GBIC 1st Grant Call
Smart Building Technologies & Solutions
R&D Outcomes

Real-Time Occupant Engaged Indoor Environmental Quality Monitoring and Control System Using Wireless Sensor-Actuator Network for Smart Indoor Environments

Project No: BCA RID 94.17.2.4

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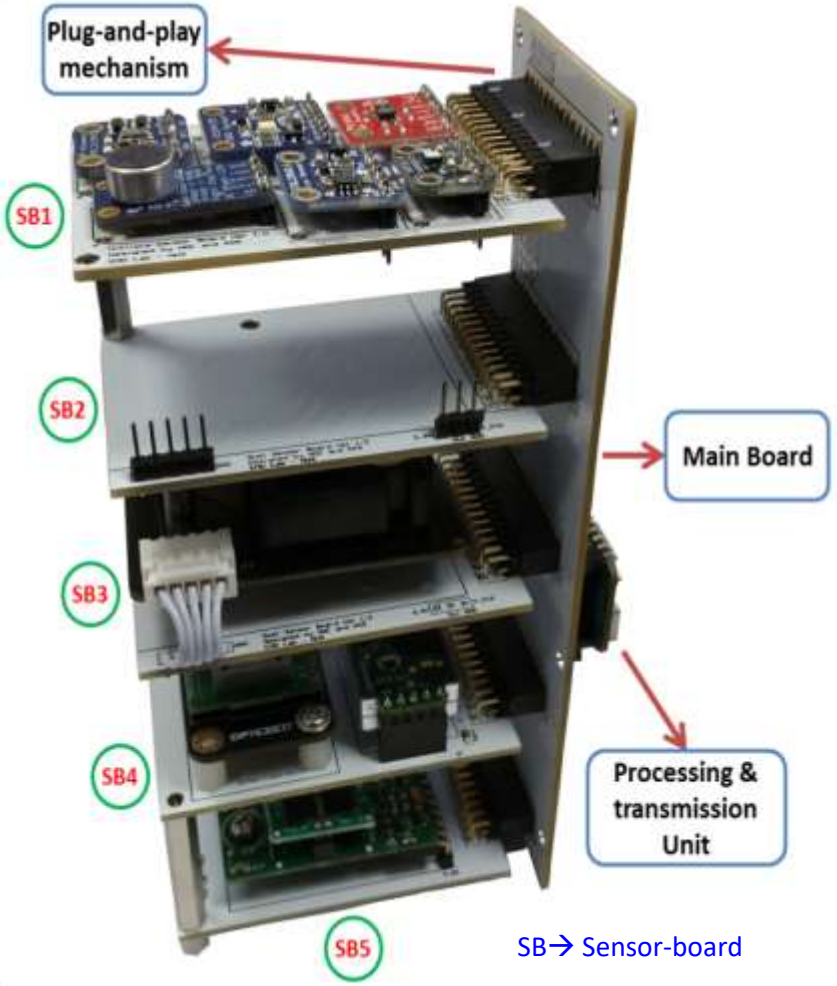
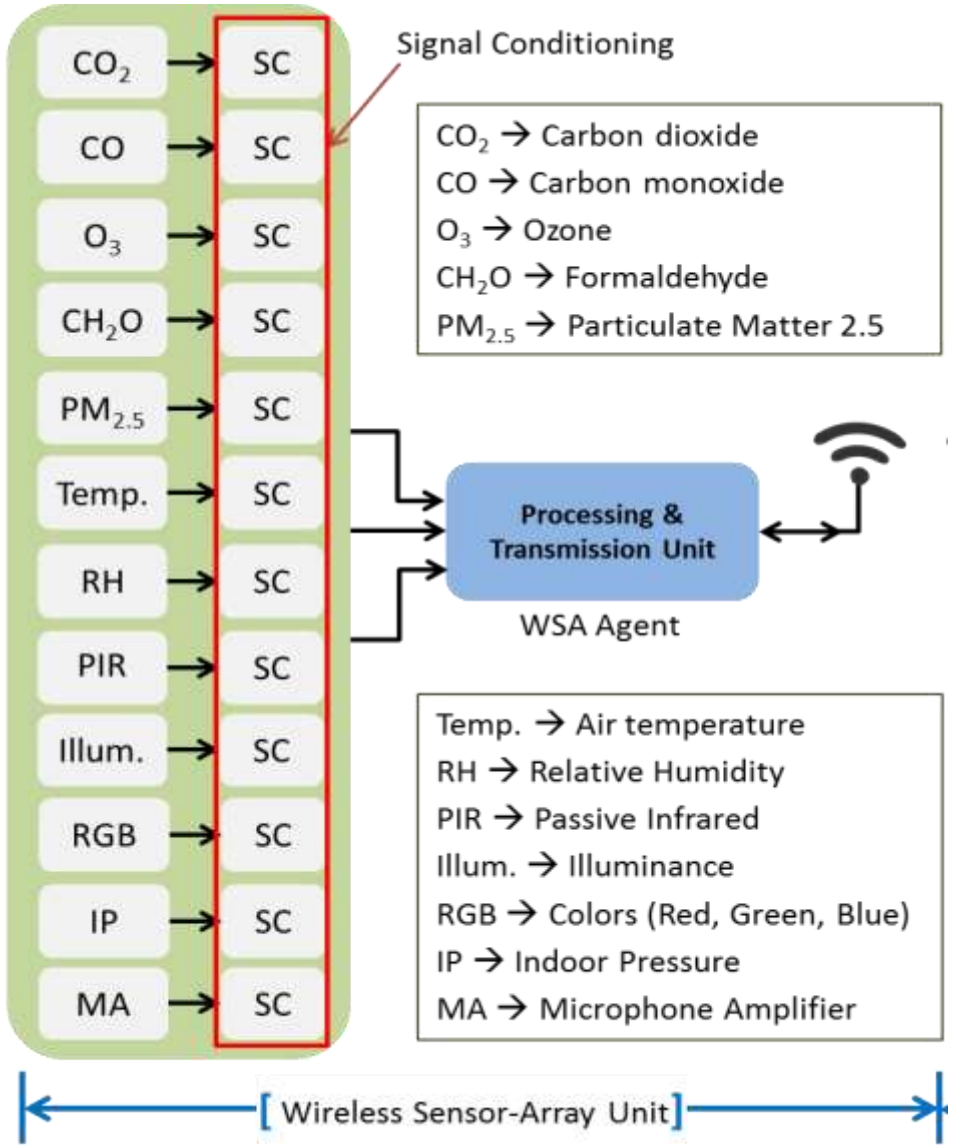
Start Date: 01-July-2016

