New Strategies for Sustainable Buildings in Extreme Environments

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Distinctive buildings in extreme environments

Extreme outdoor environment
- Very hot
- Dry or extreme humid
- Strong solar radiation

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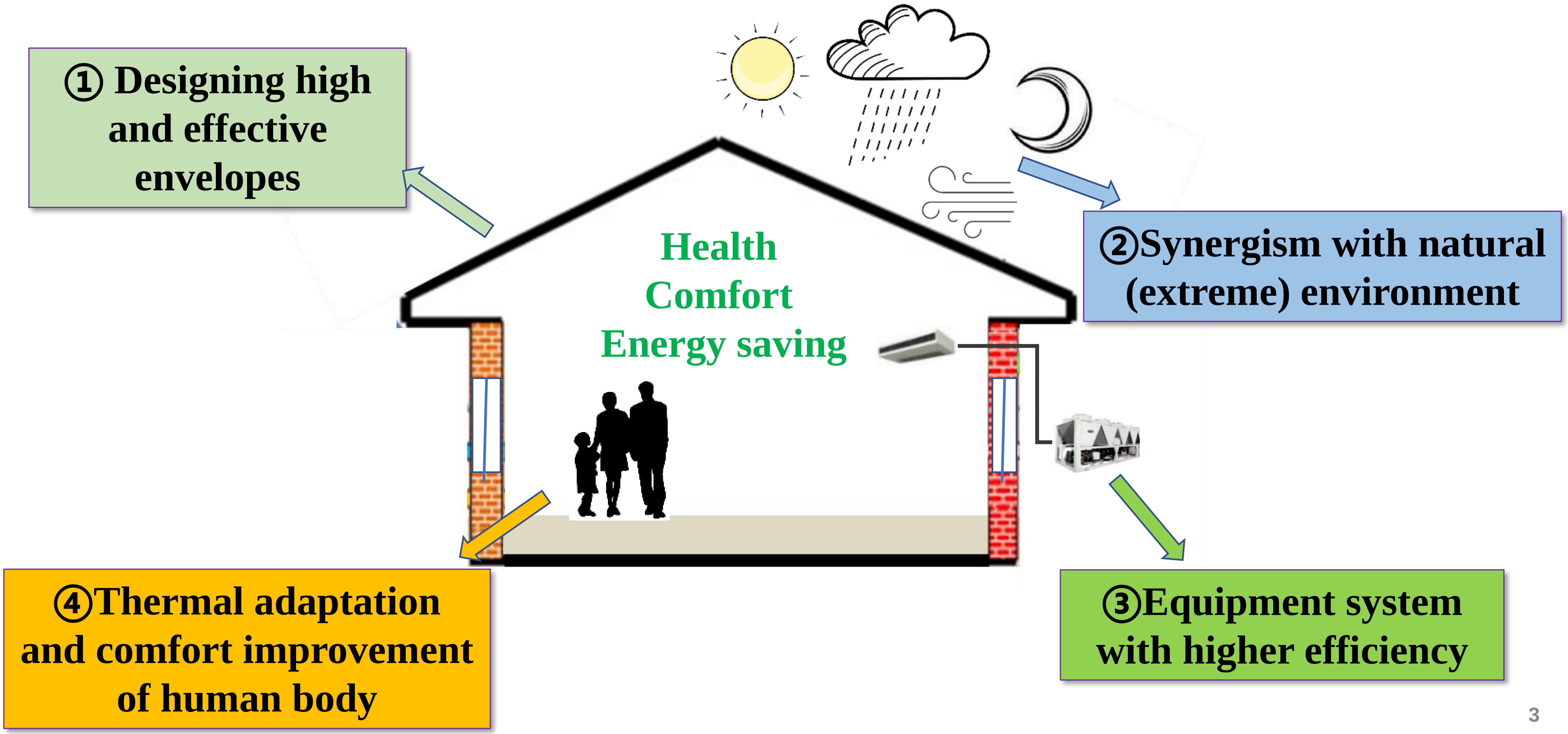
Demand for higher quality
- Health
- Thermal comfort
- Lower energy consumption

