Building Energy
Research Center
Tsinghua University

Insights from occupant behavior and implications on future sustainable cooling

Shan Hu

Building Energy Research Center

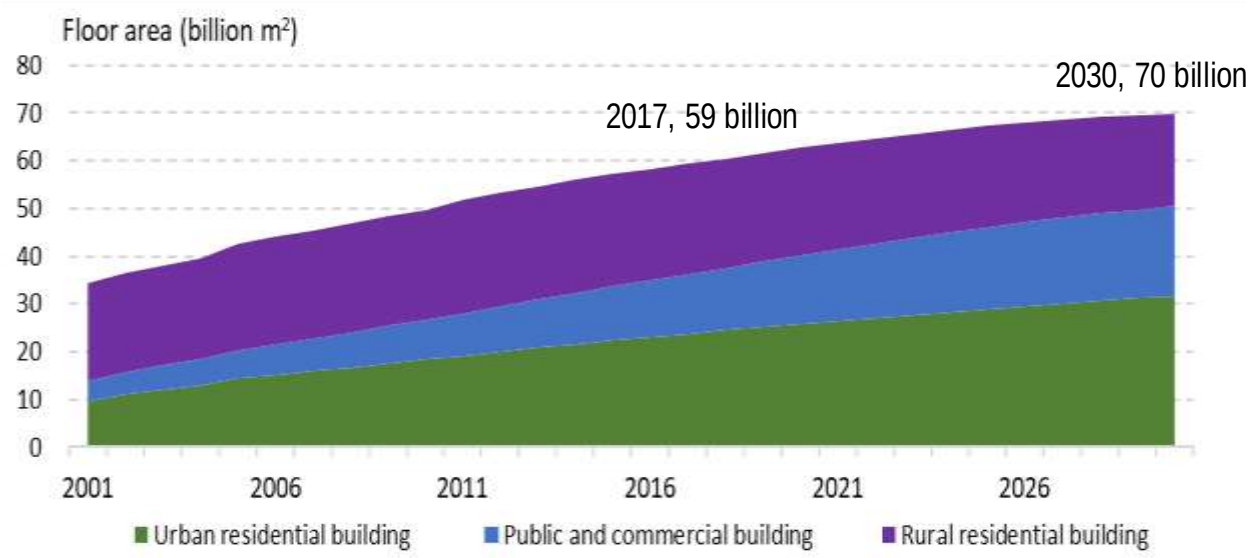
Tsinghua University

13th Dec, 2019

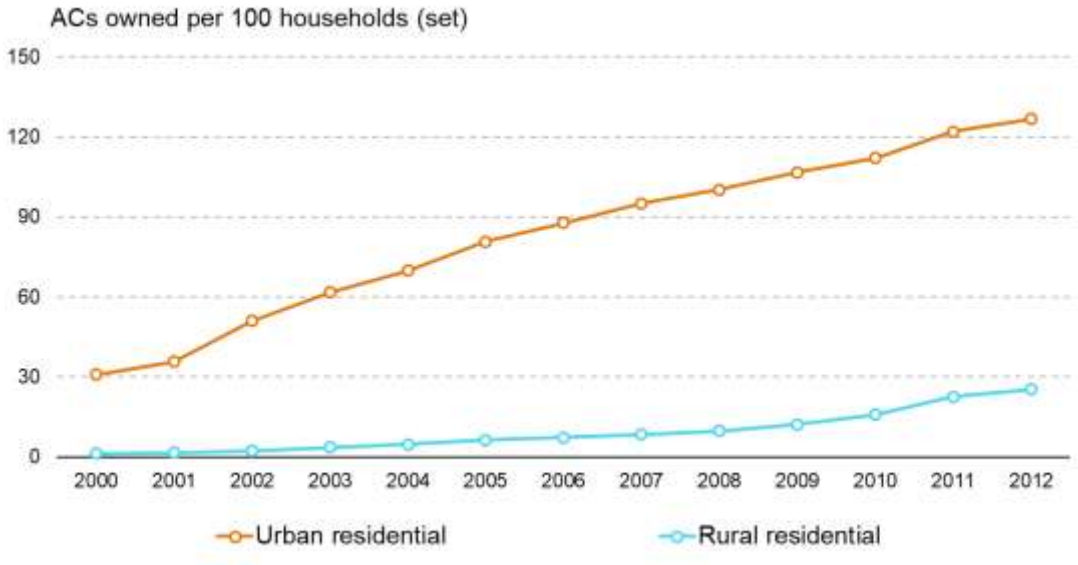
China’s cooling boom with urbanization

- With the urbanization process, China’s building stock developed fast
- The air conditioner ownership grew quite fast in last decades.