End Date: 31-Dec-2018

A) Wireless Sensor Array

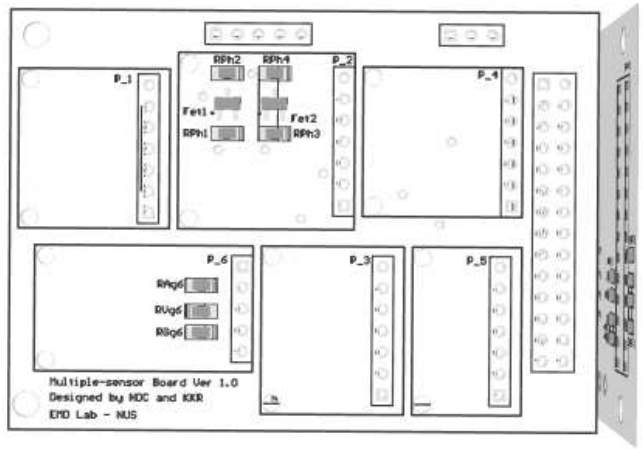


SB→ Sensor-board



A) Wireless Sensor Array

Ensemble of Sensors (multi-protocol)		
Parameter	Sensor	Interfaces
CO2	SenseAir LP8	UART
CO	SPEC CO	UART, Analog
O3	SPEC O3	UART, Analog
CH2O	DFRobot Gravity SEN0231	UART, Optional DAC
PM2.5	Telaire SM-PWM-01C	PWM output
Temperature and RH	Sensirion SHT31	I^2C
Illuminance	TAOS TSL2561	I^2C
Motion	SE-10 PIR Motion Sensor	Digital (High/Low)
RGB	TAOS TCS34725	I^2C
Pressure	NXP MPL3115A2	I^2C
Sound	Maxim MAX4466	Analog



Dr. H.D. Chinh, Krish K.R., Prof. S.K. Panda - EMDL, NUS

Innovations

- ✓ Allows flexible sensor ensembles
- ✓ 12+ Parameters sensed, 5V input
- ✓ Allows OTA (over-the-air) updates
- ✓ User is free to choose sensor boards
- ✓ Wi-Fi based, Uses MQTT open protocol
- ✓ Edge-based (no cloud needed)

Main board → 0.4-0.5 W (Wi-Fi ON), 0.09 W (Wi-Fi ON, power-save mode of the processor), 0.4 mW (deep sleep mode)
Assuming average transmission rate of 5 seconds every minute, main board consumes ~1 kWh/year, and operational cost is <S$0.25/year.

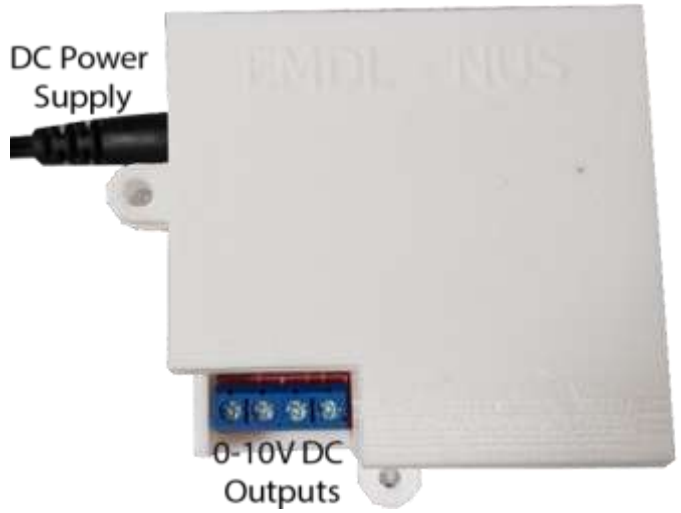
Sensor boards → Variable. Depends on the sensors connected.
Max. power of 1.5W drawn by current ensemble of sensors.