Change in Sustainable Strategies


Christophe Benichou, Sesame

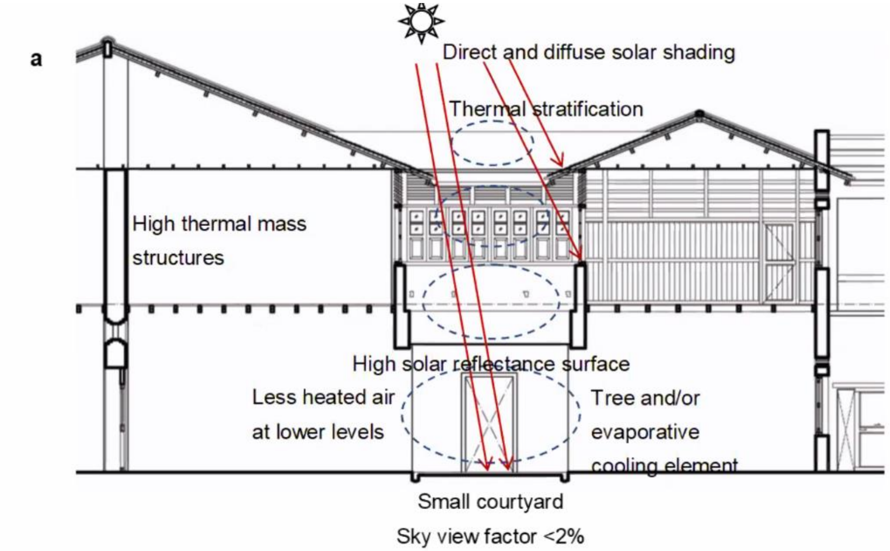

Dubarch Architects, Qasr Al Sarab Desert Resort

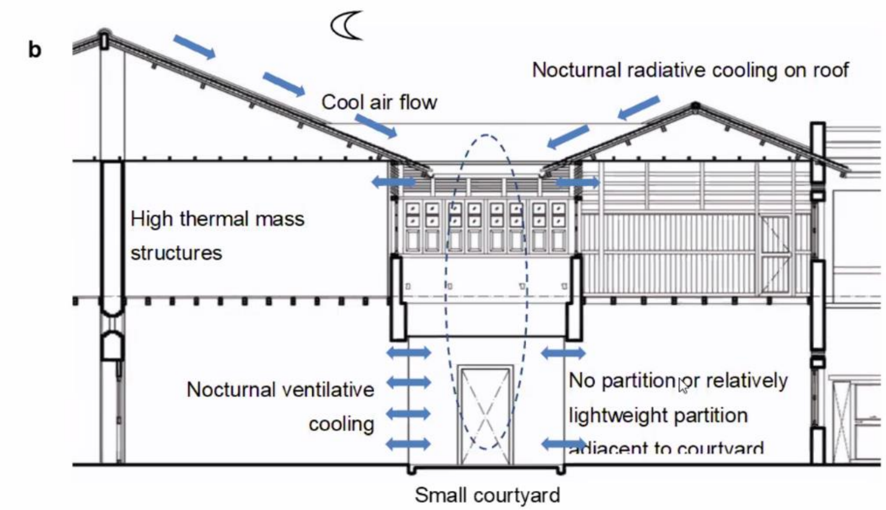
How to design sustainable buildings in extreme environments?