Building stock of China



AC ownership in urban and rural residential sectors

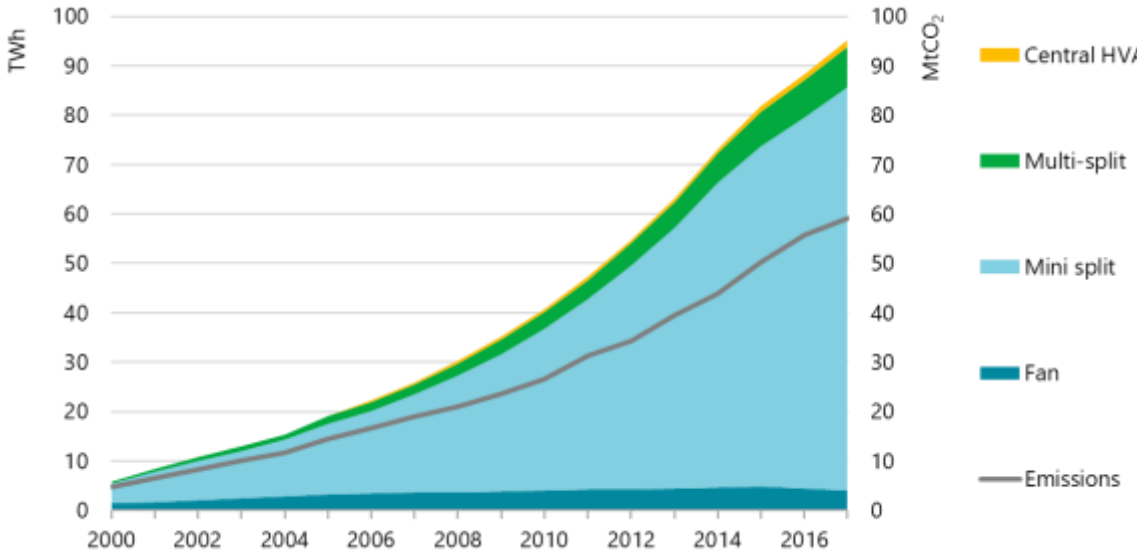


Data source: Tsinghua University, China Building Energy Use.

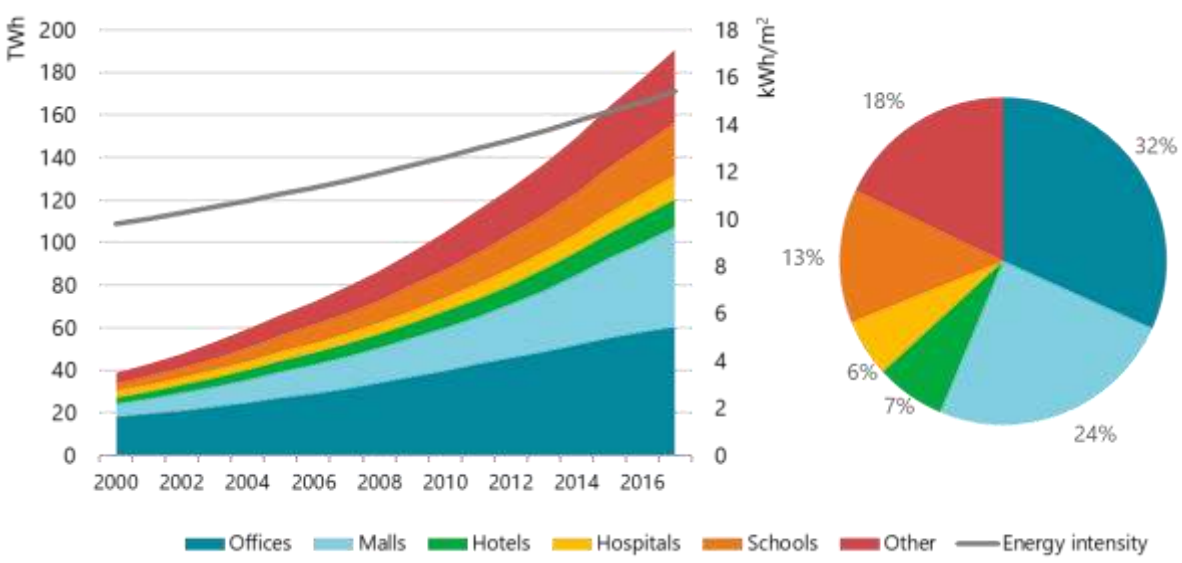
Building cooling energy dramatically increased

- In 2017, electricity used for cooling in **urban residential buildings** in China's was 95 TWh, resulting in about 60 $MtCO_2$, increased more than **ten** times.
- In 2017, electricity used for cooling **public and commercial buildings** in China's was around 190 TWh, increased by **four** times