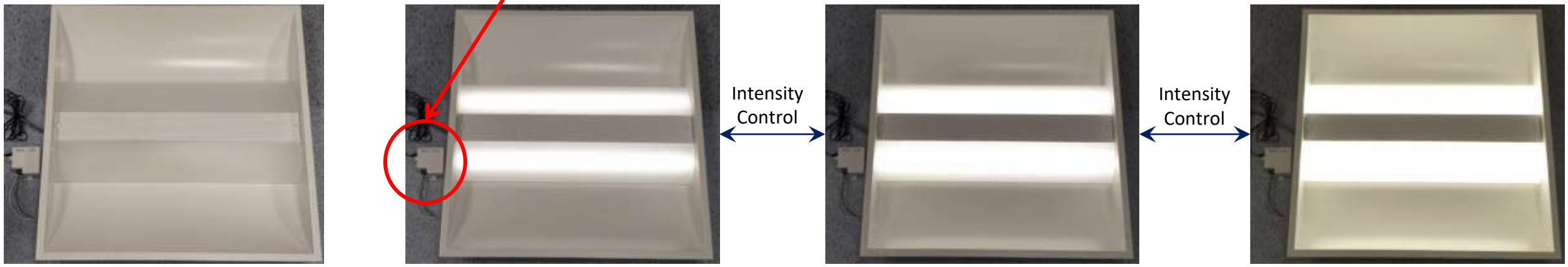
A) Wireless Sensor Array

GUI Developed

B) Background Lighting Controller

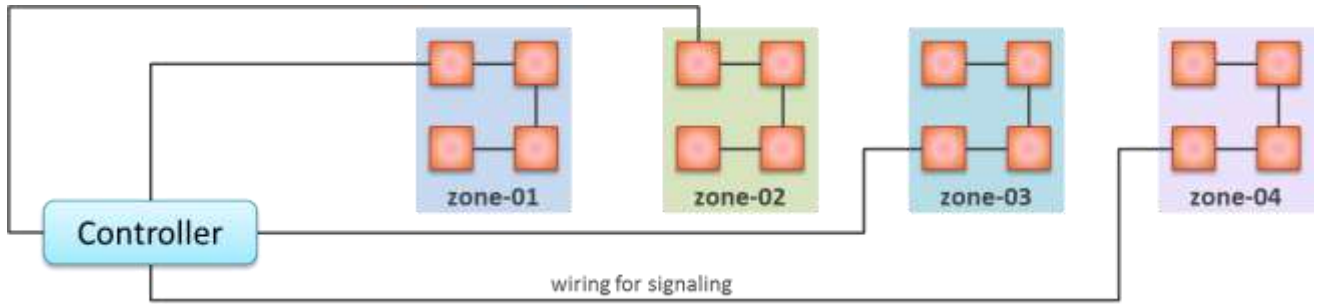
- ✓ 0-10V wireless control over local Wi-Fi network
- ✓ Uses MQTT open protocol
- ✓ Allows OTA (over-the-air) updates
- ✓ Currently allows intensity control for 2 independent channels per controller.
- ✓ Needs power supply unit of 12V





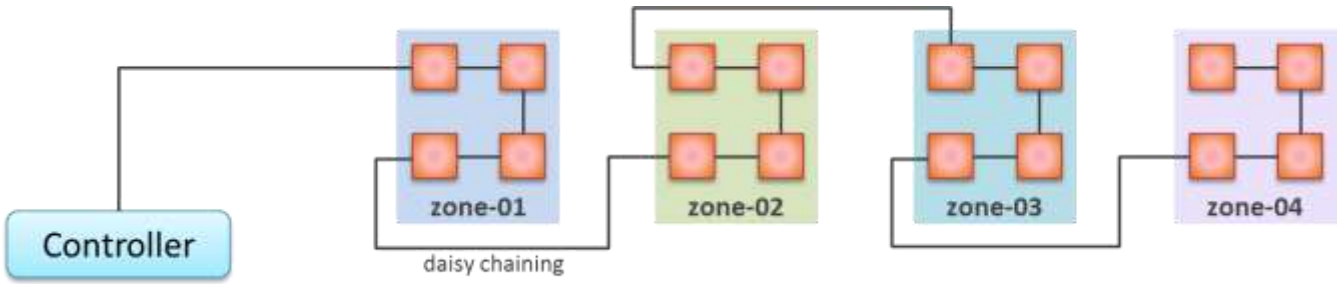
Example of wireless intensity control for a 220-240V 35W Davis luminaire used for background lighting. (Correlated Color Temperature (CCT): "Cool White")

B) Background Lighting Controller



i) Non-addressable Control

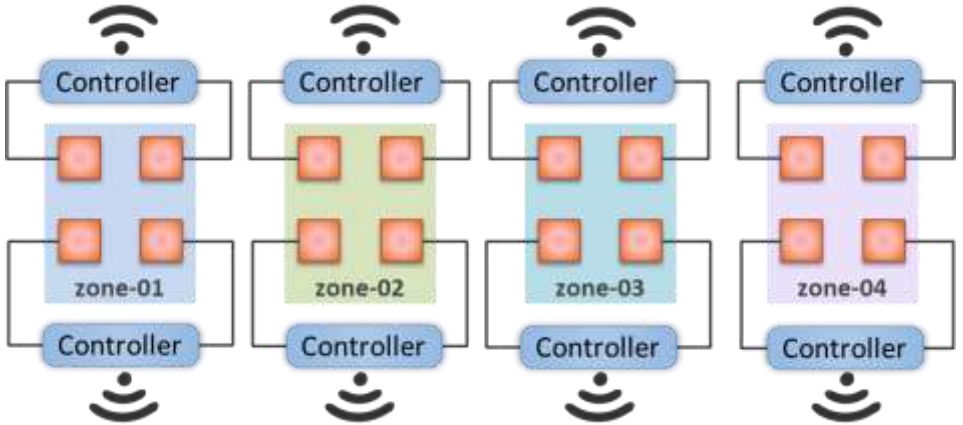
Ex: Analog 0-10 V dimming, Digital Signal Interface (**DSI**, 8-bit protocol)



ii) Wired Addressable Control

Ex: Digital Multiplex (**DMX**, 512 channels, 8-bit each),
Digital Addressable Lighting Interface (**DALI**, max 64 drivers under a DALI gateway)

