SYNOPSIS OF LOW TEMPERATURE CHILLED CEILING

APPLICATION IN TROPICAL AND SUB-TROPICAL COUNTRIES

A CASE STUDY

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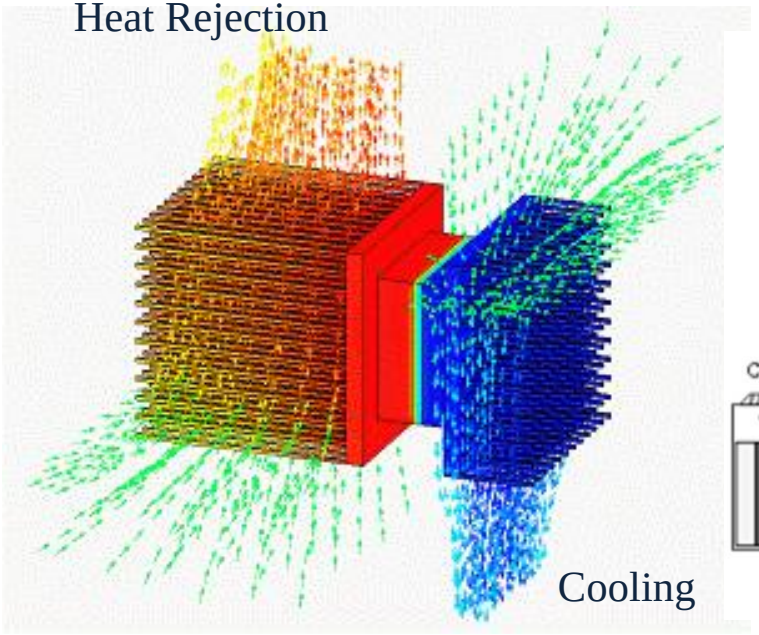
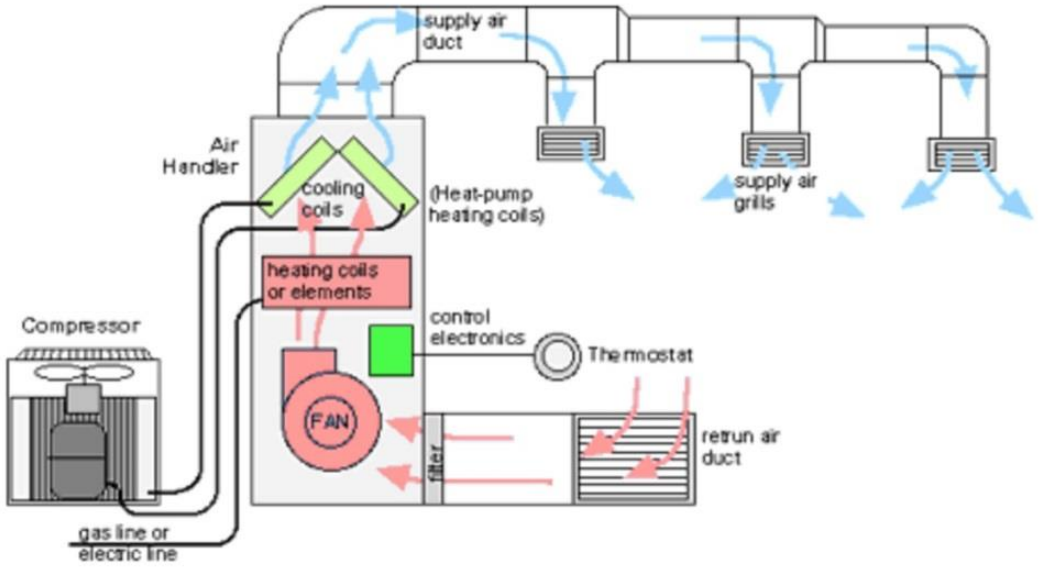
1. Radiant Cooling Design Principles

Traditional AC design adopts convective heat transfer principle using air handling units or fan coil units recirculating room air to effect heat exchange (invented by American Dr. Willis H Carrier in 1902)





Convective Heat Transfer

$Q = h A (T_s - T_f)$

For Fluid

$Q = \dot{m} Cp (T_1 - T_2)$

This convective AC design has the following disadvantages :

•Whole volume of room air needs to be recirculated and cooled resulted in energy wastage and potential cross contamination

•Large plant rooms and massive air ducts are required

•Large fan & pump power are required

•Unsatisfactory Indoor Environmental Quality (usually high humidity and undercooled) during mild and humid seasons or at light load conditions

•Existence of uncomfortable cold draft and un evenness of air distribution

•Noisy due to fan operation and excessive supply air velocity

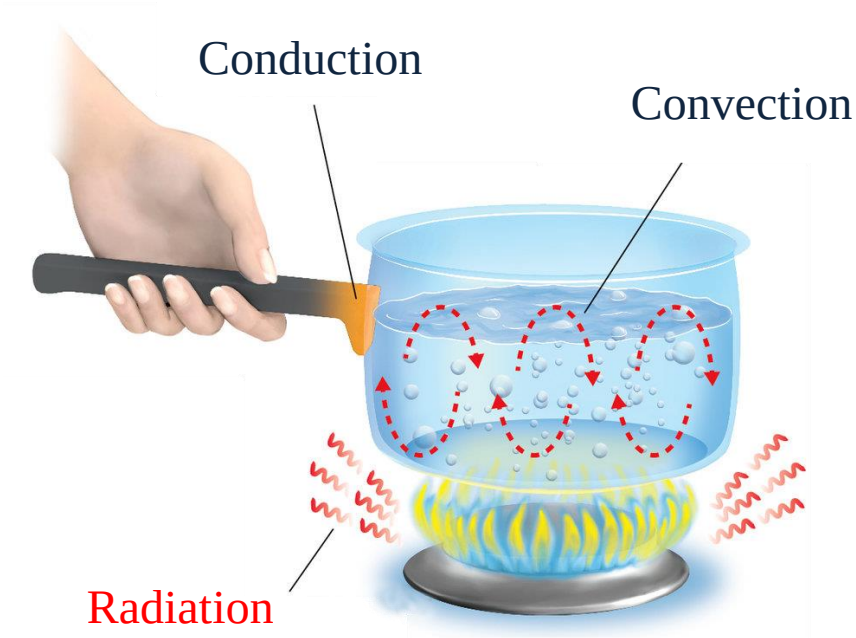
•Frequent attendance and maintenance are required e.g. filters/air ducts/drip pans cleaning, motor faults etc.

Radiant heat transfer occurs when objects temperature are above absolute 0 K.

According to Stefan Boltzmann Law :

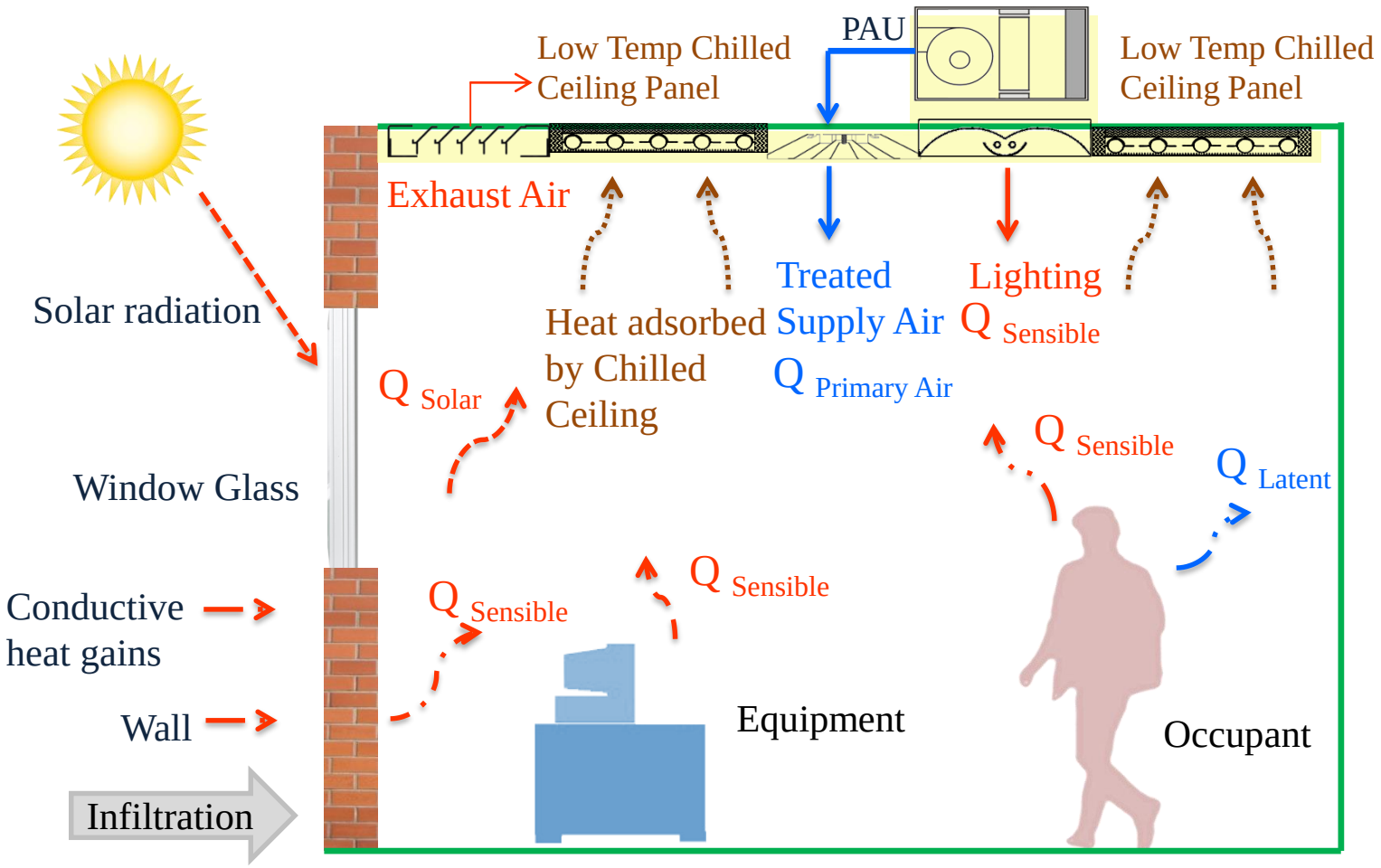
Radiation $Q = \varepsilon \sigma A (T_r^4 - T_c^4)$

Note that in this formula , heat transfer will take place in the speed of light, irrelevant to the temperature of the medium and the distance between objects to a great extent is insignificant. The heat transfer is proportional in the 4^{th} power of the difference in temperature of the objects, emissivity of the objects, area and the solid angle.



Heat transfer in the room space will be in form of 'Hybrid Cooling' in that both radiant and convective cooling process will take place via the PAU and chilled ceiling panels . In view of the low ventilation rate, radiant cooling will dominate to take up the room sensible heat load.

$$\text{Total Heat Load } Q_{\text{Total}} = Q_{\text{Solar}} + Q_{\text{ventilation}} + Q_{\text{Sensible}} + Q_{\text{Latent}}$$



This low temperature chilled ceiling system separates treatment of the ‘Latent Heat’ & ‘Sensible Heat’ loads of the environment

Latent Heat ：

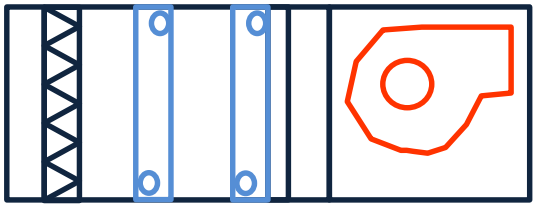
Room humidity is kept below 55 % and controlled by a special primary air handling unit where outdoor air is treated to temperature as low as 11^{o}C at 100 % saturation under the worse HK summer outdoor condition of 35^{o}C 65 % that will greatly increase the dehumidification capability of the supply air

Handle Latent Heat

Hot & Humid Outdoor Air

Temperature 35^{o}C
Relative Humidity 65%

Dual coils with separation



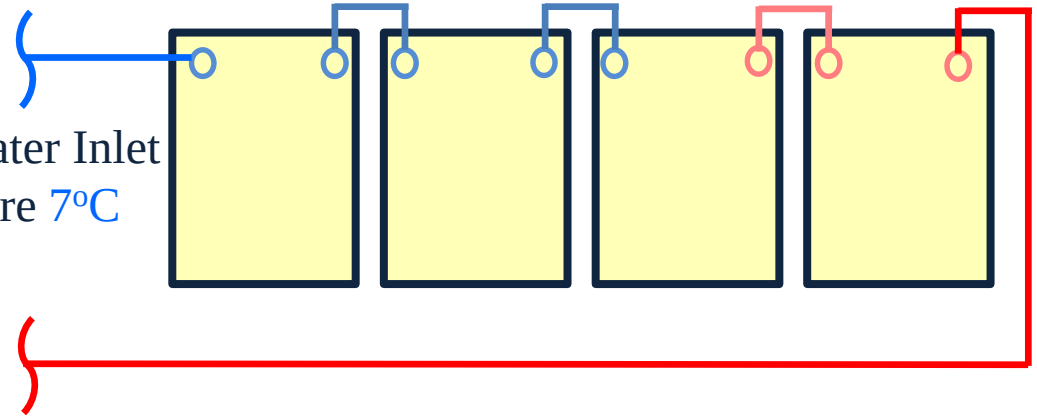
Special Primary Air Handling Unit

More accurate control of indoor humidity

Sensible Heat :

Part of the sensible heat is handled by the fresh air but the majority of this load is handled by the chilled ceiling by means of radiation heat transfer amongst all hot objects and cooled surfaces inside the room.

Surface temperature of the chilled ceiling will range from 16°C to 22°C depending on the room loading conditions and comfort control. Chilled ceiling panels are connected in series to form groups of panels to serve individual zones with separate comfort controls.



Chilled Water Inlet Temperature 7°C

Chilled Water Outlet Temperature 10°C

Low Temperature Chilled Ceiling

More energy efficient as sensible heat transfer to chilled ceiling:

- More targeted
- More effective
- Room ambient air temperature has less effect on comfort level so it can be elevated and save energy

- Room relative humidity will be kept at 55 % or below to avoid condensation on chilled ceiling panels. Chilled water will be controlled by a dew point sensor to cut off water supply when panel surface temperature reaches 16^{o}C or below.