Urban residential buildings



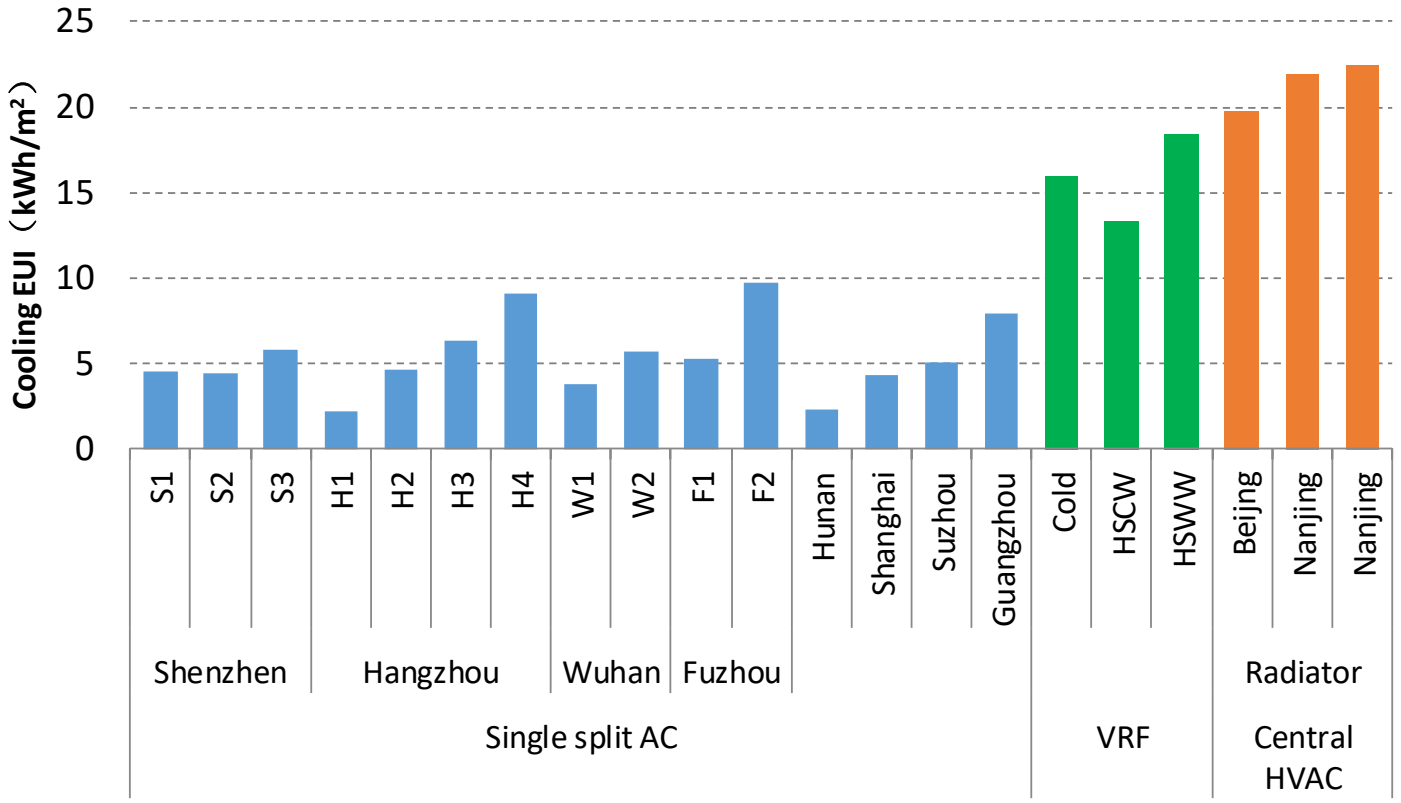
Public and commercial buildings

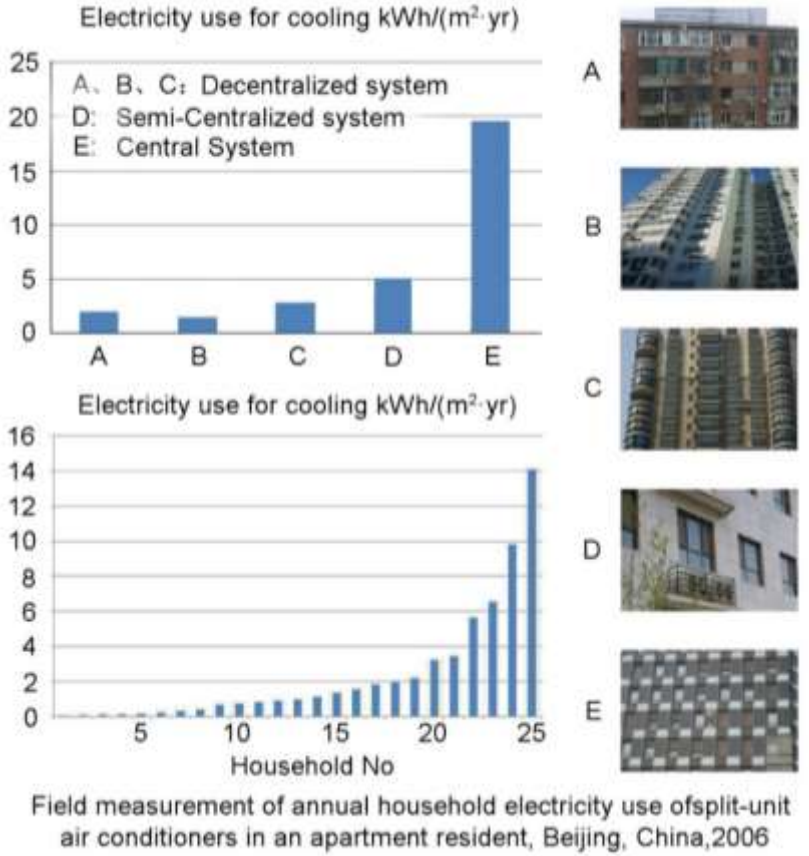


Data source: IEA & Tsinghua, The future of Cooling in China.

