Disease Resilient and Energy-Efficient Centralized Air-Conditioning Systems
Webinar 2 - Energy-Efficient Centralized Air-Conditioning Systems

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# Emerging HVAC technologies for energy efficient healthy buildings in hot and humid climates

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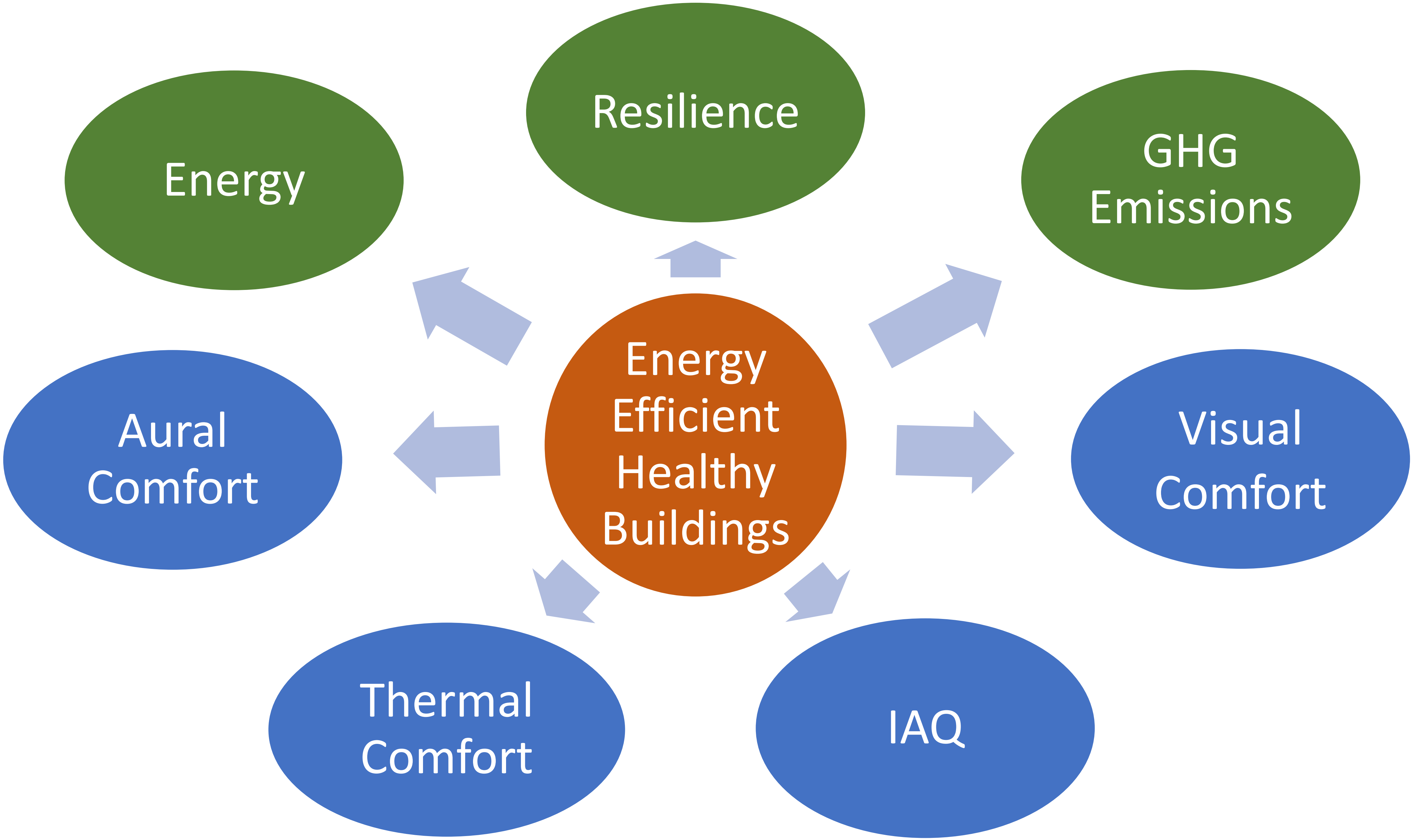
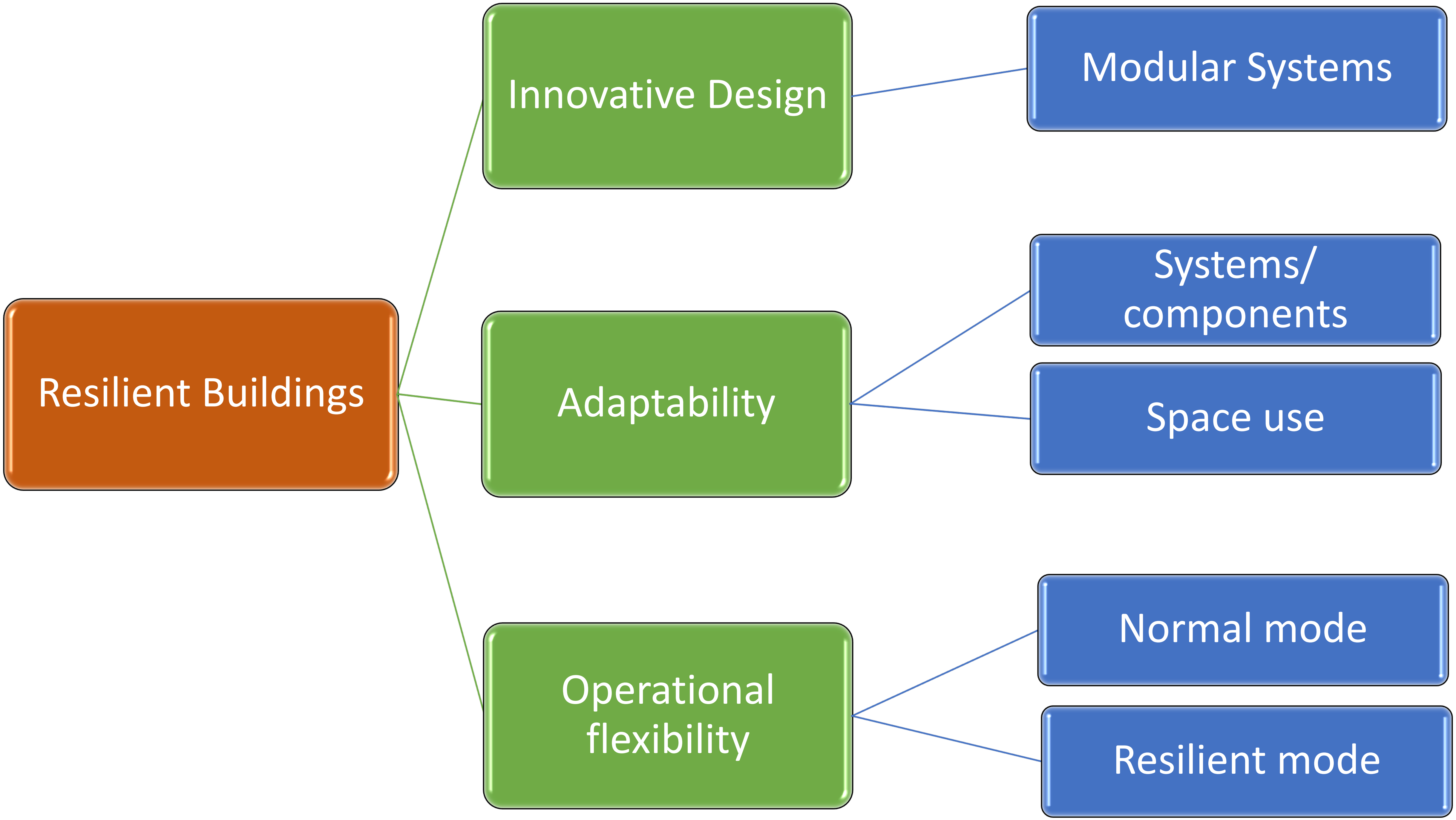
National University of Singapore


