Tsinghua University

CLIMA 2019

Built environment facing climate change

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Radiant Floor Cooling and Applications in Airport Terminals

Prof. Dr. Xiaohua Liu

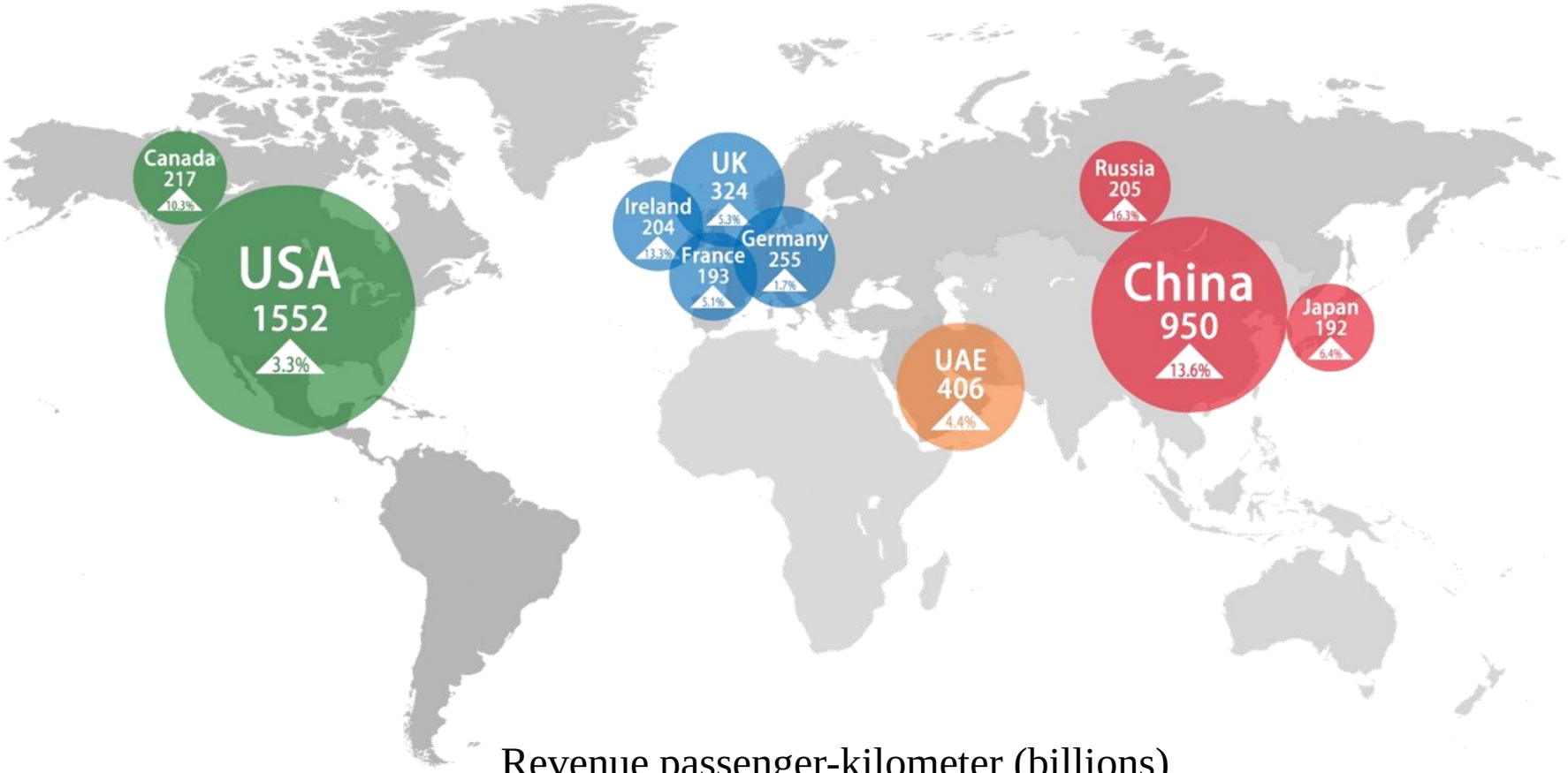
Dept. Building Science,

Tsinghua University, P.R.China

Contents

1. Background

- **Rapid development of civil aviation over the world**
  - **Top 10 countries or groups of countries in 2017**



Revenue passenger-kilometer (billions)

[1]. Data from ICAO Annual Report 2017: Air Transport Statistics, https://www.icao.int

1. Background

- **Rapid development of airports in China**
  - **2017: 229 civil airports** **2030s: over 400**

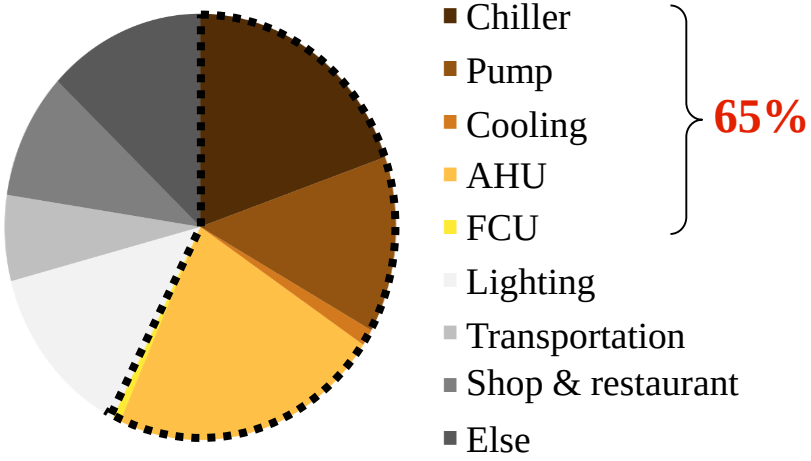
Master plan of civil airports in China by 2030

1. Background

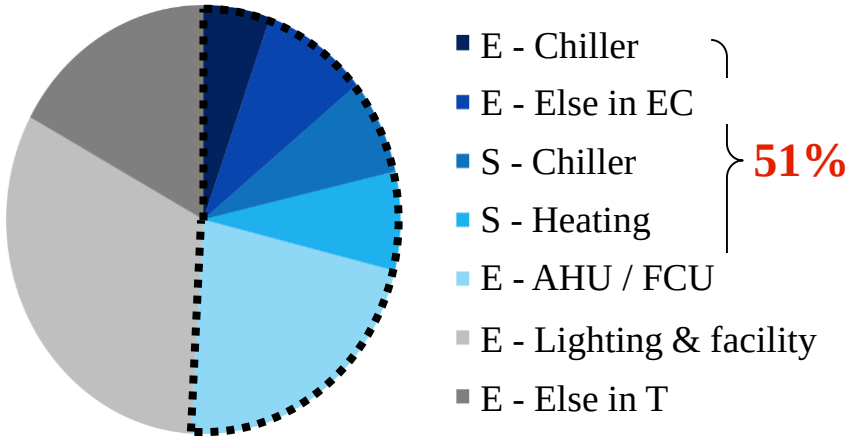
- **Energy consumption of airport terminal (AT)**
  - **China[1]: electricity 177 $kWh_e/m^2 \cdot yr$, twice**
  - **Japan[2]: primary energy 3002 $MJ/m^2 \cdot yr$, 1.7 times**
  - **Greece[3]: total energy 234 $kWh_t/m^2 \cdot yr$, 1.3 times**

  } **of office buildings**

An airport in China[1]



An airport in Japan[2]



Energy consumption of HVAC accounts for 40%~70%

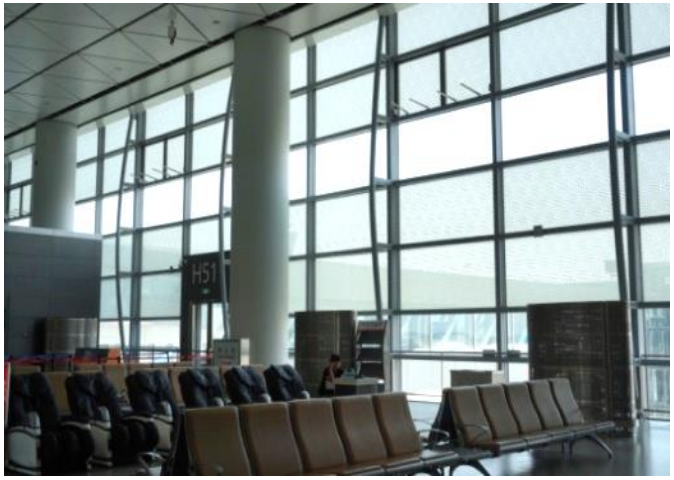
[1]. Zhao, Master Thesis, Beijing, Tsinghua University, 2015.
[2]. Liu, 2017 summer research into airport terminals in Japan, data from MLIT Japan and airports.
[3]. Balaras, et al., Energy Build. 2003, 35: 1105-1120.

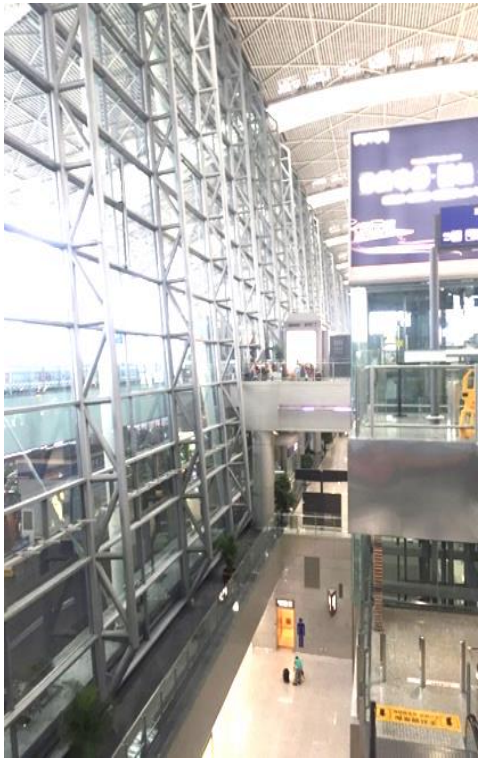
2. What's happening

Characteristic of large scale buildings

——Airport terminals, railway stations, exhibition halls, etc.