Real data reveals huge cooling EUI diversities

- Different occupant behavior modes can lead to more than 10 times' difference in cooling energy use intensity





Field measurement of annual household electricity use ofsplit-unit air conditioners in an apartment resident, Beijing, China,2006

Data source: Hu S, Yan D, Qian M. Using bottom-up model to analyze cooling energy consumption in China's urban residential building

Major reason for the huge difference on cooling EUI, occupant behavior

P^2 mode

Part time & Part space mode

Decentralized equipment/appliance

Cooling system only works when space is occupied

Switch off everything when left from home

F^2 mode

Full time & Full space

Centralized system

provides service for every space

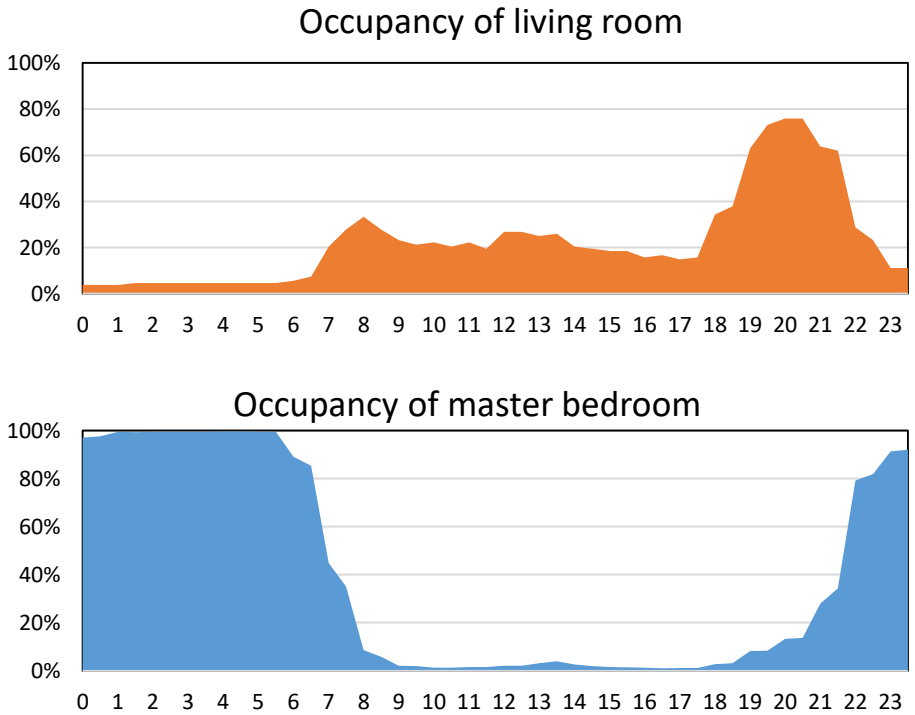
Runs 24 hours a day and 7 days a week

The two types of operation mode could cause the huge difference in cooling demand as high as **10** times !

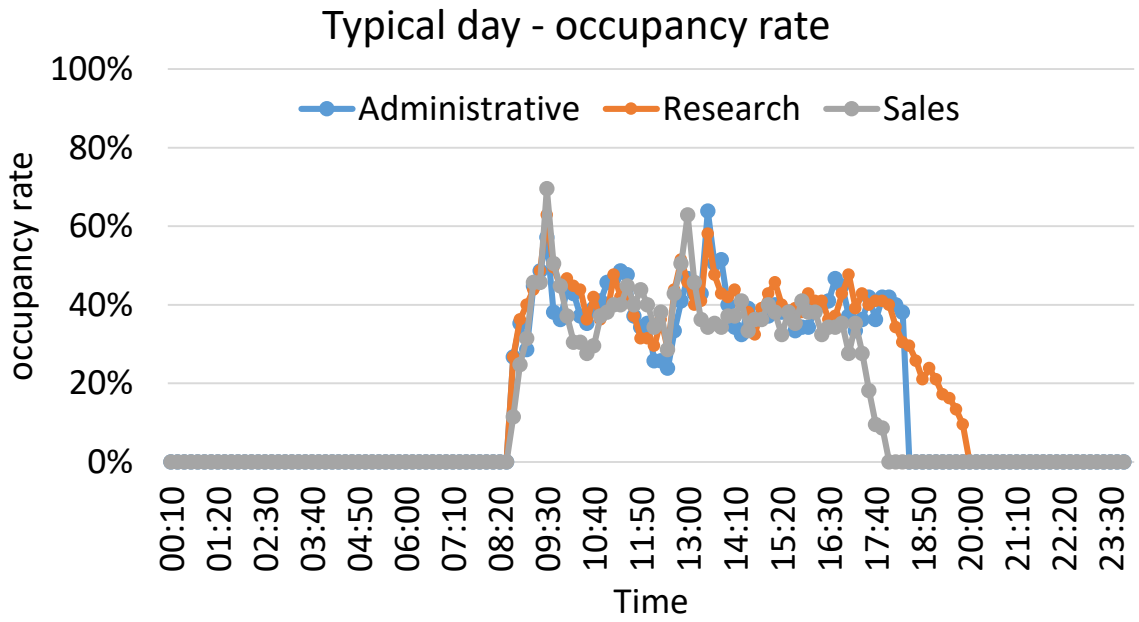
Low occupancy time and space in buildings