Resilience
Energy
GHG Emissions
Energy Efficient Healthy Buildings
Aural Comfort
Visual Comfort
Thermal Comfort
IAQ


Resilient Buildings
Innovative Design
Adaptability
Operational flexibility
Modular Systems
Systems/ components
Space use
Normal mode
Resilient mode

# IAQ

# IAQ - Source Control

**"If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure."**

Max Joseph von Pettenkofer
(1818-1901), german chemist

# IAQ - Exposure Control

## Ventilation

Ventilation and room air distribution

- What is the current practice?
- How is it evolving?

# Current Practice

Mixing Ventilation

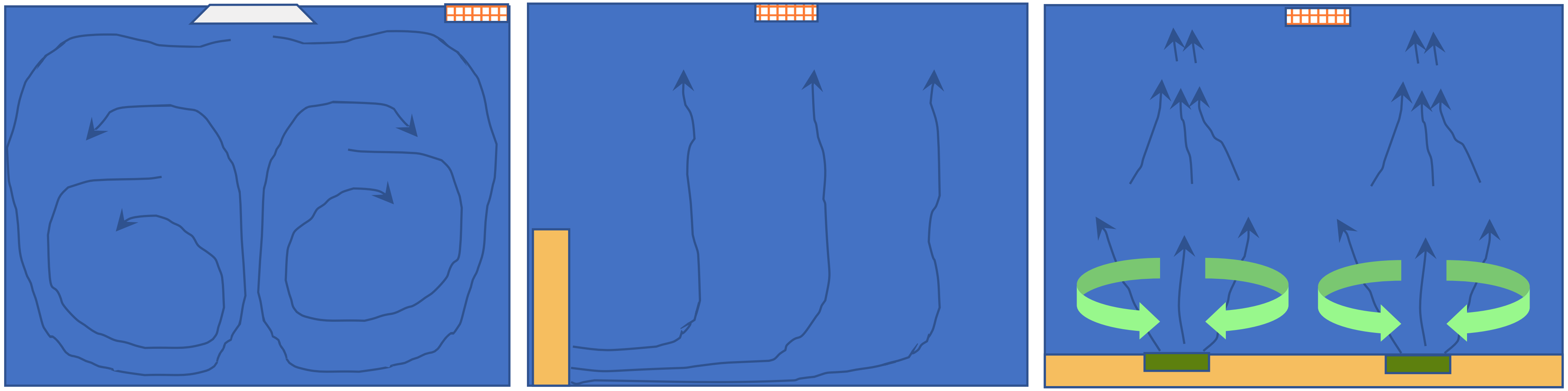
(MV)

Displacement Ventilation

(DV)

Under-Floor Air Distribution

(UFAD)



**Ventilation air**

- Quality
- Min Outdoor Air quantity
- Filtered & Disinfected air quantity

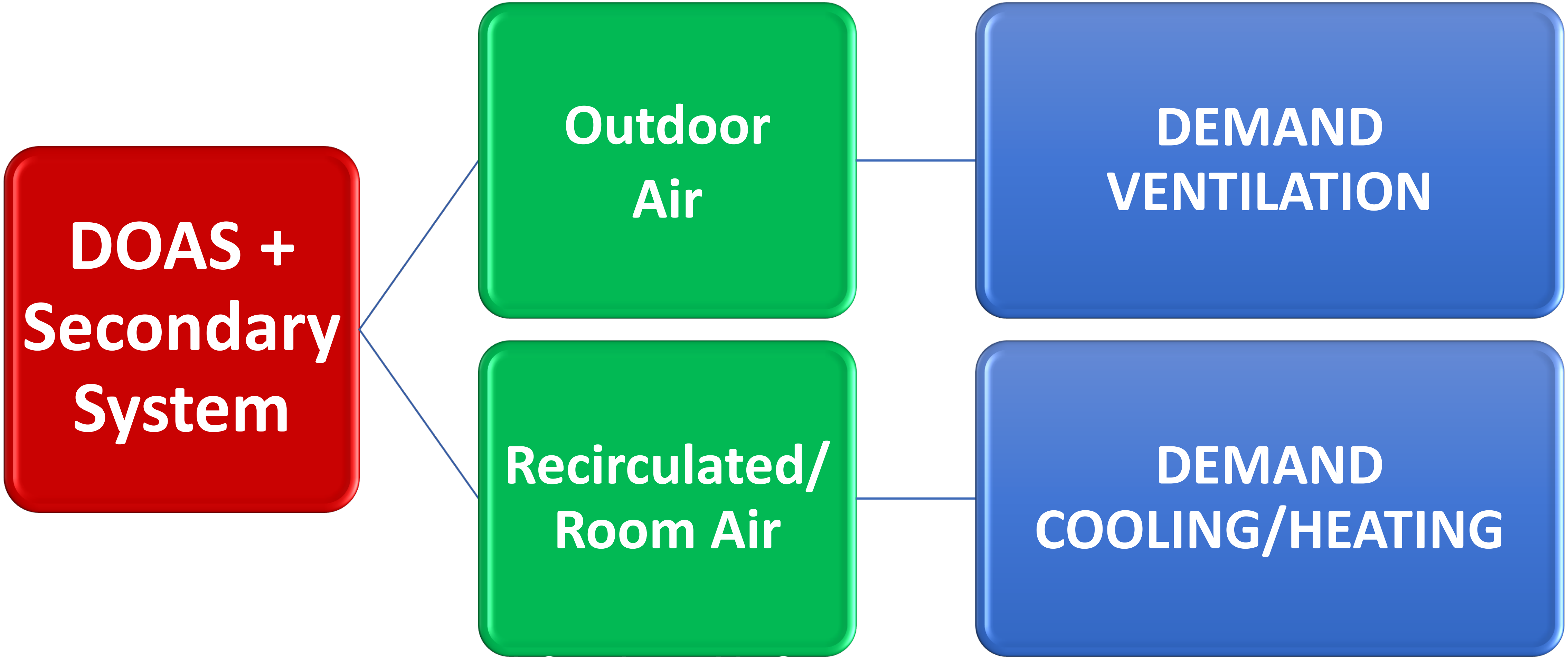
**Ventilation air distribution**

- Air Exchange effectiveness
- Personal Exposure effectiveness
- Exposure Reduction
- Intake Fraction

