Problem Statement and Motivation

New Building Design Performance Evaluation & Energy Conservation Recommendations

The positions of two proposed new buildings (SLEB & ZEB 2.0) were of particular concern to the BCA due to their potential impact on the energy performance of the existing Zero Energy Building (ZEB 1.0) located due west of the proposed development. Photovoltaic (P.V.) panels are located on the roof of the existing ZEB 1.0 building and any obstructions could potentially affect the current electrical generation performance. BCA also wanted to determine the optimal design solutions for both the SLEB & ZEB 2.0 which would allow them to meet their aggressive energy performance targets:

- SLEB achieve less than 100 kWh/ m² per year and minimum 45% energy savings compared to Green Mark NRB-2015 standard
- ZEB 2.0 achieve "Net Zero Energy" and minimum 50% energy saving compared to Green Mark NRB-2015 standard

Model Simplification

IES's Virtual Environment (VE) Software has a wide range of modules with varying levels of capability that allow users the flexibility of modelling buildings, including the mechanical and electrical systems with varying degrees of complexity. This ensures designers can make informed decisions regarding the direction of key design options at an early stage in the design process with basic energy modelling configurations that are easy to prepare and require only minimal inputs. Although these models can provide valuable design data, it is important that they be updated with more detailed design inputs as the design progresses. Defining this methodology is a critical step in ensuring the verification of building performance targets throughout the design process.

Existing Building Model Calibration and Operational Improvements

Integrating an energy model of the existing ZEB 1.0 building with its BMS data and creating a calibrated operational model, allows IES to compare the operation of the building against the design intent and possible ideal modes of building operation. This process was undertaken to determine changes to building operation that could be implemented to improve the operational performance of the building, through the novel approach of using an energy model as the brain/decision maker for determining which actions would have maximum impact.

Methodology

Model Building

Concept-level modelling and simulation of Energy Conservation Measures (ECMs) and analysis to optimise the design of the two planned new buildings (SLEB & ZEB 2.0). This work included gathering requirements from BCA and initial design assumptions, VE model creation to simulate the baseline building performance, impact of the potential Energy Conversation Measures (ECMs), and final recommendations based on these results to optimise the building design in-line with BCA requirements and constraints. The modelling was carried out using the IESVE dynamic simulation software.

Model Simplification

In order to define a methodology to simplify the building description and enable the conversion of a detailed building model into a simplified model requiring only a limited number of inputs, IES compared the following different levels of model to the calibrated model of the existing ZEB 1.0. The level of complexity varies from a simple zone box model (Level 1) through to the detailed calibrated energy model (Level 4).

Level 1 – Shell – single zone
Level 2 – Floor by floor (three zones)
Level 3 – Room by room
Level 4 – Calibrated energy model/ Baseline model

Integration with BMS

To undertake BMS data collection and interrogation, IES gathered the required data by a) Carrying out a site visit to inspect current building conditions, and b) Accessing and downloading the required BMS data and uploading this for analysis to the cloud based data analysis software – IESSCAN. This web-based platform provides an operational data analysis platform complete with capability for half-hourly data monitoring, with alerting and diagnostic analysis tools.

Model calibration

To go to the next level of reducing waste and improving energy efficiency in the existing 3-storey ZEB 1.0, a calibrated energy model was created to consider what improvements could be made to the building. The calibrated model incorporated spatial information from BIM and operation information from the BMS, and was used to suggest improved facilities' operation schedules, as well as energy efficiency improvement work.

Results

New Building Design Performance Evaluation & Energy Conservation Recommendations

In order to limit the impact on the ZEB PV system and ensure the future "Net Zero Energy" status of the ZEB building IES recommend pursuing Option 2.

The simulation results showed that:

- For the existing situation 1% of the roof is shaded
- 22% of the roof is shaded for Option 1
- 7% of the roof is shaded for Option 2

Option 1

Option 2

In order to achieve the energy performance targets a combination of Energy Efficiency Measures (ECMs) were considered. These included items such as high performance glazing, LED lighting, daylight harvesting, high efficiency chillers demand control ventilation and on site power generation with P.V. panels. An optimal combination of these ECMs was determined for each building resulting in the following savings versus the Green Mark NRB-2015 baseline model.

- Super Low Energy High Rise (SLEB) building – 77 kWh/ m² peryear (83 kWh/ m² excl. renewables) and a 57% (54% excl. renewables) energy saving
- Zero Energy Mid Rise (ZEB 2.0) building – 40 kWh/ m² per year (58 kWh/ m² excl. renewables) and a 67% (53% excl. renewables) energy saving

The results established that the majority of the performance criteria set-out by BCA can be met and exceeded by combining certain measures. However, the Mid-Rise building did not achieve "Net Zero Energy" although it did achieve an impressive Energy Use Intensity (EUI) value of 40 kWh/ m². The current Mid Rise model settings in particular the extensive operating hours are not ideally conducive to a "Net Zero Energy" building. While it is a challenge, it is not impossible to achieve the zero-energy target through increased natural ventilation or a hybrid system, and renewable energy generation beyond the building footprint boundary.

Model Simplification

Results show only a minor variation between the Level 4 and Level 3 models, which is to be expected considering the main differences, are on the lighting and equipment gains. The internal gain values used in the Level 3 model are derived from the Level 4 values that are based on BMS data. There are more significant differences between the Level 4, Level 2 and Level 1 models with the main differences recorded in cooling system energy leading to a maximum total energy consumption difference of 11%.

This is mainly due to the following reasons:

- Level 1 and Level 2 models are 100% air conditioned
- Level 1 and Level 2 models are using fixed operating periods for HVAC systems and internal gains
- Level 1 model has significantly less thermal mass due to the removal of the internal floors

Model Level	Model Type	Energy Performance	
		Annual Energy Consumption (MWh)	Variation Against Level 4 Model (%)
Level 1	Shell	58.52	- 11.1%
Level 2	Floor by Floor	69.33	5.3%
Level 3	Rooms	65.72	- 0.2%
Level 4	Calibrated Model	65.83	–

Table 22: Energy consumption results

Model Level	Chiller, Cooling Towers Distribution Fans and Pumps	Lighting	Equipment
Level 1	17.4%	0.1%	- 0.3%
Level 2	- 8.2%	- 0.3%	- 0.3%
Level 3	0.5%	0.1%	-1.2%

Table 23: Variation in energy end use results between model levels 1, 2, 3 and model level 4

Although an 11% variation between the level 4 and level 1 model may be within acceptable tolerances, the results for the energy end use values are less favourable with large variations recorded in cooling system energy. The simple models (level 1 and level 2) use cooling system seasonal efficiency values that have been prepared based on the performance of the level 4 model HVAC systems. An issue with these models however is that they do not account for rooms that are not conditioned or only used sporadically. Further testing is required to investigate methods of adding diversity to internal space conditioning set points and methods to counteract reduced thermal mass by compensating through the properties of the assigned constructions (level 1 model). These steps may help in narrowing the margin of error between advanced and simple models.