Occupied time and Space P^2 mode : F^2 mode = 1: 4~10

- **Residential buildings**
- $\frac{\text{Occupied rooms amount}}{\text{All rooms amount}}$ = 10%-50%



- **Office buildings**
- $\frac{\text{Occupied rooms amount}}{\text{All rooms amount}}$ less than 50%



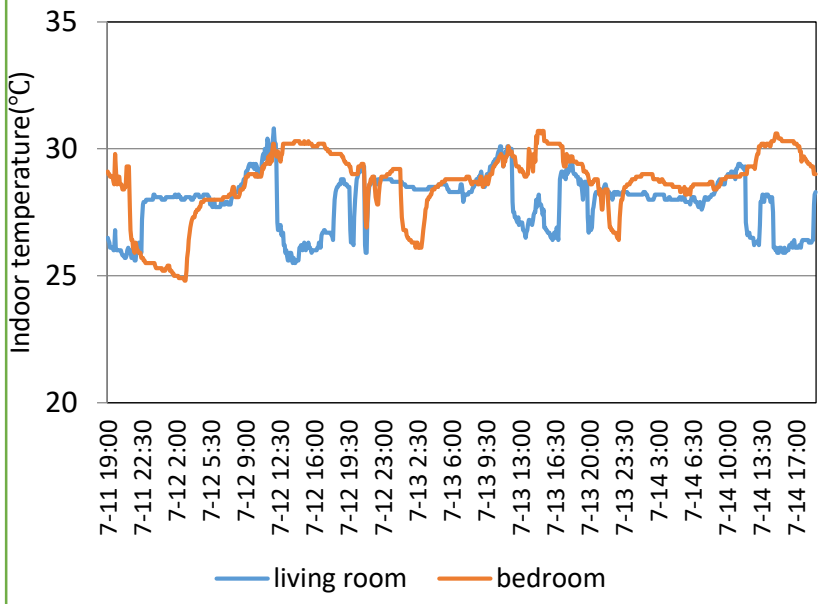
Data source： residential building, from 825 questionnaire in Chengdu. Office buildings, from occupancy simulation.

Occupants require different indoor temp. and humid.

Cooling demand diff. P^2 mode : F^2 mode = 1: 1.5~3

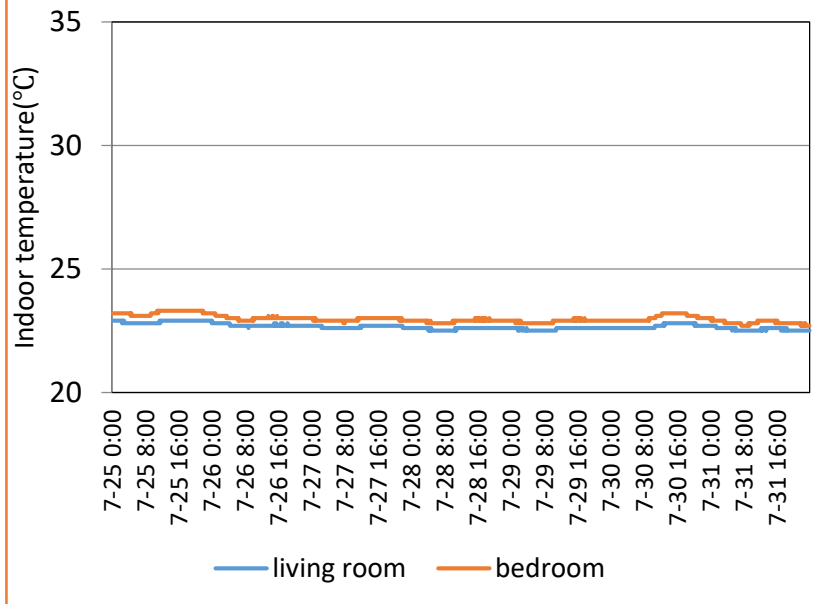
P^2 mode

Indoor Temp.: 25~30 ℃

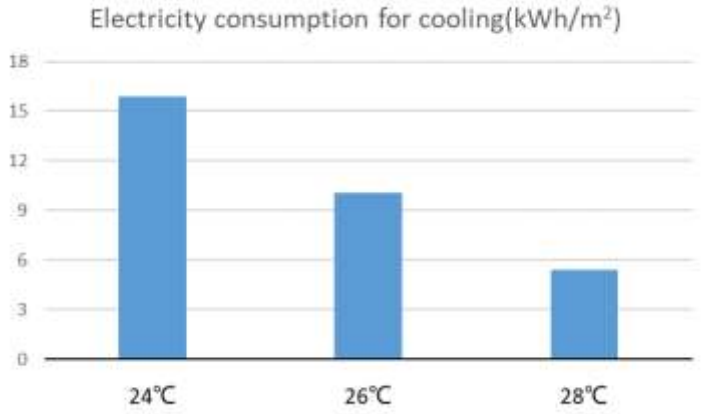


F^2 mode

Indoor Temp.: constant 24 ℃



Set point temperature greatly influenced operating hours and cooling EUI.