# Adaptable and Resilient Systems/Strategies – Non Residential Buildings

# Strategy

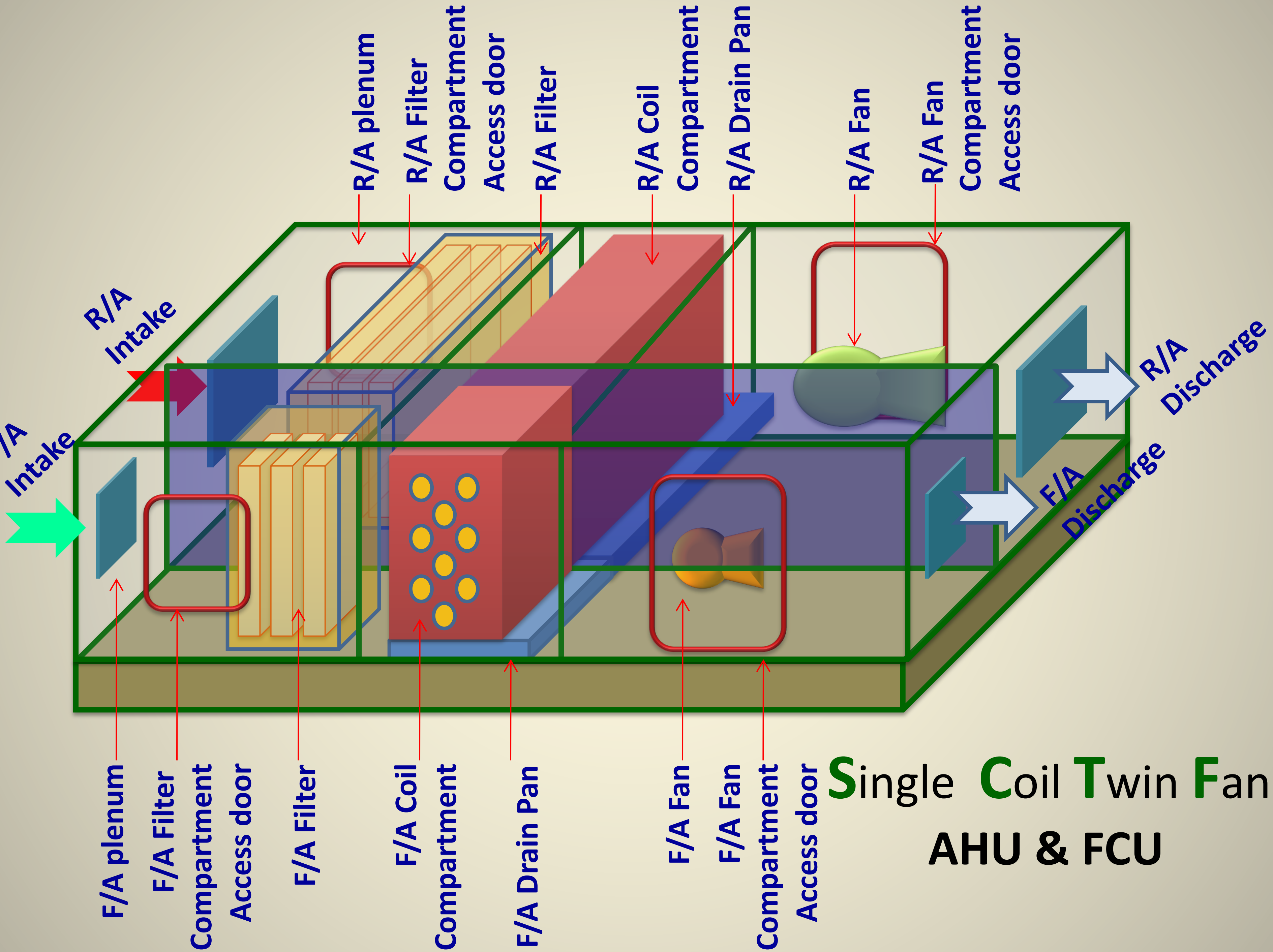
## Decoupling Ventilation from Cooling/Heating



# Single Coil Twin Fan (SCTF) Air-conditioning & Air distribution system

*Sekhar, S.C., Uma Maheswaran, C.R., Tham, K.W, and Cheong K.W, 2004. Development of energy efficient single coil twin fan air-conditioning system with zonal ventilation control, ASHRAE Transactions, 2004, Vol. 110, Pt 2, pp 204-217 (Paper presented in Nashville, June 2004).*