- **High interior space (10~20m or even higher)**
- **Occupancy zone mostly within 2m**
- **Transparent glass curtain wall**



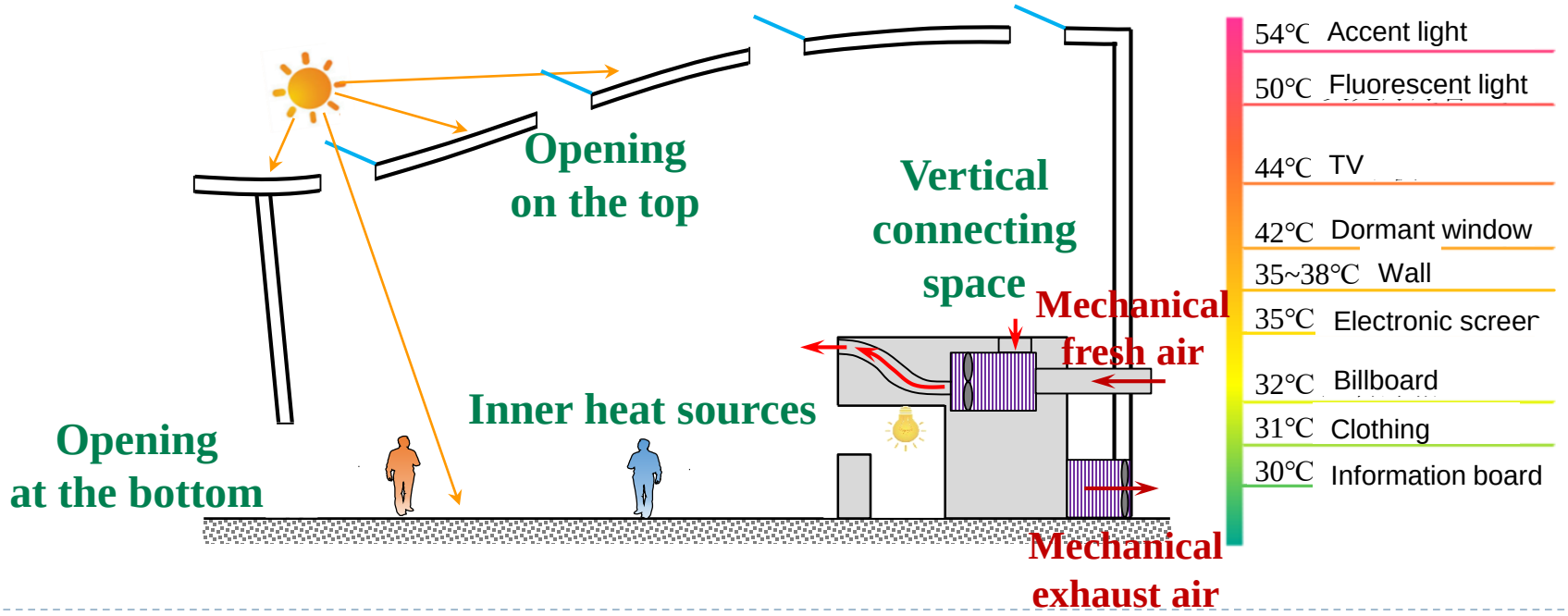


2. What's happening

Characteristic of large scale buildings

——Airport terminals, railway stations, exhibition halls, etc.

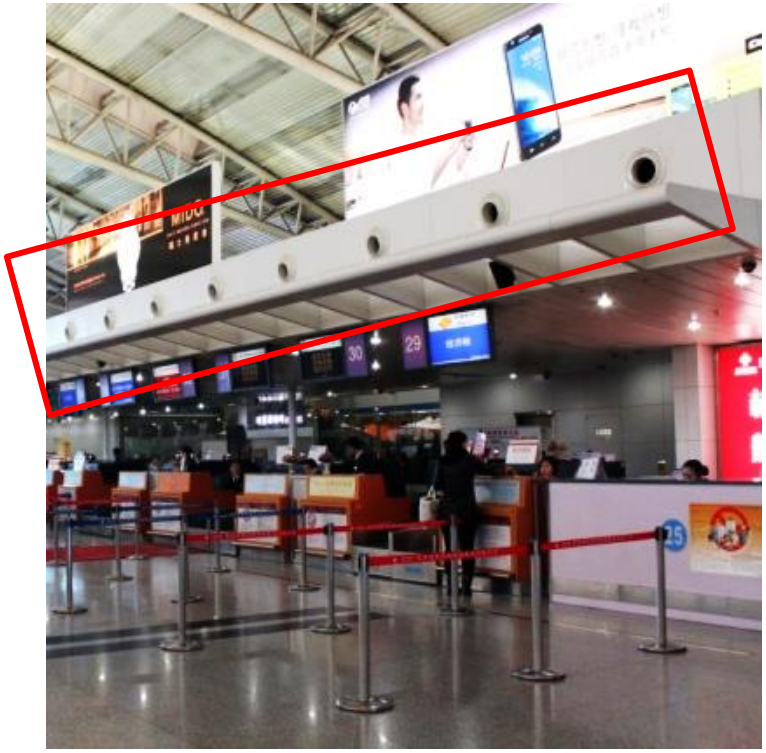
- **Solar radiation from envelope**
- **Complex heat sources**