Existing Building Model Calibration and Operational Improvements

Operational errors that would save 12% and 7% were discovered and a 21% saving was shown to be possible if the existing chiller was upgraded. IES was able to accurately estimate energy savings by achieving an exceptional level of model calibration with only a 1.1% variation (MBE) between simulated and real building operation. ASHRAE Guideline 14-2014 "Measurement of Energy, Demand and Water", sets the acceptable calibration tolerances for monthly calibration at +/- 5%. And typically targets of +-10% are deemed an acceptable calibration. Using its unique calibration approach, IES regularly achieves an MBE of 3-6% on similar projects, but was able to achieve such an exceptionally good calibration on this building due to the high availability of operational data.

Using the data alone, IES was able to identify a number of operational faults, which it then investigated in detail using the calibrated model.

- Night time energy consumption (savings of 12% if eliminated)
- FCUs operating during the weekend (saving of 7% if only operated when required)
- High CO2 levels at VAV Box 3-2

The calibrated model also allowed IES to investigate opportunities for Energy Conservation Measure (ECM) or Retrofit improvements, and accurately estimate expected energy savings. For example, it looked at the impact of replacing the existing ZEB chiller, with two options: a chiller with a supply temperature of 11°C and the other 7°C. The calculated energy consumptions per month and associated savings were 21% for the 11°C chiller and 14% for the 7°C chiller respectively.

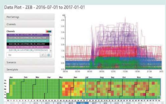

Figure 42: Overlay of all BMS lighting power values. Graphs shows significant night time lighting energy consumption

Figure 48: Level 1 Ojffice FCU fan power values. FCUs are operating during the weekends

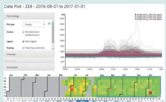

Figure 57: Overlay of AHU 3-1 VAV Box CO2 values

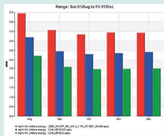

Figure 96: Comparison of chiller energy consumption between current chiller (red), VSD centrifugal chiller with a CHW water supply temperature of 7°C (blue) and a VSD centrifugal chiller with a CHW water temperature of 11°C (green)

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INTEGRATED ENVIRONMENTAL SOLUTIONS

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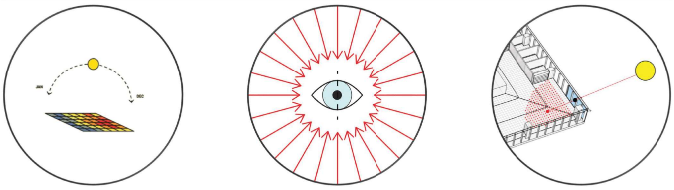
GBIC – R&D (DCP)

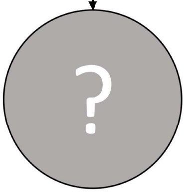
Daylighting in Singapore: Lighting Preferences, Design Guidelines, and Predictive Methods

J. Alstan Jakubiec, Zhe Kong, Geraldine Quek, Thanyalak Srisamranrungruang, Denise Kwok

1. Problem Statement



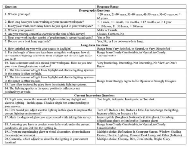
Daylighting Metrics | Visual Discomfort | Window Shades



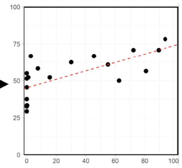
Design for Daylighting

- Current lighting sufficiency and visual discomfort metrics have been developed far from the tropics but are being applied here.
- Window shades are predominantly closed in new building designs, missing out on the natural resource of light and a connection to the outside.
- We aim to develop understanding of lighting preferences based on measured data in Singapore and translate them into actionable design measures to improve future lighting quality.

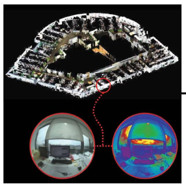
2. Methodology (Office Study)



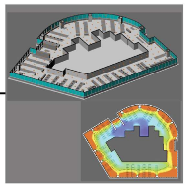
Subjective Survey



Correlate Data



Measurements
(Light + Space)



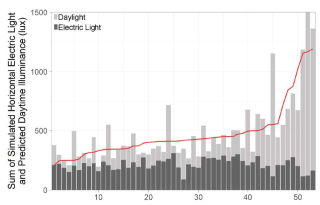
Simulations
(Daylight + Visual Comfort)

Outcomes

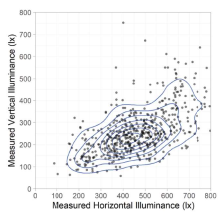
- Daylighting metrics and lighting standards based on specific impressions of Singaporeans
- Simple predictive methods for use in design

3. Data Collection

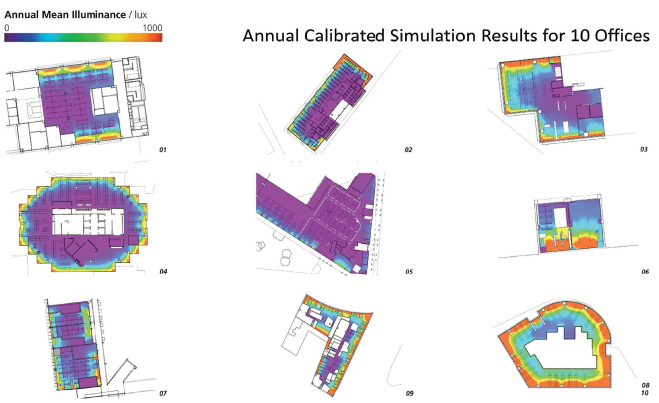
Ten Office Spaces Surveyed, 543 Participants



Calibration Analysis
Simulated versus Measured (Red Line) Data

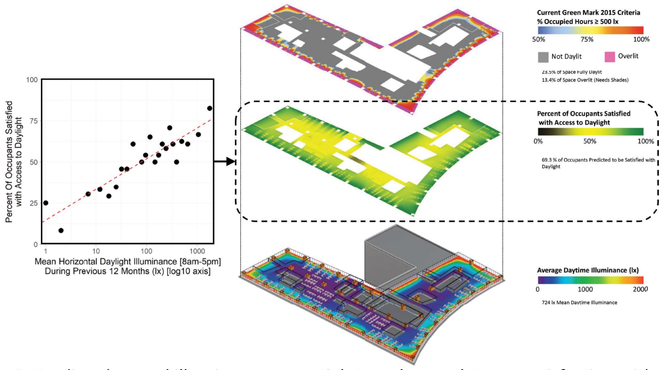


Instantaneous Measured Illuminance Levels

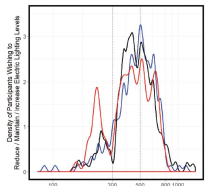


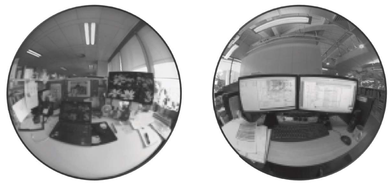
Annual Calibrated Simulation Results for 10 Offices

4. Initial Findings



A. Predicted annual illuminance potential strongly correlates to satisfaction with daylight access and view quality at far lower lighting levels than current standards.