- ✓ No long wires, digitally addressable
- ✓ Software-based rezoning, add new services
- ✓ Low controller/component cost
- ✓ Easier for retrofitting, low installation cost



iii) Wireless IoT-based Control

C) Personalized Task Lighting Controller

- ✓ 0-10V wireless control over local Wi-Fi network
- ✓ Uses MQTT open protocol
- ✓ Includes intensity control.
- ✓ Augments background lighting using lower power consumption.

Task Lighting Load (65V input, 18.5W)

Local Area Network (LAN)

Supervisory Hub (Edge Device)

Building Operator

Controller

LED Driver

LED Driver

User: 1

User: 2

Mobile App

Controller

LED Driver

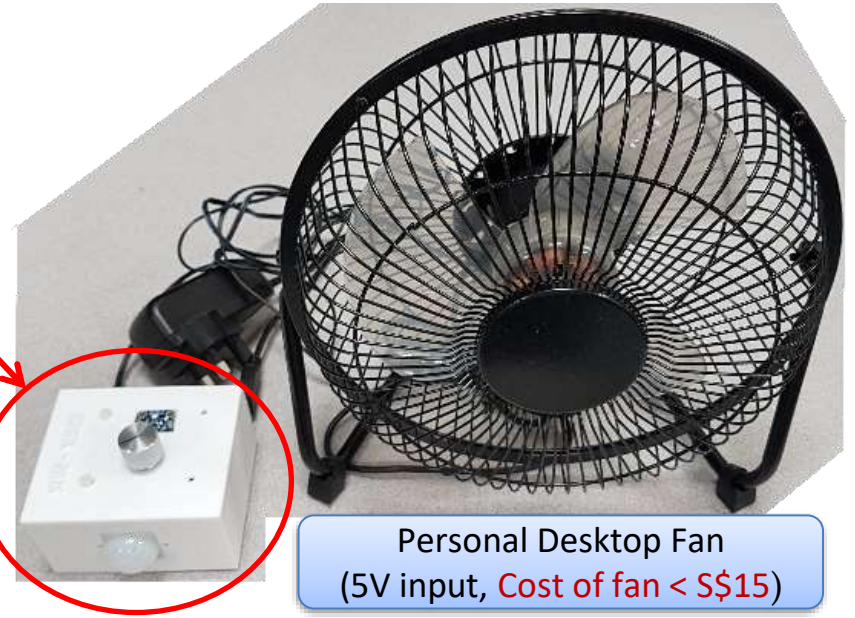
LED Driver

User: (N-1)

User: N

D) Personalized Fan Controller

- ✓ Wi-Fi based, uses MQTT open protocol
- ✓ Personalized fan control, with manual and automated speed control options
- ✓ Needs power supply unit of 7.5V
- ✓ Augments indoor air-conditioning and facilitates setting of higher temperature for background air-conditioning to save energy



Personal Desktop Fan
(5V input, Cost of fan < S$15)

E) Personalized Ventilation Controller

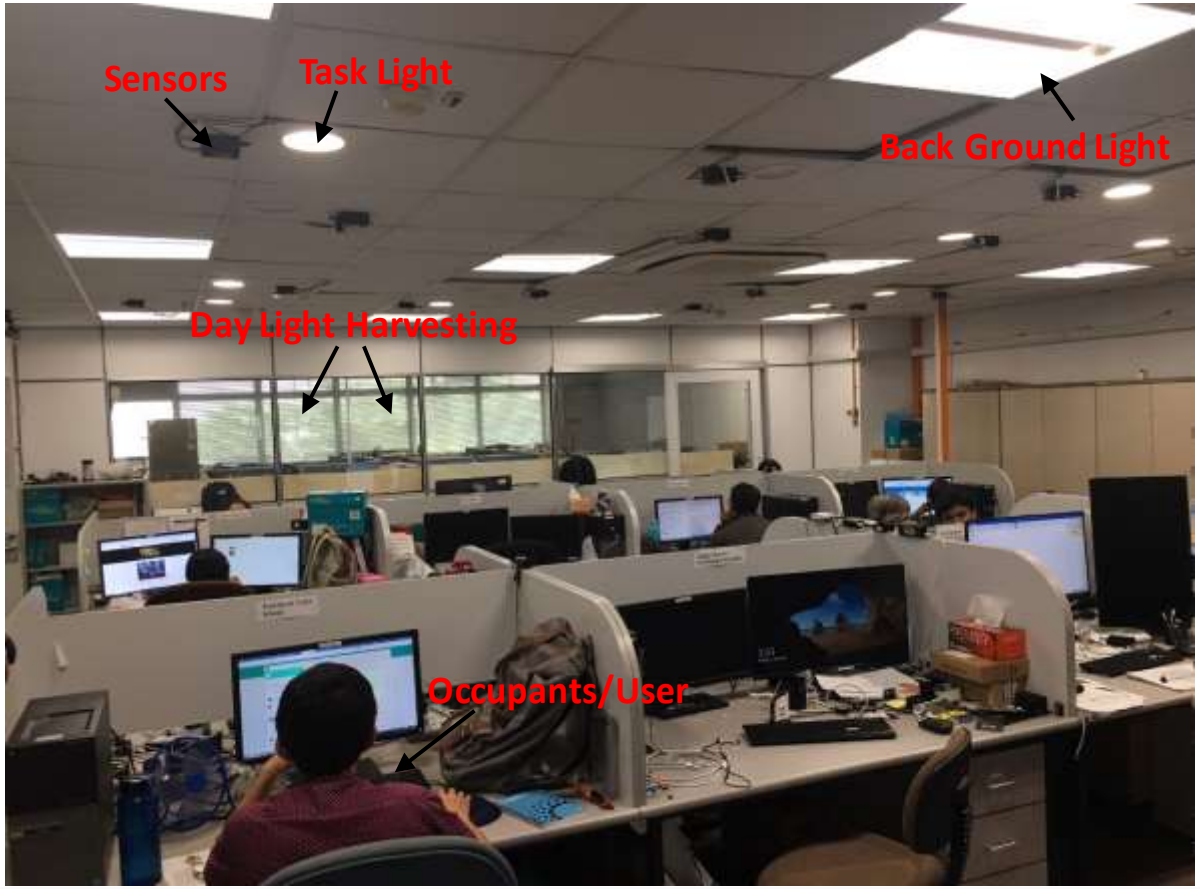
- ✓ Personalized ducting and ventilation for desktop fresh air delivery (prior infrastructure needed).
- ✓ Needs power supply unit of 12V
- ✓ Wi-Fi based, uses MQTT open protocol