Liu XH, ... Springer Press, 2014

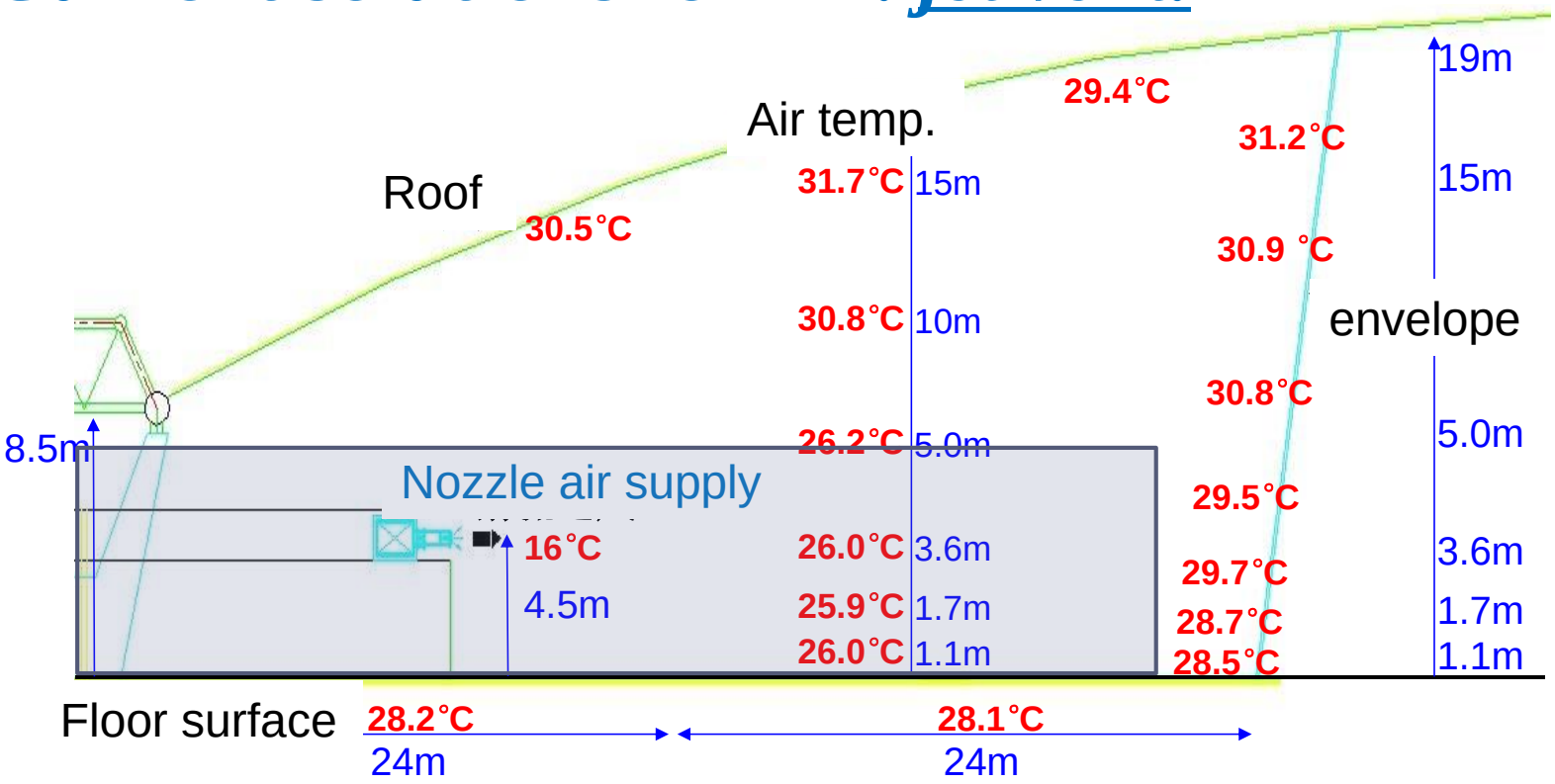
2. What's happening

- **Current solutions for AT: *jet vent.***



2. What's happening

- **Current solutions for AT: *jet vent.***

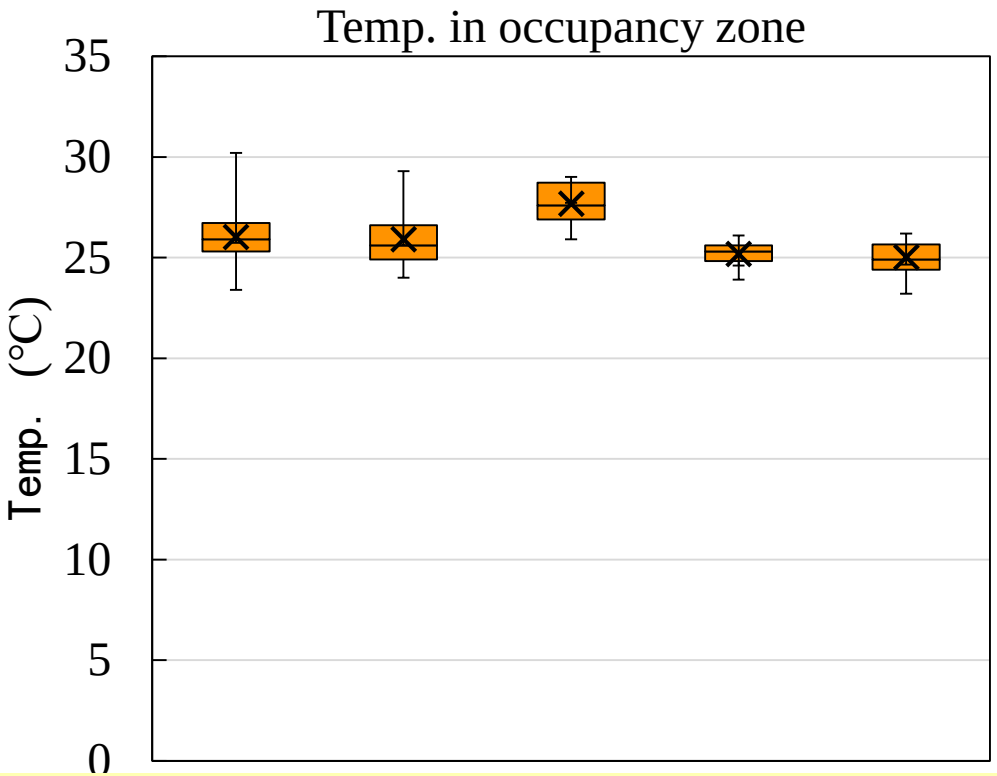


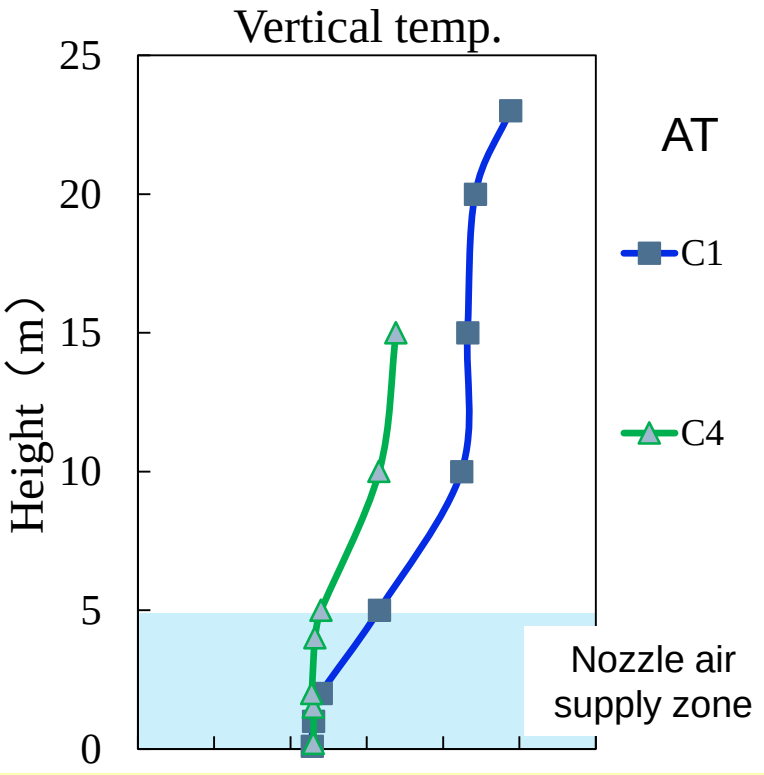
Temp. control under the height (3~5m) of jet vent., realizing stratified AC system in large spaces

Liu XH, ... Springer Press, 2014

2. What's happening

Current solutions for AT-summer



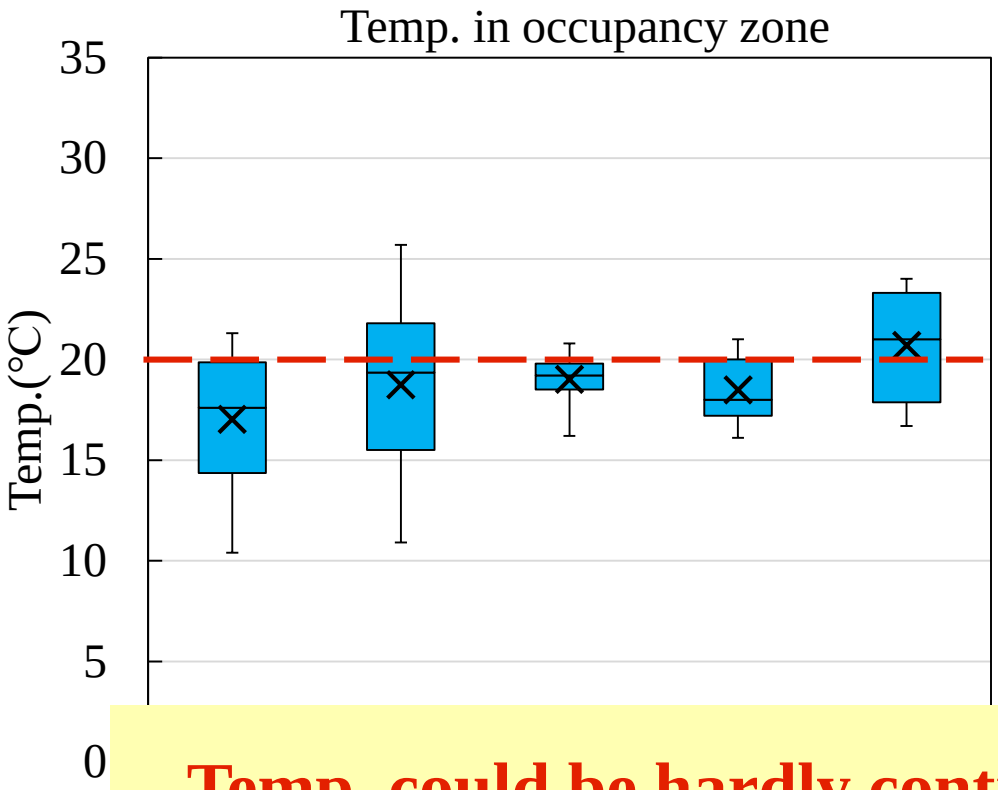


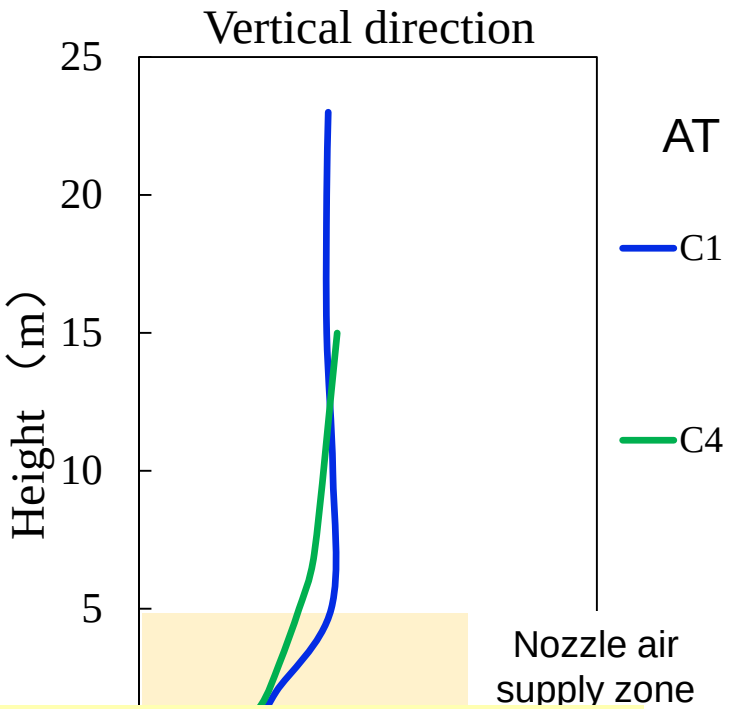
Temp. could be well controlled within jet vent. height (3~5m)

*Liu XC, **Liu XH**, ... Energy and Buildings, 2019 (submitted)*

2. What's happening

Current solutions for AT-winter





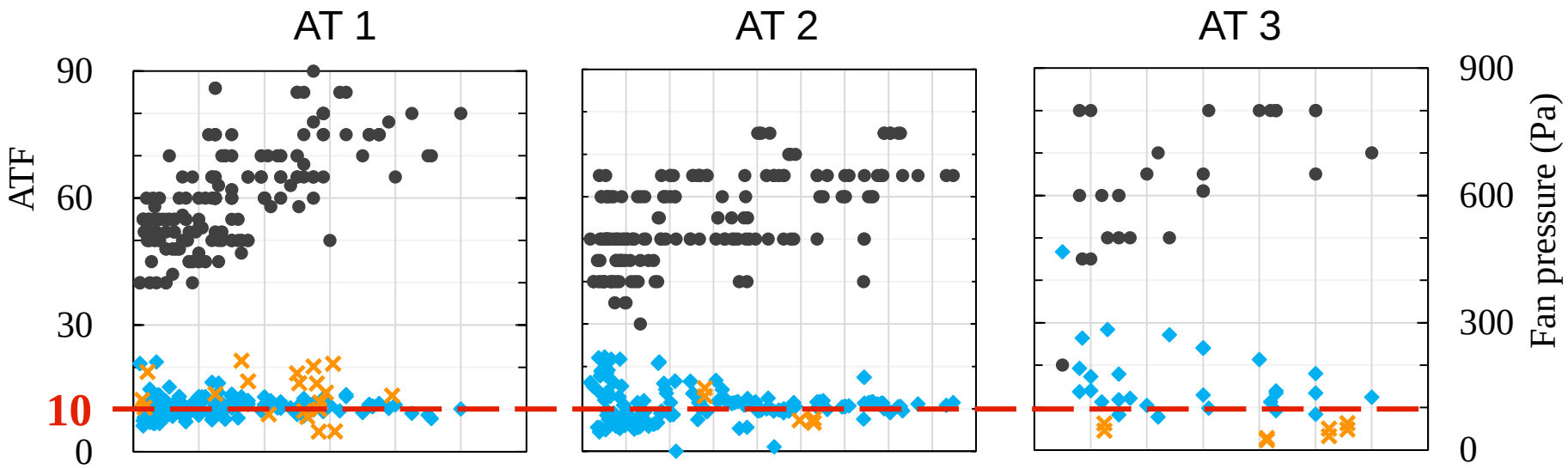
Temp. could be hardly controlled in lower space due to the lower density of hot air supply

*Liu XC, **Liu XH**, ... Energy and Buildings, 2019 (submitted)*

2. What's happening

Current solutions for AT

$$\textit{ATF of air handling unit} = \frac{\textit{Cooling/heating capacity}}{\text{Fan power}}$$