Traditional sustainable strategies for extreme climate

Shading, Natural ventilation, Atomization/fogger cooling…

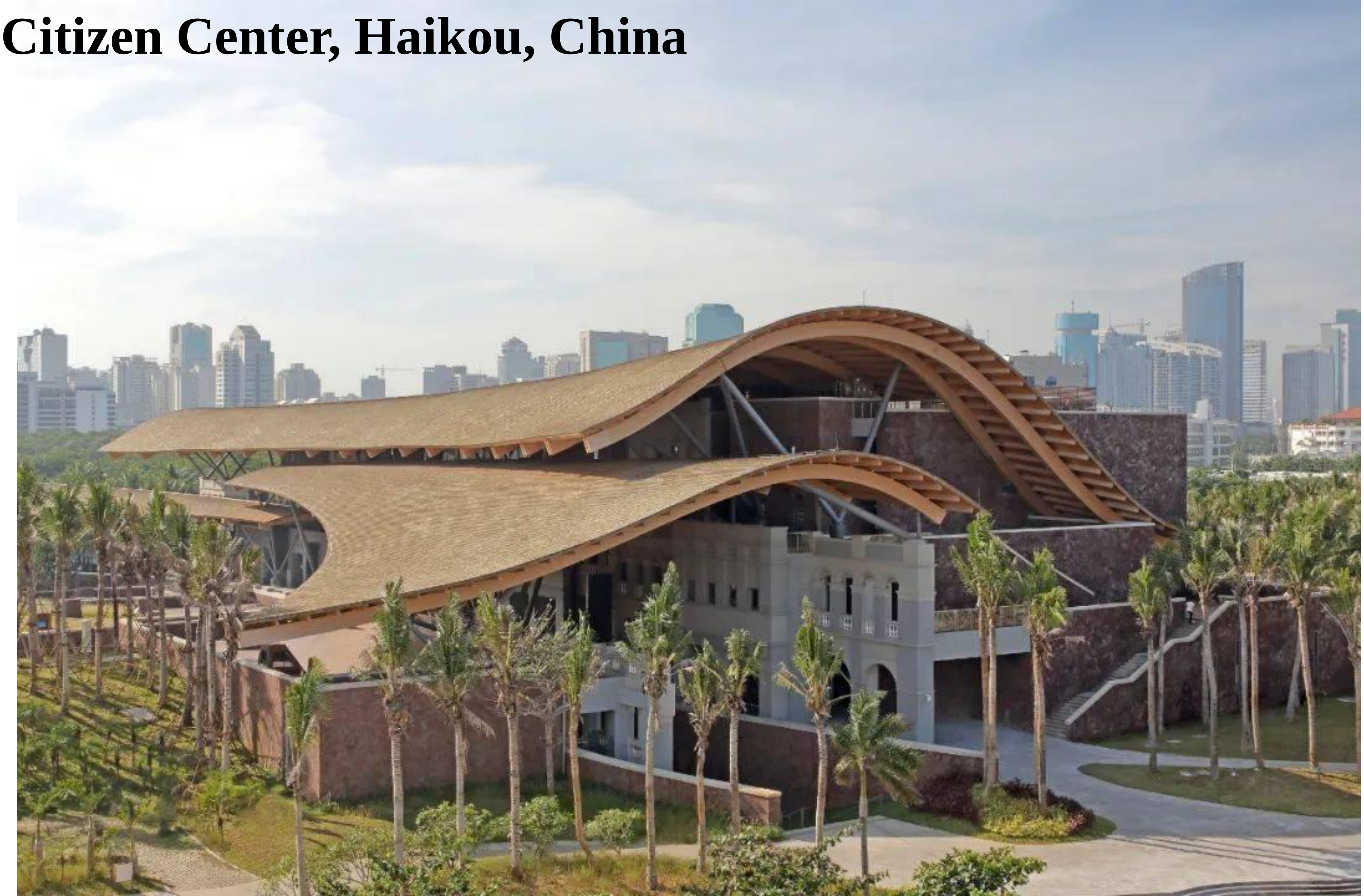





Wind tower


Atomization/fogger cooling

Citizen Center, Haikou, China



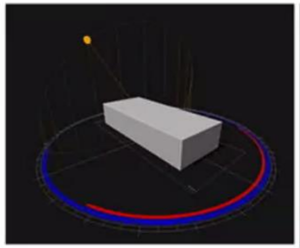
Citizen Center, Haikou, China

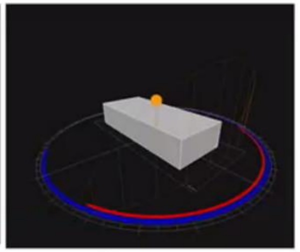
I-6 Shading Analysis 遮阳分析

太阳高度角：
47° （冬）–90° （夏）
日照时长：
10h55min（冬至）–13h21min（夏至）

夏季太阳方位角随时间变化较大
冬季太阳方位角随时间变化较小
在最热的 5 月中旬 –8 月中旬，太阳主要在北侧
在夏季太阳高度角高，中午在 80–90 度之间
在冬季太阳高度角低，中午在 55–65 度之间