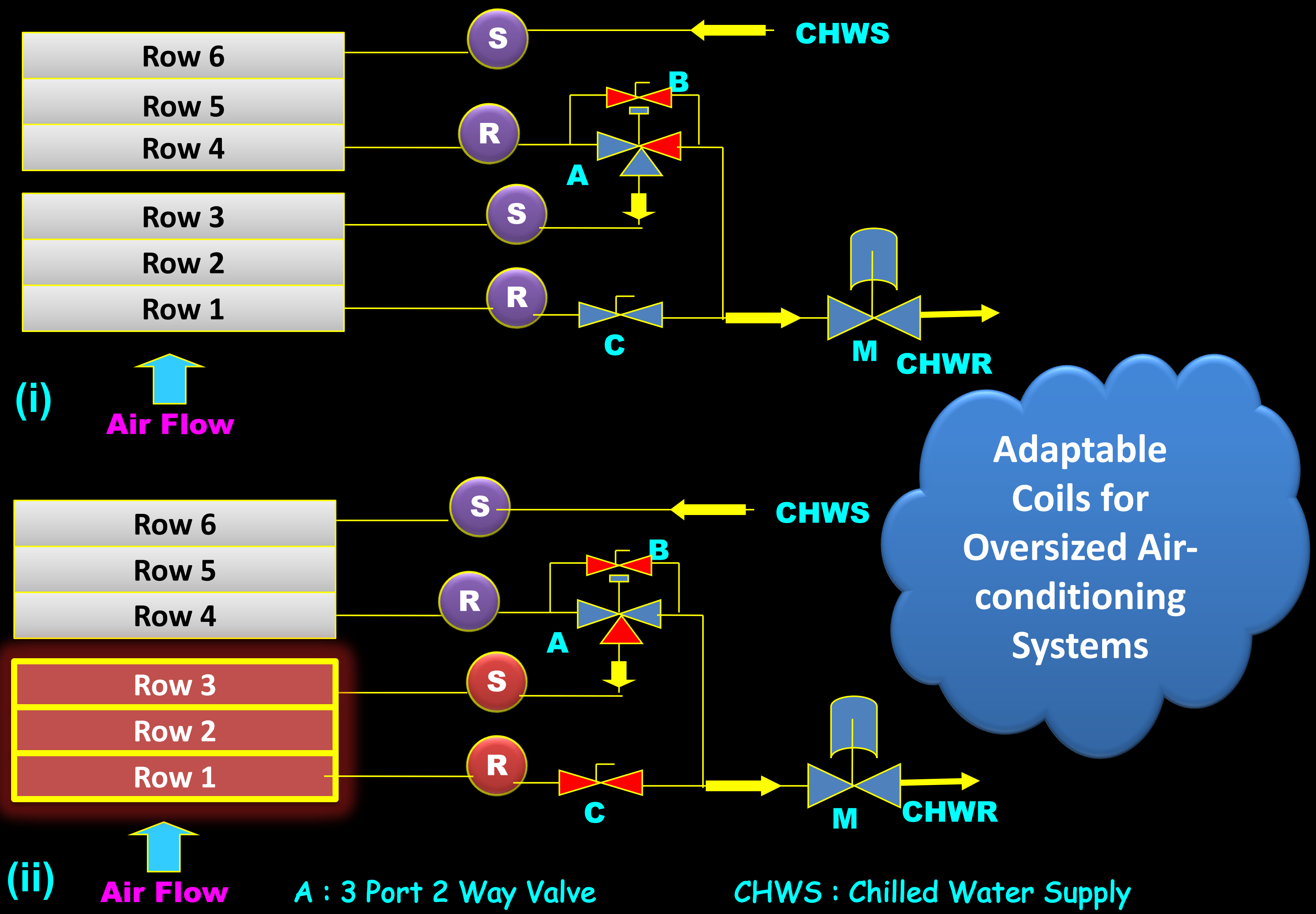
*Cheyyar, R U M, S C Sekhar, K W Tham and K W Cheong, "Single coil twin fan air-conditioning and air distribution system - Towards the development of a mathematical model of the compartmented coil". HVAC&R RESEARCH - International Journal of Heating, Ventilating, Air-conditioning and Refrigerating Research, 12, no. 3c, pp 825-842 (Special Issue) (October 2006).*




# Single Coil Twin Fan

## AHU & FCU

# Adaptable Coils

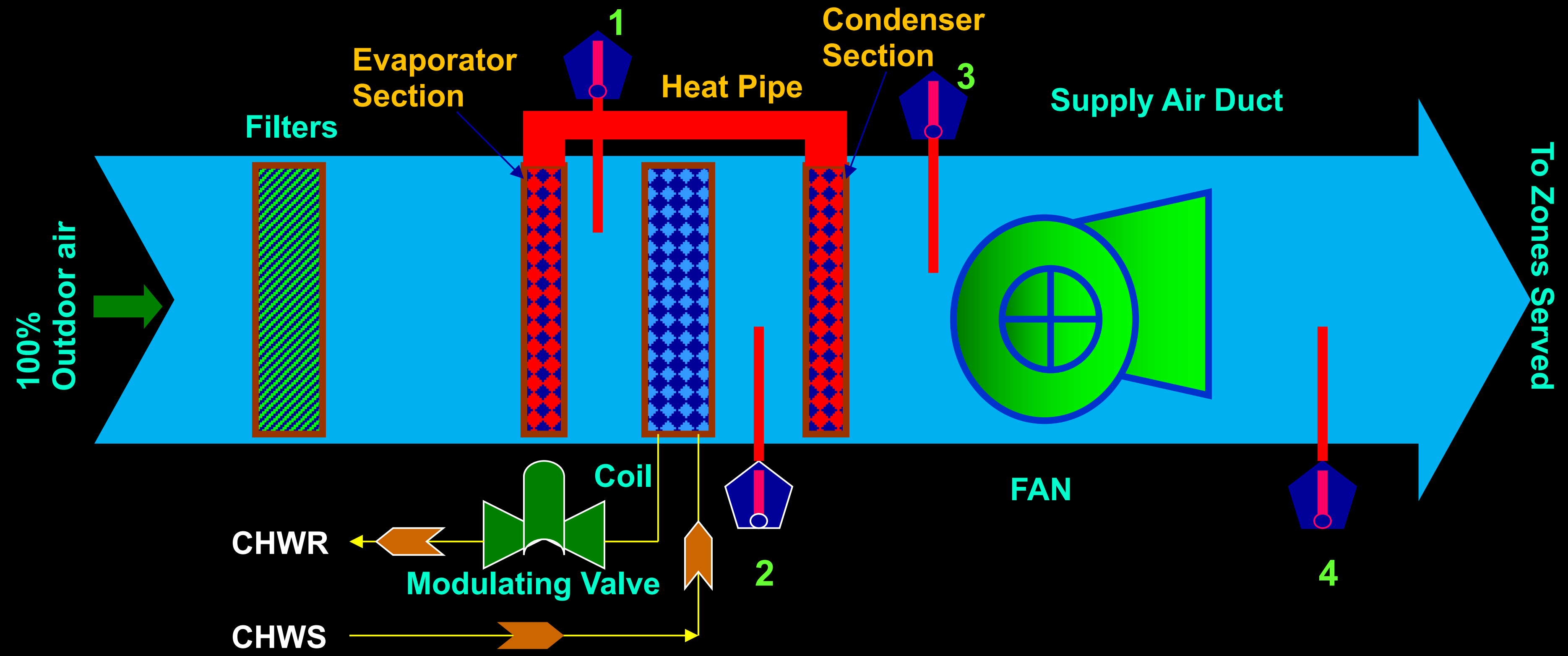



A : 3 Port 2 Way Valve
B : By-Pass Valve
C : On/Off Valve
M : Modulating Valve R : Return Manifold