3D Printed Air Terminal Device

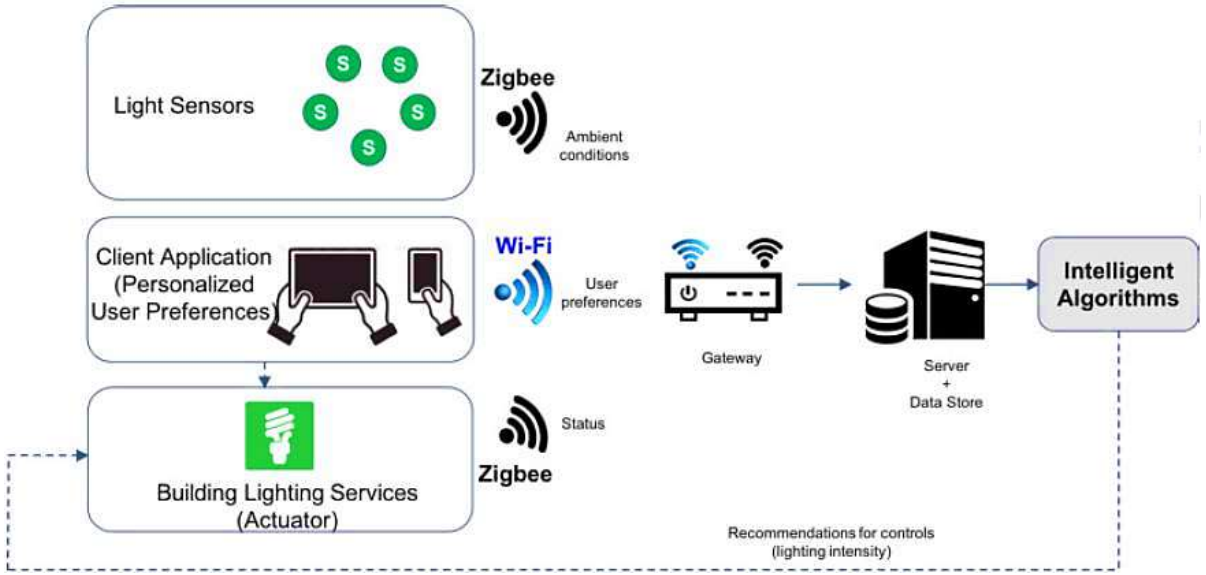
Rotation Controller

Rotary Damper Actuator (230V input)

F) ReViCEE – Recommender-system based Visual Comfort and Energy Efficient preference learning



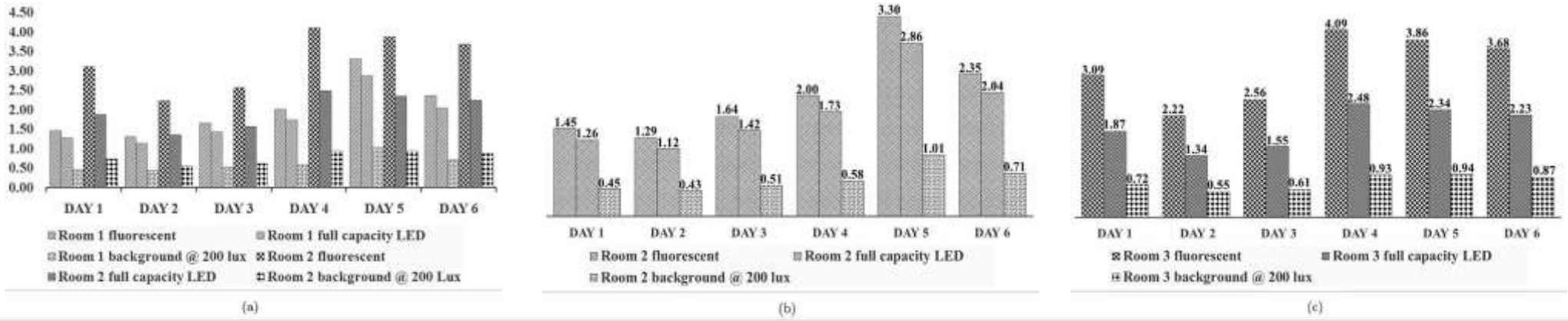
EMD Living Lab at NUS Engineering Workshop2 in 2017