- Room CO_2 level will be kept at 800 ppm or below using variable speed drive primary air units

- Room CO_2 level/humidity level, room temperature and chilled ceiling panel temperature sensors will be installed to facilitate control of the chilled ceiling system.

- Many factors will affect ceiling coverage design of chilled ceiling panels such as façade design, heat sources (human, lighting & equipment etc.) and building usage type. In general chilled ceiling coverage of around 40 to 55% should be sufficient to handle sensible load in most cases.

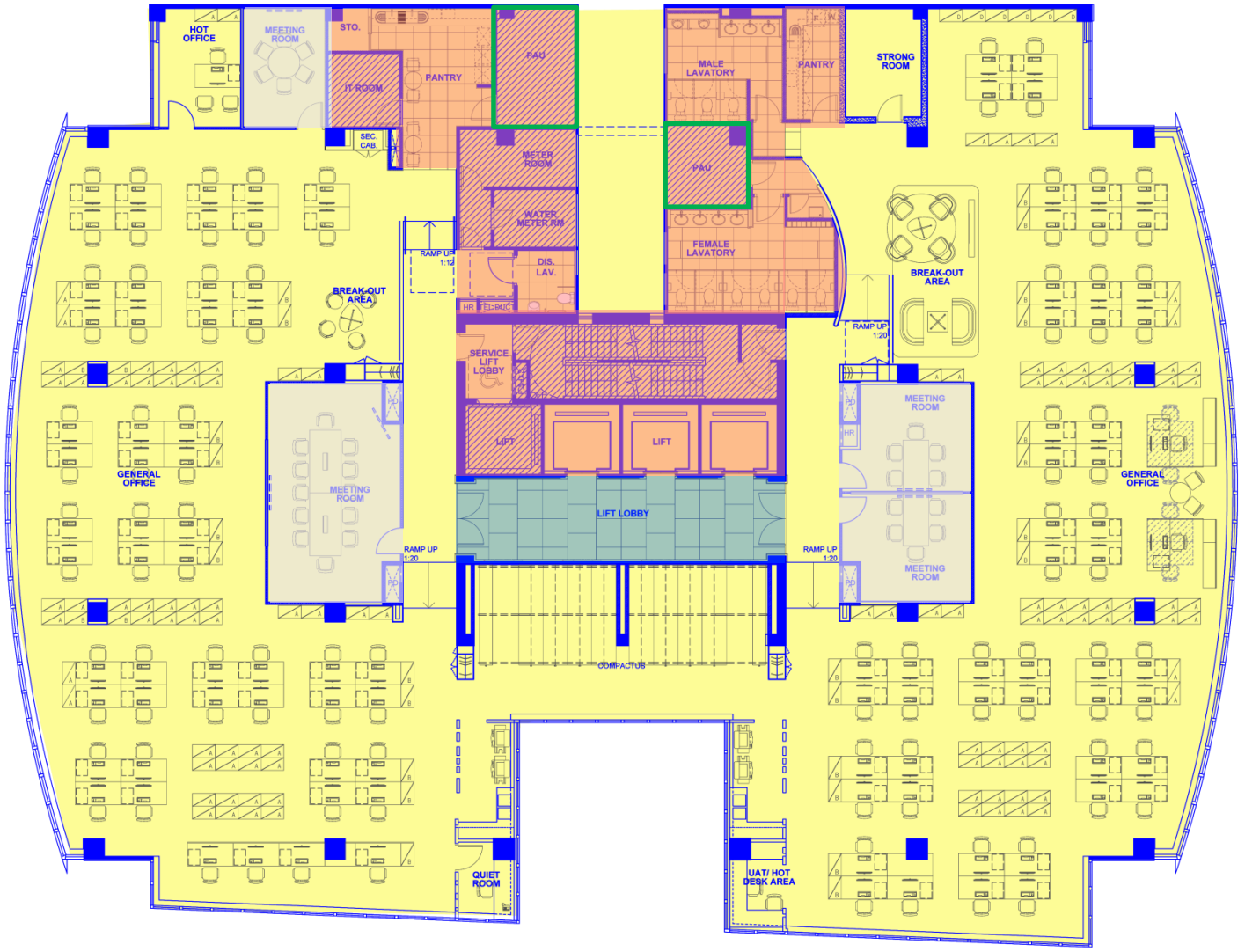
2. A Case Study – HK Hang Seng Bank at MongKok Regional HQ

2.1 Project Details

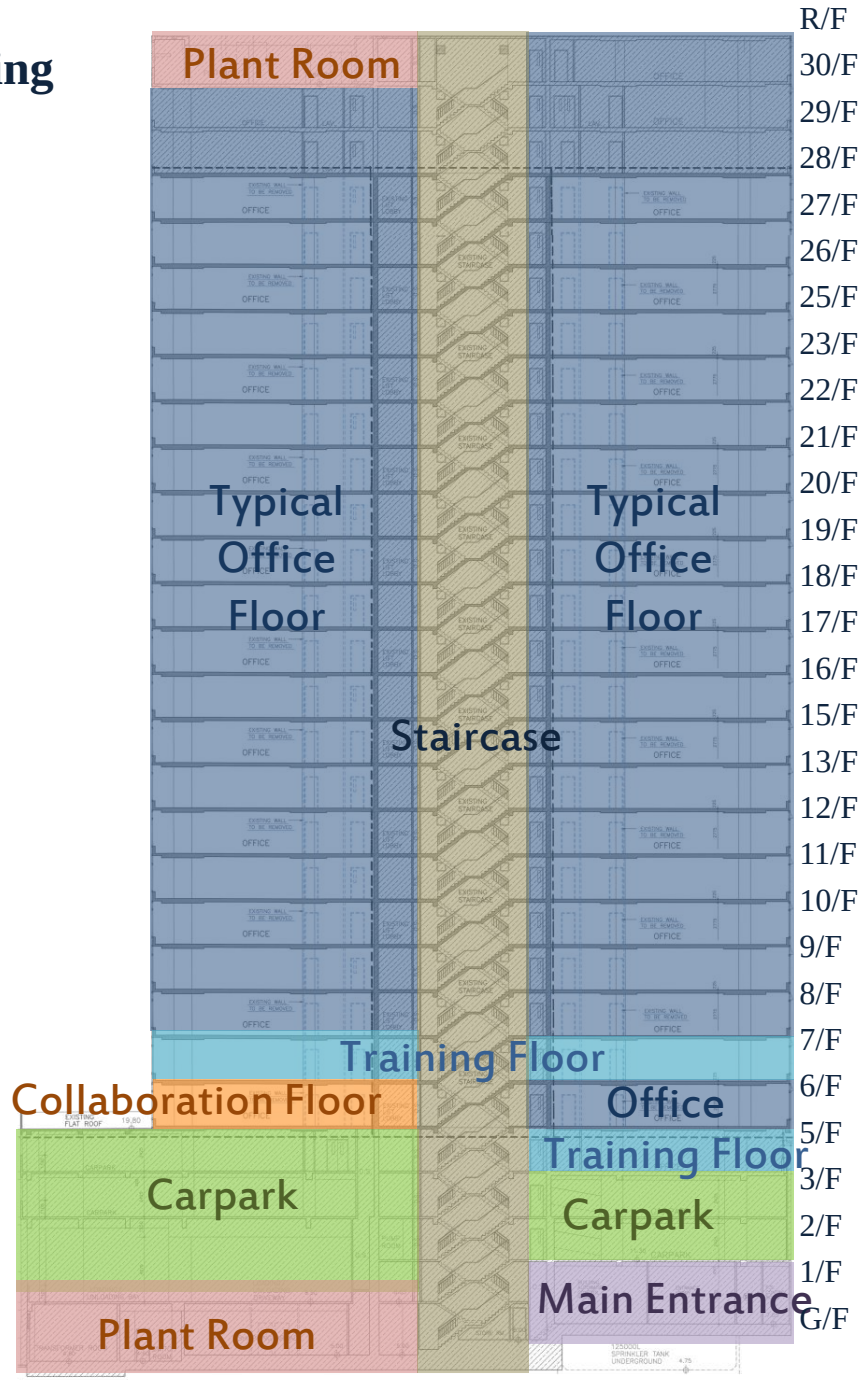
This is a renovation of an existing office building to a high performance modern Bank Regional Headquarters

Details of the building	113-115, Argyle Street, MongKok, HK. completed in 1996, with limited floor to floor headroom of 3000 mm, 23 floors of office and other supporting floors
Total Floor Area	Approximately 30,100 m^2 and typical floor plate is around 900m^2
Site Area	2,000 m^2
Total Population	Max. 110 persons/floor (approx. 3,000 people in total after completion)
Building envelope	Curtain Wall, Tinted Glass with Single Glazing
E&M Provision	Air Conditioning – 1350TR (4750kW) Installed Capacity Electrical Services – 4 nos. of 1500KVA Transformers Fire Services – Full sprinkler protected Lift Services – 7 nos. of Passenger Lift

Typical Floor Plan



Section of the Building

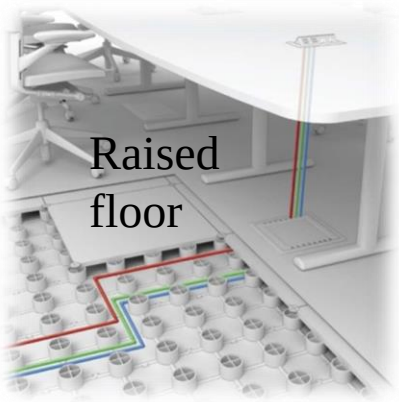


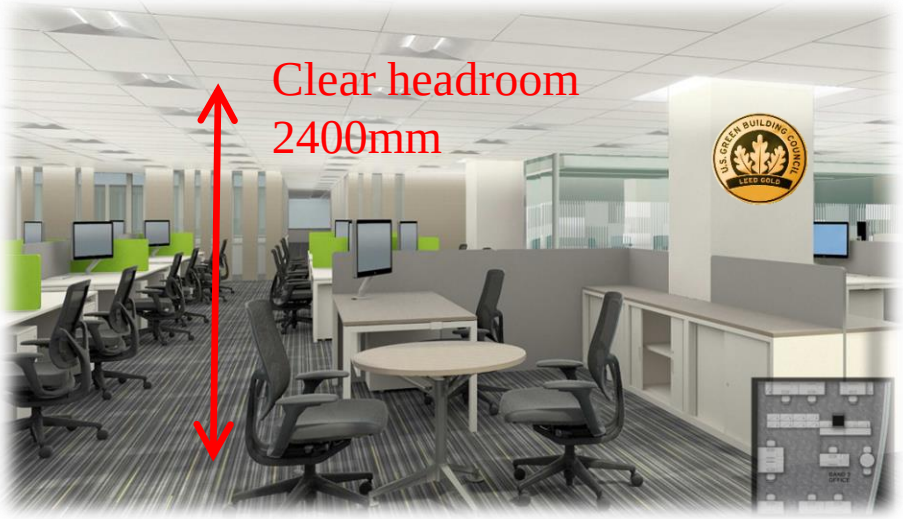
Floor to Floor Height
3000mm

2.2 Client's Brief

Hang Seng Bank intends to renovate the existing building into a grade A regional office building to accommodate staff relocated from various Kowloon sites. An open plan workplace modelling approach had been adopted as the basis of interior design layout

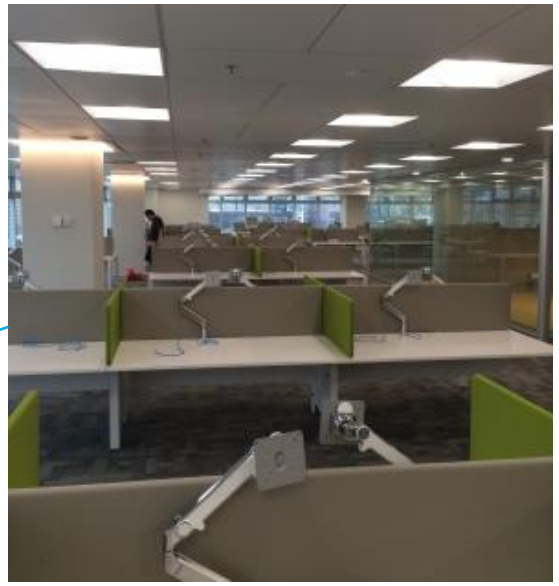
- To achieve a clear office ceiling height of 2400 mm
- To provide a 90 mm raised floor for power & communication cable containment
- To achieve a minimum of 'LEED' Gold certification
- Energy saving MEP design and yet to achieve a highly comfortable and healthy Indoor Environmental Quality
- Flexible workplace concept