CHWS : Chilled Water Supply
CHWR : Chilled Water Return
S : Supply Manifold

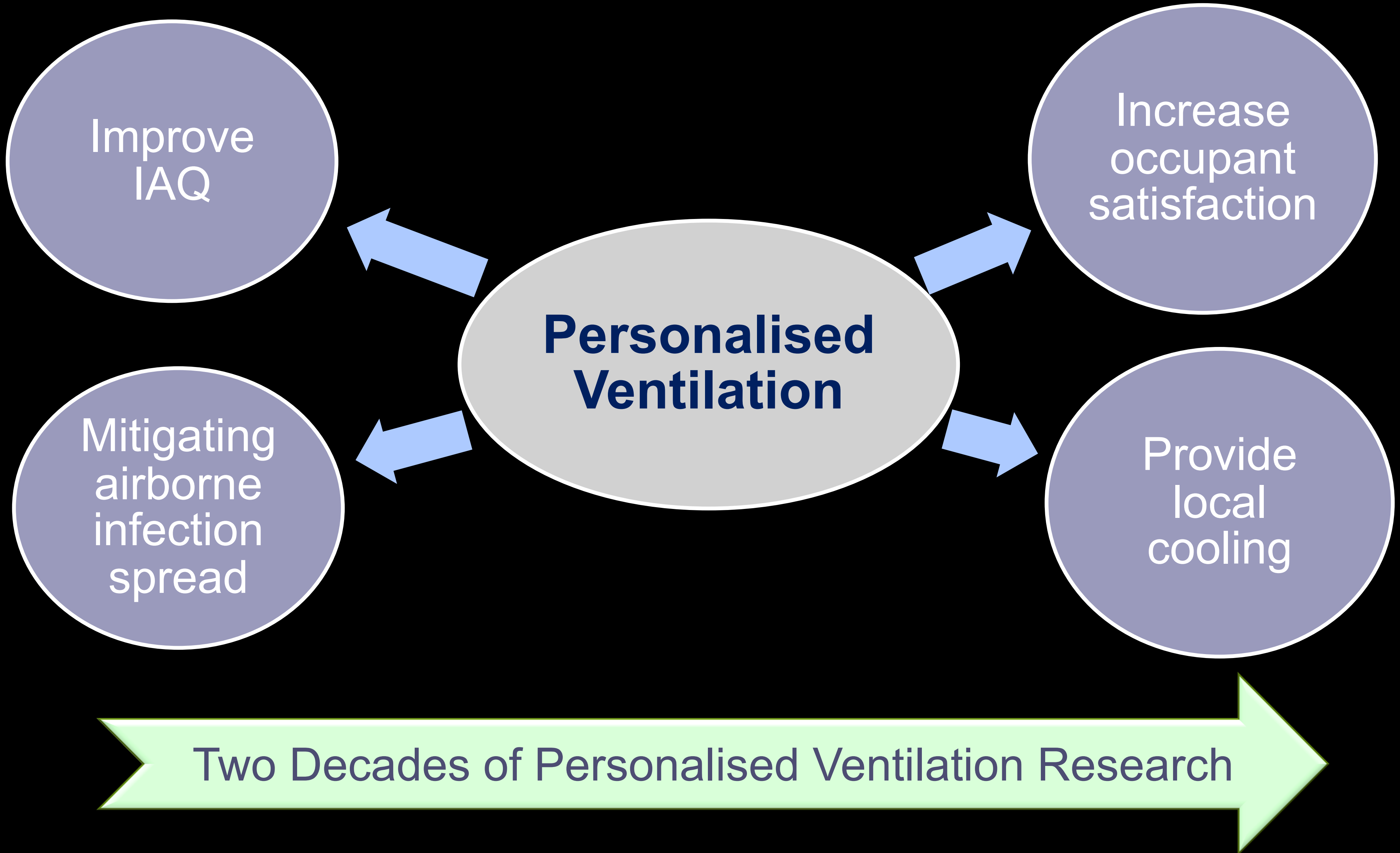
# Heat Pipe integrated AHU

Heat Pipes




*A Tropical Study - 18% Energy Savings*

# Advanced Room Air Distribution Strategies



# Personalised Ventilation (PV) System

Deliver fresh air directly to the Occupant breathing zone

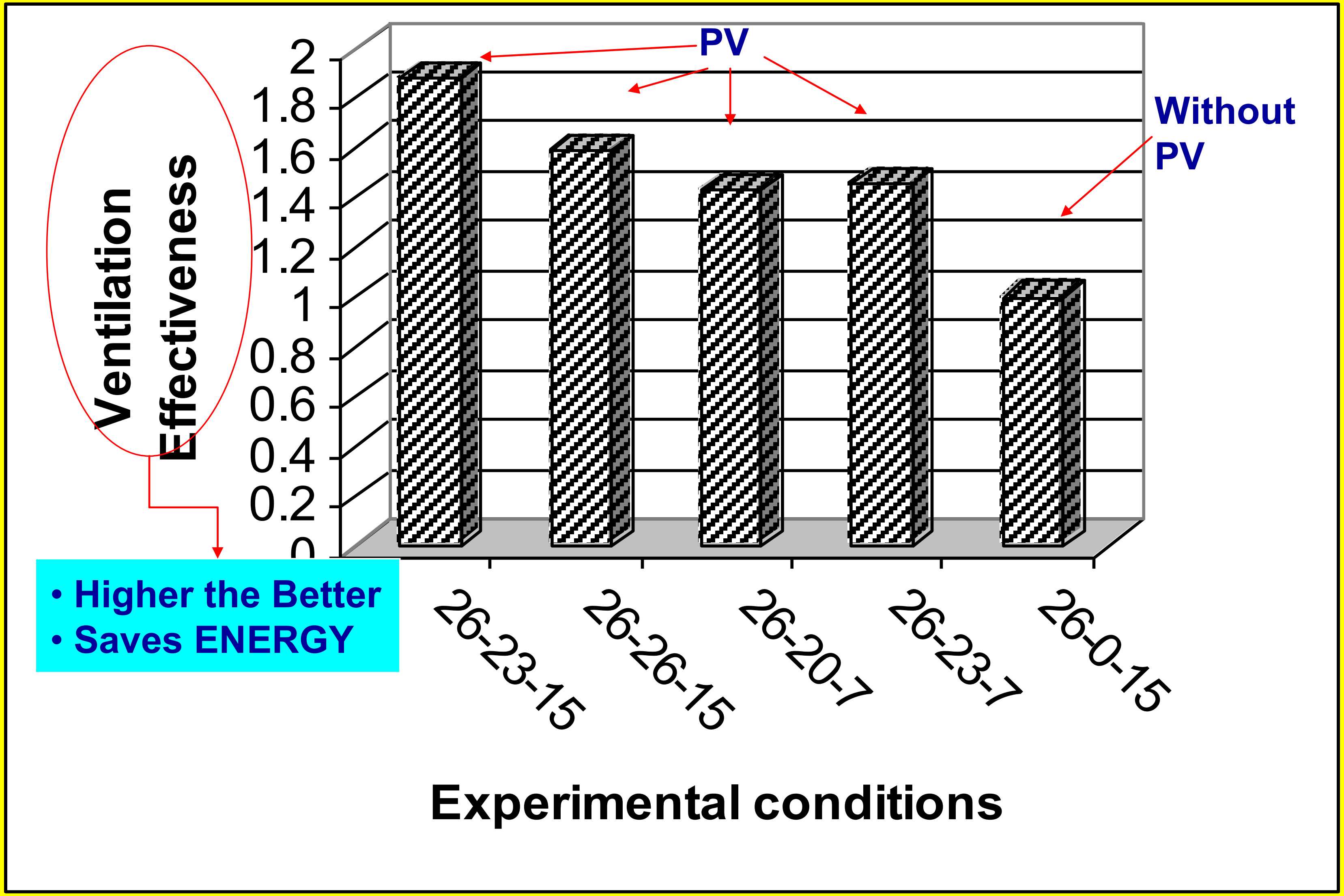
Potential to enhance

- Acceptability of ventilation
- Indoor Air Quality
- Thermal comfort

# Desk-mounted PV System integrated with Ceiling Supply MV System

Sekhar, S C, N Gong, K W Tham, K W Cheong, A.K. Melikov, D.P. Wyon and P.O. Fanger, "Findings of personalised ventilation studies in a hot and humid climate". International Journal of Heating, Ventilating, Air-conditioning and Refrigerating Research (HVAC&R Research), Vol 11, no. 4