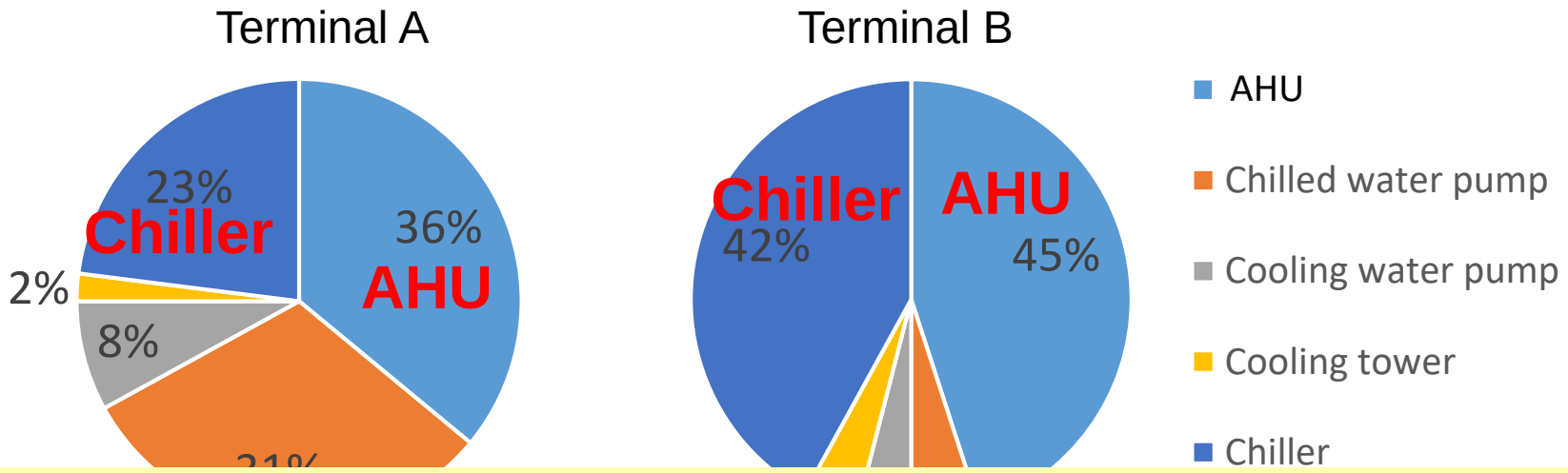


Tested ATF ≈ 10 or even lower, restricting the energy performance of the AC system

2. What's happening

Current all-air system

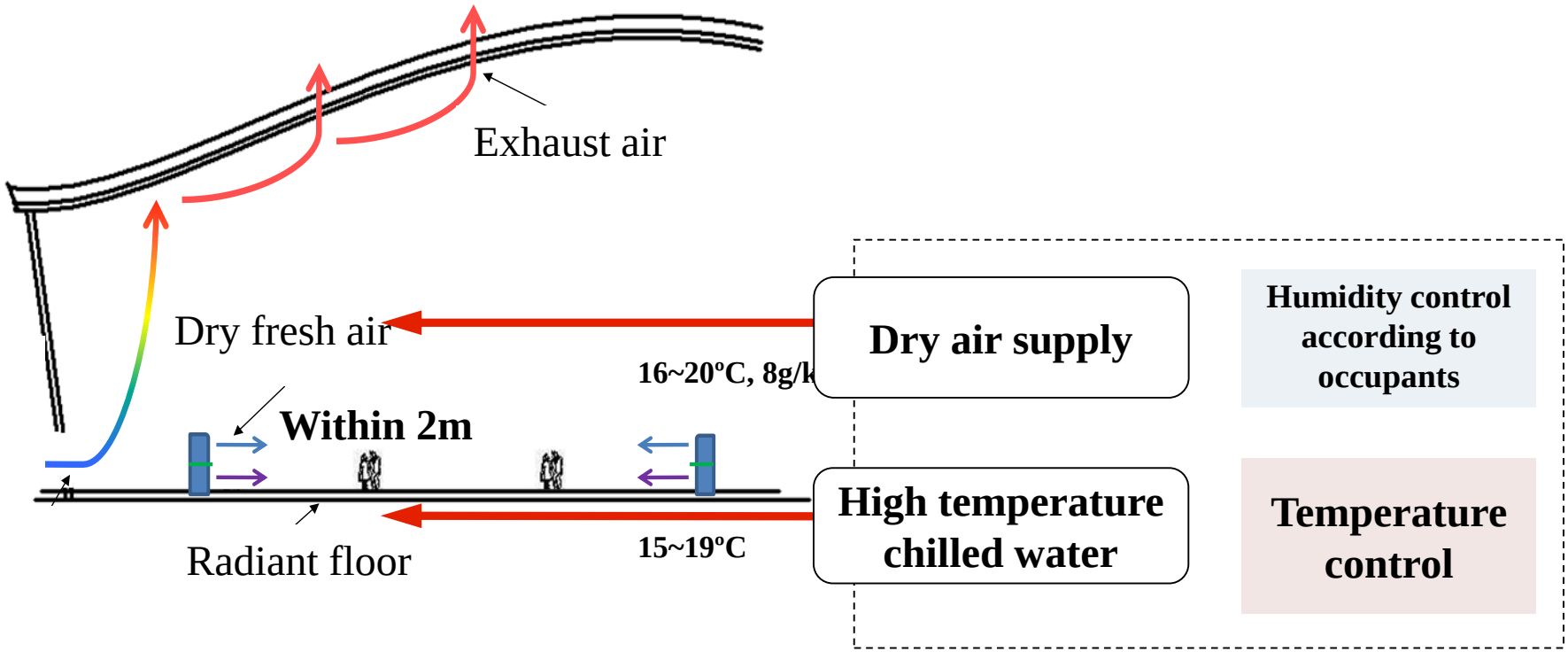
- Significant energy consumption for air transportation
- Accounting for 30%~50%, even higher than that of chiller



Terminal solution for improving thermal environment and reducing energy consumption is required!

3. How to improve

Radiant floor in AT

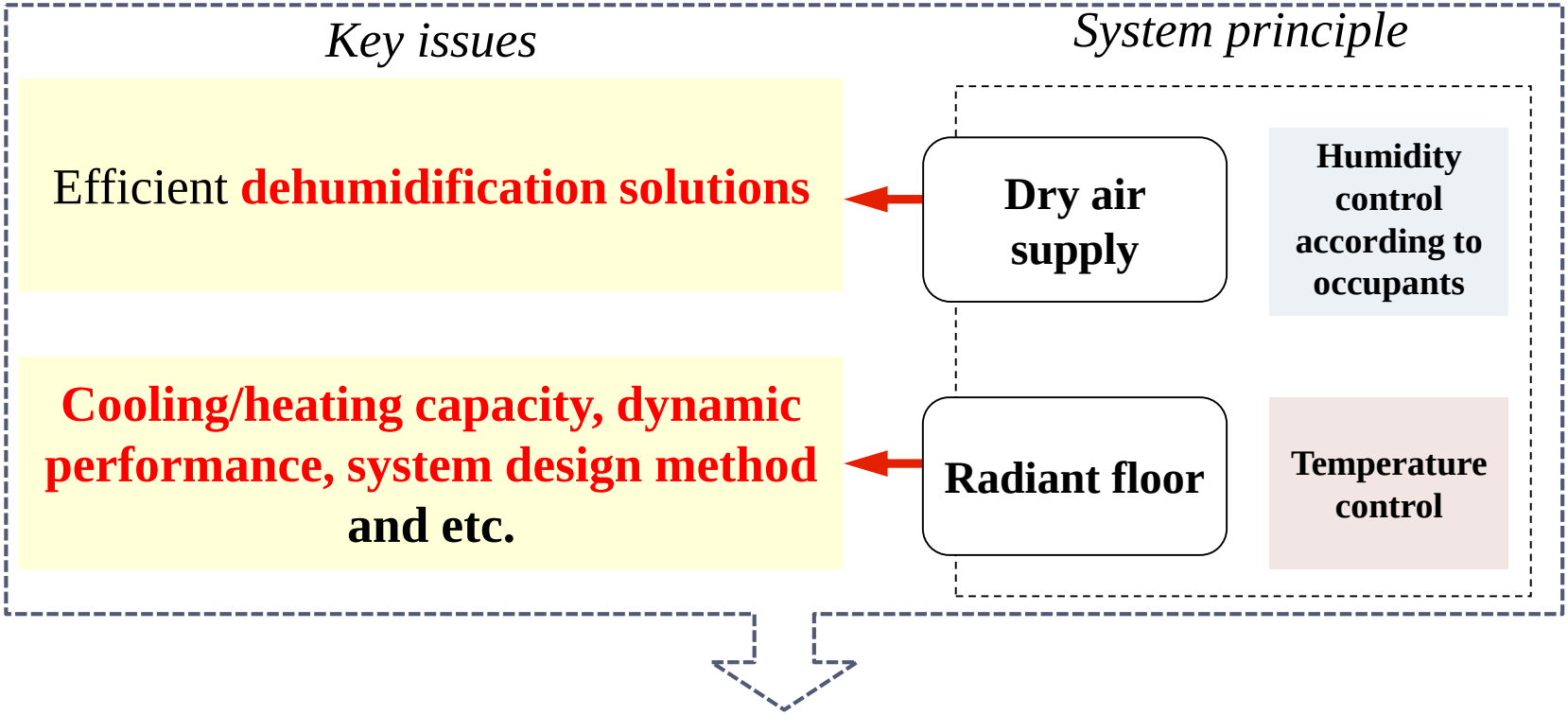


Radiant floor **acts as the terminal device** ***improving thermal environ.*****, realizing** ***high T cooling/ low T heating***