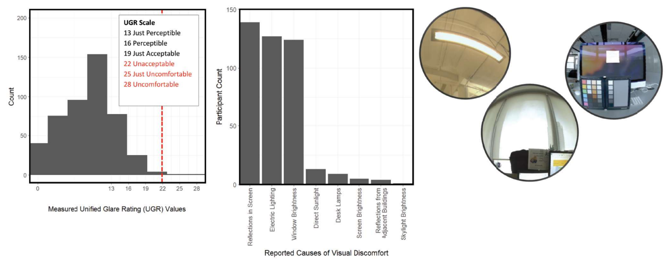


Blue Line, Decrease Electric Light
Black Line, Maintain Electric Light
Red Line, Increase Electric Light

300 lx | 500 lx

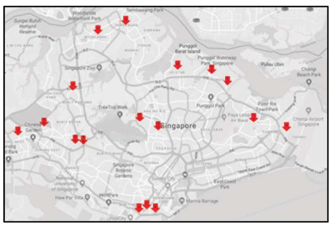
*Note: Images are partially pixelated to preserve participant privacy.

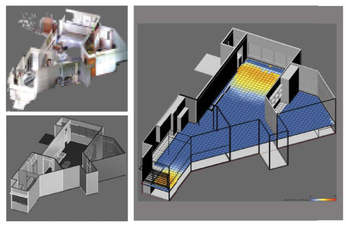
B. Occupants cannot differentiate between lighting supply at 300 lx—a lower energy design criteria—and 500 lx.



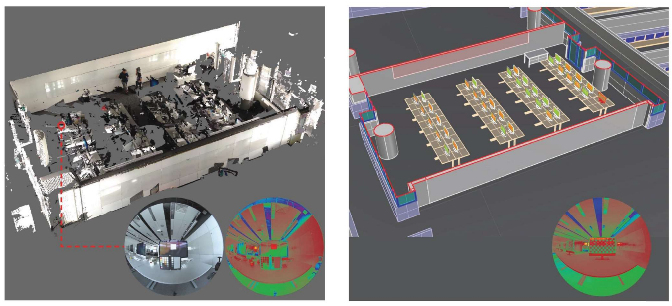
C. Measured, standardized glare metrics do not match reported discomfort.

5. Ongoing Work





Study in 17 Residences Throughout Singapore



Study in Institutes of Higher Learning

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Singapore

GBIC – R&D (DCP)

Laboratory Energy Performance Benchmarking Study in Singapore

Nilesh Jadhav, Noel Tan Leong Peng, Dr. Derrick Tan, Sunnee Ng, Leow Yock Keng, Wong Ngian Chung, Yong Siew Hwa, Jordan Liang, Derek Ang

INTRODUCTION

The Building and Construction Authority (BCA) of Singapore had rolled out environmental sustainable rating systems comprising various schemes to suit different type of buildings and interior. To develop a scheme for Laboratory buildings or spaces, which are highly energy-intensive (approximate 5 to 10 times more than offices), requires comprehensive studies due to complexity of design, equipment, and 24/7 operation

Starting in Feb 2016, ERI@N and S^2Lab Group (I^2SL Singapore Chapter) carried out a study funded by the National Research Foundation under the Green Buildings Innovation Cluster (GBIC) programme to analyse the energy consumption patterns in laboratories and identify energy saving opportunities in view of recommending a rating system to evaluate laboratory spaces.

OBJECTIVES

1. Measure and analyze the energy consumption pattern for laboratories in Singapore
2. Identify potential energy saving opportunities in labs
3. Provide recommendations to facilitate the development of the 1st green certification scheme in the world dedicated for laboratories design and operation: BCA Green Mark for Laboratories

TYPES OF LAB INVOLVED

1. Biological Lab
2. Chemical Lab
3. Physical Lab

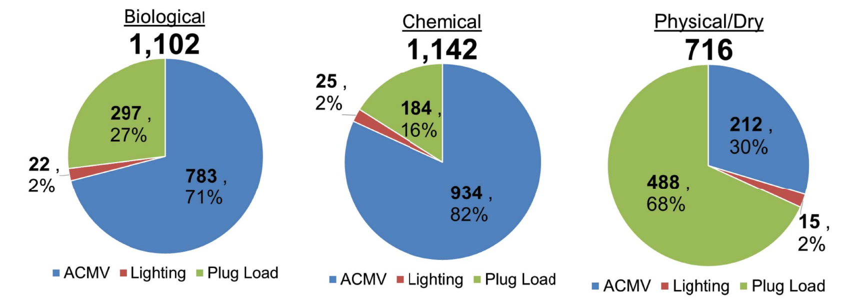
In total of 18 labs participated.

PERFORMANCE PARAMTETERS

1. Cooling load
2. Lab Ventilation rate
3. Indoor Air Sampling
4. Fume Hood face velocity
5. Plug load intensity
6. Equipment Efficiency
7. Energy Efficiency Index

and more

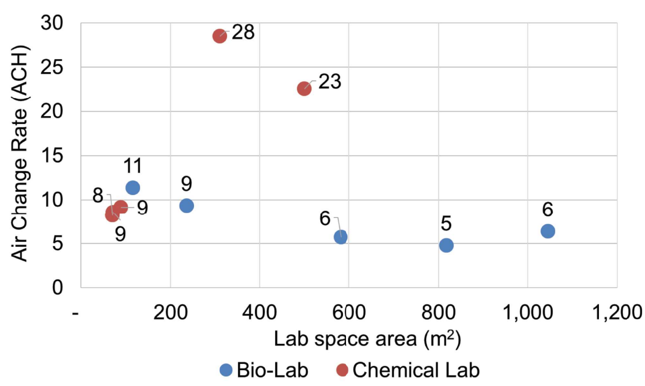
AVERAGE ENERGY EFFICIENCY INDEX (EEI) FOR LABS



CONCLUSIONS

- The study helped the development of BCA Green Mark for laboratories criteria that was launched in June 2017.
- The study confirmed the high energy intensity of labs compared to office buildings (~5x).
- Benchmarking is essential and continuous data collection is required to improve local standards.
- Lab best practices and improvements can lead to substantial energy savings (25 to 30%).
- Balancing Safety & Sustainability is important for labs.