Gong, N, K W Tham, AK Melikov, DP Wyon, S C Sekhar and K W Cheong, "The acceptable air velocity range for local air movement in the Tropics". HVAC&R Research, International Journal of Heating, Ventilating and Air-Conditioning Engineers (ASHRAE), Vol 12, No. 4, pp 1065-1076, (October 2006). (United States).



Ventilation Effectiveness
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
PV
Without PV
26-23-15
26-26-15
26-20-7
26-23-7
26-0-15
Experimental conditions
• Higher the Better
• Saves ENERGY

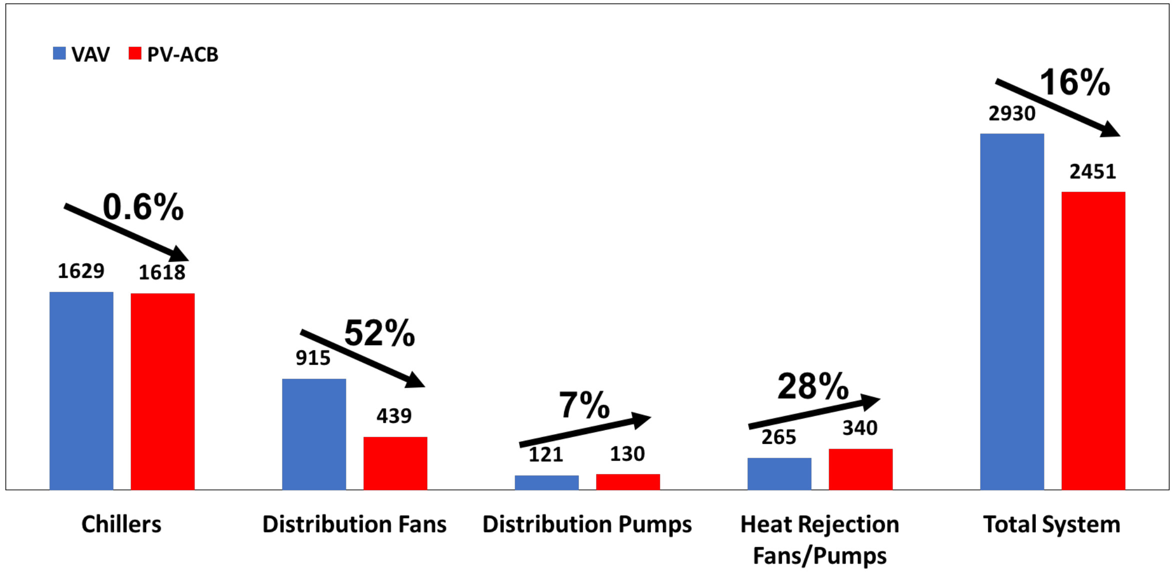
## Energy savings occur due to

- A warmer space temperature, such as 26 °C, accompanied by a PV air temperature of 23 °C, implies that the space cooling load is reduced in comparison with a conventional air-conditioning system in which the space is typically maintained at 23 °C.

- An absolute reduction in the total fresh air quantity provided is possible, as it is now directly supplied as inhaled air to the occupant breathing zone.

# PV System coupled with Chilled Beams

Sekhar, C. & Zheng, L. Study of an integrated personalized ventilation and local fan-induced active chilled beam air conditioning system in hot and humid climate. Build. Simul. (2018) 11: 787.
https://doi-org.libproxy1.nus.edu.sg/10.1007/s12273-018-0438-8




Annual Energy Consumptions of Main Components in VAV and PV-ACB Air Conditioning Systems (Unit: MWh)

# PV System
# Integrated with
# Personalized Exhaust System

# Personalised Ventilation with Personalised Exhaust

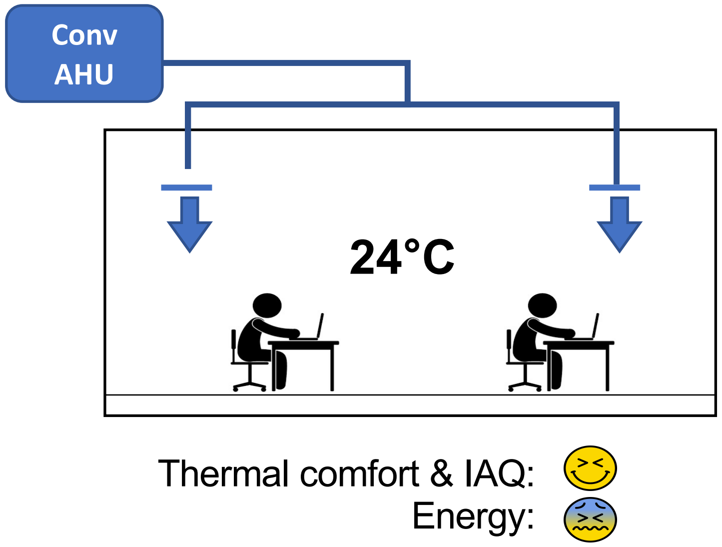

Yang, J., Sekhar, S. C., Cheong, K. W. D., & Raphael, B. (2015). Performance evaluation of a novel personalized ventilation-personalized exhaust system for airborne infection control. *INDOOR AIR*, *25*(2), 176-187. doi:10.1111/ina.12127

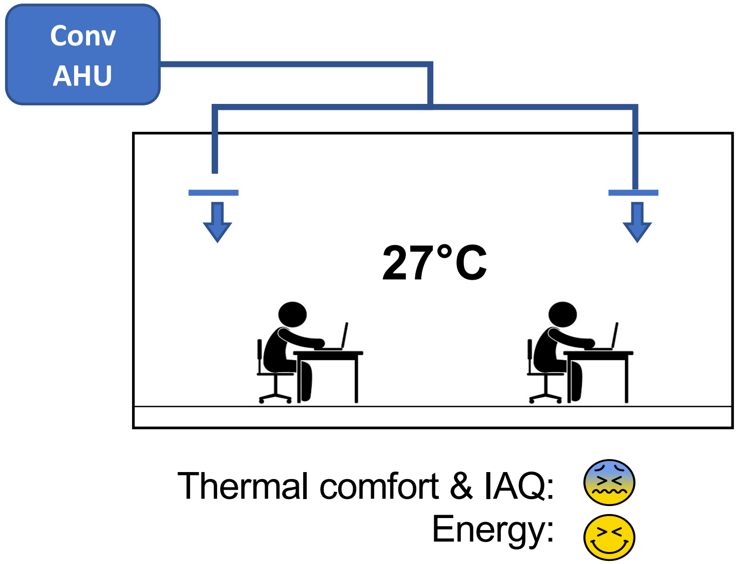
Yang, J., Sekhar, C., Cheong, D., & Raphael, B. (2014). Performance evaluation of an integrated Personalized Ventilation-Personalized Exhaust system in conjunction with two background ventilation systems. *BUILDING AND ENVIRONMENT*, *78*, 103-110. doi:10.1016/j.buildenv.2014.04.015