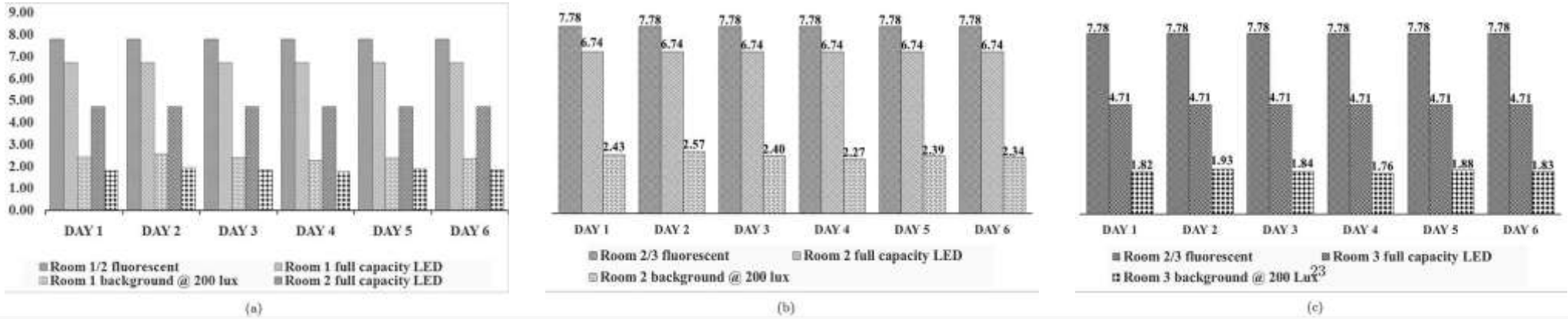
- ✓ Learn both individual and collaborative user-preferences from historical data and offer recommendations (i.e. appropriate illumination set-points) for intelligent building lighting control.

Project Deliverables, Outcomes, and Impact

F) ReViCEE – Recommender-system based Visual Comfort and Energy Efficient preference learning



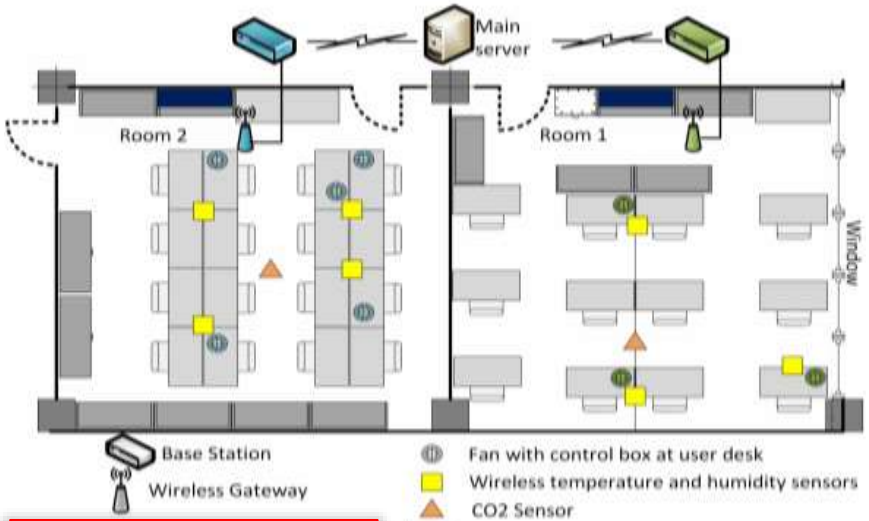
Energy consumption (kWh) per user in 9 hrs interval, (a) average energy consumption, (b) Room 1 - Energy consumption and (c) Room 2 - Energy consumption.



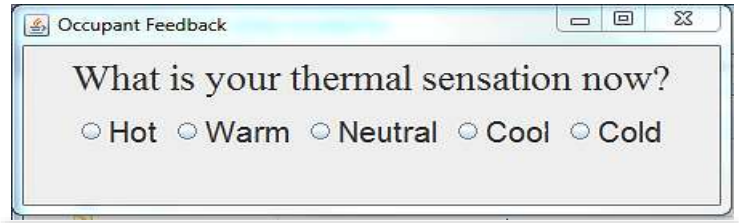
Energy consumption (kWh) in 9 hrs interval, (a) Total energy consumption, (b) Room 1 - Total energy consumption and (c) Room 2 - Total energy consumption

Two months field experiments in EMDL present a potential energy savings up to 72%.