AIR CHANGE RATE (ACH)



In collaboration with:
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
Energy Research Institute @ NTU
Singapore Sustainable Laboratory Group (S2Lab)
SEAS Sustainable Energy Association of Singapore
I2SL International Institute for Sustainable Laboratories Singapore

Brought to you by:
Building and Construction Authority

Funded by:
NATIONAL RESEARCH FOUNDATION
PRIME MINISTER'S OFFICE
SINGAPORE

GBIC – R&D (DCP)

Development of New Computational Fluid Dynamics (CFD) Simulation Methodology for Green Mark for Residential Buildings GM RB: 2016

Ms Lee Sui Fung, Ms Chan Vun Ching, Ms Neo Hwei Fern, Mr Tan Phay Ping, Mr Po Woei Ken, Ms Jocelyn Chan, Ms Tan Hwee Sien

1 BACKGROUND

To develop new CFD Framework for GM RB:2016

- ✓ Robust
- ✓ Cost Effective
- ✓ Quick to Process & Assess

2 OBJECTIVES

- ✓ Promote the use of CFD analysis to incorporate design with better natural ventilation
- ✓ Leading to substantial energy savings and economic benefits

3 NEW CFD FRAMEWORK

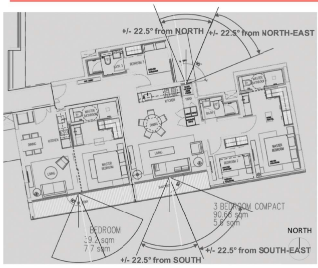
Prerequisite requirement for Green Mark (Residential Building) Platinum Rating

Primary Evaluation Parameters

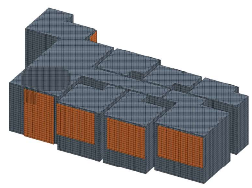
	Either	Or
Percentage of dwelling units with window openings facing prevailing wind directions North or North-East and South or South-East	< 60%	≥ 60%
Global Pressure Differential of Dwelling Units Located at building mid-height level (Capped at 20 storey height)	≥ 4.3Pa	≥ 2.7Pa

Step 1
Conduct Macro Level CFD Simulation.
Does it meet the *Primary Evaluation Parameters*?

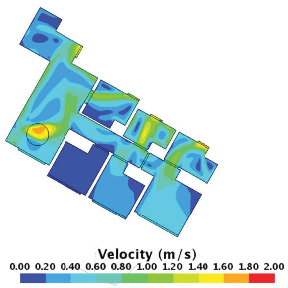
- Yes → Conduct decoupled unit CFD simulation for selected units using façade pressure derived in Step 1. To achieve a minimum 70% of the selected unit with weighted average velocity of 0.60 m/s.
  - Yes → Eligible for Green Mark Platinum Rating
- No → **Step 2**
  Conduct Micro Level CFD Simulation.
  To achieve a minimum 70% of the selected unit with weighted average velocity of 0.60 m/s.
  - Yes → Eligible for Green Mark Platinum Rating
  - No → Does it achieve a minimum 70% of the selected units with weighted average velocity of 0.20 m/s?
    - Yes → **Step 3**
      Conduct Unit CFD Simulation with mechanical aid to meet thermal comfort requirement
      - Yes → Eligible for Green Mark Platinum Rating



Identifying percentage of dwelling units facing prevailing wind directions



Decoupled Unit CFD simulation for selected units using façade pressure on window openings (highlighted in orange)



Velocity Profile within selected unit using Decoupled Unit CFD simulation

4 CONCLUSIONS

- ✓ Time saving (Decoupled Unit vs. Micro Level) as high as 60%
- ✓ Reduction in turnaround time
  - → $$ saving
  - → wider adoption of CFD
- ✓ Adoption of assisted ventilation (in Step 3) welcomed by industry

Prepared by: BSD building system & diagnostics

Brought to you by: Building and Construction Authority

Funded by: National Research Foundation, Prime Minister's Office, Singapore

GBIC – R&D (DCP)

Evaluation and Validation of Key Technology Solutions

Yann Grynberg, Prof. Y. W. Wong, Shashwat, N. Naphade, H. L. Aw, A. Anantharam

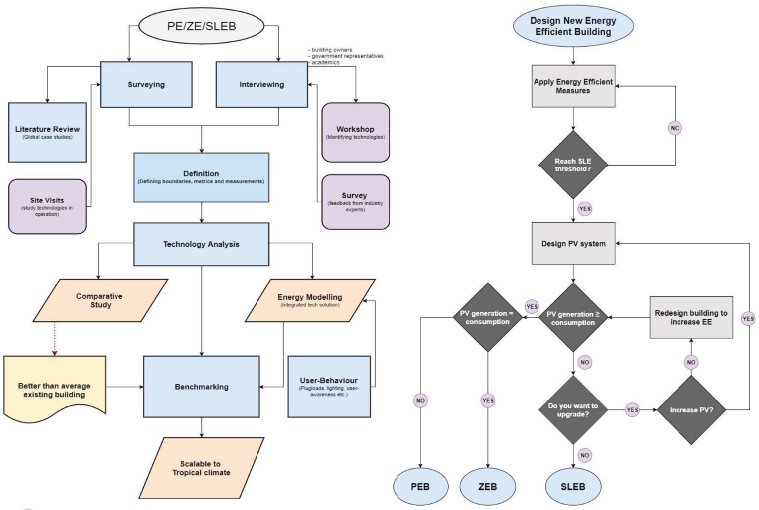
1 Problem Statement & Motivation

Assess the achievability, with the **current technological advancement,** of 3 energy-efficiency targets in **typical Singapore buildings**:

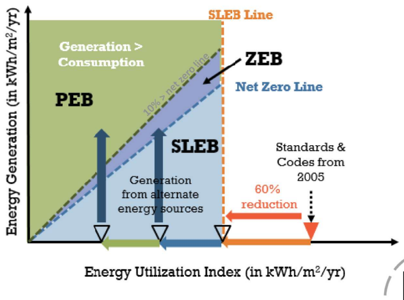
Positive energy (PEB)	Zero energy (ZEB)	Super-low energy (SLEB)
Typical low-rise	Typical medium-rise	Typical high-rise

- ➢Buildings sector offers one of the best near-term opportunities to mitigate climate change
- ➢Concur with smart nation initiative