2.3 Design

Chilled Ceiling layout Plan



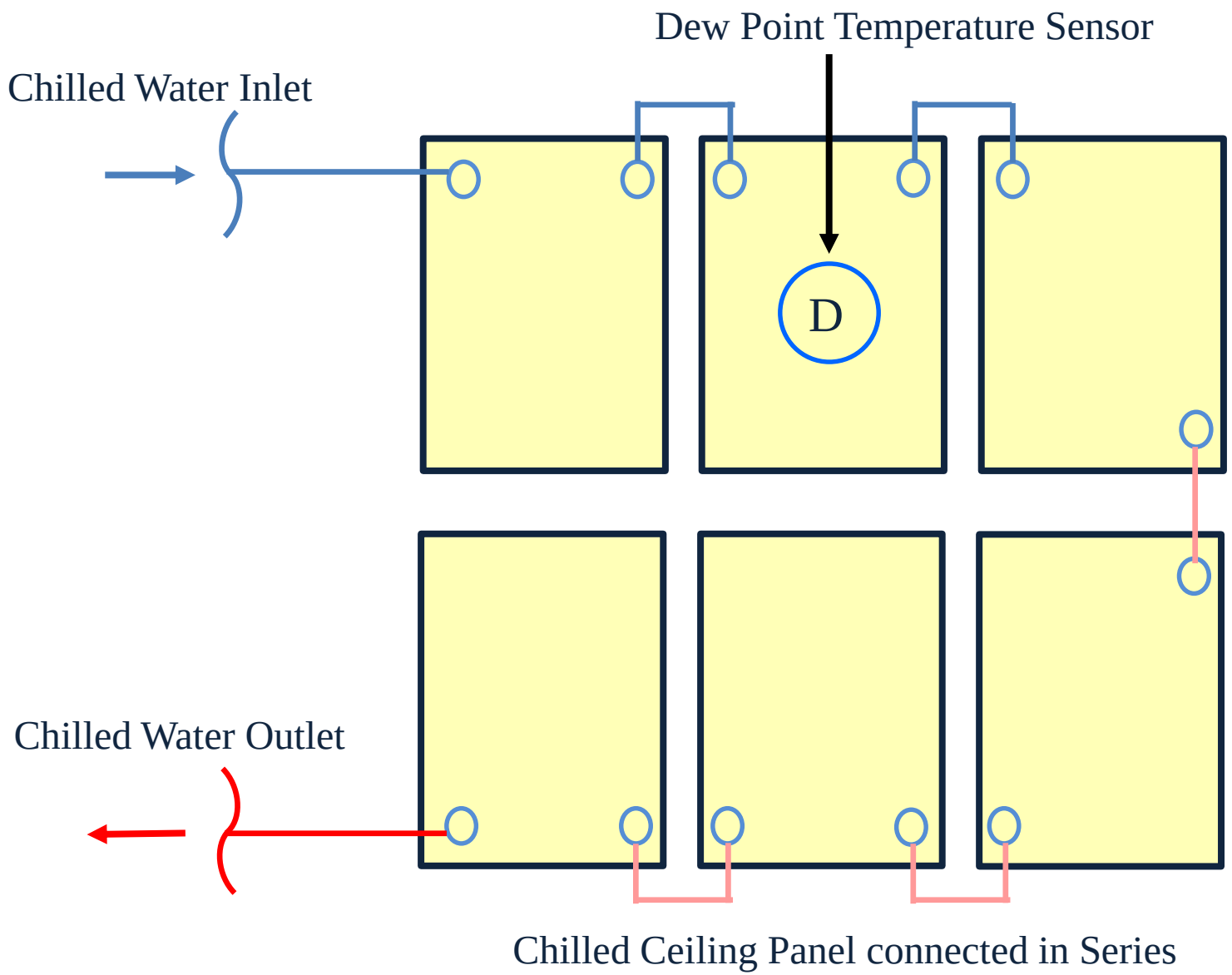
Chilled Ceiling Panel at Open Plan Office

Chilled Ceiling Panel at Meeting Room

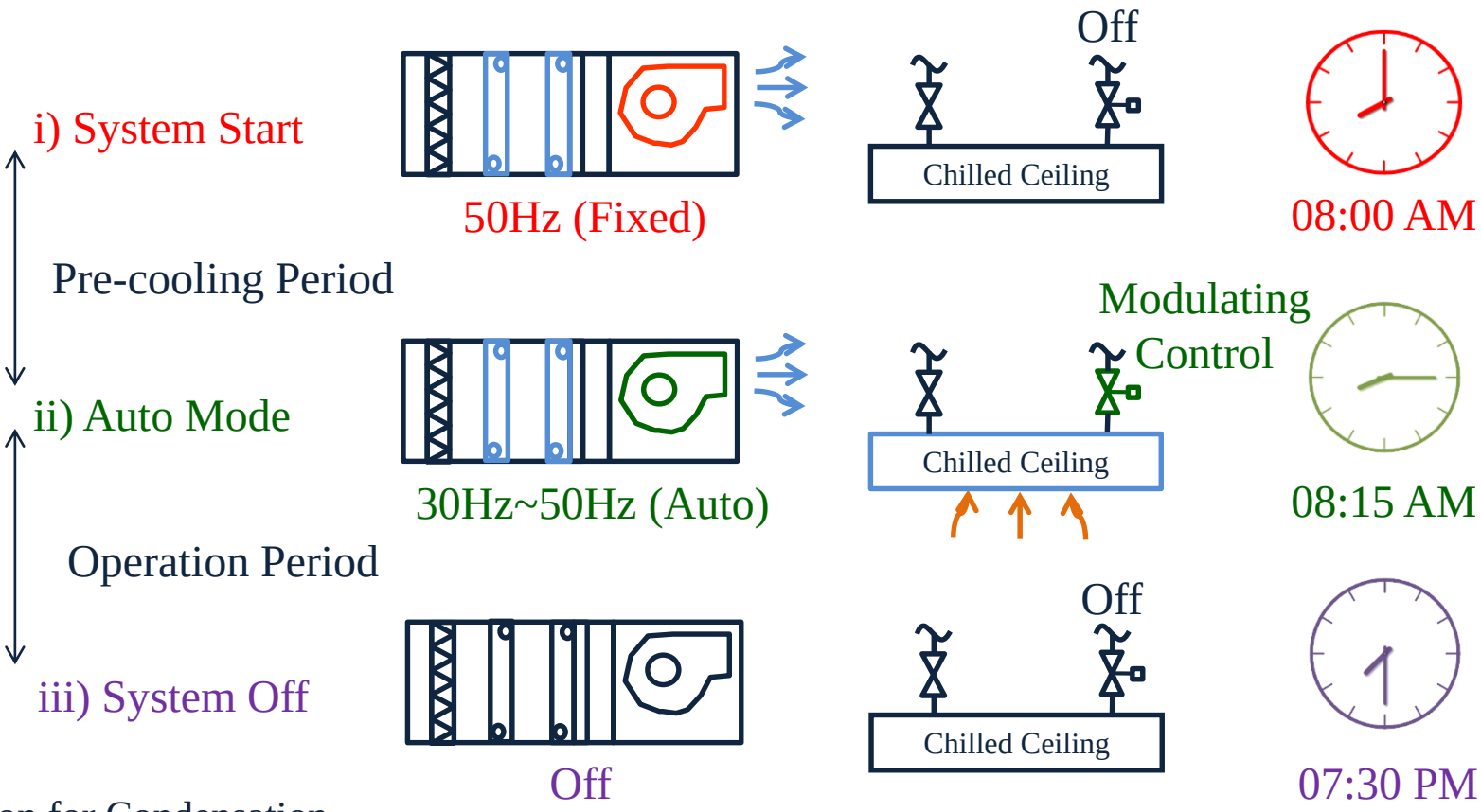
LEGEND

- Chilled Ceiling Panel (Coverage 45%)
- Fan Coil Unit
- Primary Air Handling Unit

Proposed Chilled Ceiling Grouping



Chilled Ceiling System Control Strategy



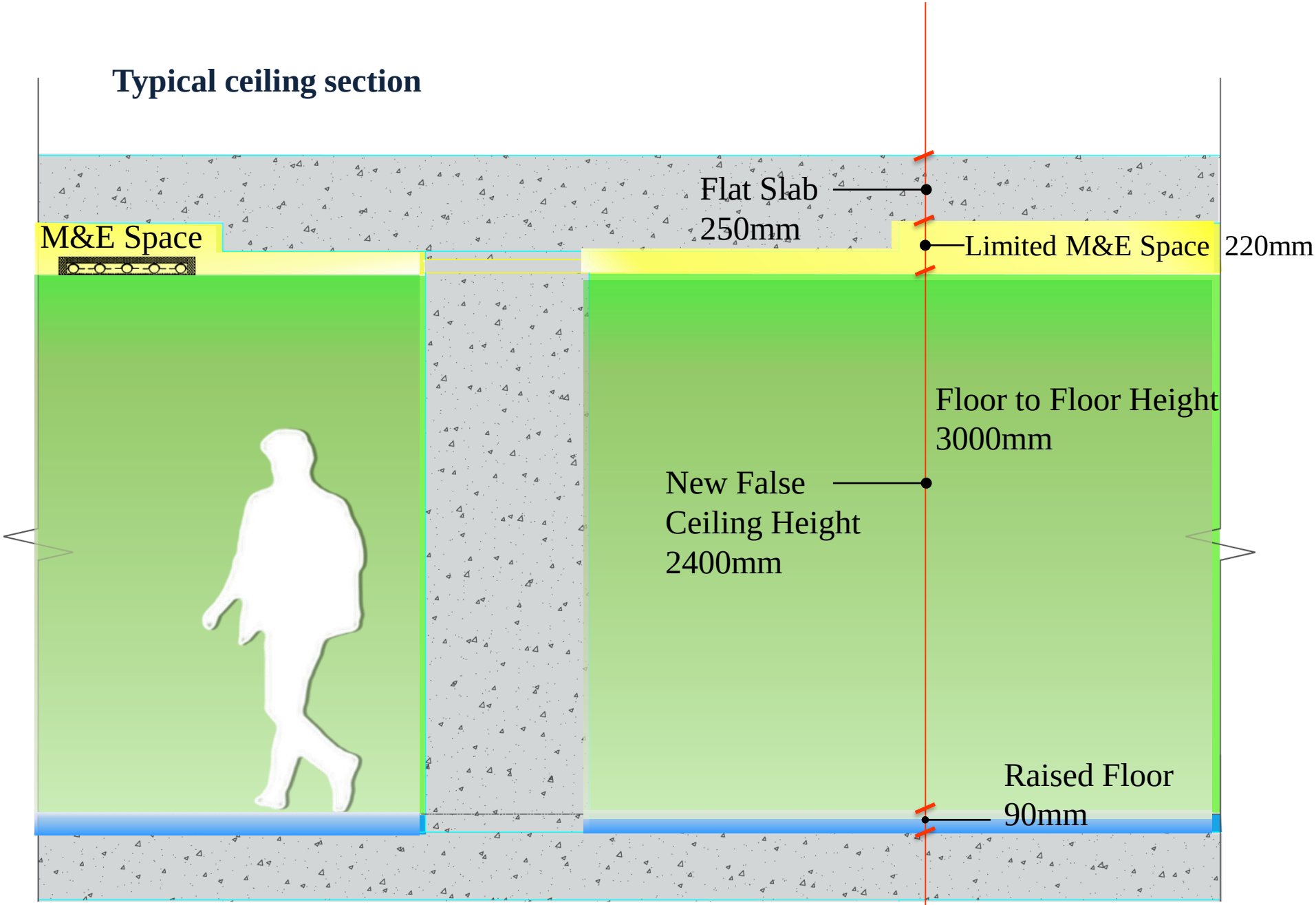
Protection for Condensation

- Chilled ceiling panel surface temperature will be set 2 ˚C above the dew point temperature of the corresponding zone. Chilled water supply to panel will be cut off when panels temperature reach this setting.

Free Cooling Mode

- Free cooling will be performed when the outdoor dew point temperature below14 ˚C and resume normal control when outdoor dew point temperature above16 ˚C

Typical ceiling section



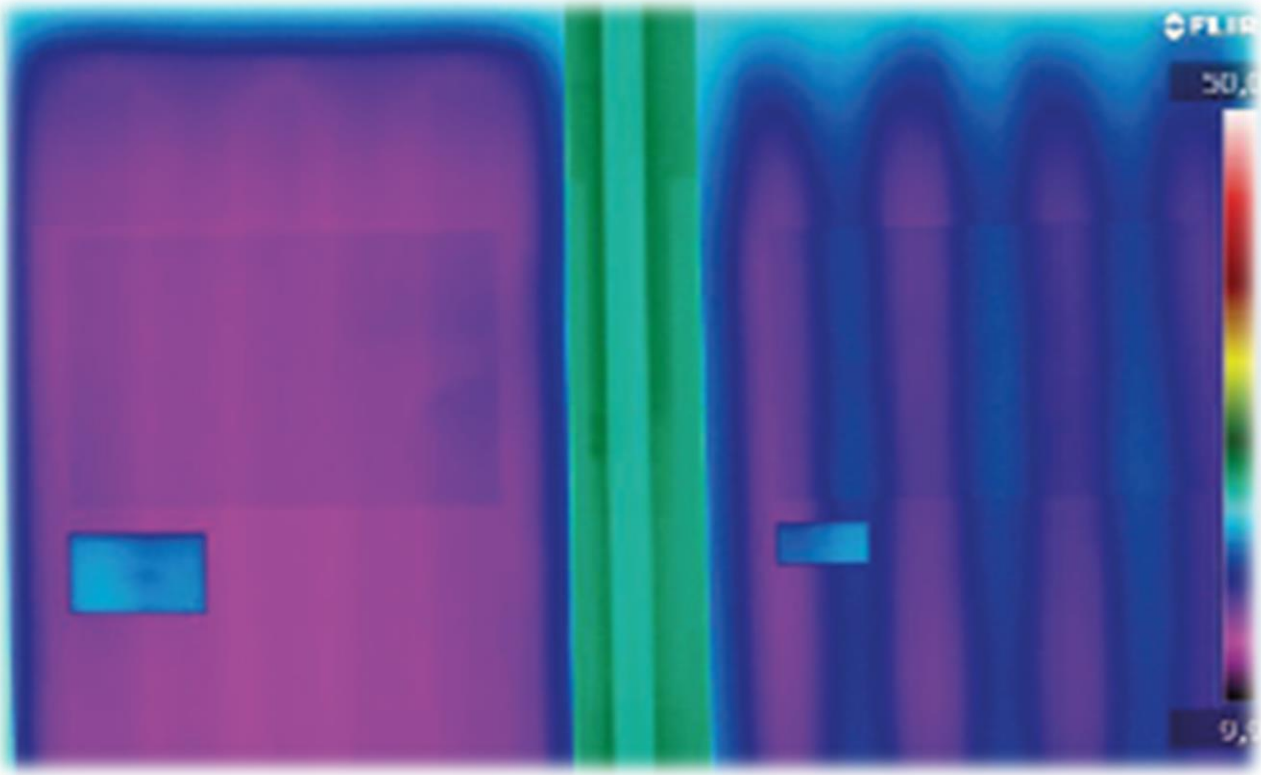
Existing Site Constraints

- Floor to Floor 3000mm (Under Slab 2750mm)
- Drop Slab thickness 375mm
- Flat Slab thickness 250mm

Thermography Image & Comparison between Low Temperature Chilled Ceiling and Other Chilled Ceiling Products