Data source: monitoring data from Zhengzhou and Nanjing, located in HSCW zones of China.

Cooling demand difference resulted by OB diversity

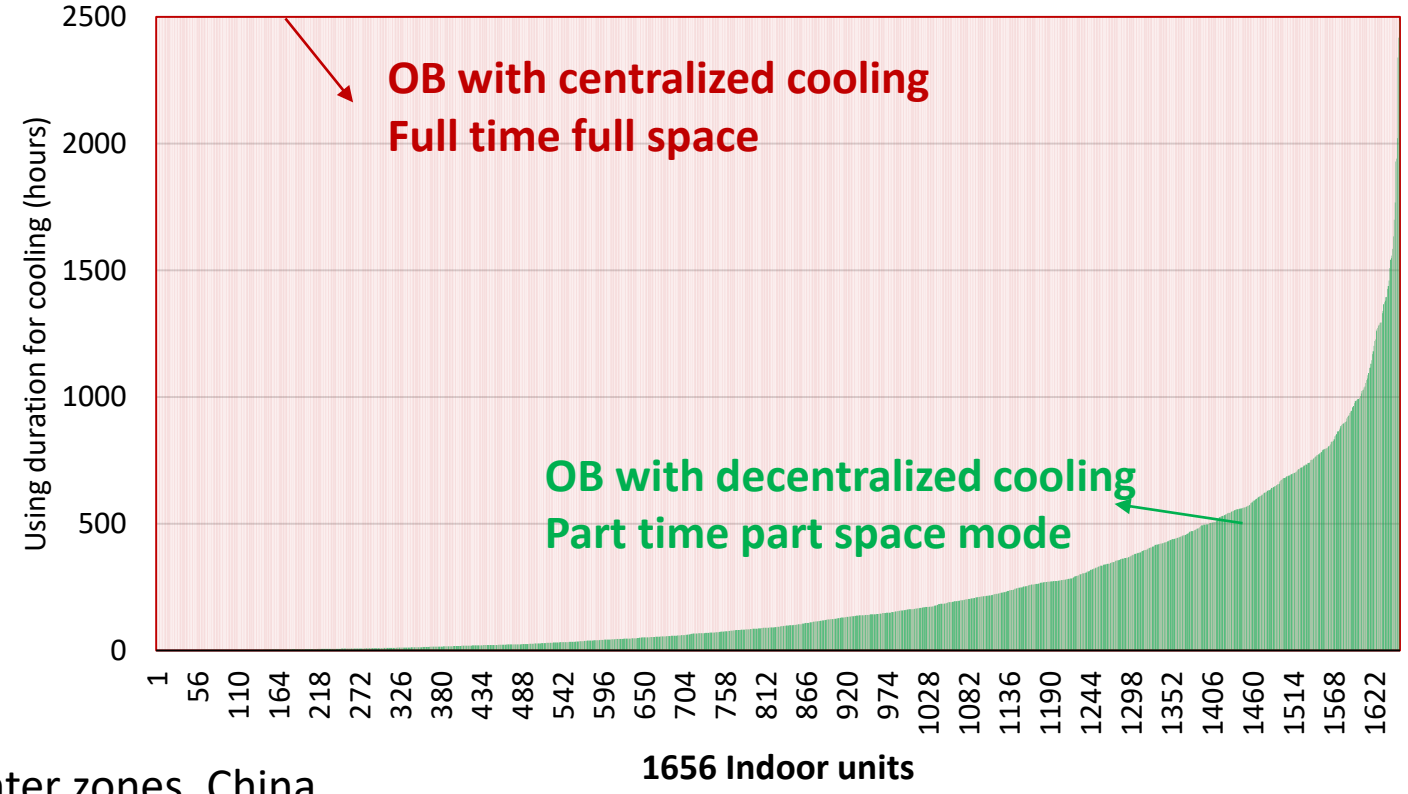
Cooling hours diff. P^2 mode : F^2 mode = 1: 11

P^2 mode

Part time & Part space mode

Average cooling hours **227** hours/summer

Median cooling hours **93** hours/summer



F^2 mode

Full time & Full space mode

Unformed cooling hours : more than **2500** hours/summer

Hot summer and cold winter zones, China

Data source: monitored indoor unit operation hours of VRF systems in hot summer and cold winter China.