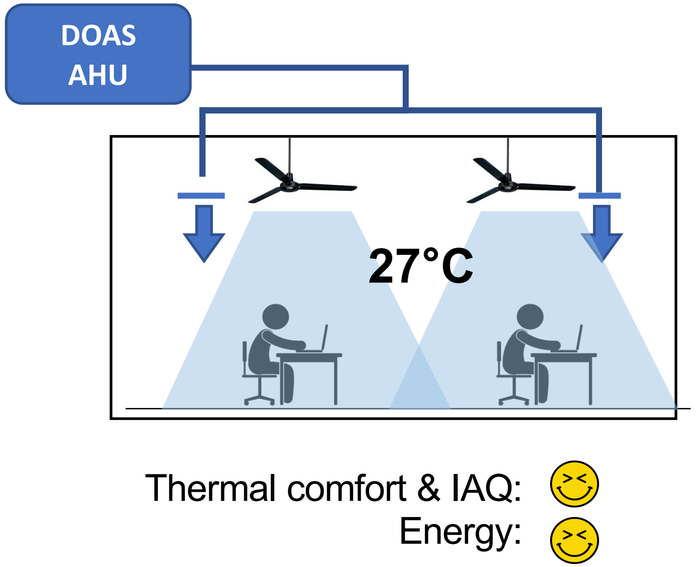
# DOAS coupled with Ceiling Fans

# Concept of Hybrid Air-conditioning: DOAS-CF System

Reduce the cooling demand by increasing the room temperature and to improve thermal comfort and IAQ by elevated air movement



Average temperature, relative humidity and globe temperature.

| Location | Temperature [°C] | | | | | RH [%] | Globe T [°C] |
|---|---|---|---|---|---|---|---|
| | 0.1 m | 0.6 m | 1.1 m | 1.7 m | 2.2 m | | |
| S1 | 27.0 ± 0.09 | 27.0 ± 0.10 | 27.0 ± 0.09 | 27.2 ± 0.10 | 27.1 ± 0.09 | 58.4 ± 0.41 | 27.1 ± 0.08 |
| S2 | 26.7 ± 0.11 | 26.5 ± 0.12 | 26.5 ± 0.10 | 26.3 ± 0.20 | 26.2 ± 0.24 | 61.6 ± 0.45 | 26.5 ± 0.08 |
| S3 | 26.7 ± 0.13 | 26.6 ± 0.11 | 26.6 ± 0.10 | 26.6 ± 0.10 | 26.7 ± 0.10 | 60.5 ± 0.50 | 26.8 ± 0.08 |
| S4 | 27.3 ± 0.07 | 27.3 ± 0.08 | 27.3 ± 0.07 | 27.3 ± 0.08 | 27.3 ± 0.07 | 57.7 ± 0.51 | 27.4 ± 0.06 |
| Computer lab | 24.2 ± 0.21 (1.4 m) | | | | | 55.4 ± 1.3 | – |

*Kuniaki Mihara, Chandra Sekhar, Yuichi Takemasa, Bertrand Lasternas, Kwok Wai Tham, 2021. Thermal and perceived air quality responses between a dedicated outdoor air system with ceiling fans and conventional air-conditioning system. Building and Environment, Vol. 190. https://doi.org/10.1016/j.buildenv.2020.107574*