Low Temperature Chilled Ceiling

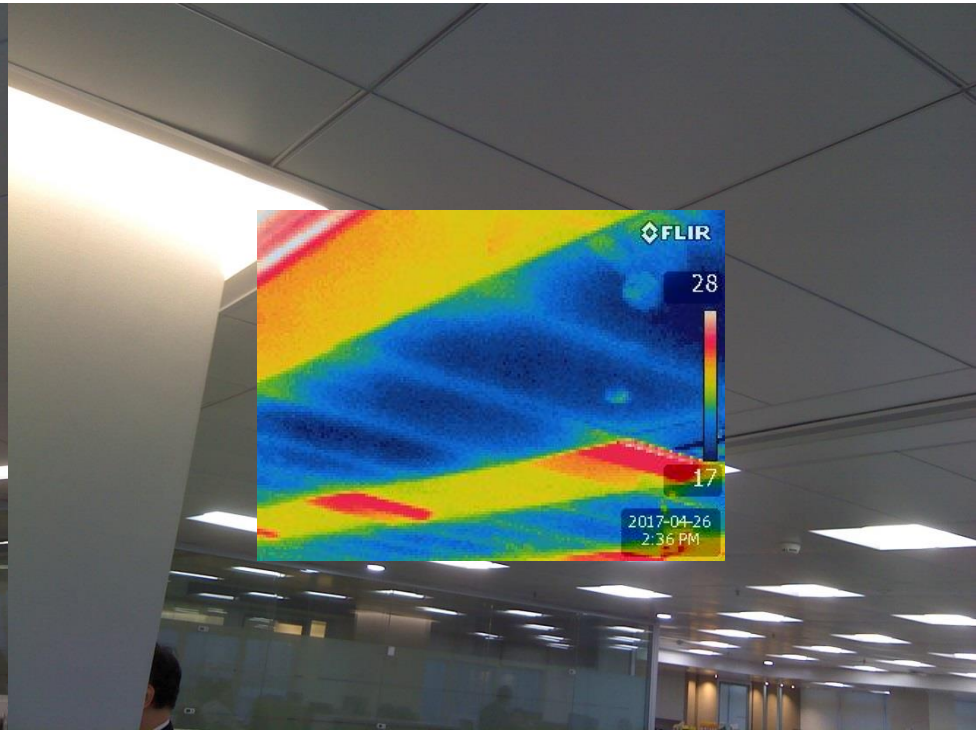
Other Chilled Ceiling Products



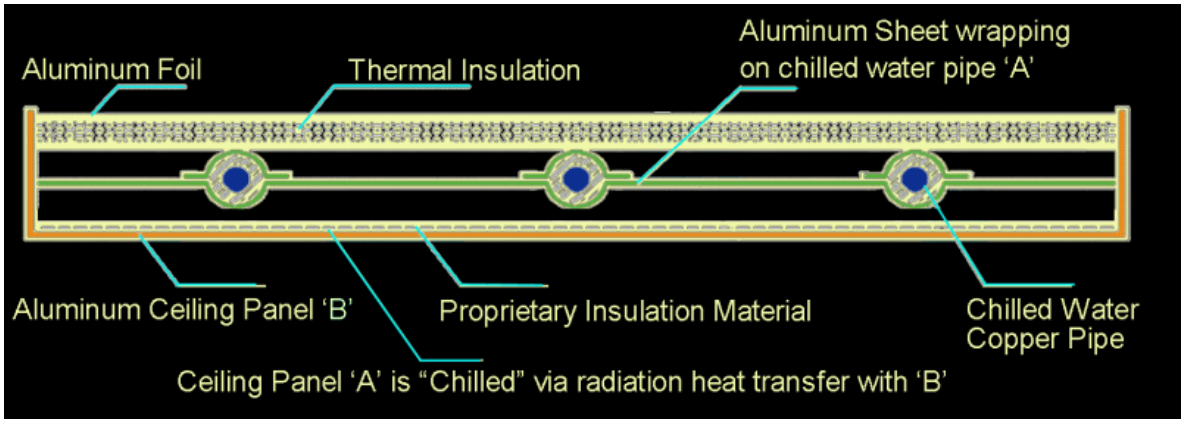
This thermo graphic image shows the surface temperature of two different types Radiant Ceiling panel under load condition. Hence it can be seen that the low temp chilled ceiling has a much better cooling performance than other radiant cooling products in that it can maintain even low temperature for a large portion of the radiant area.

Thermography Images for Typical Office Ceiling

Low Temperature Chilled Ceiling



Low Temperature Chilled Ceiling Construction Details



Risks and Limitations

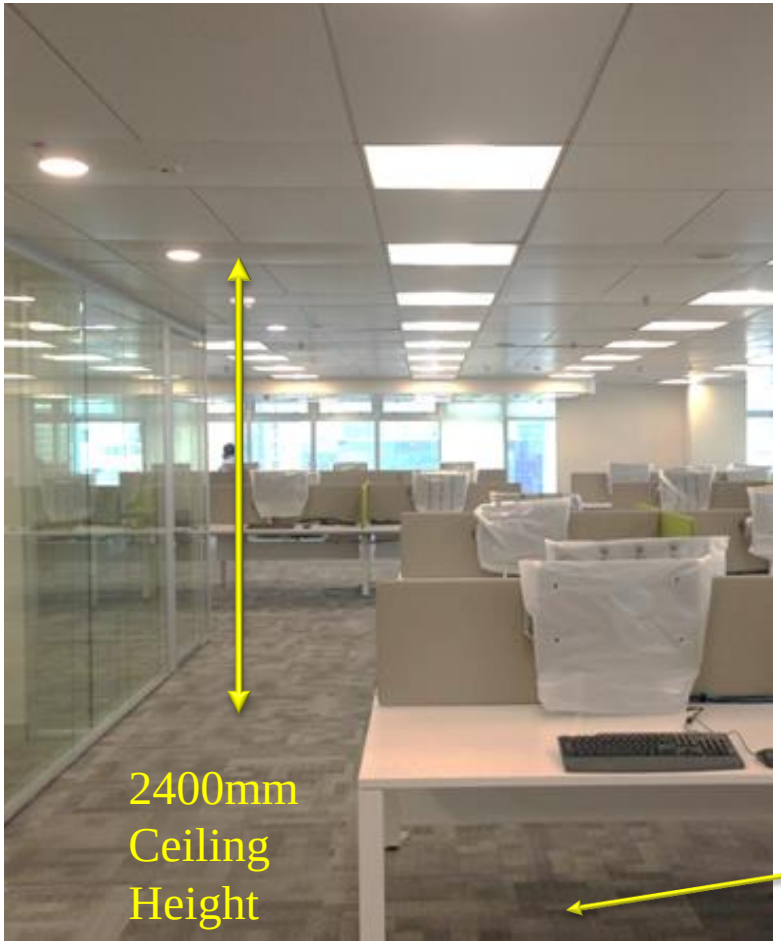
1. Rely on sensor setting and performance
   - Regular sensor calibration is required

2. Less Air Movement
   - Heat transfer by means of radiation
3. No Validated Standard for Cooling Load Calculation
   - No simulation tools for radiant cooling system
   - Only refer to project reference

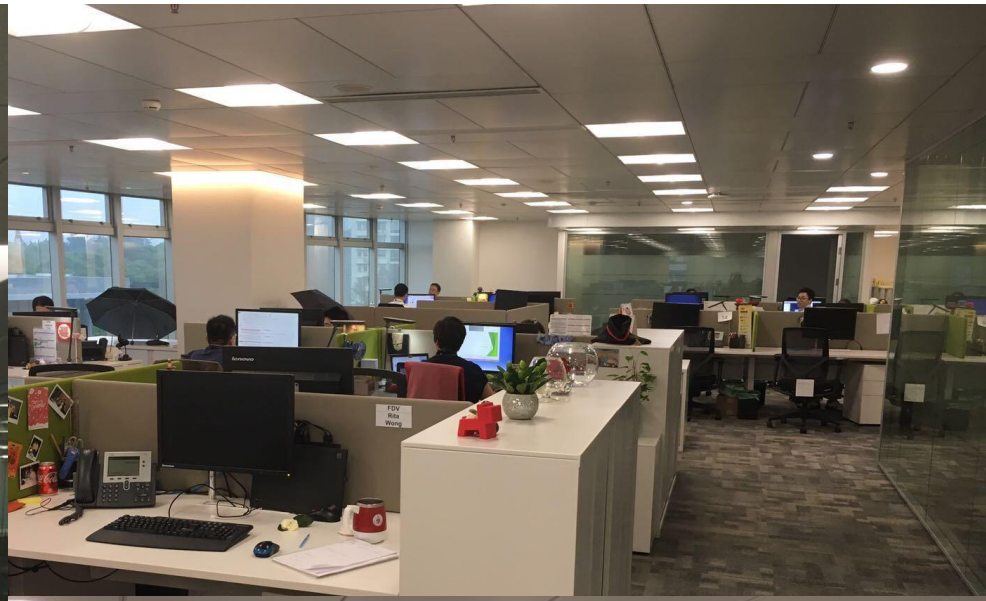
2.4 Performance Results

Original Office Condition using convectional AC (Fan Coil) Design

New Office Condition using radiant cooling (Chilled Ceiling) Design



Completed Hang Seng Argyle 113 Office



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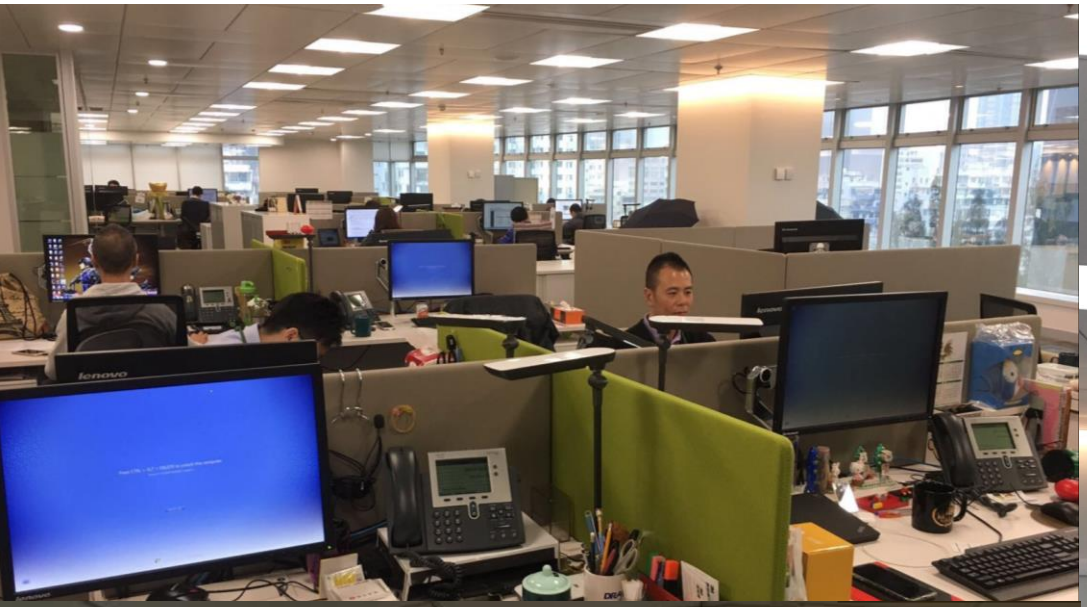
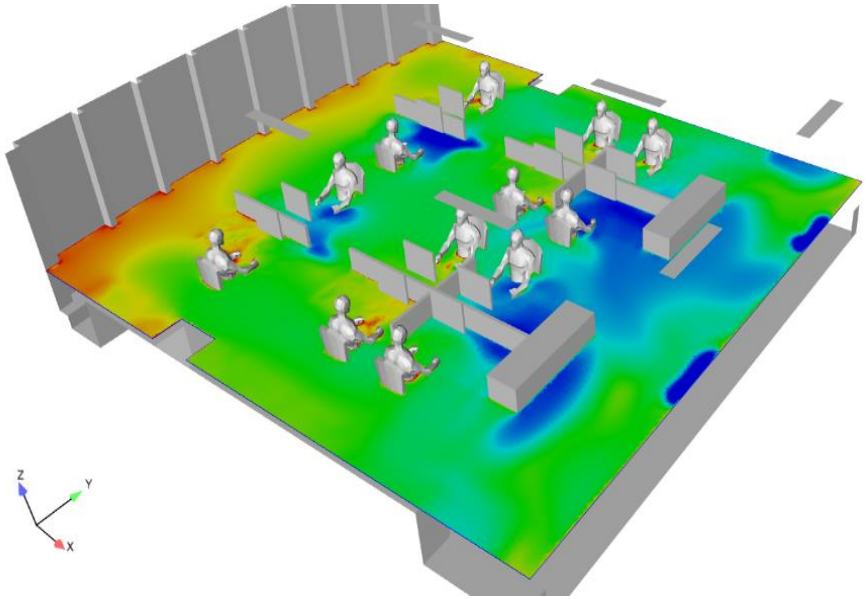


Merits of radiant cooling compared with convective cooling

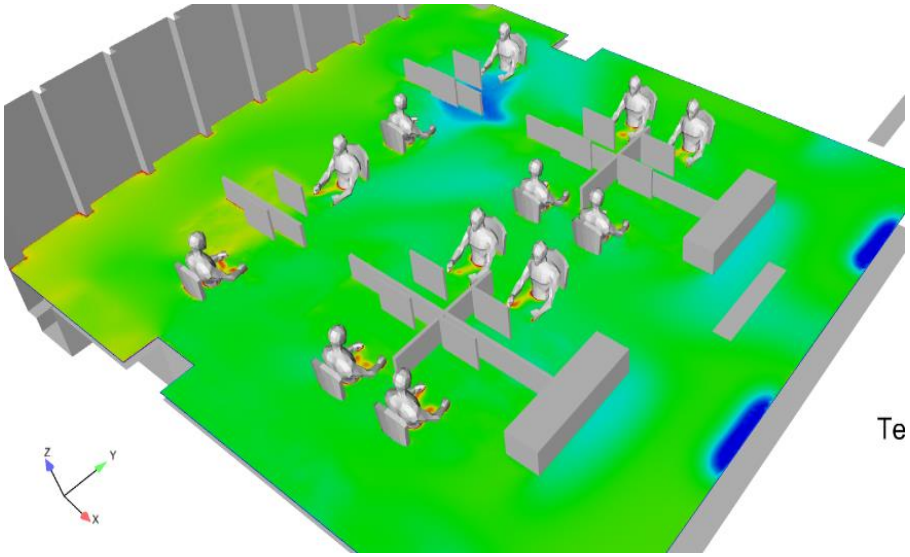
Less Temperature Stratification

Fan coil unit system



Local cold and hot spots are found with a fan coil unit system.