Liu XH*, … Springer Press, 2014*

3. How to improve

Radiant floor in AT



The same terminal device both in winter and summer

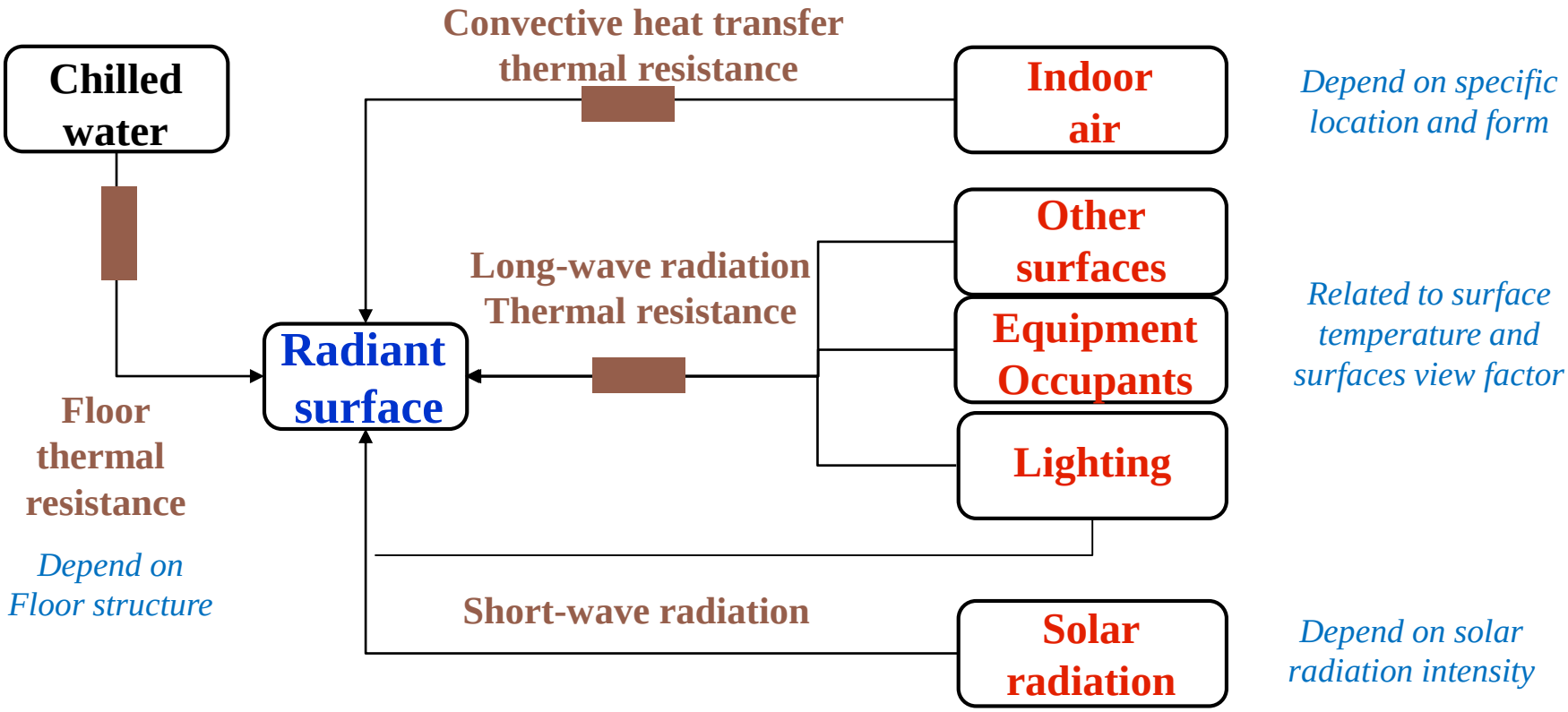
Energy saving potential in AT

Liu XH, ... Springer Press, 2014

3. How to improve

Characteristic of radiant cooling

- **Heat transfer process from cooling medium to heat sources**



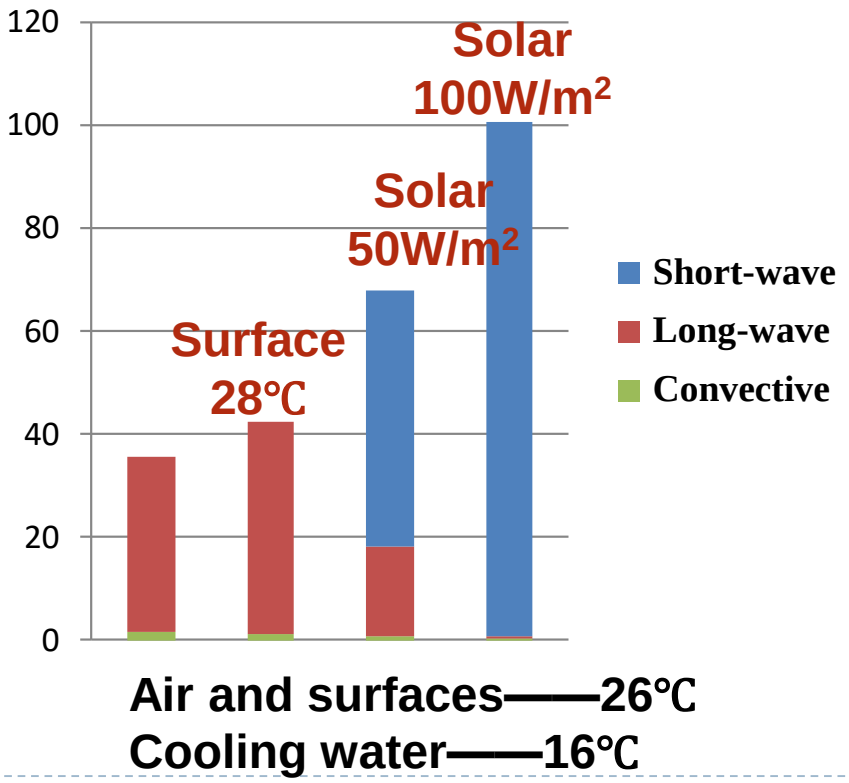
*Zhao K, **Liu XH**, … Solar Energy, 2014*