2 Methodology



3 Definition & Boundaries



Non ZEB building: $E_x < E_d$

ZEB building: $E_x = E_d$

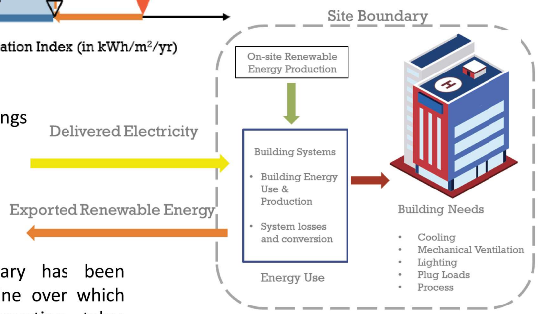
PEB building: $E_x > E_d$

SLEB building: $E_x < E_d$ and EUI > 60% savings over EUI_{2005}

E_x - total on-site annually exported renewable energy

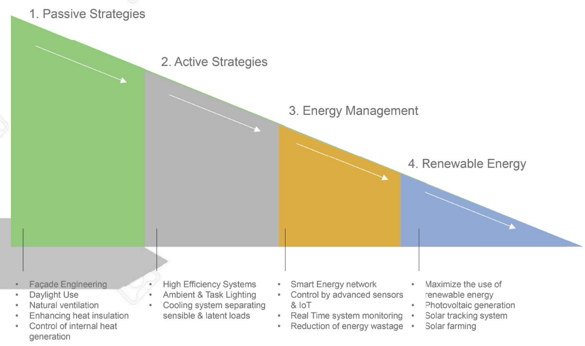
E_d – total annual delivered building energy

- ➢New buildings
- ➢Stand alone buildings

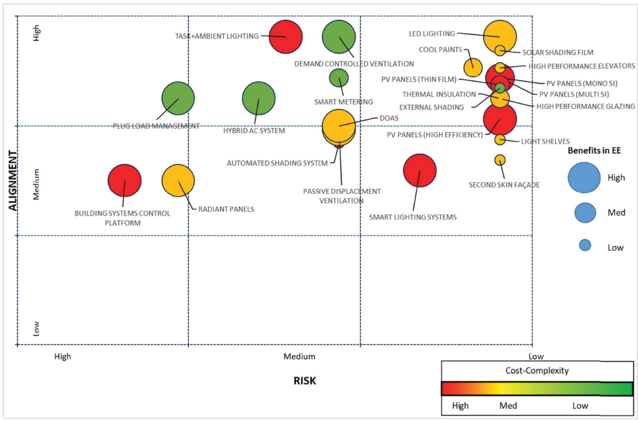


- ➢The site boundary has been defined as the line over which the energy accounting takes place. This boundary is an imaginary line which the building owner demarcates.

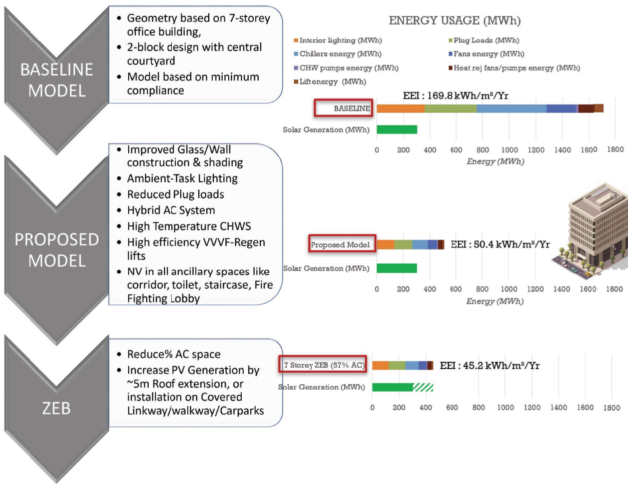
4 Technologies towards PE/ZE/SLEB



5 Technology Prioritization Chart



6 Simulation Results for ZEB



6 Conclusion for ZEB

A ZE office building of up to 7 storeys employing best class technologies would be feasible today by reducing air-conditioned space, use alternative methods of cooling and adopting paradigm shift in building design.

In our urban setting, focus on further technological development and guidance is needed to make mainstream buildings reach Super Low Energy status as a target for 2030.

Project Team: Nanyang Technological University Singapore

Brought to you by: Building and Construction Authority

Funded by: National Research Foundation, Prime Minister's Office, Singapore

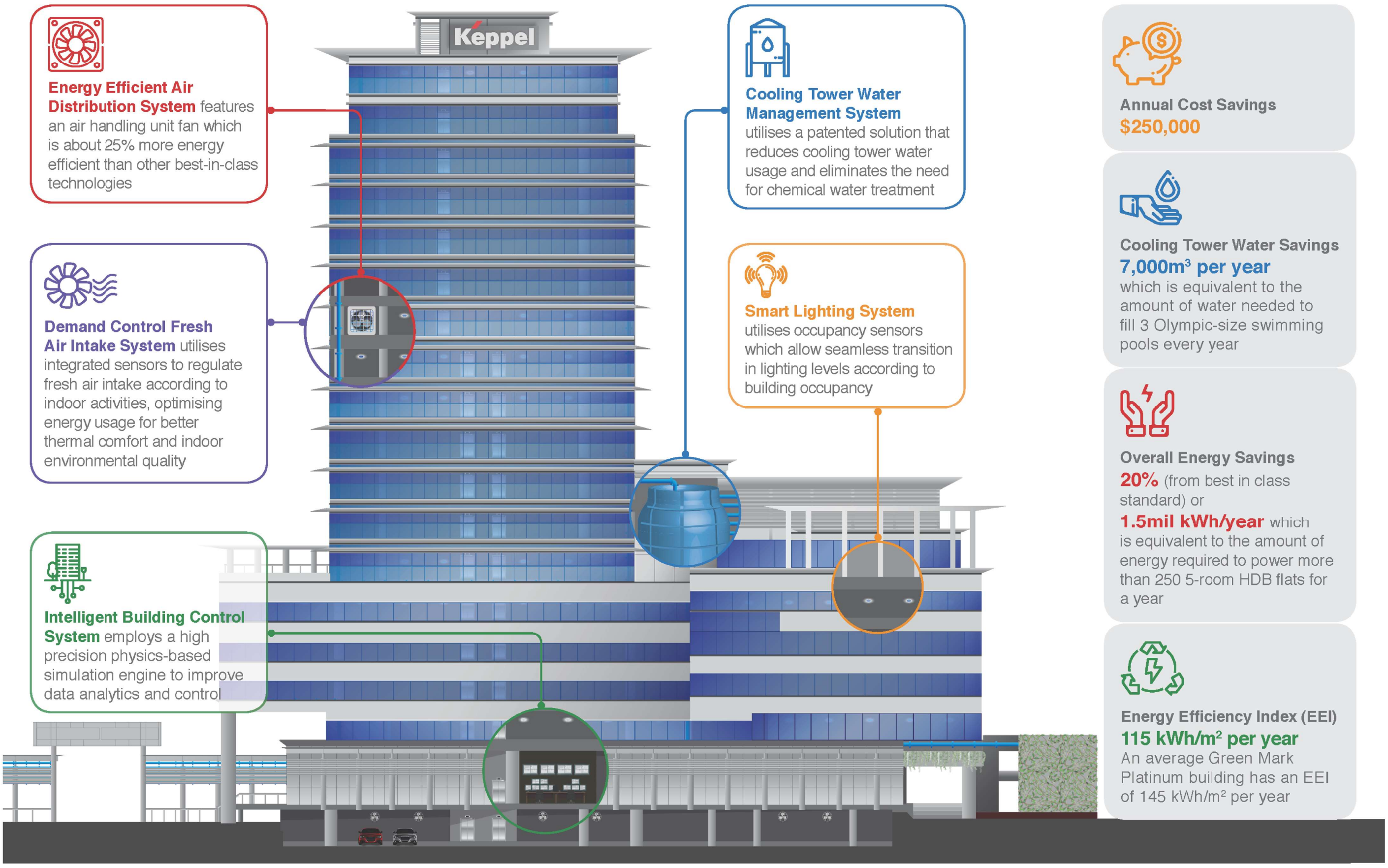
GBIC – Demo

Super Low Energy Building – Keppel Bay Tower

Target

To push the performance limits of a Green Mark Platinum building (Keppel Bay Tower) and achieve Super Low Energy Building status