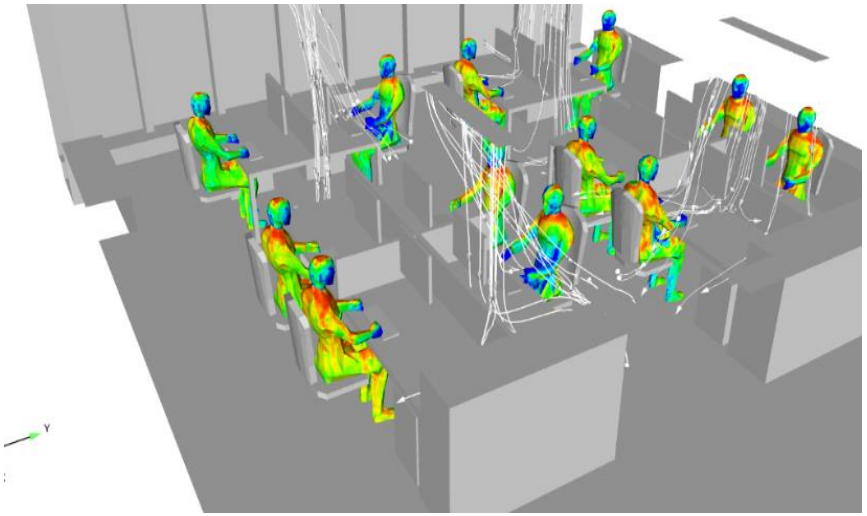
Chilled ceiling system



Temperature is more consistent and evenly distributed with a chilled ceiling system.

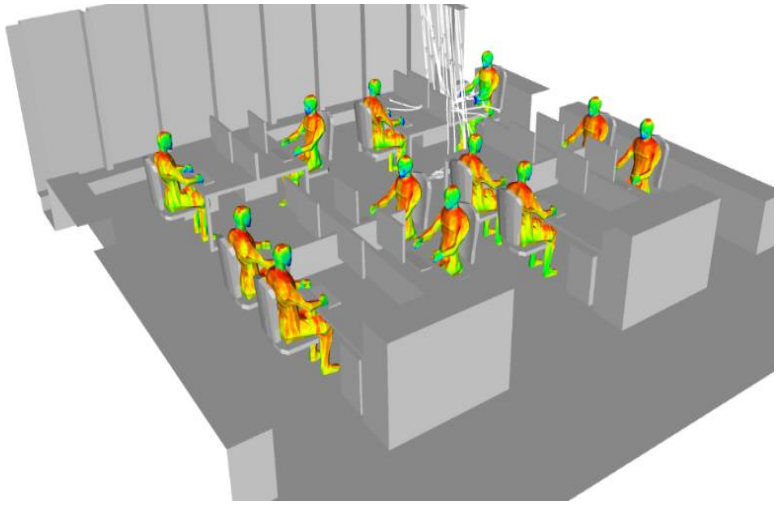
Absence of Cold Drafts & Better Thermal Comfort

Fan coil unit system



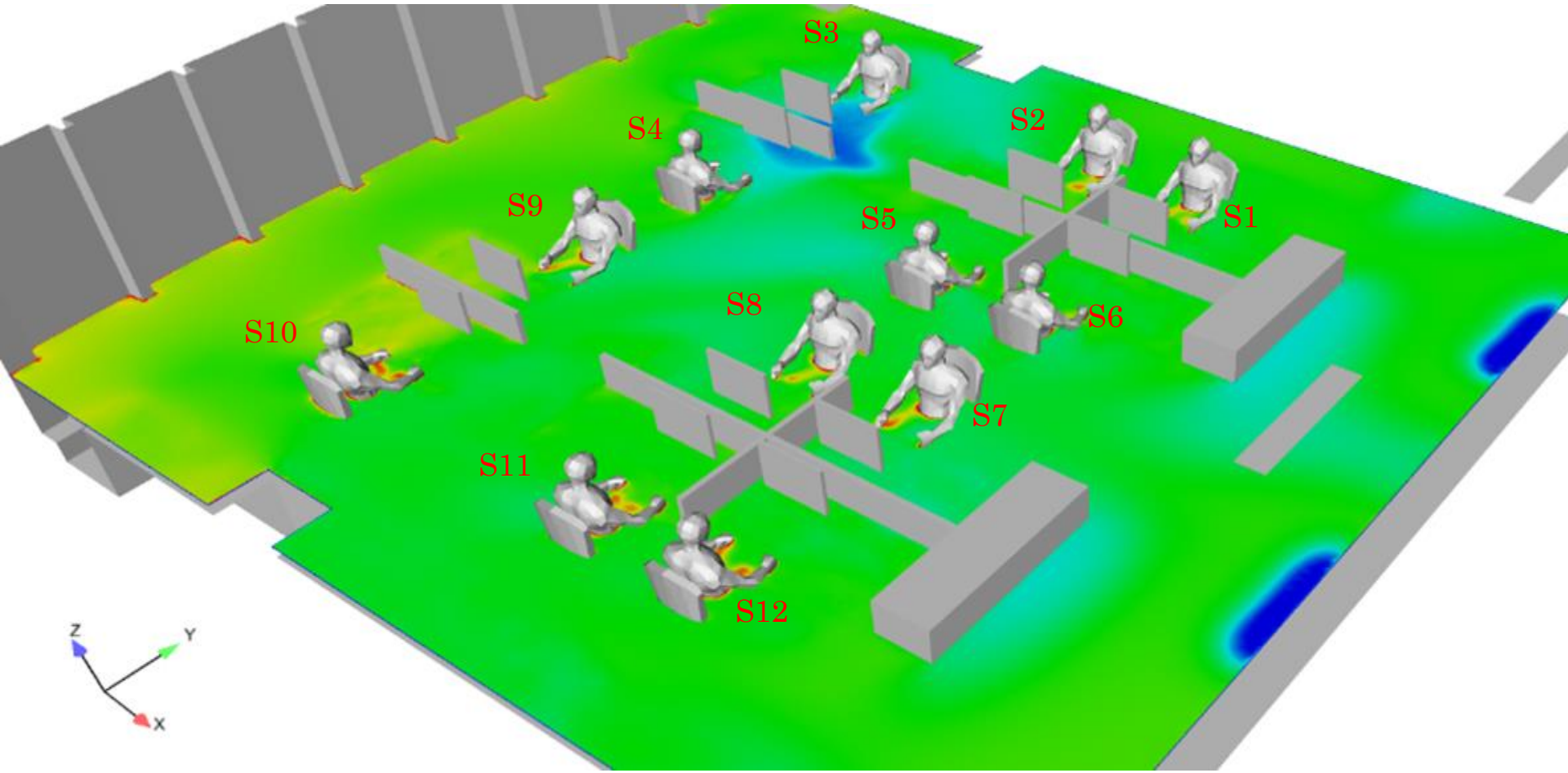
Local cold drafts are found in a fan coil unit system. (excessive heat loss)

Chilled ceiling system



Absence of cold drafts result in better thermal comfort for occupants.

Occupant Comfort Survey (based on PMV method of Assessment)



Analytical Comfort Zone Method

ASHRAE Thermal Sensation Scale

Comfort Zone ⟷

Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
-3	-2	-1	0	1	2	3

Survey Results

Time	Location											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
2:00 pm	-1	-1	-1	1	0	0	0	0	-1	0	0	-1
3:00 pm	0	0	0	0	0	1	-1	1	-1	1	-1	0
4:00 pm	0	0	0	1	0	0	0	1	0	0	0	0

Cooling Load at Different Outdoor Conditions

Outdoor conditions	:	35 ˚C (DB) , 29 ˚C (WB)		
Population	:	110 person		
Fresh air flow rate	:	10 l/s/person		
Single glazing façade with 0.85 shading coefficient				
Design Fresh Air Load	:	75	kW	(~40 %)
Design Sensible Heat Load	:	100	kW	(~60 %)
Design Total Load	:	175	kW	

Case 1: Free Cooling at 27 Nov, 2015 at 15:30 – a typical HK Autumn condition

Outdoor condition	:	20.0 ◦C, 40% RH (Population 72 person)	
PAU Total Load	:	0	kW
Chilled Ceiling Total Load	:	2	kW
Total Load	:	2	kW

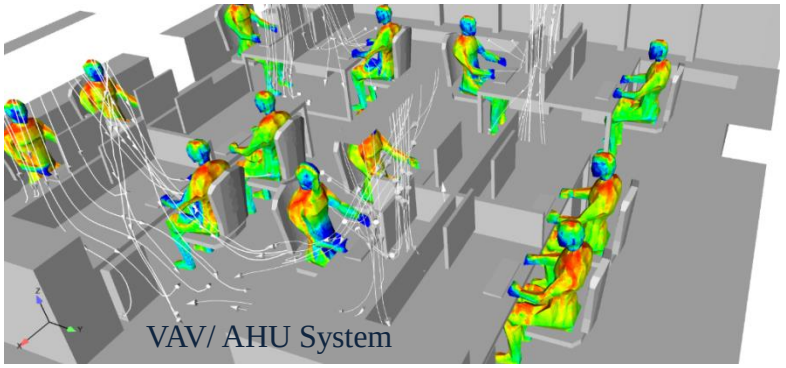
Case 2: Cooling at 26 Aug, 2016 at 16:26 – a typical HK summer condition

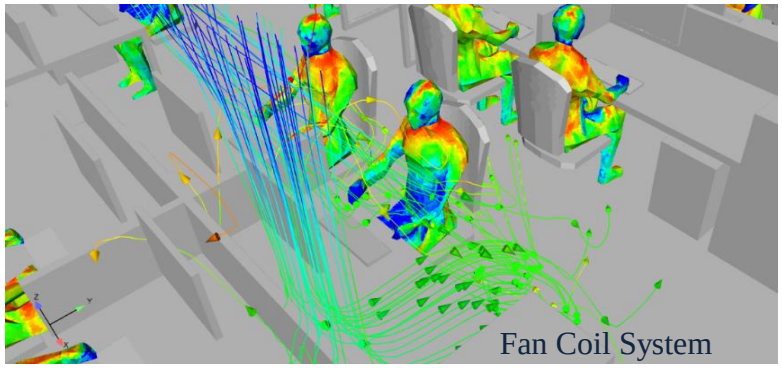
Outdoor condition	:	32.6 ◦C, 67% RH (Population 72 person)	
PAU Total Load	:	60	kW
Chilled Ceiling Total Load	:	22	kW
Total Load	:	82	kW

Merits of Chilled Ceiling versus Conventional AC systems

VAV/ AHU System

- Space Temperature 23°C ± 1 °C
- Relative Humidity 55 % - 70 %
- Heating/ Cooling Both but not common/ not well accepted
- CO_2 Concentration Average 900-1000 ppm
- Recirculation Air 80 %
- Acoustic Medium NC 38
- Air Draft Problem Exist
- Temperature Uniformity Average


VAV/ AHU System

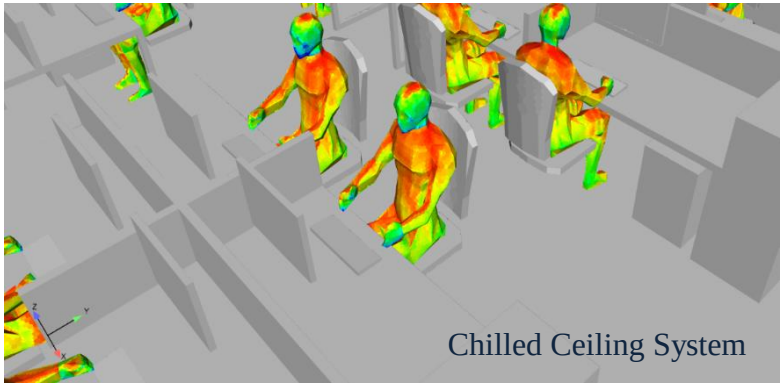

Fan Coil System

Fan Coil System

- Space Temperature 23°C ± 1 °C
- Relative Humidity 60 % - 75 %
- Heating/ Cooling Both but not common/ not well accepted
- CO_2 Concentration Average 1000-1400 ppm
- Recirculation Air 80 to 90 %
- Acoustic Noisy NC 40 average
- Air Draft Problem Exist
- Temperature Uniformity Fluctuating

Chilled Ceiling System

- Space Temperature 23°C - 27 °C
- Relative Humidity 50 % - 55 %
- Heating/ Cooling Both and relatively comfortable
- CO_2 Concentration Average 600 ppm
- Recirculation Air Flexible and can be full fresh air
- Acoustic Extremely quiet typical under NC35
- Air Draft Problem Very minimum
- Temperature Uniformity Very Even


Chilled Ceiling System

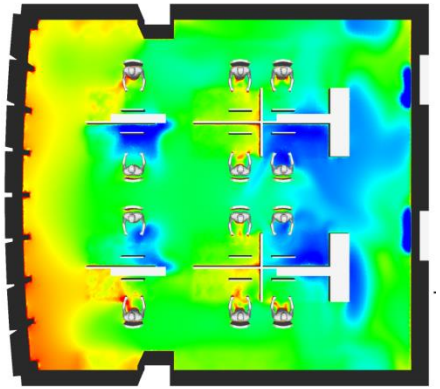
Merits of Chilled Ceiling versus Conventional AC systems

VAV/ AHU System
Energy Performance
- Cooling Load Calculation (Office) 200 W/m^2
- Water Pump Power 'A' kW
- Air Fan Power 'B' kW

Operation and Maintenance
- Ease of Operation Complicated
- Maintenance Cost High

Plant Spatial Requirement High

Cost
- Capital Cost High
- Running Cost High



VAV/ AHU / Fan Coil System

Fan Coil System
Energy Performance
- Cooling Load Calculation (Office) 180 W/m^2
- Water Pump Power 'A' kW
- Air Fan Power 40% of 'B' kW

Operation and Maintenance
- Ease of Operation Less Complicated
- Maintenance Cost High

Plant Spatial Requirement Medium

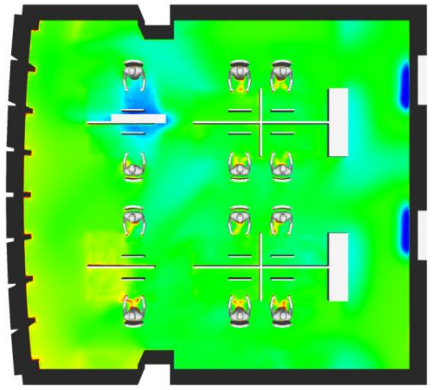
Cost
- Capital Cost Low
- Running Cost Medium