Major reason for the huge difference on cooling EUI - occupant behavior

P^2 mode

Part time & Part space mode

Decentralized system

-Single-split AC

-Multi-split AC

Cooling system only works when space is occupied

- Flexible indoor terminals

- Openable windows

Switch off everything when left from home

Cooling demand

1	5-10

Cooling energy efficiency

1	1-2



Cooling energy consumption

1	3-10

F^2 mode

Full time & Full space

Centralized system

-GSHP, CHP, chillers…

provides service for every space

-radiator terminals

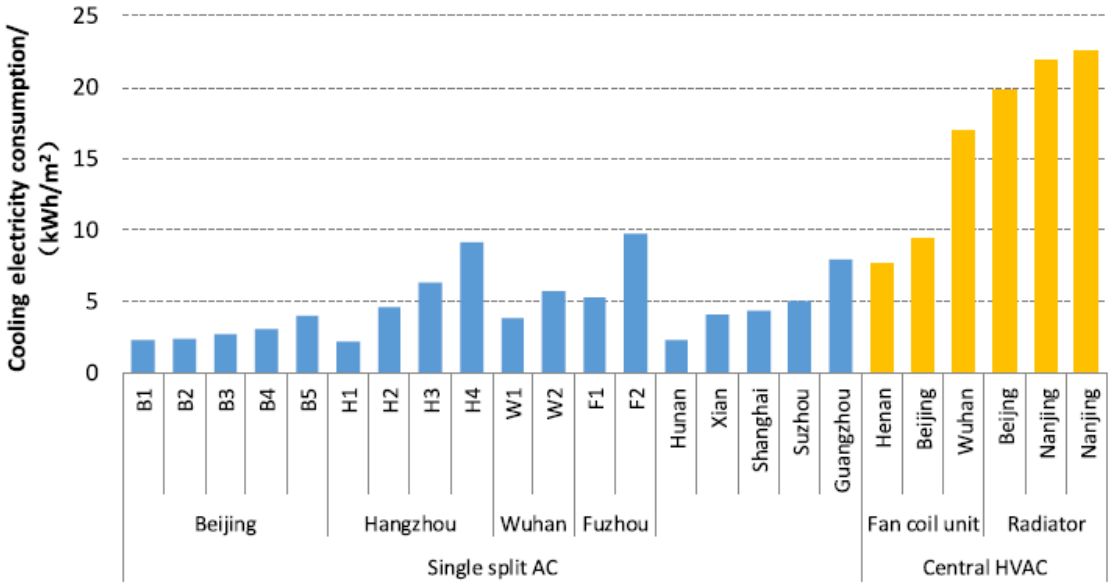
-VAV/CAV terminals

Runs 24 hours a day and 7 days a week

No obvious difference on indoor thermal comfortable level

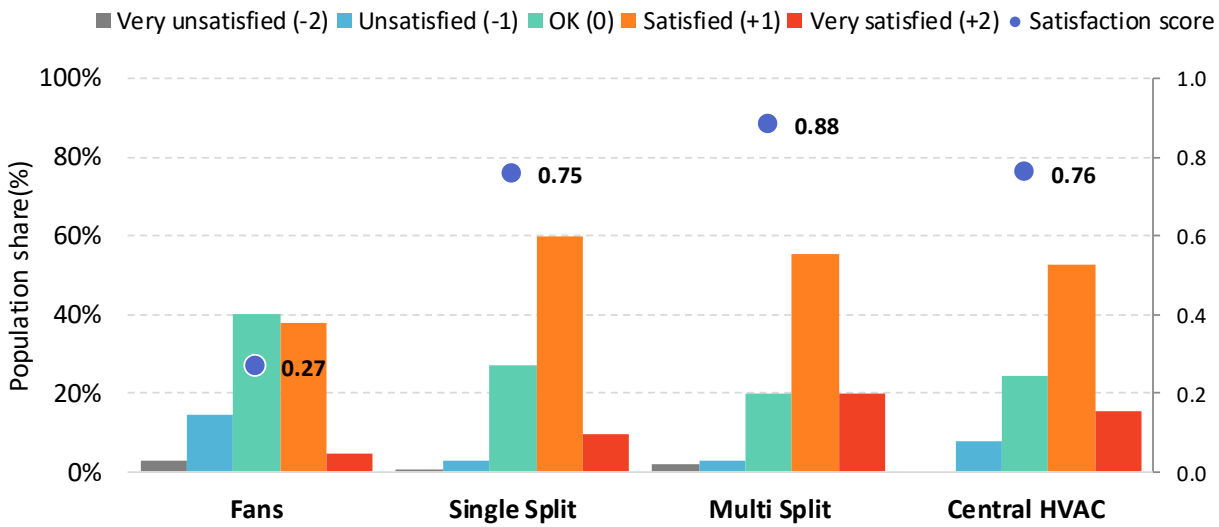
- F^2 mode provide constant indoor environment with cost of 3-5 more energy usage
- But F^2 mode does not provide better indoor environment according to occupant feed back