遮阳罩遮挡了下午的阳光，减弱了西晒对建筑内部热舒适的影响。

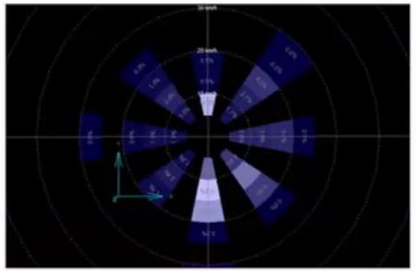

夏至日日照情况

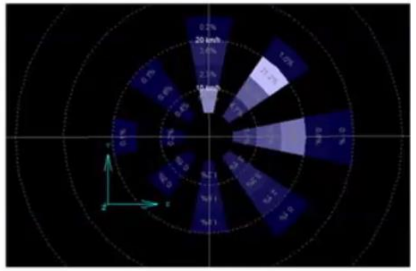

冬至日日照情况

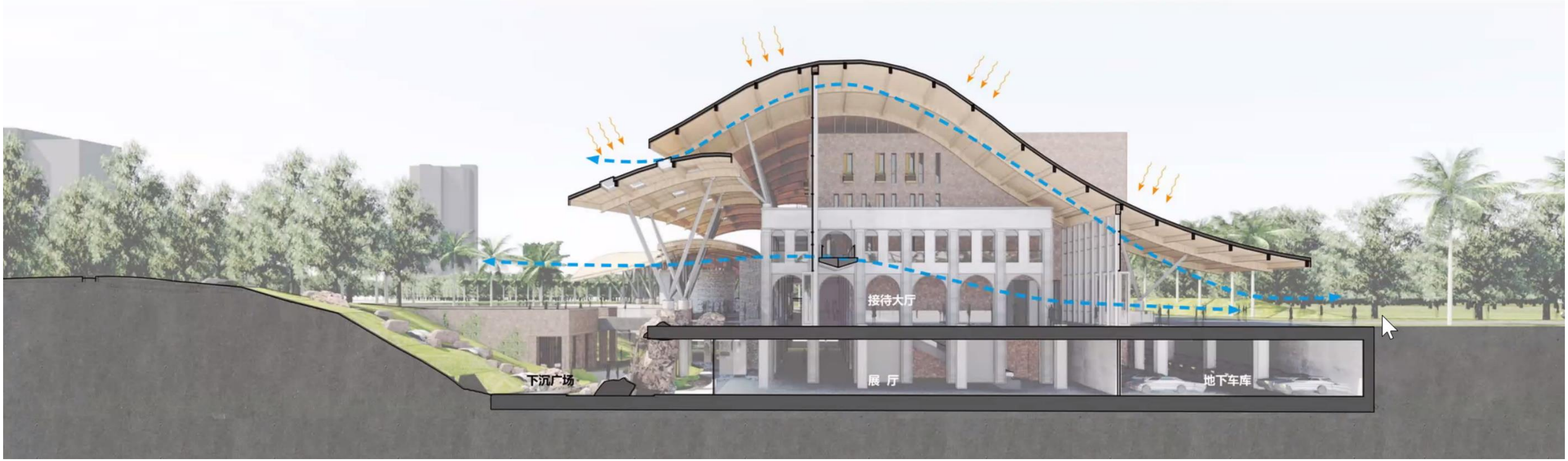
I-7 Ventilation Analysis 通风分析

夏季主导风：
南风 10–15km/h
北风 5–10km/h