Chilled Ceiling System
Energy Performance
- Cooling Load Calculation (Office) 100 W/m^2
- Water Pump Power 75% of 'A' kW
- Air Fan Power 25% of 'B' kW

Operation and Maintenance
- Ease of Operation Medium Complicated Complicated
- Maintenance Cost Low

Plant Spatial Requirement Low

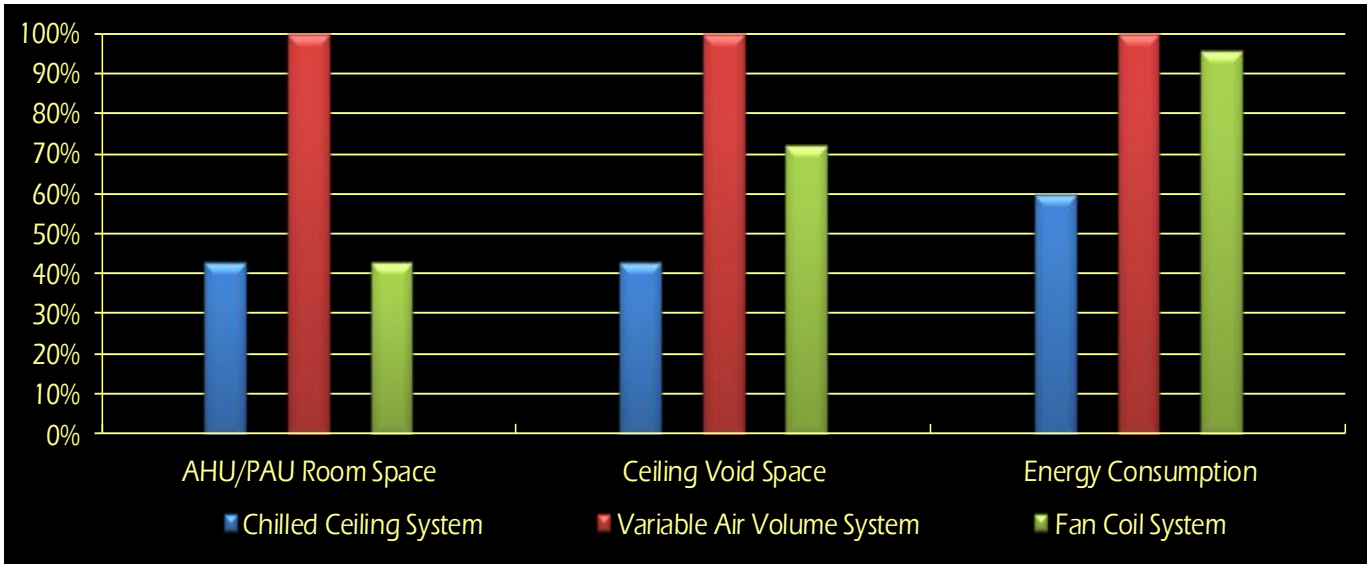
Cost
- Capital Cost Medium(due to limited Suppliers)
- Running Cost Low



Chilled Ceiling System

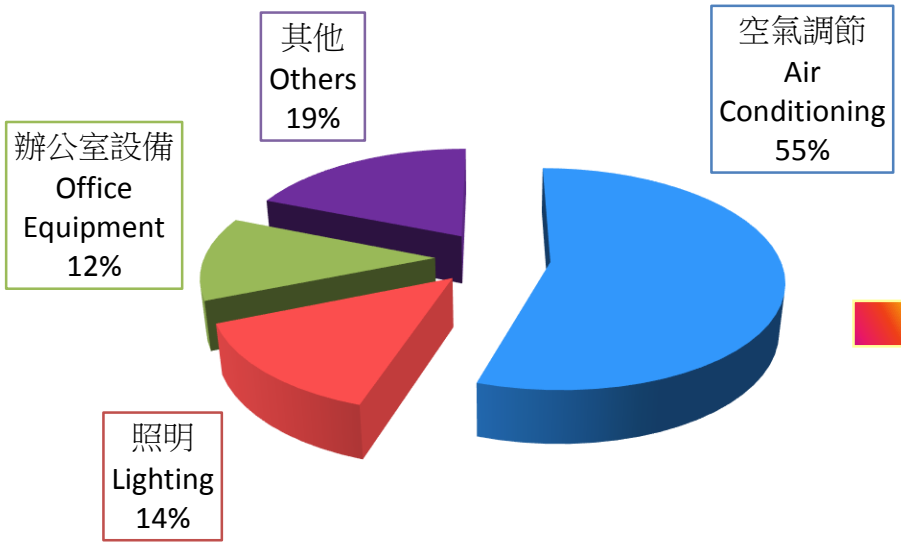
Summary of Comparison (for a Typical 1000 sq. m Office)

Item \ System	Chilled Ceiling System	VAV System	Fan Coil System	Chilled ceiling vs VAV
AHU/ PAU Room Space	15m2	40 m2	-	Around 63 % Saving
Ceiling Void Space	250mm	650 mm	400mm	Around 60 % Saving
Comfort Control	Adjust Panel Surface Temperature	Adjust Supply Air temp and volume	Adjust Supply Air temp and volume	-
Energy Consumption	Low	High	Medium	Around 40% Saving (+ 50 % if pump and fan power are included)
Acoustic Performance	Excellent	Good	Poor	-
Room Temperature	23 ℃ – 27 ℃	22 ℃ to 25 ℃	22 ℃ to 25 ℃	-

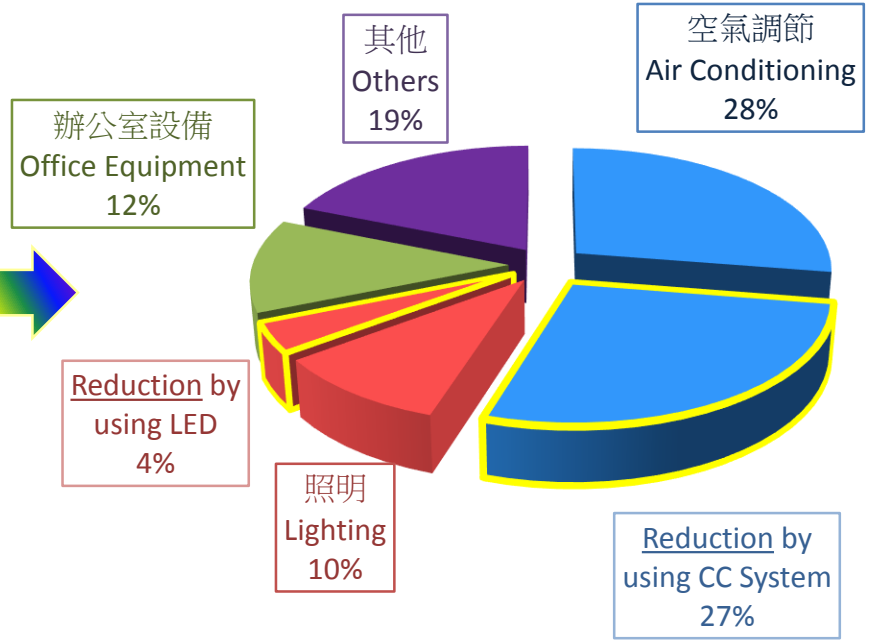


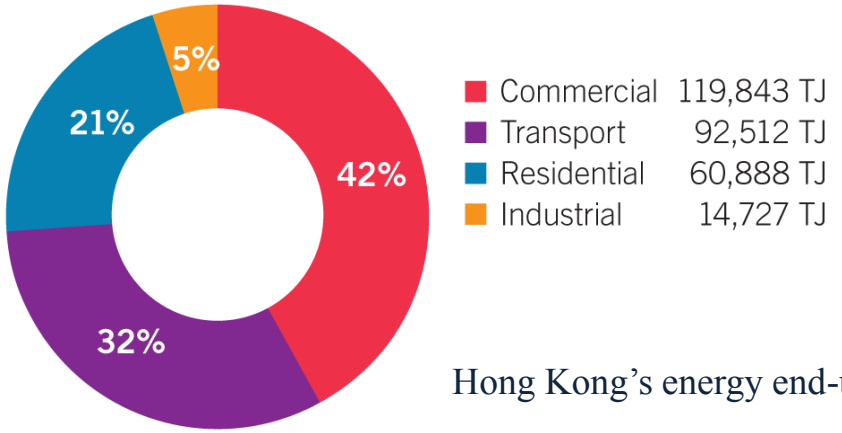
Energy Performance

Energy consumption in a typical office building



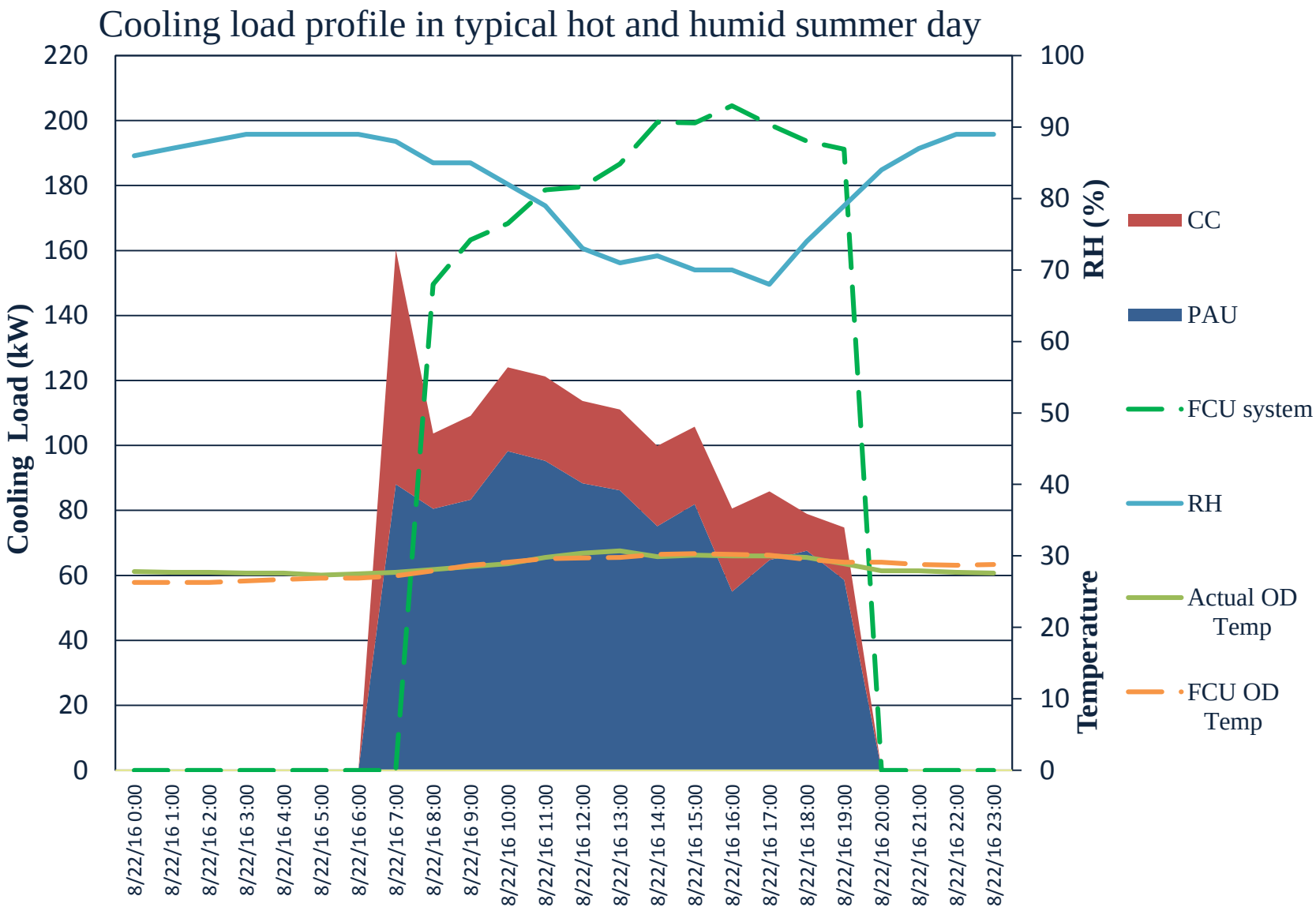
Energy consumption in a office building using chilled ceiling system & LED





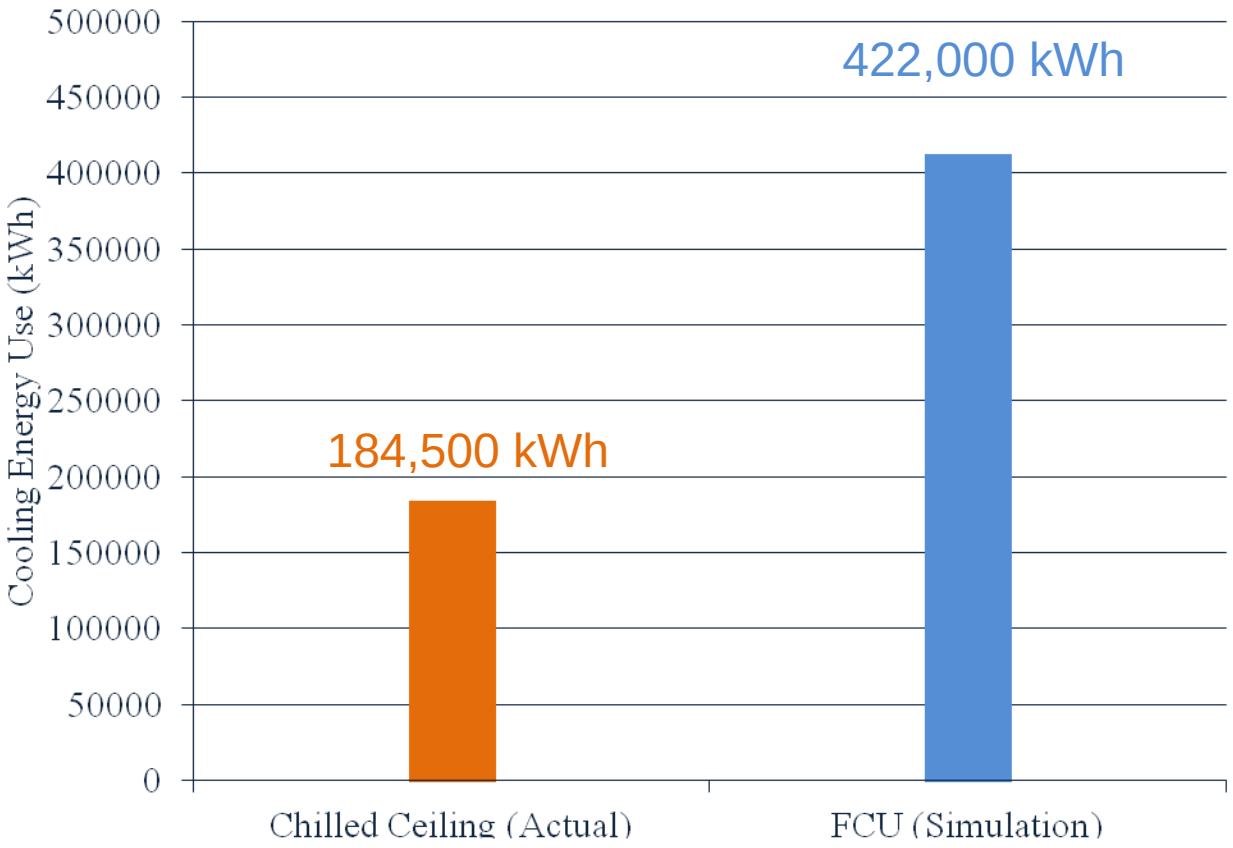
Hong Kong's energy end-use distribution

Energy Performance



Annual Energy Consumption for a Typical 1000 sq.m Office Floor

Cooling Energy in 2016 (kWh)	Total	Chilled Ceiling (Actual)	FCU (Simulation)*
		184,500	422,000