G) Occupant Engaged Personalized Fans



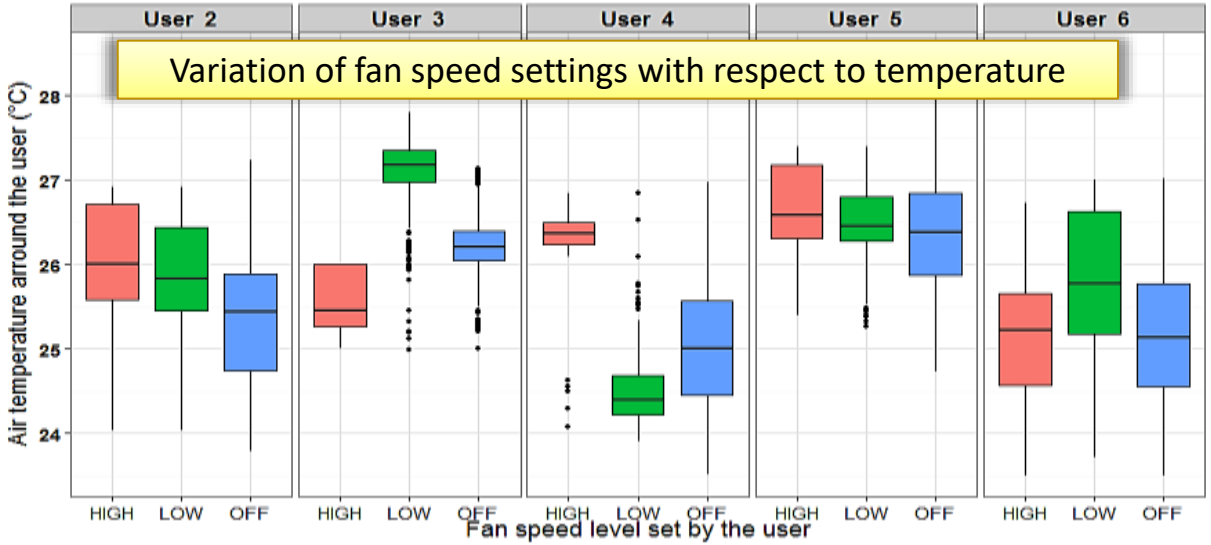
Sensor deployment



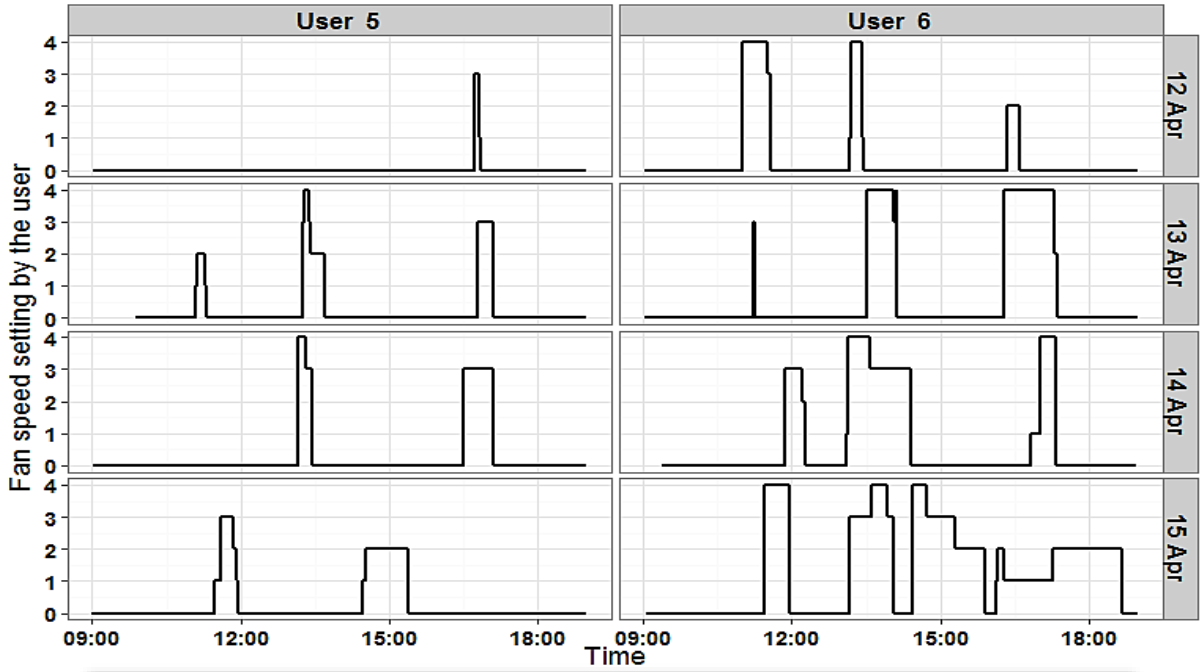
Thermal sensation feedback application
(pops up every 30mins during working hours)

Fan speed setting	Air speed (m/s)	Power Consumption (W)
0	0	1.3
1	0.36	3.6
2	0.66	5.1
3	0.94	6.7
4	1.26	7.5