Deployed Technologies & Location of Demonstration



Source: Keppel Land

Replication & Future Deployment

Project Team :

Keppel Land
Thinking Unboxed™

G-ENERGY GLOBAL

Brought to you by:

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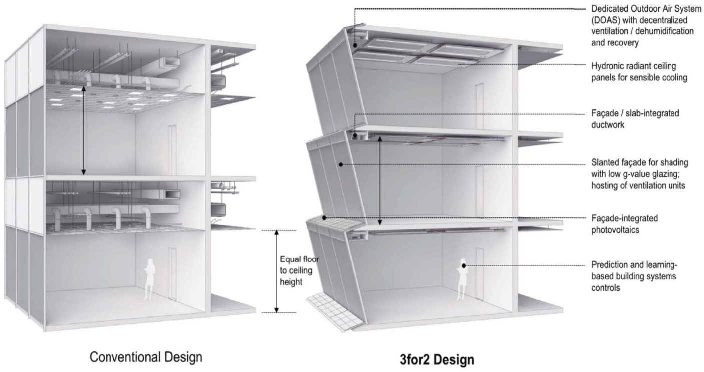
Prime Minister's Office
Singapore

GBIC – Demo

3for2 Beyond Efficiency

Prof. Dr. Arno Schlueter, Asst. Prof. Dr Adam Rysanek, Bharath Seshadri, Simon Thomas

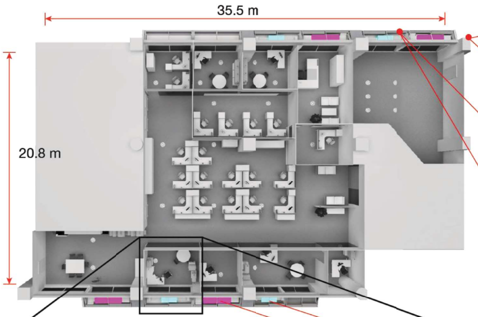
❶ Design Concept



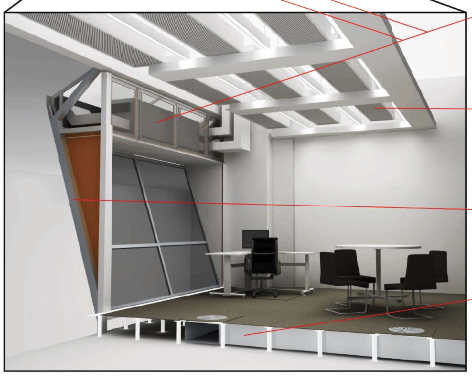
The '3for2 Beyond Efficiency' project is a paradigm shift in the development of low-carbon high-rise buildings: integrating the design and construction of structural, mechanical, and electrical systems to lower material, space, and energy use.

Schlueter, A., Rysanek, A., & Meggers, F. (2016). 3for2: Realizing Spatial, Material, and Energy Savings through Integrated Design. CTBUH Journal, (2), 40-45.

❷ Pilot Implementation at UWCSEA



- Approx. 550 m² floor area
- Daily occupancy between 26 and 35 staff; up to 55 when board room in occupation
- Net facade U-value (incl. glazing and structure) below 2 W/m2K
- Maximum infiltration rate below 2 m3/hr per m2 facade area, as tested at 50 Pa

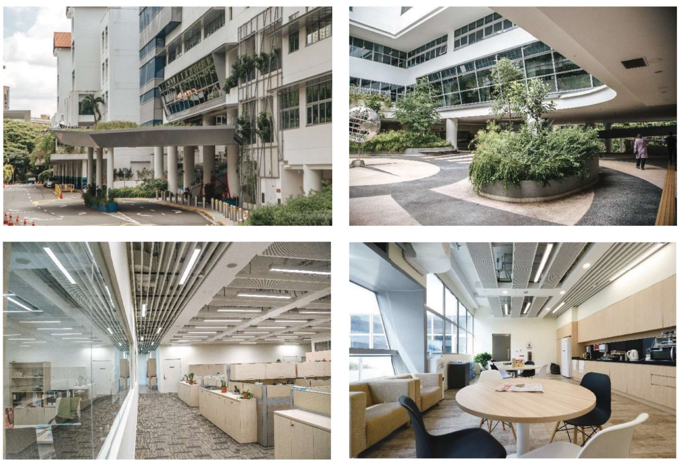


Decentralized latent cooling and ventilation: Alternately installed Dedicated Outdoor Air Systems (DOAS) or 100% recirculated air Fan Coil Units

Sensible cooling: Passive chilled beams control indoor tempertures through natural convection and radiant heat transfer

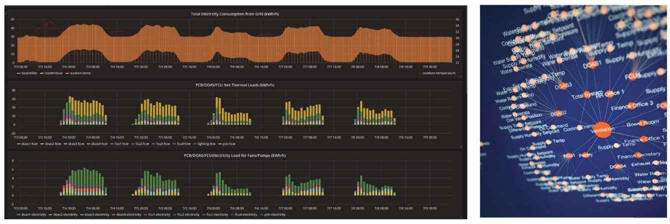
Integrated façade: Sloped façade with integrated plenum area for installation of decentral-ized air handling units

Meshed underfloor air distribution: Ventilation air is ducted into a raised floor meshed network of ducts and diffusers covering the entire project area



Site photos of the completed project: north and south façades (top row), open plan office space (bottom-left) and staff pantry (bottom-right). Photo credits: ETH Globe.