EUI of different cooling devices



P^2 mode | F^2 mode

Feedback from occupant with different cooling devices

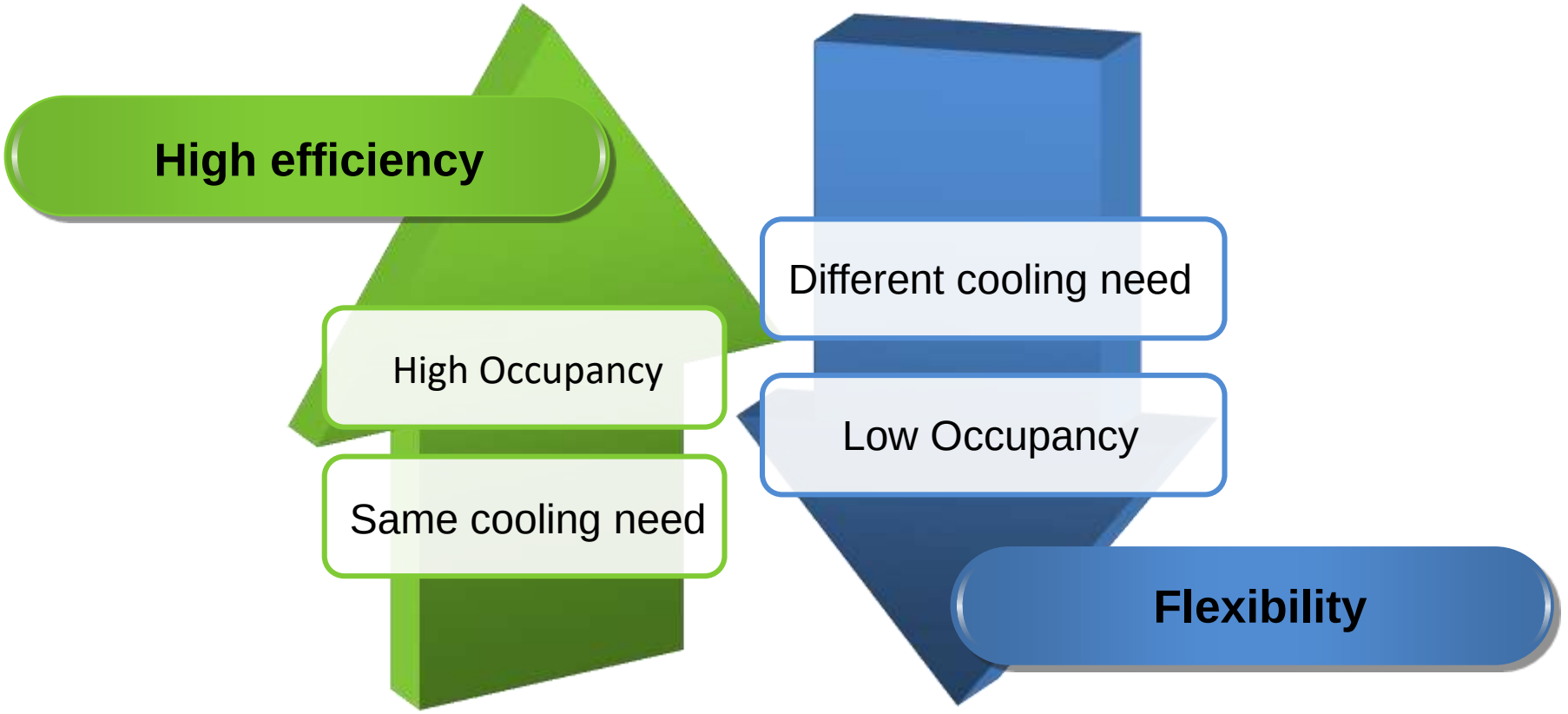


P^2 mode | F^2 mode

Data source: National online questionnaire survey, sample N =11287.

Implications on future sustainable cooling

- For China's sustainable cooling, high efficiency is important but flexibility should be the priority



Implications on future sustainable cooling

$$\text{Energy consumption} = \frac{\text{Service demand}}{\text{Efficiency}} = \frac{Effective\ \text{demand} + Non\text{-}effective\ \text{demand}}{Efficiency}$$

Non-effective service demand

P^2 mode rather than **F^2 mode**

Control according to **complain** rather than T setting-point

Openable windows for outdoor air rather than fully relied on mechanical system

Avoid overcooling, avoid constant indoor thermal environment which is not healthy

Efficiency

High efficiency is important

But flexibility should be the priority

Implications on future sustainable cooling

- It is notable the rapid increasing trend of building cooling energy and emission
- New approach should be developed to meet low energy and low carbon target
- Low energy approach for cooling in civil buildings
  - **P^2 mode** service rather than the **F^2 mode** should be the key issue
  - **Flexibility** may be the priority rather than the efficiency
  - Therefore **decentralized cooling system** should be the priority rather than **centralized cooling system**
  - **Openable windows** for natural ventilation is another important measure
  - **External shading** rather than external insulation is the priority for envelope
  - **Avoiding over cooling**, suitable indoor environment control methods

Thank You!

Shan Hu

hushan@tsinghua.edu.cn

Building Energy Research Center

Tsinghua University

Beijing, China