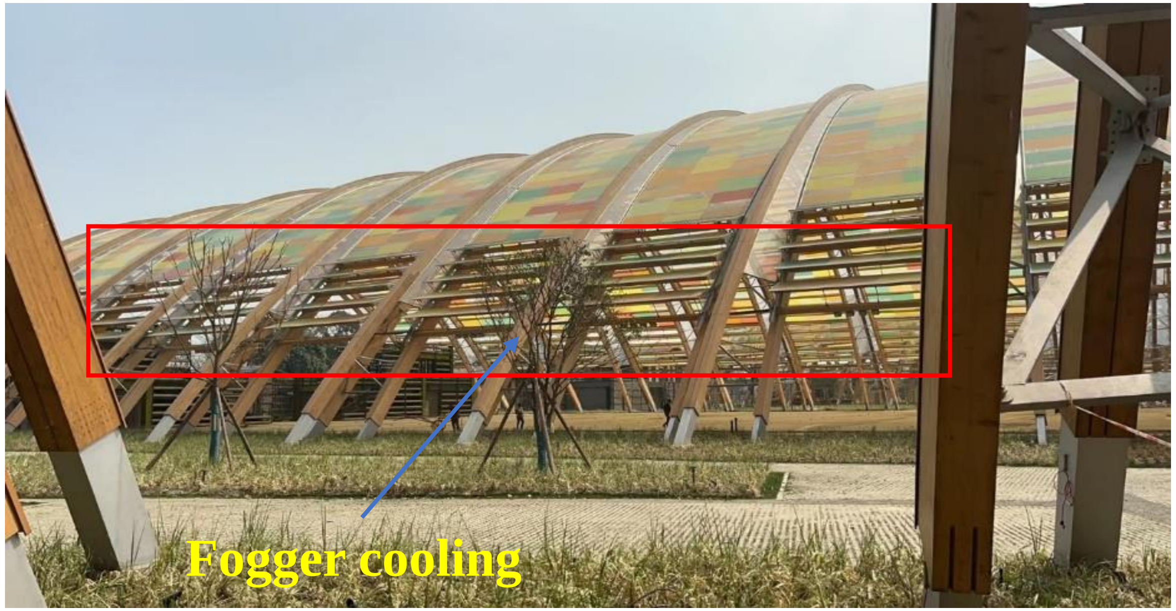
冬季主导风：
东北风 15–20km/h

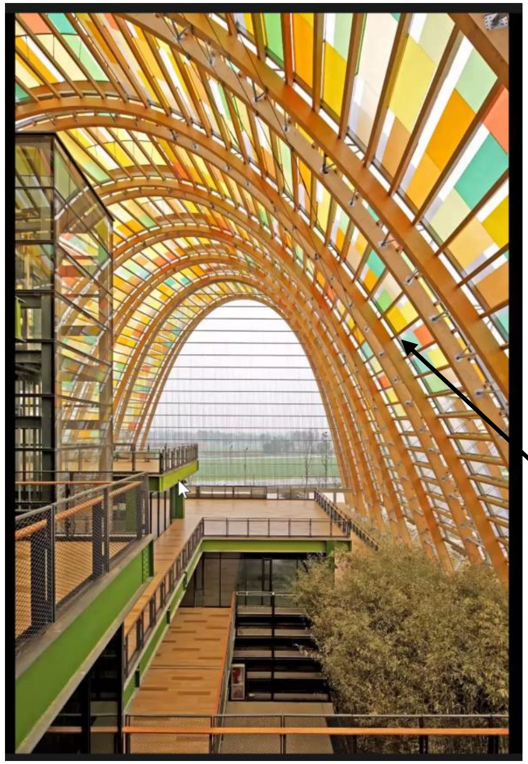


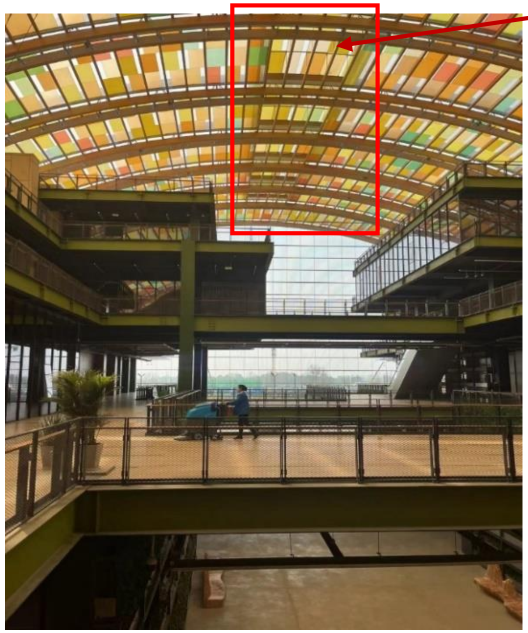




Agricultural Expo Exhibition Hall, Chengdu, China







Shading