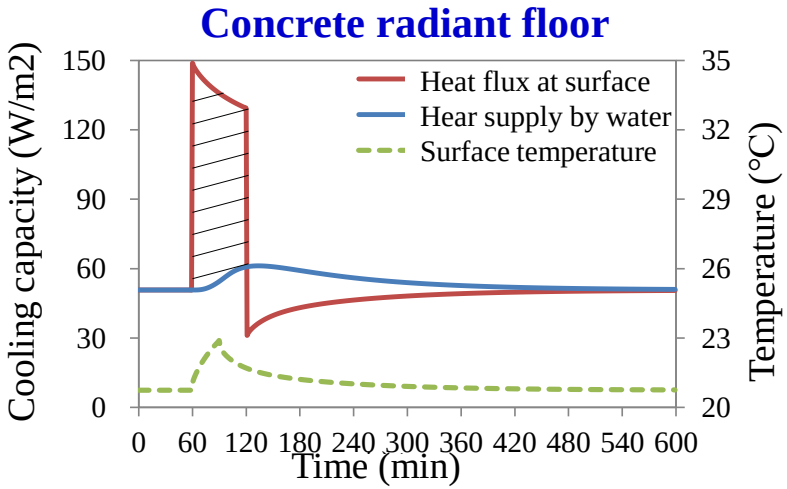
3. How to improve

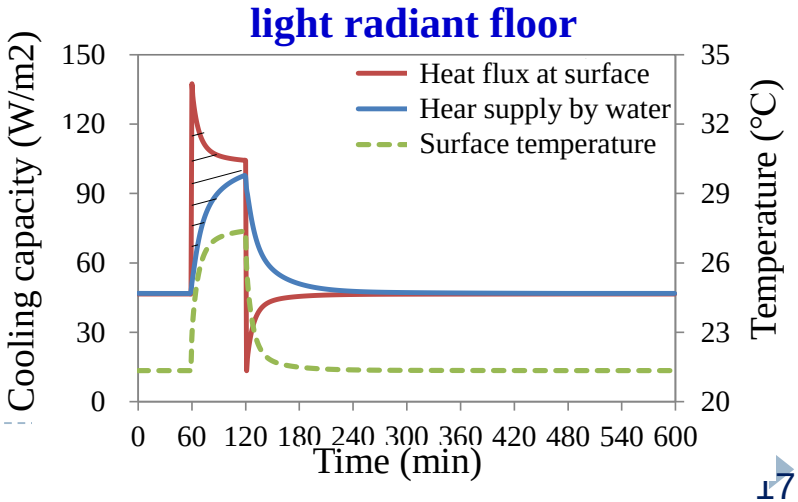
Transient response of solar radiation

Solar intensity: 100W/m², 60min~120min

$$q = q_{cov} + q_{longwave} + q_{shortwave}$$





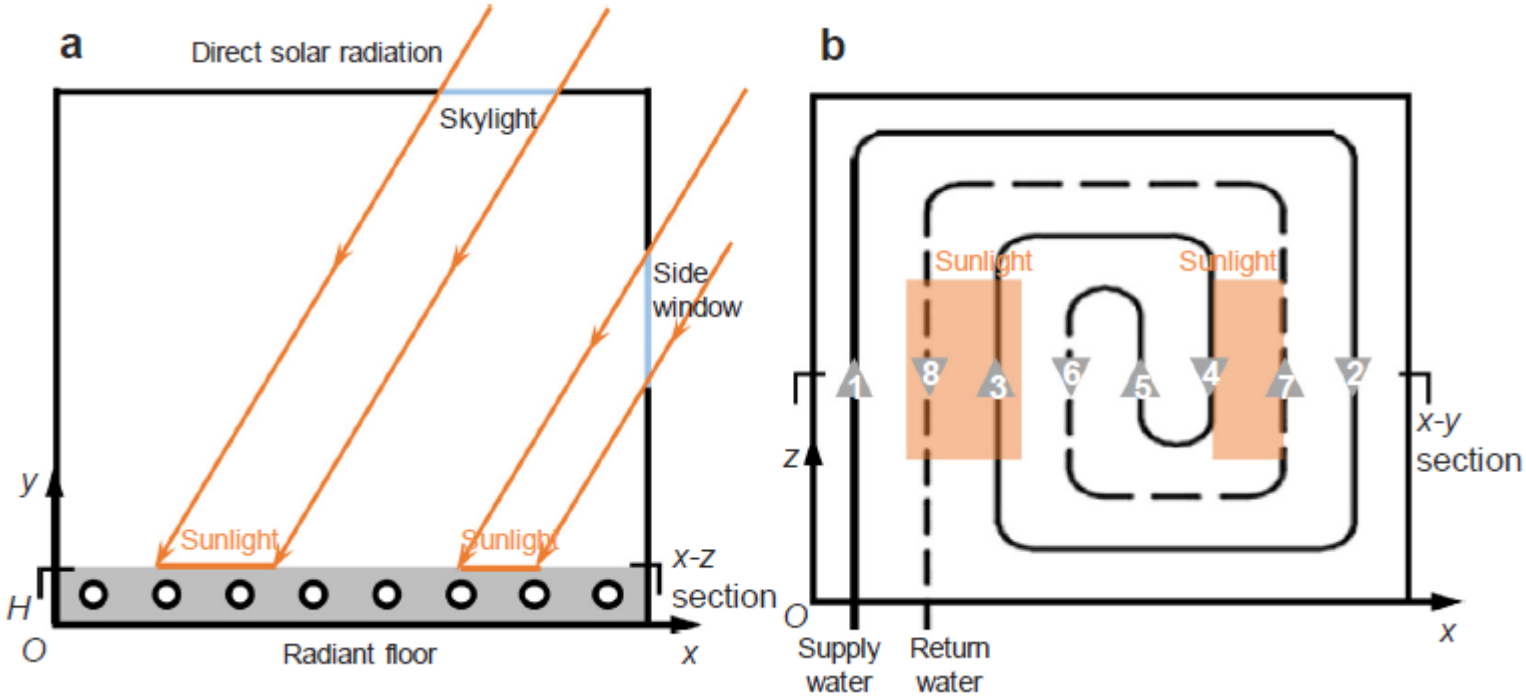


*Zhao K, **Liu XH**, … Solar Energy, 2014*

3. How to improve

Characteristic of radiant cooling

How to calculate indoor solar radiation for system design



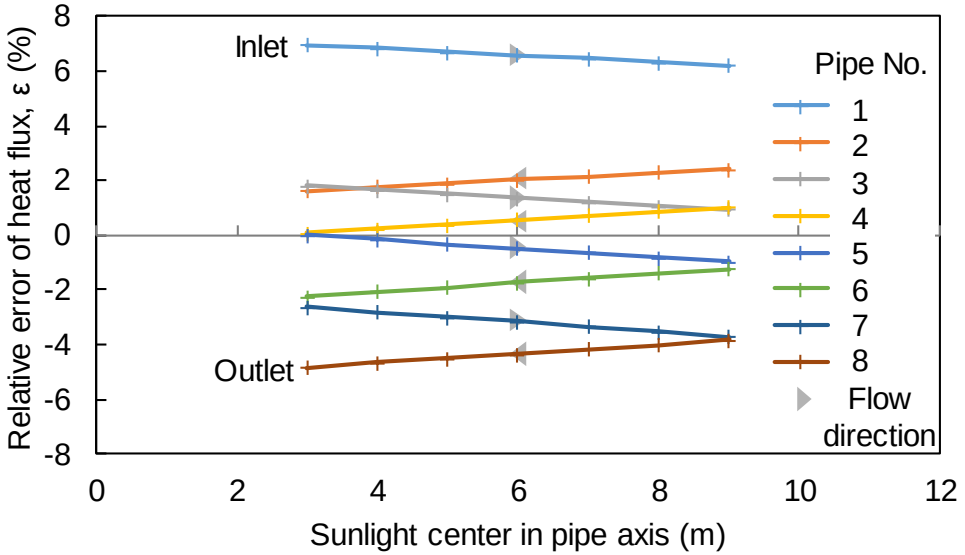
Homogenizing spatial solar distribution

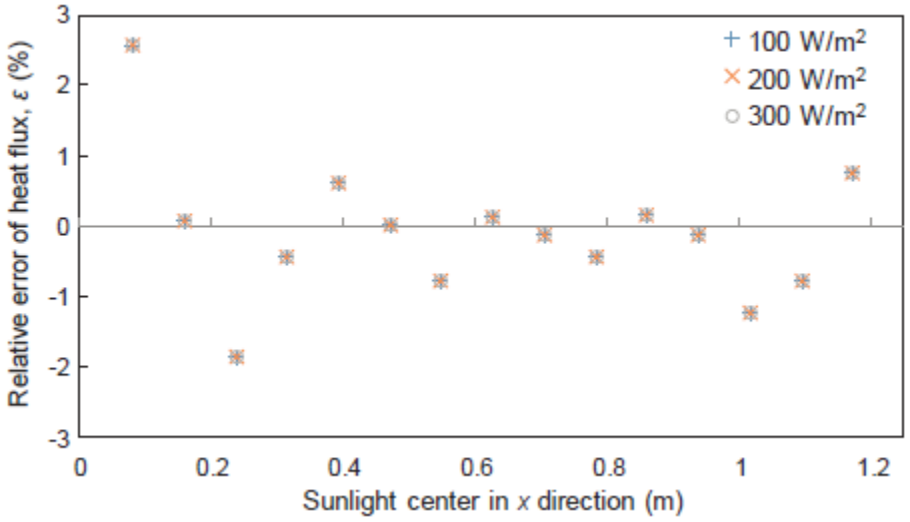
$$\varepsilon = \frac{V_{\text{hom}\,ogenize} - V_{accurate}}{V_{accurate} - V_{nosolar}} \times 100\%$$

3. How to improve

Characteristic of radiant cooling

Limited relative difference for heat flux, cooling capacity





Homogenizing spatial solar distribution

- ***Taking the dynamic solar radiation into account***
- ***Enough accuracy for system design***

*Tang HD, Zhang T, **Liu XH**, … Solar Energy, 2018*

4. Applications in China

Xi'an International Airport- Terminal 3

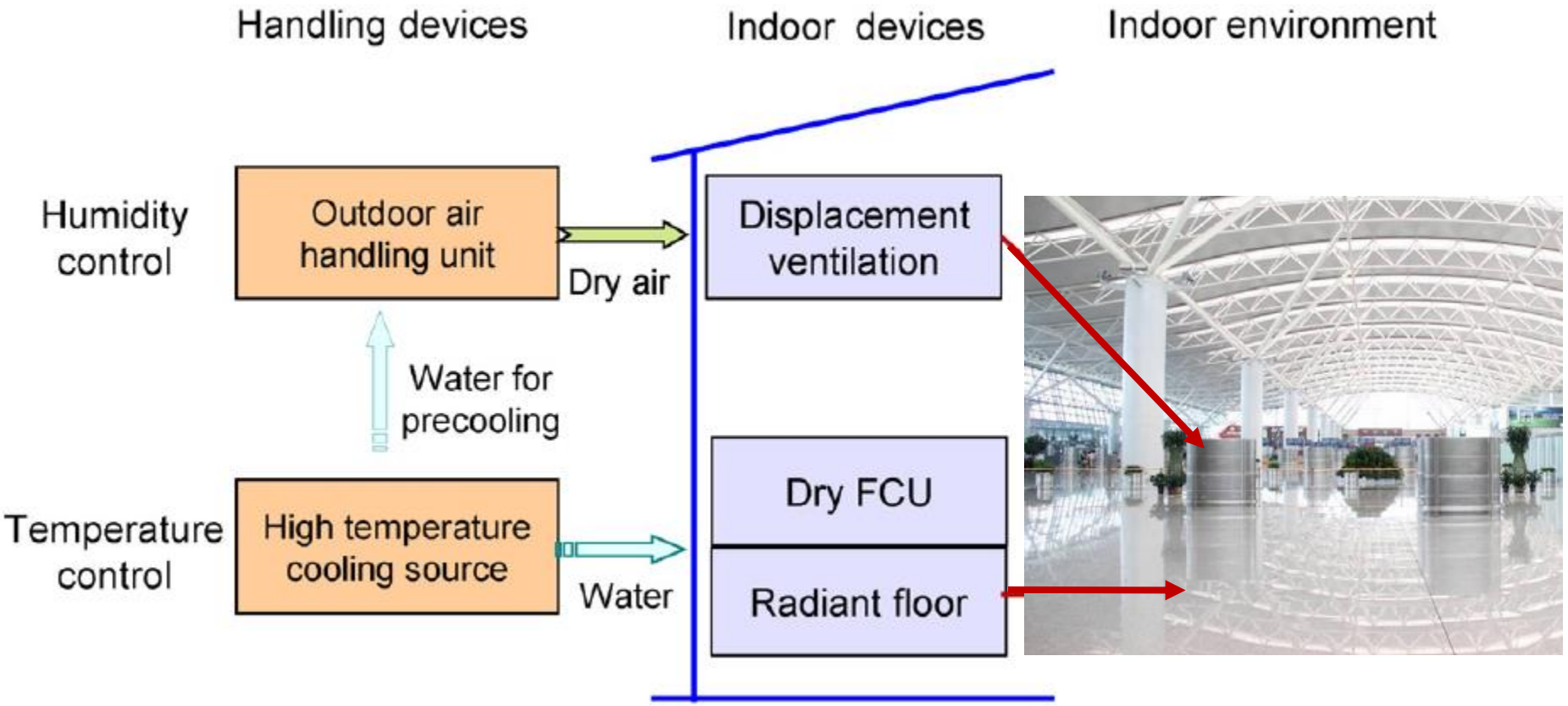
- Cold area in China, with an area of over 280,000 m^2
- Check-in hall - 27m departure hall- 10m
- Radiant floor as cooling/heating terminal