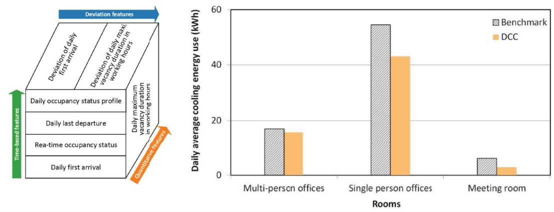
❸ Cyber-Physical Middleware for Data Aggregation and Visualization



The 3for2@UWCSEA pilot implementation is a highly instrumented office with 1600 data points from sensors, actuators, meters across multiple zones. To handle the large volume of data, a non-intrusive, cyber-physical middleware was developed to liberate data from a conventional BMS system in a real building. It integrates (a) a wide range of sensors, meters, and actuators native to building management infrastructure (b) an appropriate cloud-based, centralized database and (c) an intuitive front-end visualization platform. The project demonstrated an approach to building such a middleware using open-source tools that allows scalable implementation across buildings in cities.

Kalluri, B., Miller, C., Seshadri, B., & Schlueter, A. (2018 – In-press). A cyber-physical middleware platform for buildings in smart cities. In 35th CIB W78 2018 Conference: IT in Design, Construction, and Management. Chicago, US.

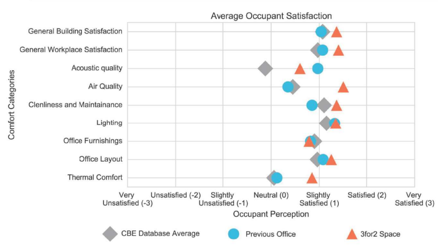
❹ Artificial Intelligence in Occupancy Prediction and Controls



The project successfully implemented a occupancy-learning control for air-conditioning. The results show that a 7 to 52% energy saving was obtained by the adaptive cooling system, depending on occupancy rates, with average savings in the order of 21% across the entire space, as compared to using the conventional control system. It was further found, at least in this study, that the achieved energy savings are inversely correlated to the occupancy rates of individual rooms. (Peng, 2017)

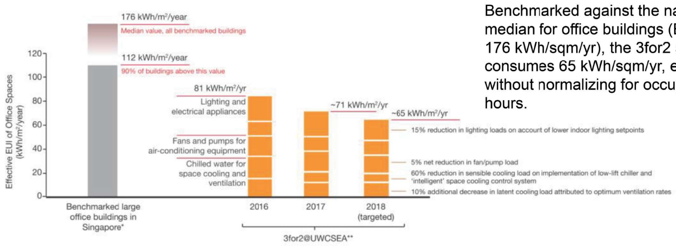
Peng, Y., Rysanek, A., Nagy, Z., & Schlüter, A. (2017). Occupancy learning-based demand-driven cooling control for office spaces. Building and Environment, 122, 145-160.

❺ Indoor Environmental Quality and Energy Efficiency



Compared to the conditions of the previous office and the data collected from the CBE database, the perceived thermal comfort and air quality of the occupants were markedly higher due to (1) enabling occupants to set their preferred temperature, (2) ventilating with more outdoor air, and (3) operating a decentralized system that could precisely and uniformly meet room set points. (Pantelic, 2017)

Pantelic, J., Rysanek, A., Miller, C., Peng, Y., Teitelbaum, E., Meggers, F., & Schlüter, A. (2018). Comparing the indoor environmental quality of a displacement ventilation and passive chilled beam application to conventional air-conditioning in the Tropics. Building and Environment, 130, 128-142.



Benchmarked against the national median for office buildings (EUI = 176 kWh/sqm/yr), the 3for2 space consumes 65 kWh/sqm/yr, even without normalizing for occupancy hours.

Prepared by:

ETH zürich
UWCSEA
SIEMENS

Brought to you by:

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Singapore

GBIC – Demo

Tahir Foundation Connexion

Singapore Management University

First onsite Net-Zero Energy Building with MET Construction in City

Estimated
EUI 58.6 kWh/m²/year
45% better Energy Performance than Green Mark (Platinum) Building

1) Native Landscaping

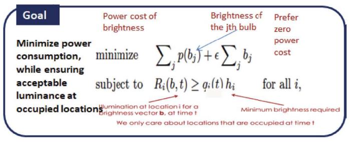
Alternating trees and palms give a rhythm of vertically and circularity to building

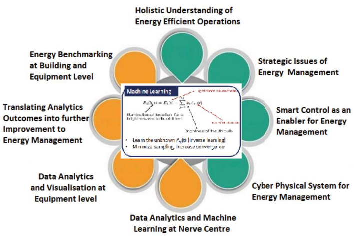
2) Enhanced Building Envelope

ETTV 26 W/m2

Inputs from CD Team

12) Analytics & Machine Learning for Energy System Optimization



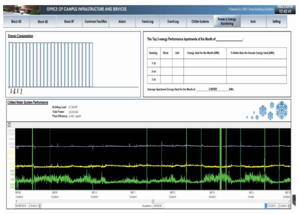


3) Photovoltaic Array

100%

Energy Creation

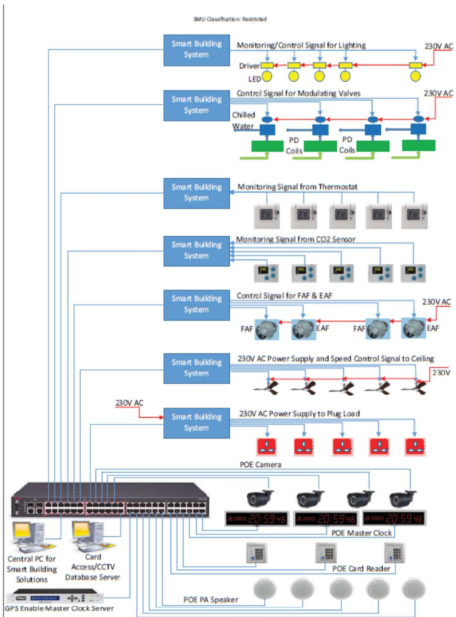
450kWp PV panels array on the roof will generate 100% of the building's electricity consumption



11) Energy Performance Display

Building energy production, consumption and systems' performance

7) Operation Centric Smart Control System for Energy Efficient Operation



Smart Building Solutions System Architecture

4) Enhanced Passive Displacement Cooling (EPDC)

44%

Energy Savings

Building is equipped 100% with EPDC which also reduces maintenance cost and saves 300m2 of GFA

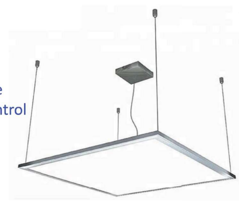
10) IAQ Monitoring and Ventilation Control

Occupancy responsive localised fresh air supply and air purging system

5) LED Lighting and Smart Control

43%

Energy Savings



Occupancy responsive automatic lighting control system

9) Converged Power System (CPS)

68%

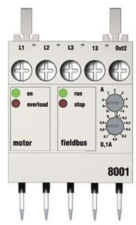
Energy Savings

Conventional UPS systems replaced by CPS also saves space, maintenance cost and reduces heat load