# Filtration and Disinfection

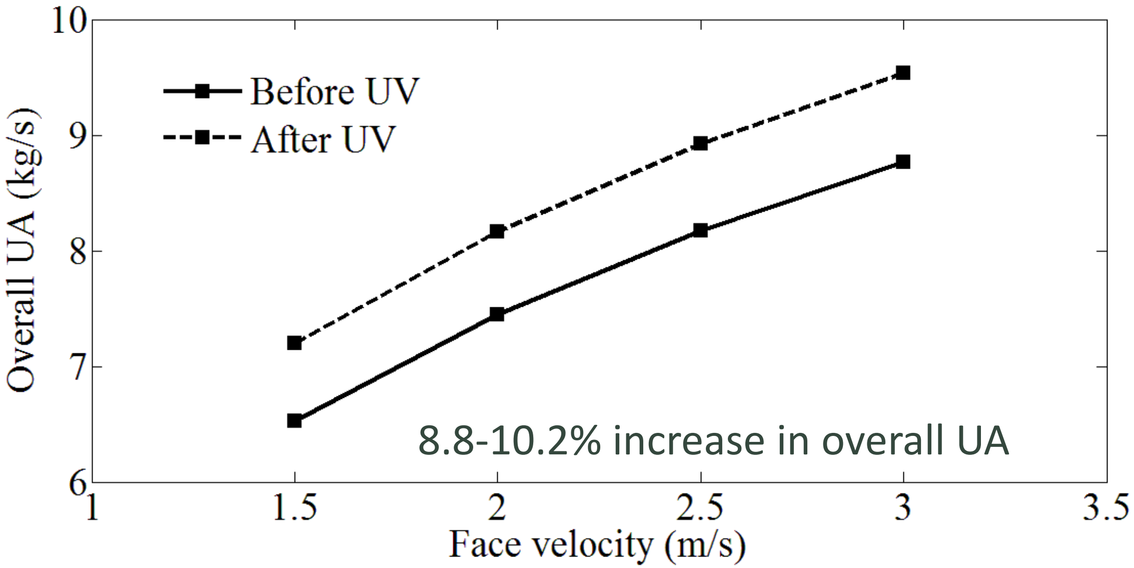
# UVGI

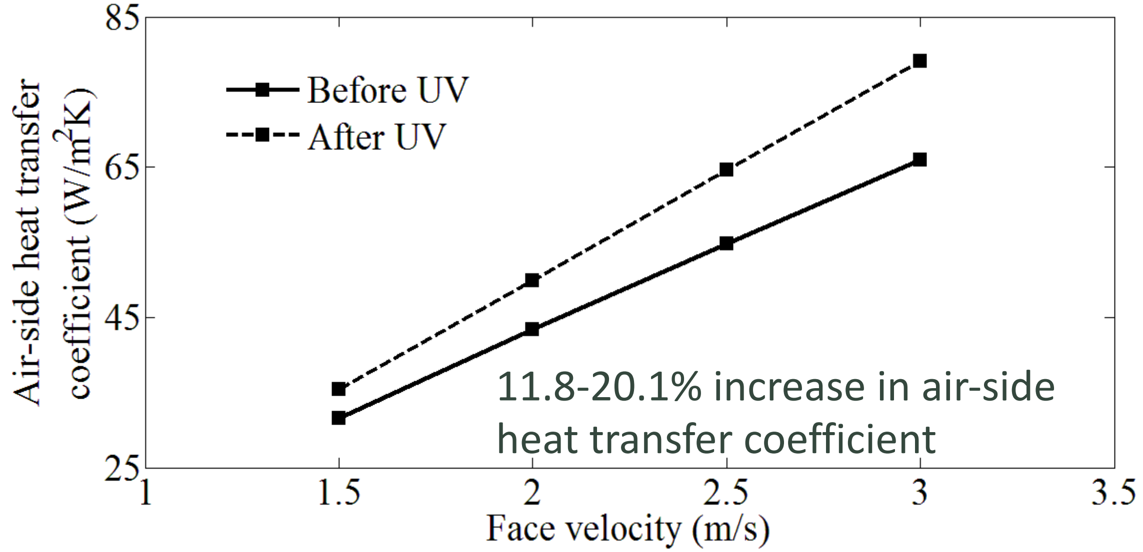
ASHRAE COVID-19 RESPONSE RESOURCES

Types of disinfection systems using UV-C energy:

- In-duct air disinfection
- Upper-air disinfection
- In-duct surface disinfection
- Portable room decontamination

# UVGI Intervention Study - Overall thermal conductance and air side heat transfer coefficient characteristics





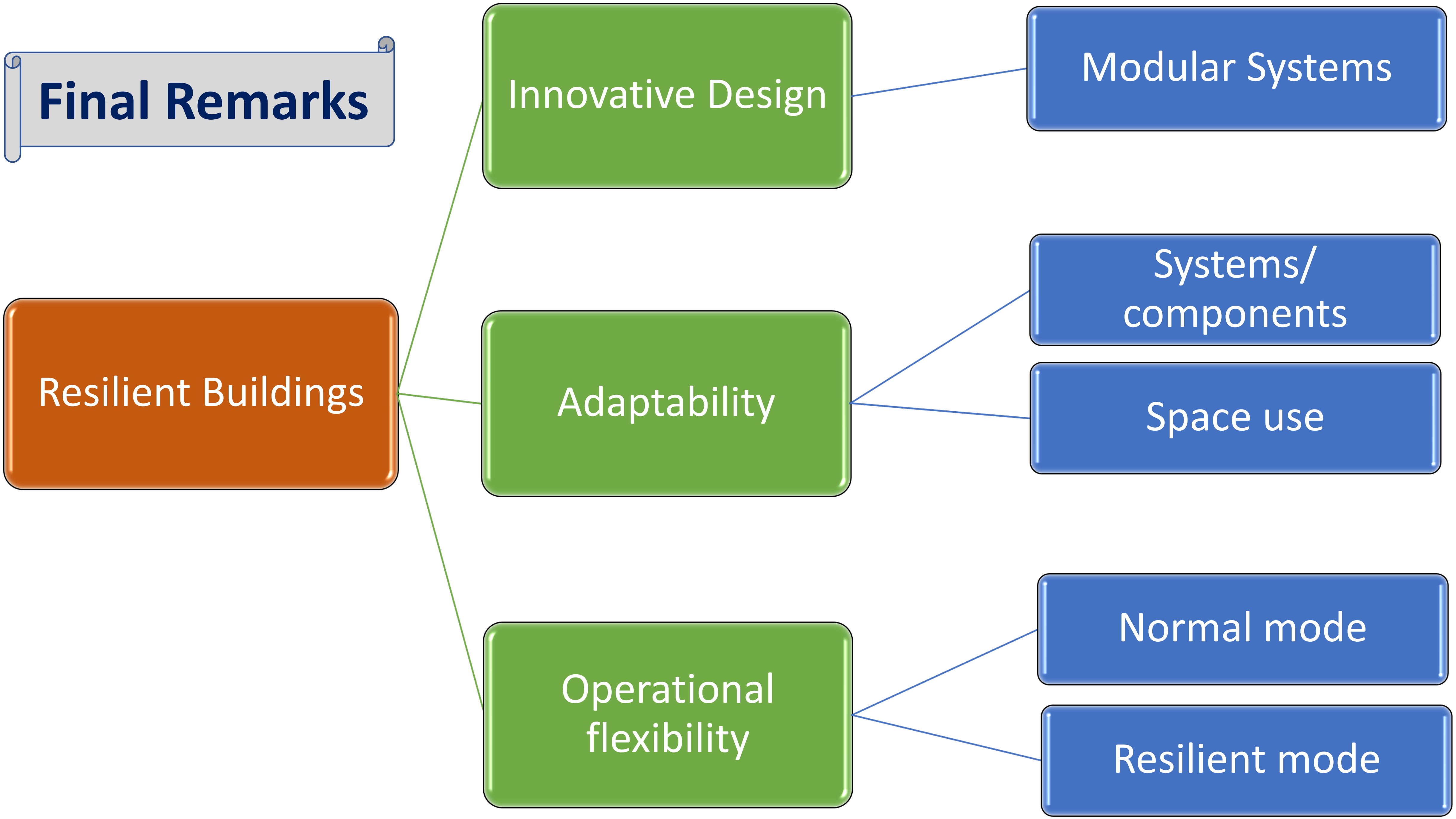
- Wang, Y., Sekhar, C., Bahnfleth, W. P., Cheong, K. W., & Firrantello, J. (2017). Effects of an ultraviolet coil irradiation system on the airside heat transfer coefficient and low ΔT syndrome in a hot and humid climate. *Science and Technology for the Built Environment*, *23*(4), 582-593. doi:10.1080/23744731.2016.1232115
- Wang, Y., Sekhar, C., Bahnfleth, W. P., Cheong, K. W., & Firrantello, J. (2016). Effectiveness of an ultraviolet germicidal irradiation system in enhancing cooling coil energy performance in a hot and humid climate. *ENERGY AND BUILDINGS*, *130*, 321-329. doi:10.1016/j.enbuild.2016.08.063

# UVGI for coils

In a hot and humid climate,

- Coil irradiation systems improve heat transfer and pressure drop performance of cooling coils - improvement is most rapid initially
- Net reduction in energy cost after applying UVGI for cooling coils - eventually cost effective, depending on ACMV system operating hours and project scale
- In addition to surface and condensate water disinfection benefits, coil irradiation systems specifically designed for coil surface disinfection can have collateral air disinfection benefits

# Final Remarks



# Thank You for your Attention