Power consumption of fan at different speeds

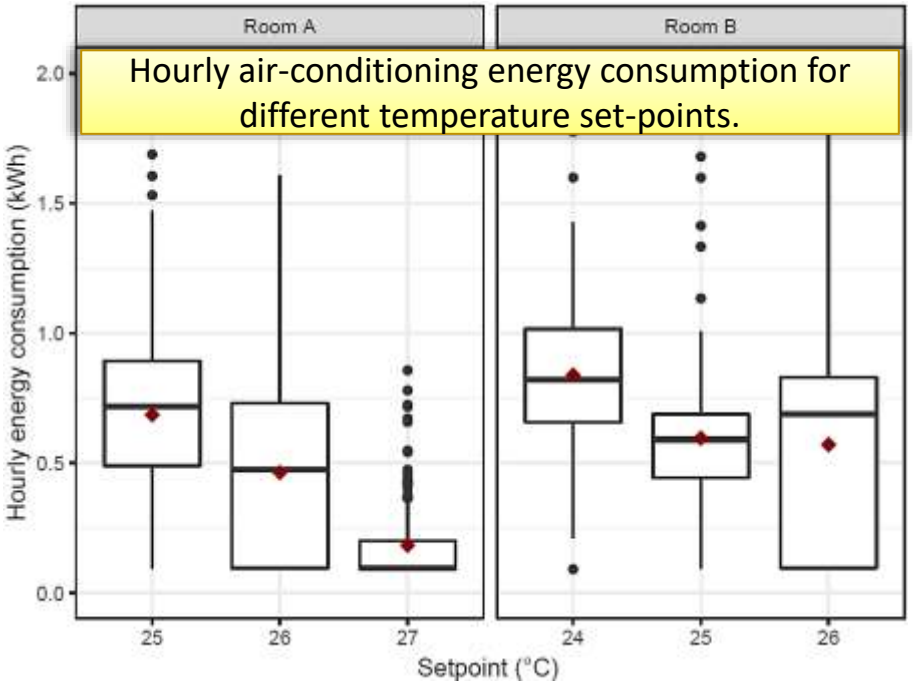


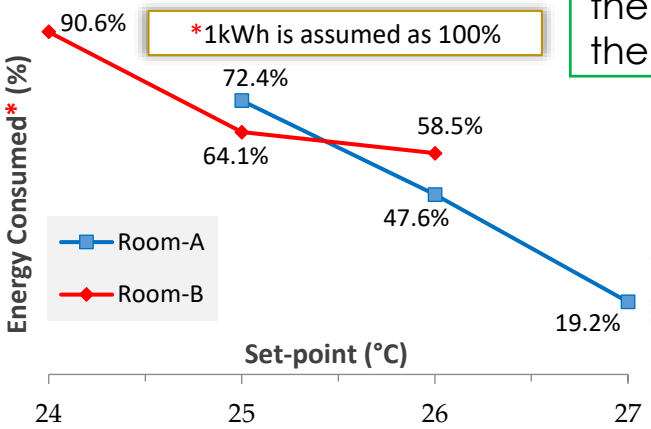
Variation of fan speed settings with respect to temperature



Fan speed settings by same occupants on different days

G) Occupant Engaged Personalized Fans and Background Air-conditioning – Energy Measurements



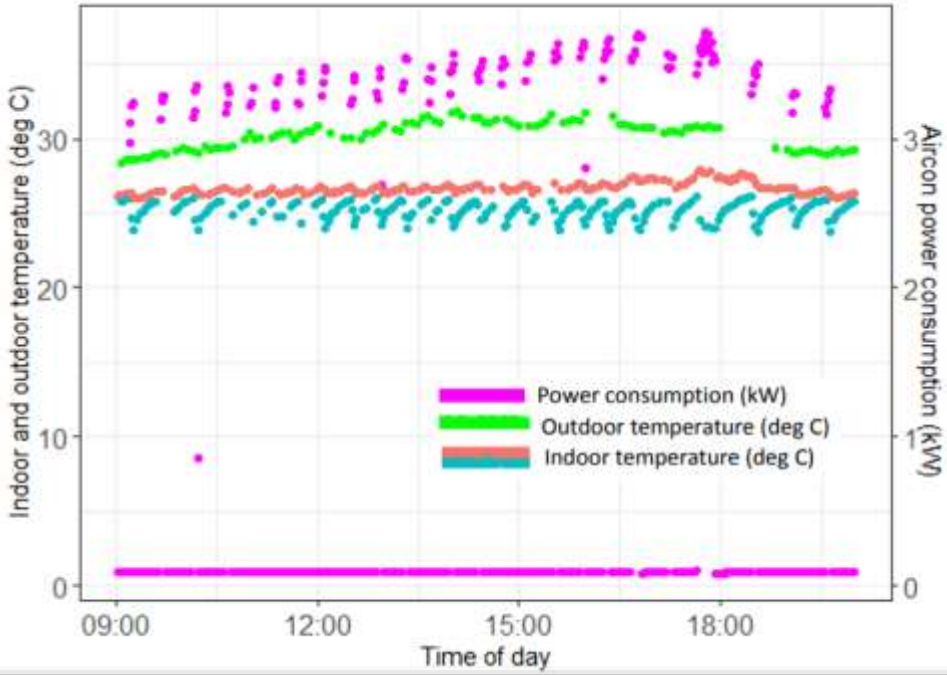


In existing buildings with legacy systems, it can be challenging to implement an automated set-point control for background air-conditioning. Instead, with localized cooling through personal comfort devices, the set-point can be set at a higher value throughout the day and energy savings can still be realized without the need for automated set-point control.

If outdoor unit (compressor) is ON: 3.5kW

If only the indoor unit (fan) is ON : 90-100W

Location	Setpoint (°C)	Max. users	Hourly average of aircon energy (kWh)	Hourly average of fan energy (kWh)		Total energy (Aircon with fan usage in kWh)	
				Average	Worst-case	Average	Worst-case
Room A	25	12	0.717	0.0072	0.0794	0.724	0.797
	26	12	0.468	0.0082		0.476	0.548
	27	12	0.183	0.0091		0.192	0.263
Room B	24	16	0.899	0.0071	0.1060	0.906	1.000
	25	16	0.631	0.0099		0.641	0.737
	26	16	0.571	0.0134		0.585	0.677



(watts/100) of aircon recorded along with the indoor and outdoor temperature for Room A on a typical day

Thank you