*Zhang T, **Liu XH**, … Energy and Buildings, 2013*

4. Applications in China

Xi'an Airport- Terminal 3

- **Design supply/return temperature:14℃/19℃**



*Zhang T, **Liu XH**, … Energy and Buildings, 2013*

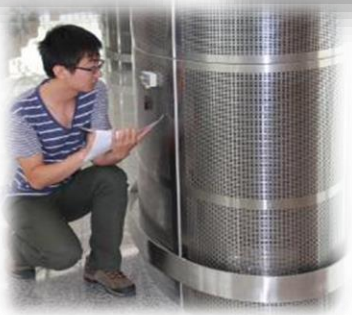
4. Applications in China

Xi'an Airport- Terminal 3

On-site measurements of the applications throughout 2012-2018



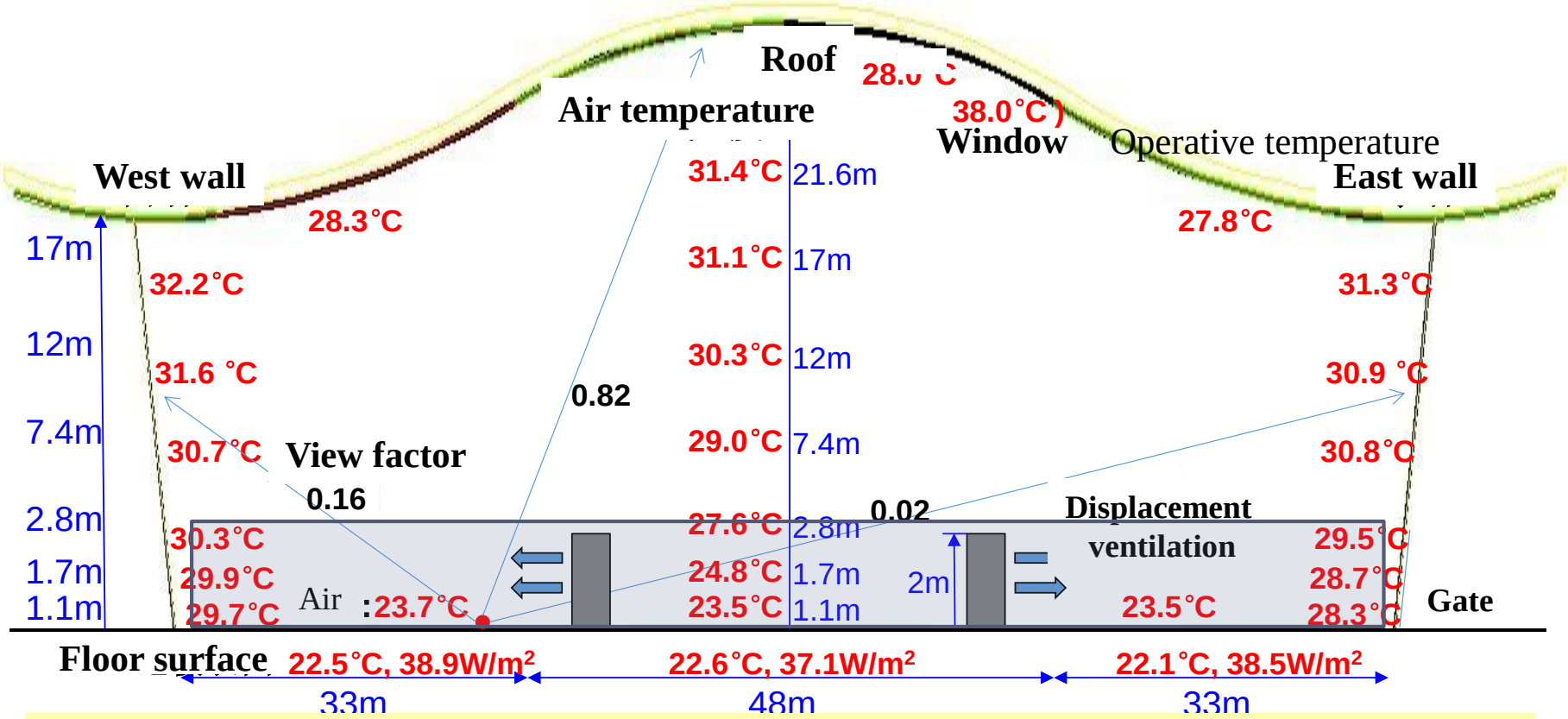



*Zhang T, **Liu XH**, … Energy and Buildings, 2013*

4. Applications in China

Vertical temperature distribution

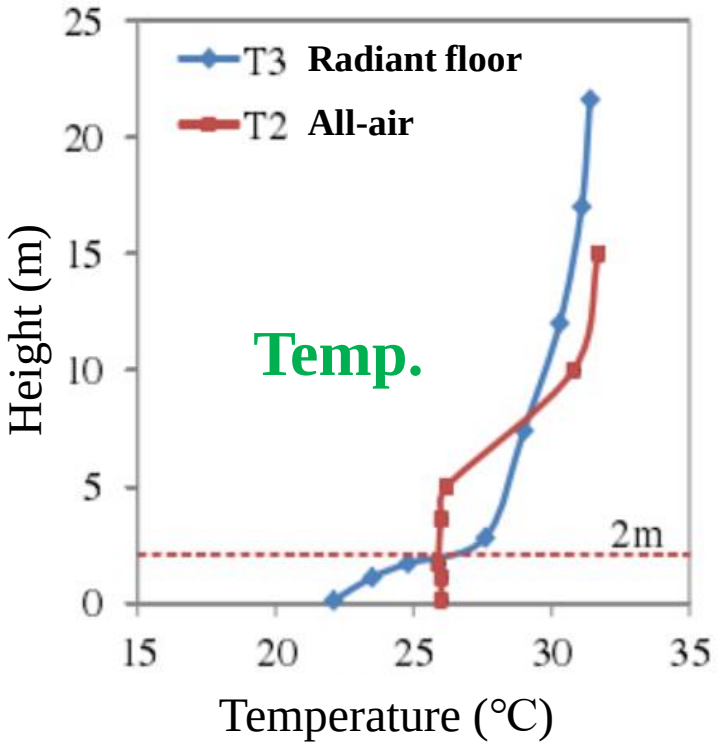


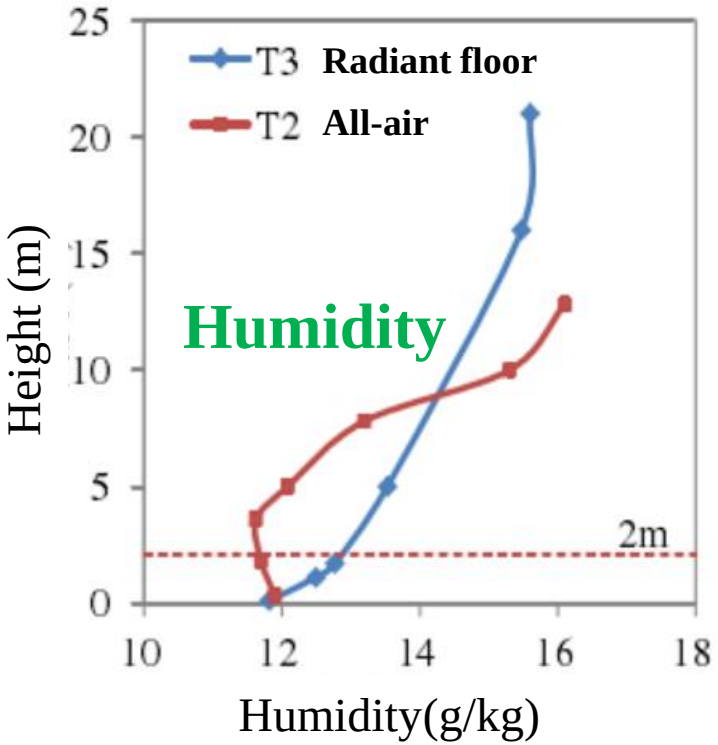
A lower stratified cooling effect compared with jet vent.

*Zhao K, **Liu XH**, ... Solar Energy, 2014*

4. Applications in China

Comparison between T2 and T3



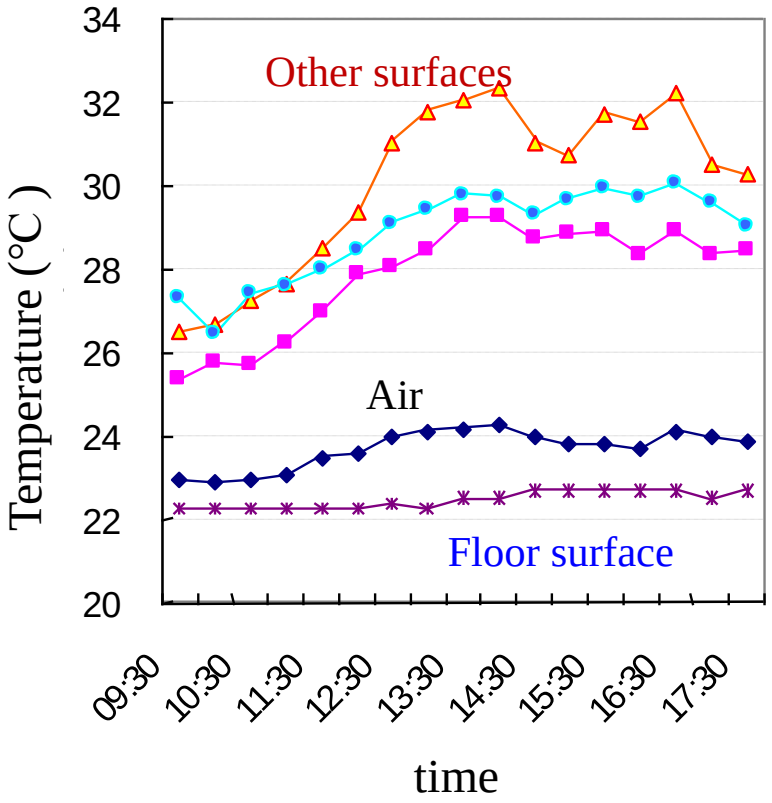


Stratified cooling realized owing to the radiant floor system

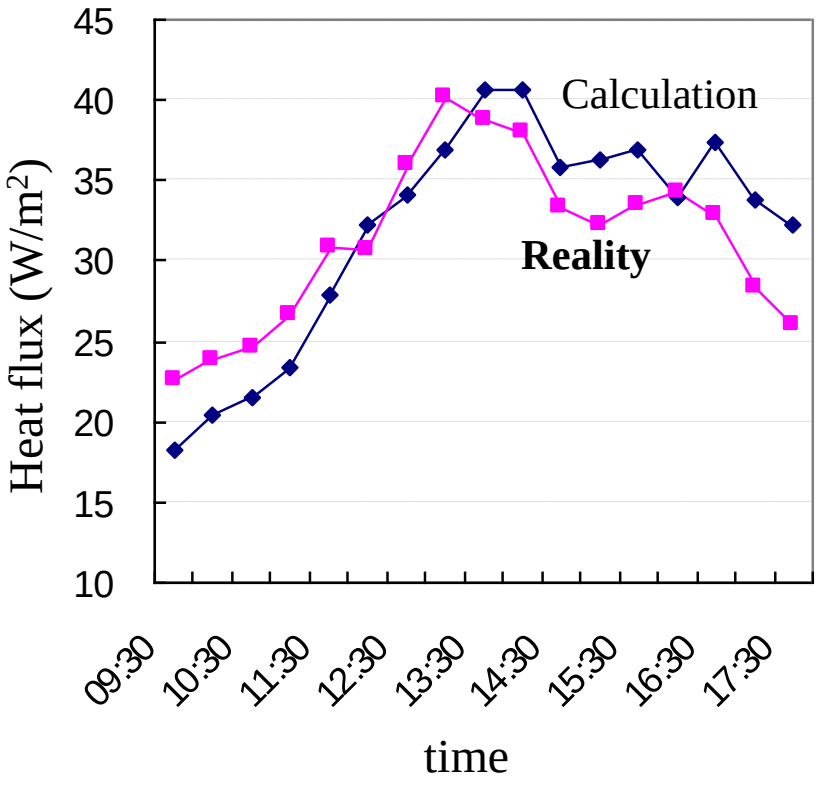
*Zhao K, **Liu XH**, … Renewable & Sustainable Energy Reviews, 2016*

4. Applications in China

Cooling capacity (Cloudy day)