*simulated result by Hourly Analysis Program (E20)

Energy Performance

Energy Performance – Energy Utilization Index

Building Energy Utilization Index (EUI)

- A valuable index to manage energy usage
- Compare the whole-building energy use to other similar buildings
- Used for individual energy audits

$$\text{Annual Energy Utilization Index (EUI)} = \frac{\text{Total annual energy consumption of the central building services installations in a building}}{\text{Total internal floor area* of the building.}}$$

(Unit of EUI = kWh/m^2/annum)

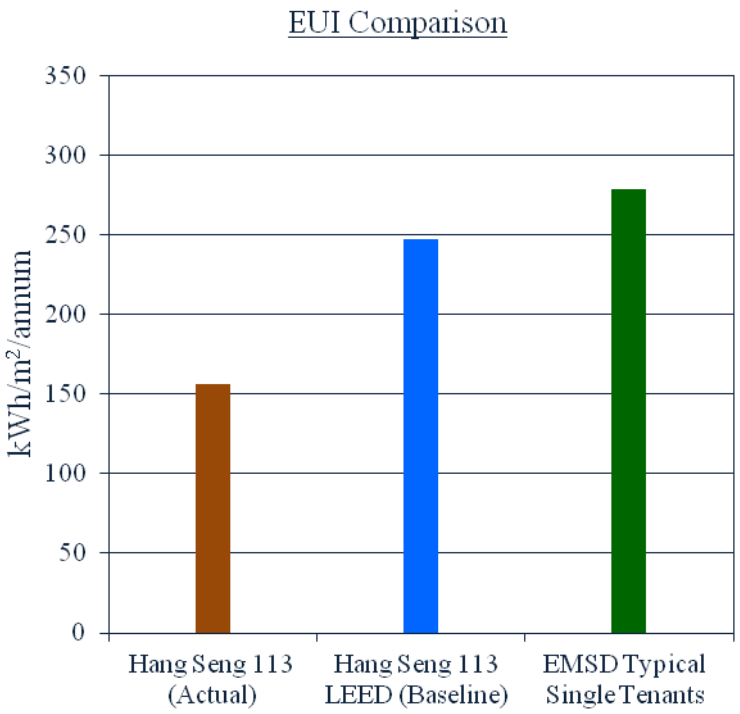
	Annual Energy Consumption per Area EUI (kWh/m^2/annum)
Typical Office (Multiple tenants)	132
Typical Office (Single tenants)	279
Hang Seng Office (Single tenants, Chilled Ceiling)	156

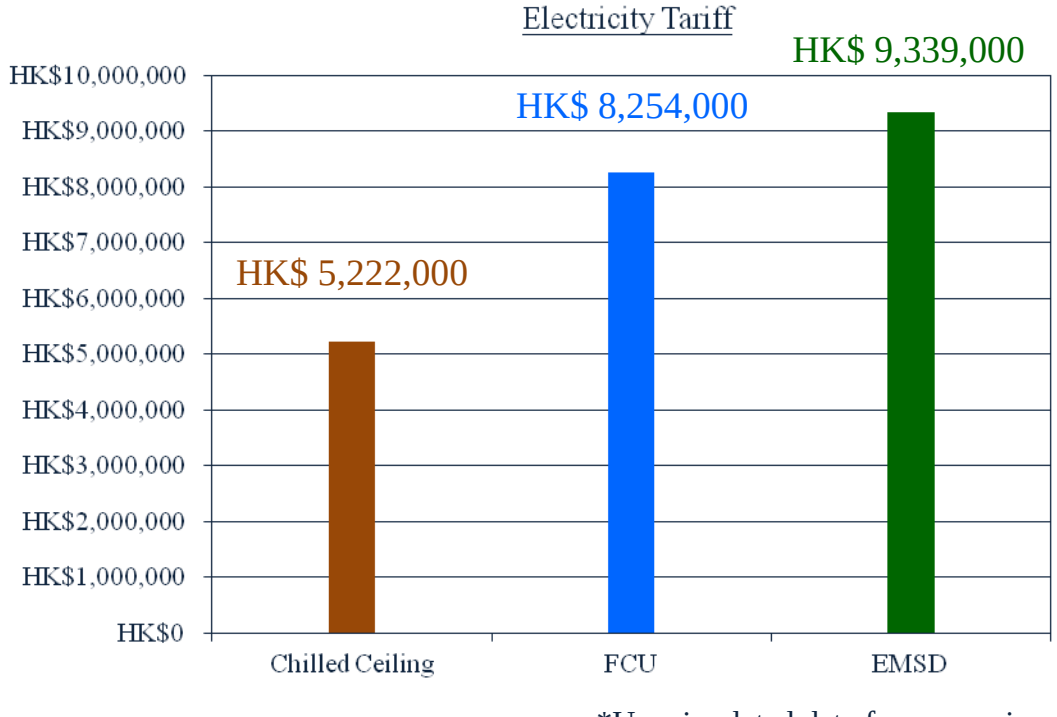
*Total Internal Floor Area (IFA)

- The area of all enclosed space of the unit measured to the internal face of enclosing walls
- Commonly known as Construction Floor Area (CFA) in HK

Energy Consumption for Whole Building

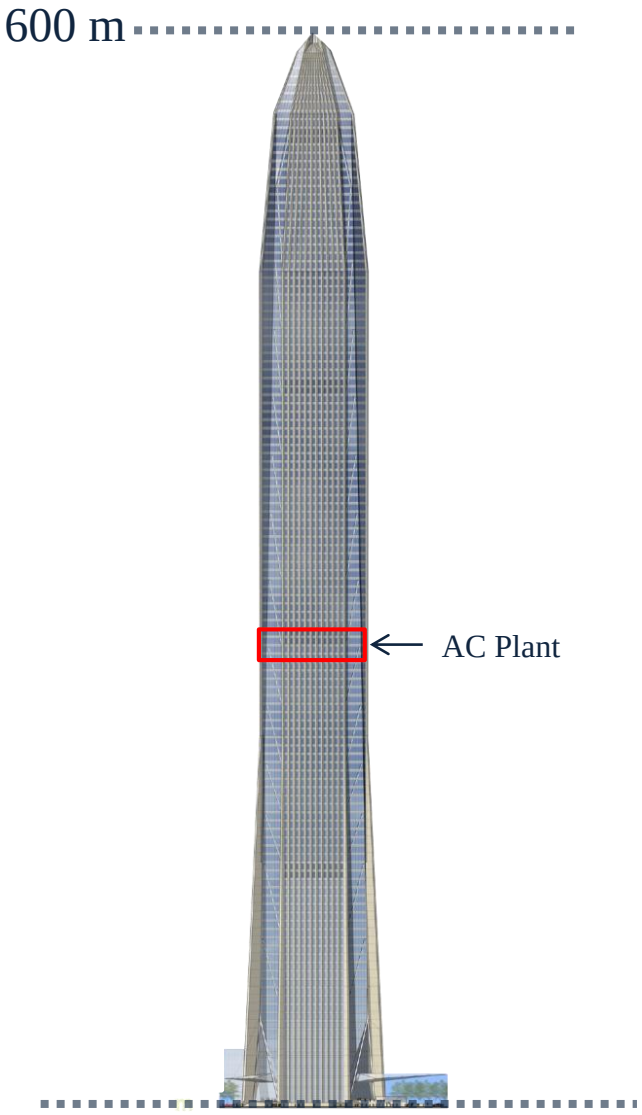
	Hang Seng 113 (Actual)	Hang Seng 113 LEED (Baseline)	EMSD Typical Single Tenants
AC System	Chilled Ceiling	LEED Baseline (FCU)	-
EUI (kWh/m^2/annum)	156	247*	279
HOT (MPP113) Internal Floor Area (m^2)	33472		
Annual Energy Consumption (kWh/annual)	5,221,000	8,254,000	9,339,000
Electricity Tariff Saving (HK$ 1/kWh)	-	HK$ 3,033,000	HK$ 4,118,000





*Use simulated data for comparison

Opportunities of Low Temperature Chilled Ceiling



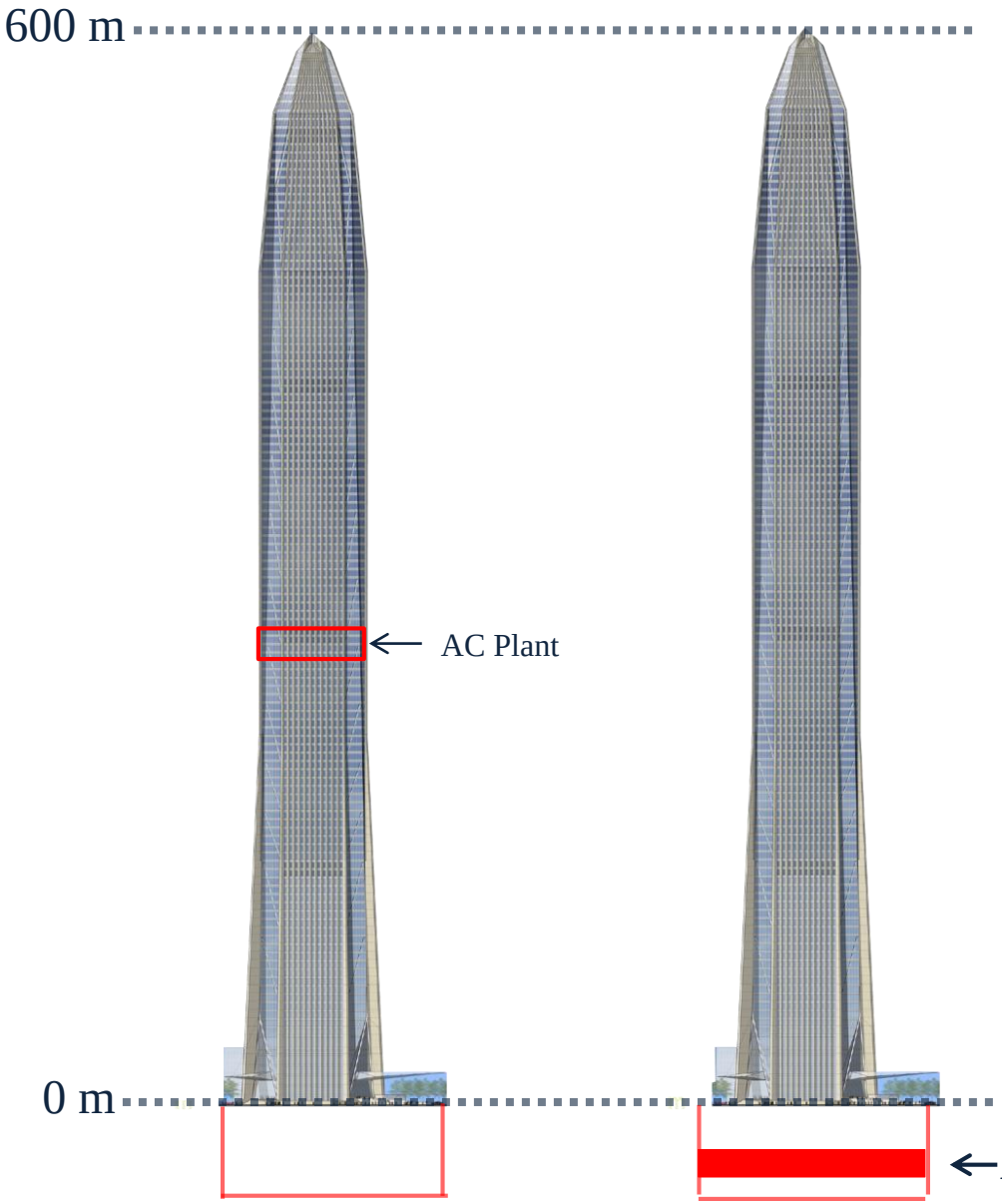
Skyscraper Ping An International Finance Centre

2nd Tallest building in China (Shenzhen)

4th in the World

- Floor to Floor Height 4500 mm
- False Ceiling 3150 mm
- MEP Ceiling Space + Structure 1350 mm
- AC Cooling Capacity 13000 TR
- AC Plant Room 2000 m^2
- Typical floor AHU room 4 x 80 m^2