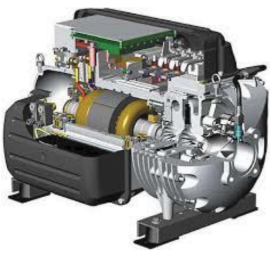
6) Plug Load Management

19%

Energy Savings



Manage the plug load energy consumption by deployment of occupancy sensors and smart contactors



8) Oil-Free Chiller

47%

Energy Savings

Chilled water tapped from the main campus saves xxxm2 of GFA

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Funded by:

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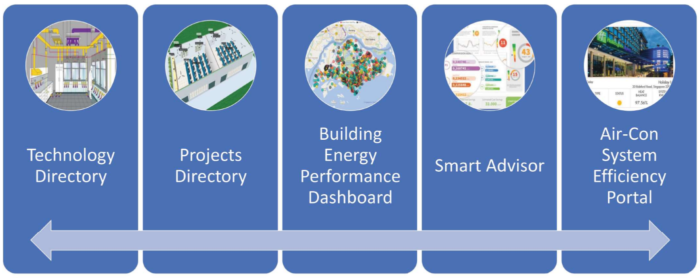
Prime Minister's Office
Singapore

GBIC – Repository

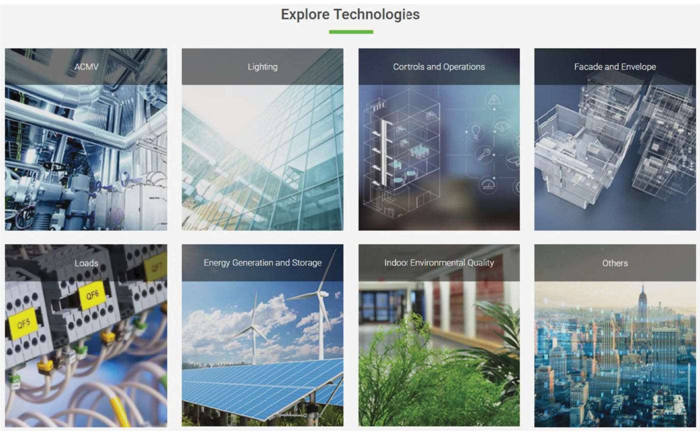
SLEB Smart Hub – A National Building Energy Efficiency Smart Hub

What is SLEB Smart Hub

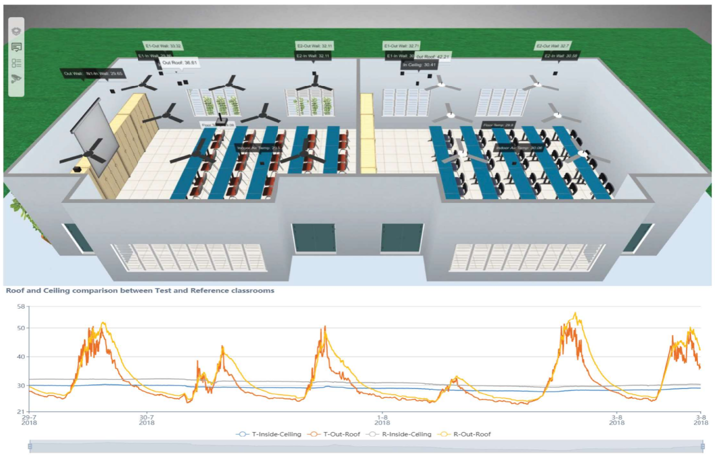
The development of Super Low Energy Building (SLEB) Smart Hub is funded by National Research Foundation's fund. It is envisioned as a central database to accelerate adoption of energy-efficiency technologies of built environment towards Super Low Energy Building target.



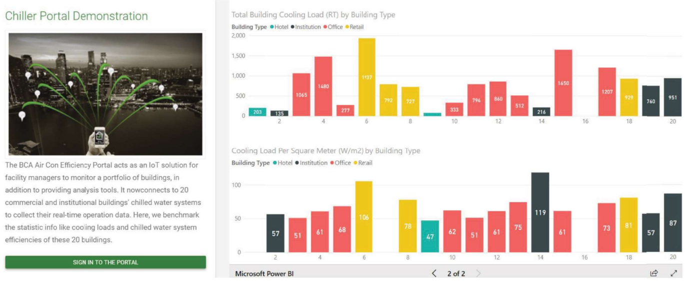
Technology Directory



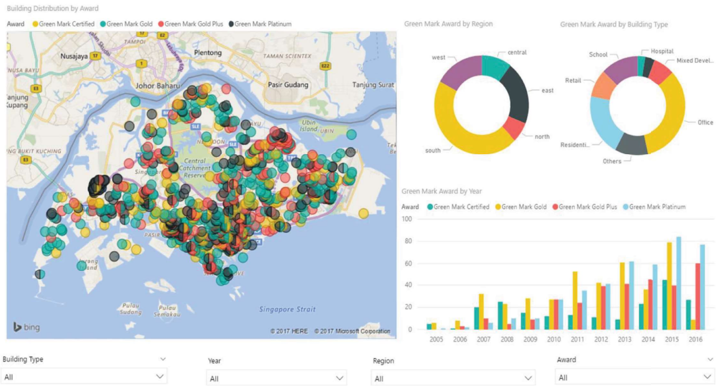
Projects Directory



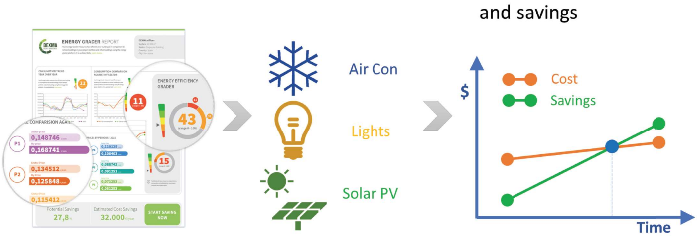
Air Con Efficiency Portal

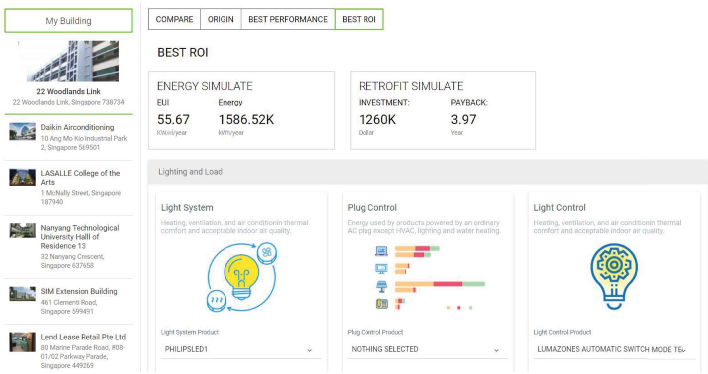


Energy Efficiency Dashboards



Smart Advisor





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Or you may would like to scan the QR code at right:

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