Temperature



Cooling capacity

*Zhang T, **Liu XH**, … Energy and Buildings, 2013*

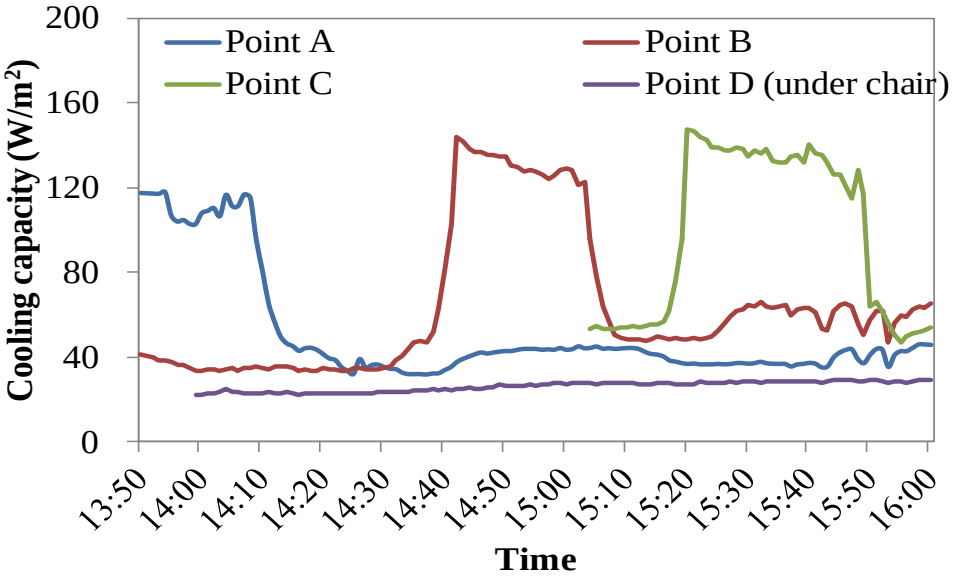
4. Applications in China

Solar radiation processing

- **Discontinuity of solar spot**

Influence of solar radiation?

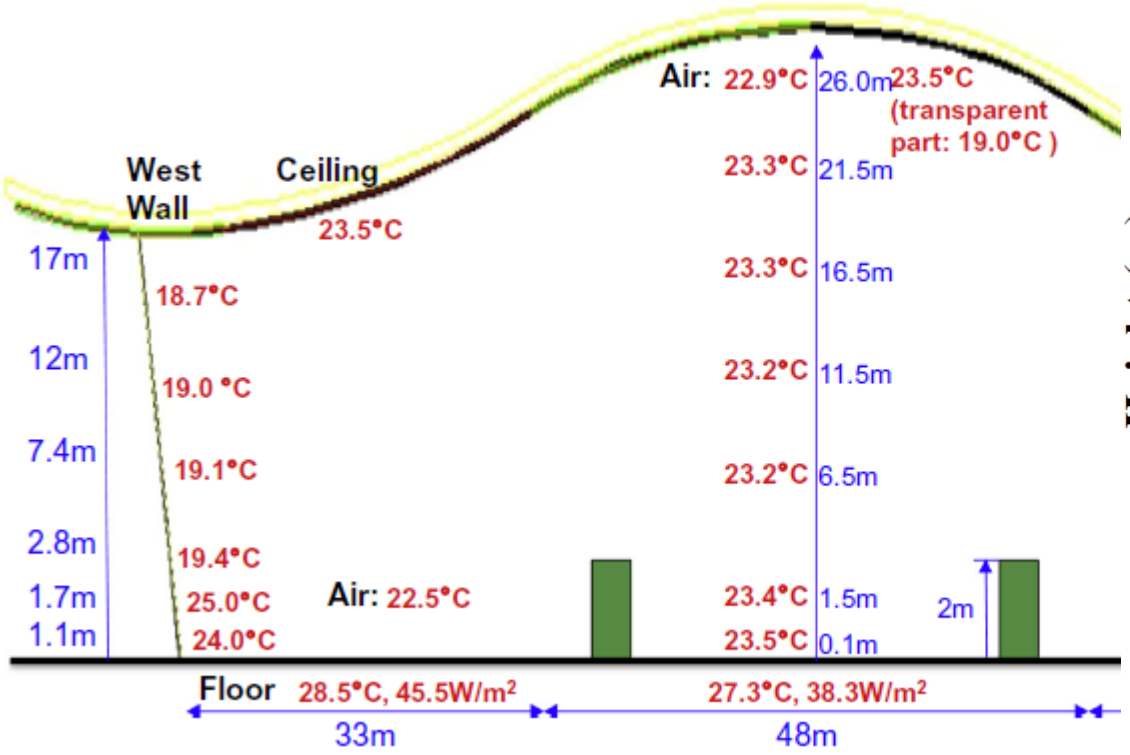
- **YES: 120~150 W/m^2**
- **NO : 30~40 W/m^2**

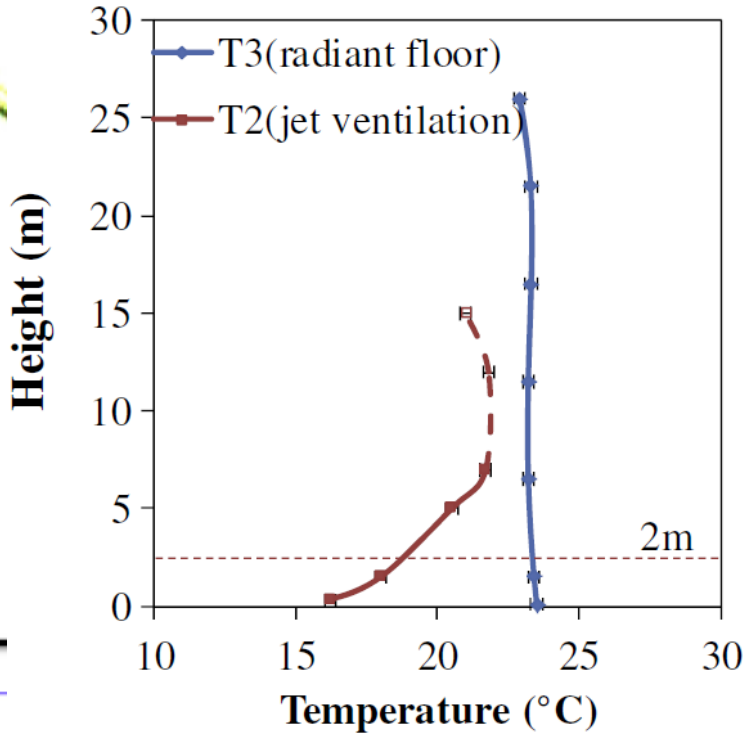


*Zhao K, **Liu XH**, ... Solar Energy, 2014*

4. Applications in China

- **Winter performance**





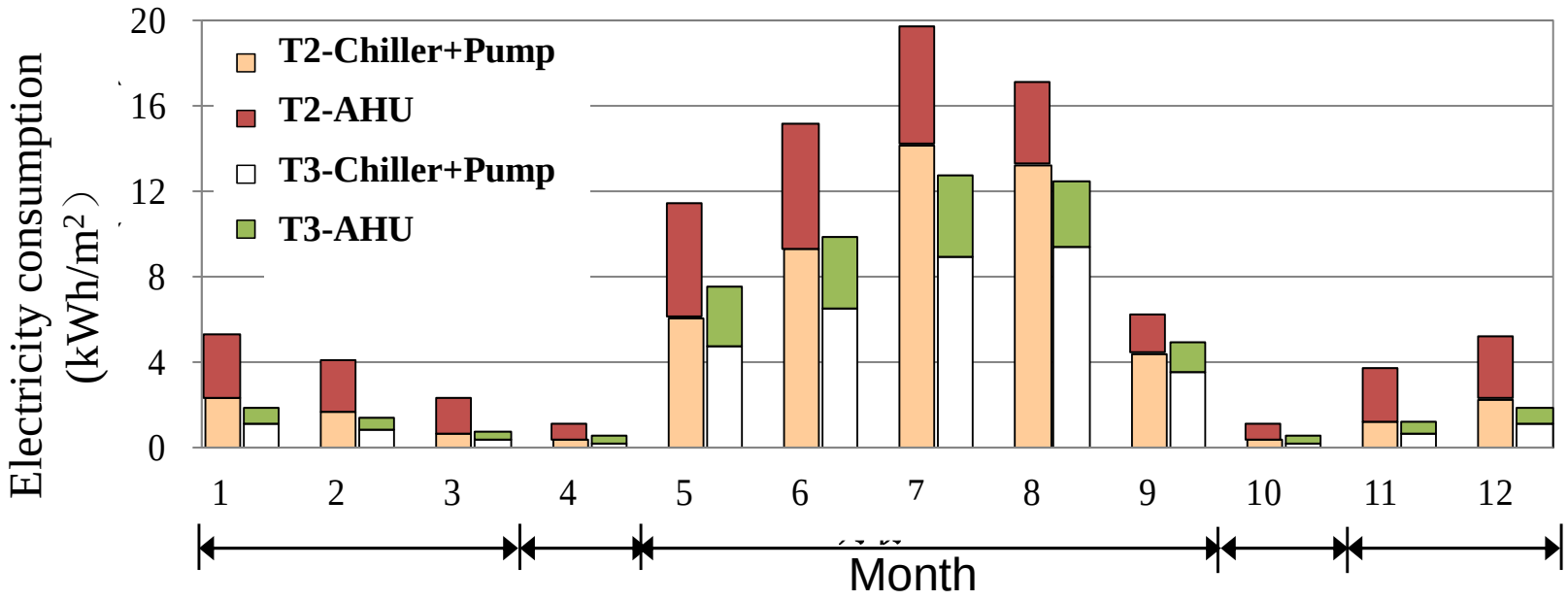
Uniform vertical temp. distribution in winter, improving indoor thermal environment

*Zhao K, **Liu XH**, … Solar Energy, 2014*

4. Applications in China

Comparison between T2 and T3

- Significant energy saving for air transportation



AC energy consumption of T3 is reduced by ~40%

*Zhao K, **Liu XH**, … Renewable & Sustainable Energy Reviews, 2016*

4. Applications in China

- **Further applications in terminals**

Qingdao airport

~450,000 m²

2020

Chengdu airport

~500,000 m²

2021

5. Conclusion

Task: Reducing energy consumed in AT

Terminal solution for AT requires novel method

1. **Radiant floor helps to create a stratified environment**
2. **Reducing transportation energy** **air → water**
3. **Achieving high temp. cooling and low temp. heating: reducing energy of heating/cooling sources**

THANKS

Dr. Xiaohua Liu
Tsinghua University
lxh@tsinghua.edu.cn