Scenario 1

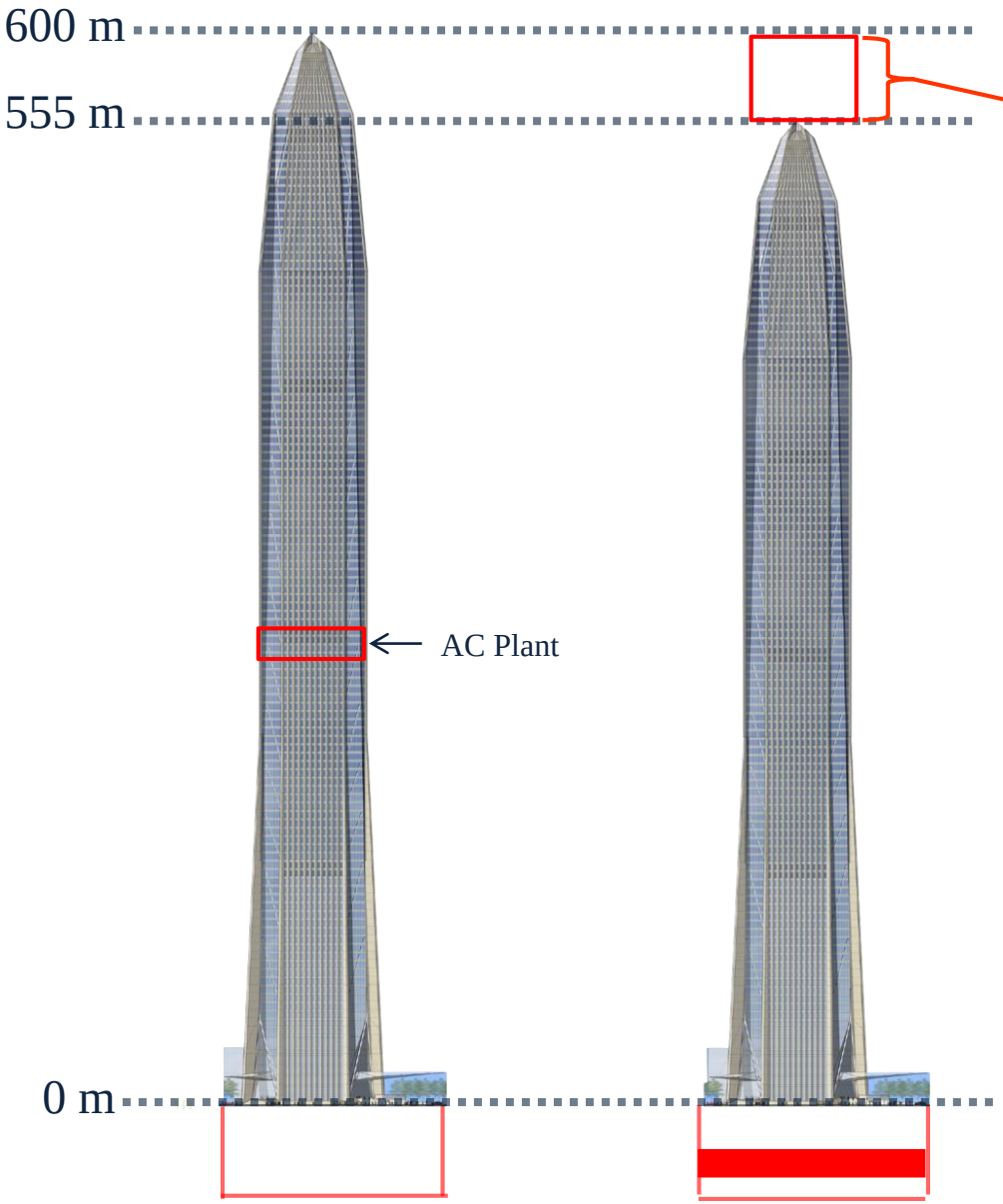


Central chiller plant can be significantly reduced and relocated to less valuable basement floors that eases maintenance and operation.

Same height of the building but office false ceiling height can be increased by 350 mm

AC plant can be relocated to Basement

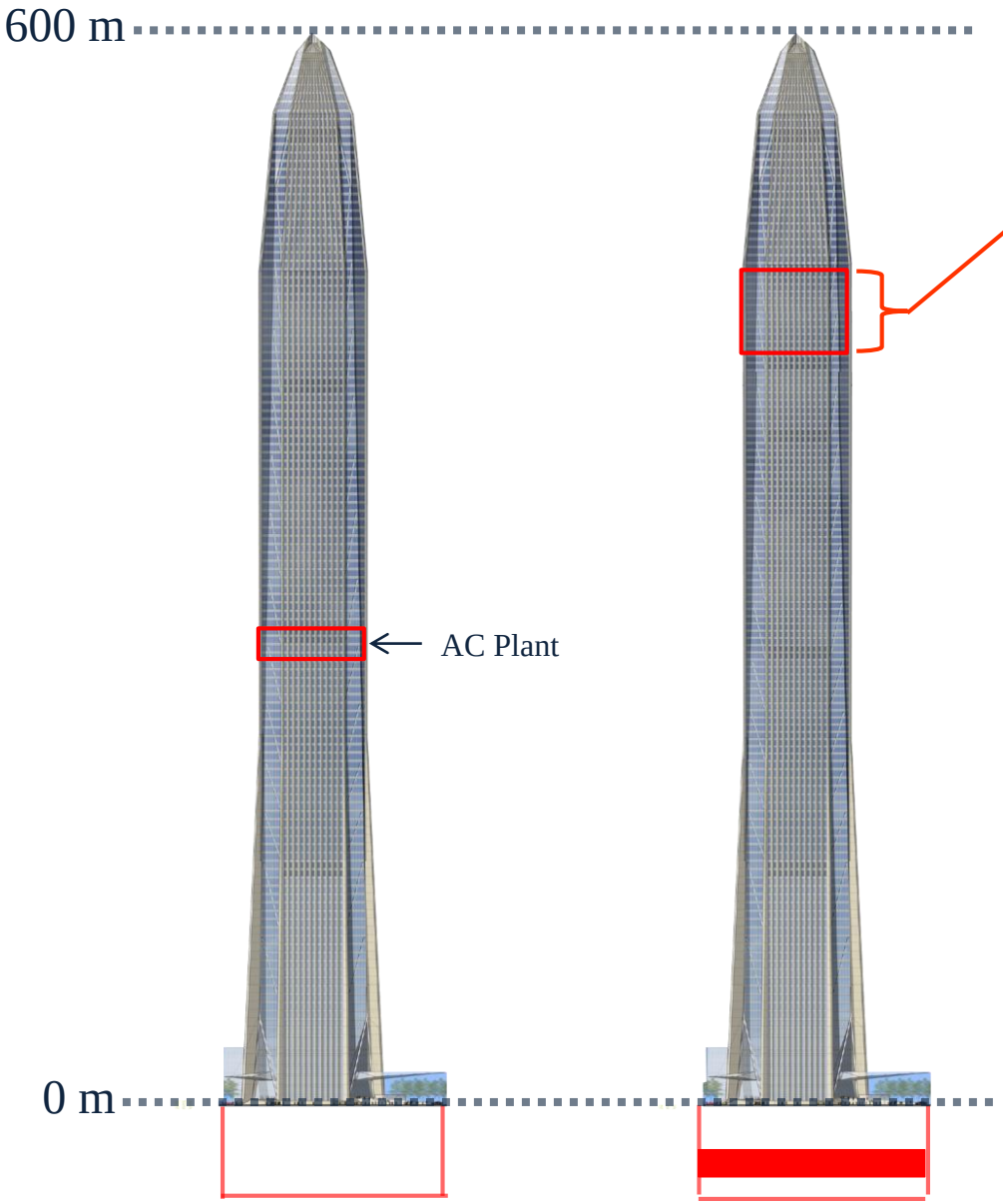
Scenario 2



45m Reduction in Building Height

Same false ceiling height but overall building height can be reduced and save construction cost

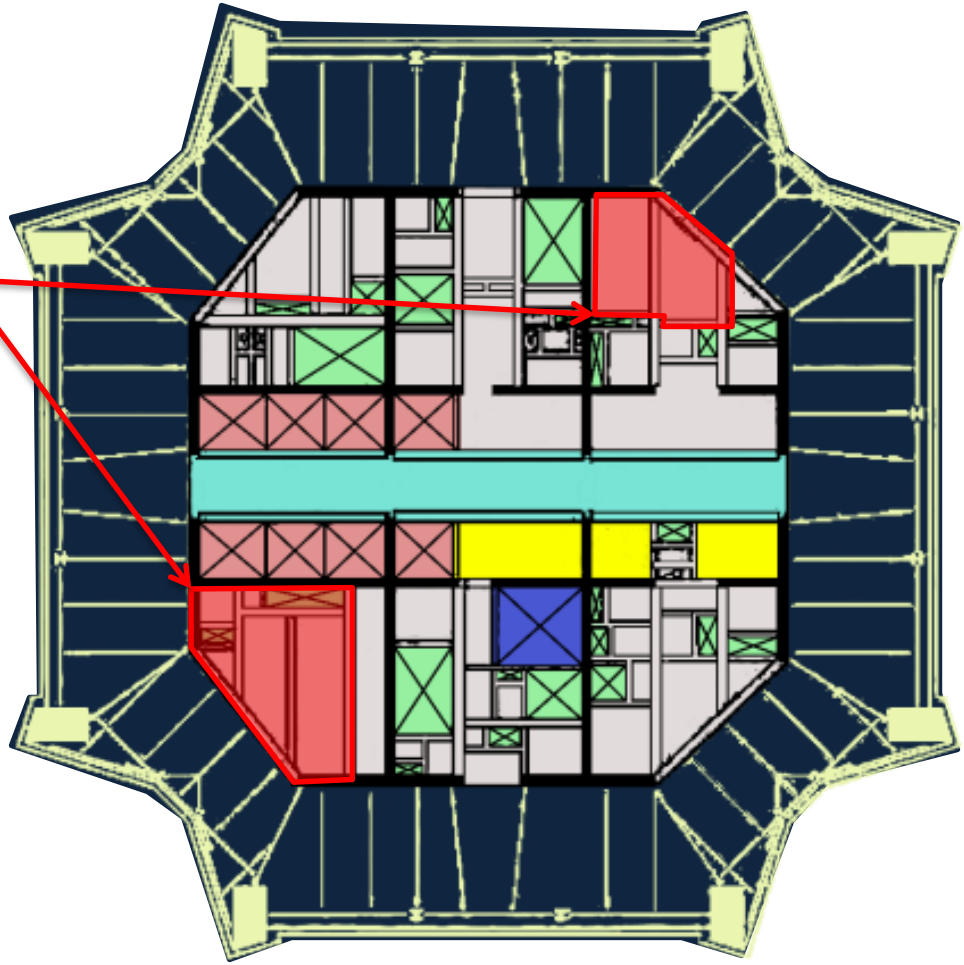
Scenario 3



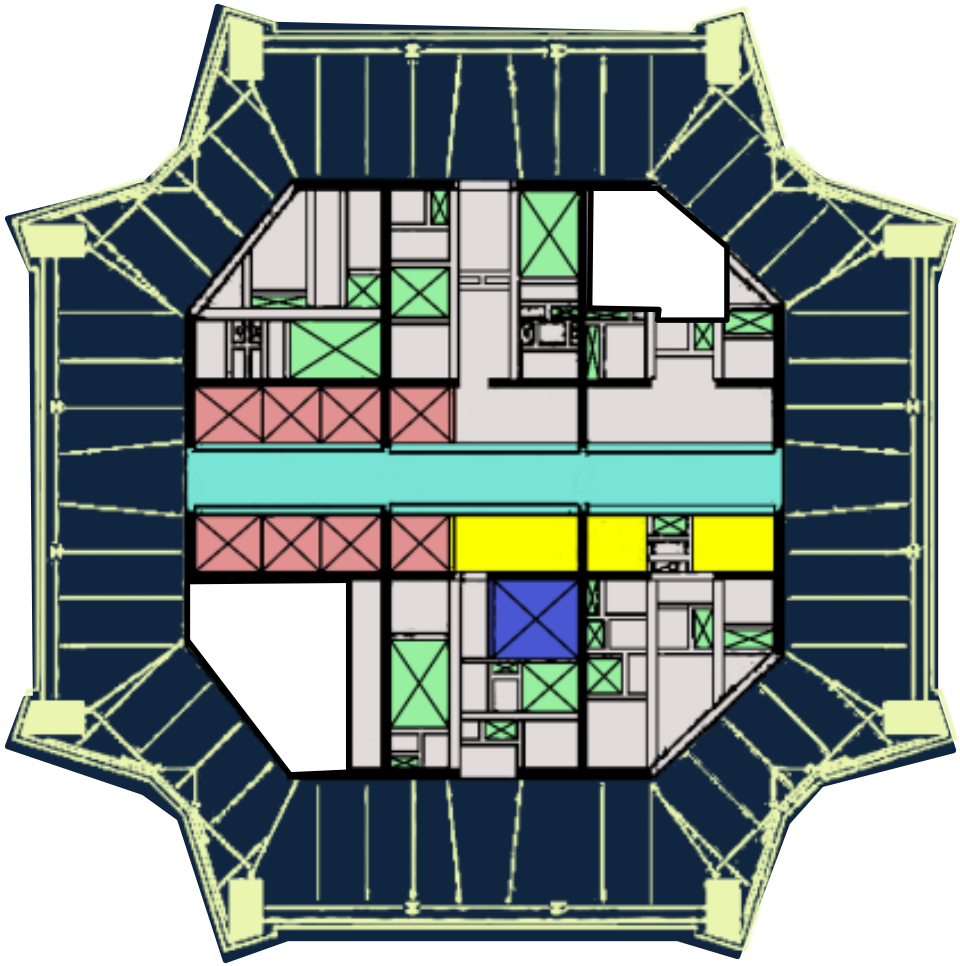
Same height but approximately 10 more office floors can be built with same false ceiling height

Advantages of more useful floor space

With the adoption of low temperature chilled ceiling design, the bulky AHU rooms for conventional VAV system will be disappeared.



- GFA 3900m^2



Opportunities of Low Temperature Chilled Ceiling

Hospital Projects

- Silent Operation
- Excellent Indoor Air Quality
- Energy Conservation
- Flexibility in Separation of Fresh Air Treatment
- 100% fresh Air Supply
- Even Temperature No Draft
- Easy Changeover to Heating / Cooling

Infrastructure Projects

- Suitable for High Space Large Volume Environment
- Excellent Indoor Air Quality
- Energy Conservation
- Much adopted to free cooling
- Easy Changeover to Heating / Cooling

- Office
- Hotel
- Academic Buildings & Student Hostel
- Exhibition/ Convention Area
- Luxurious Residential Development
- Industrial Undertaking and Factories

THANK YOU