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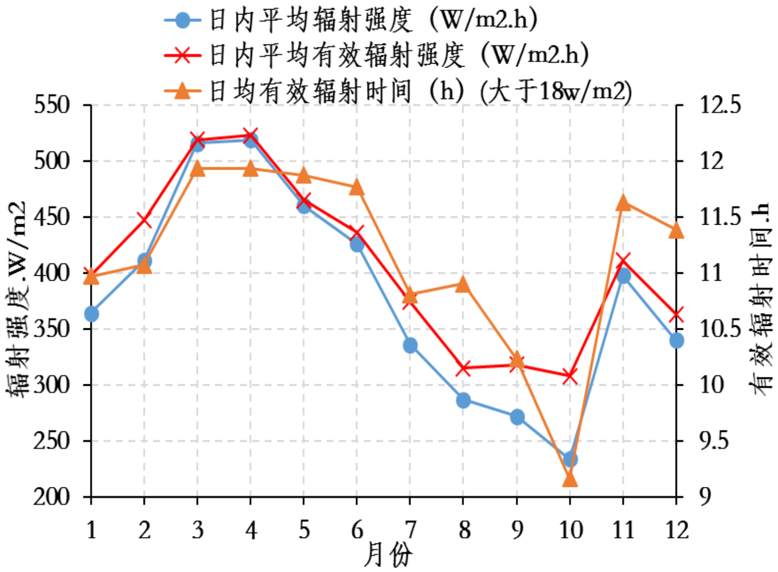
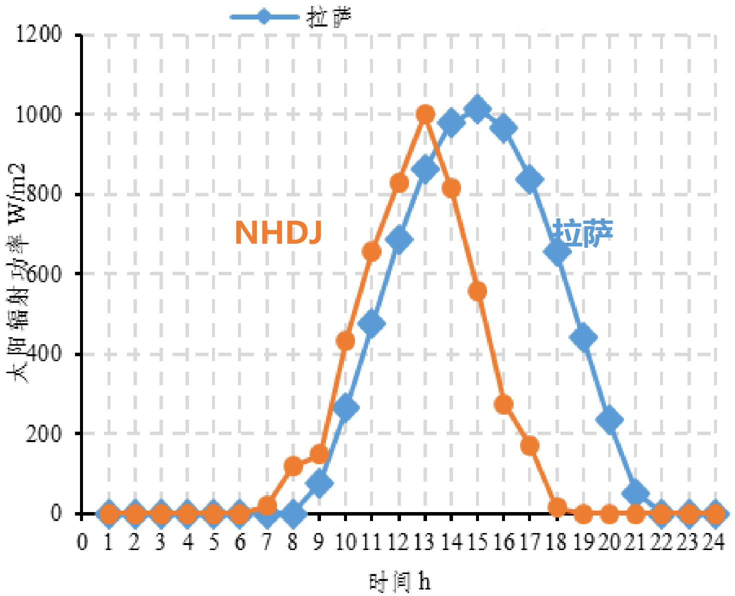
Natural ventilation,

+

Fogger cooling…

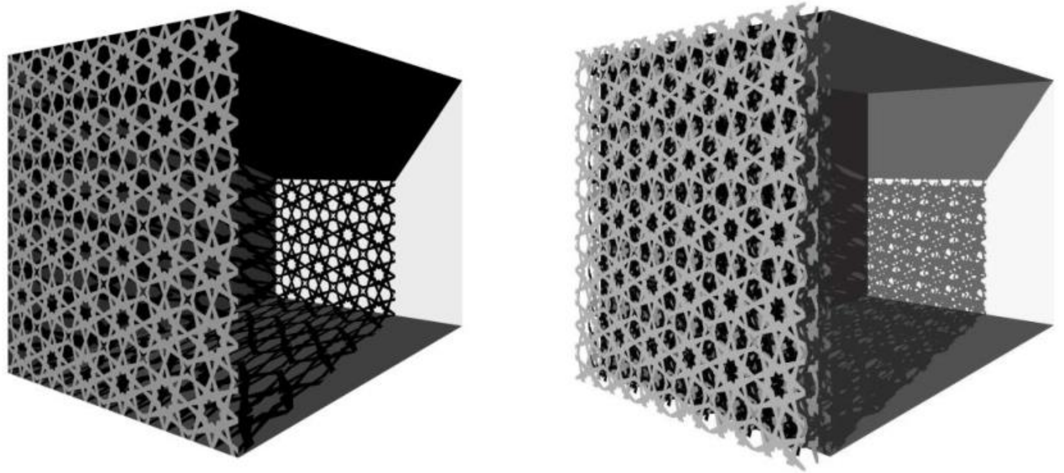
Apartments, Haikou south, China

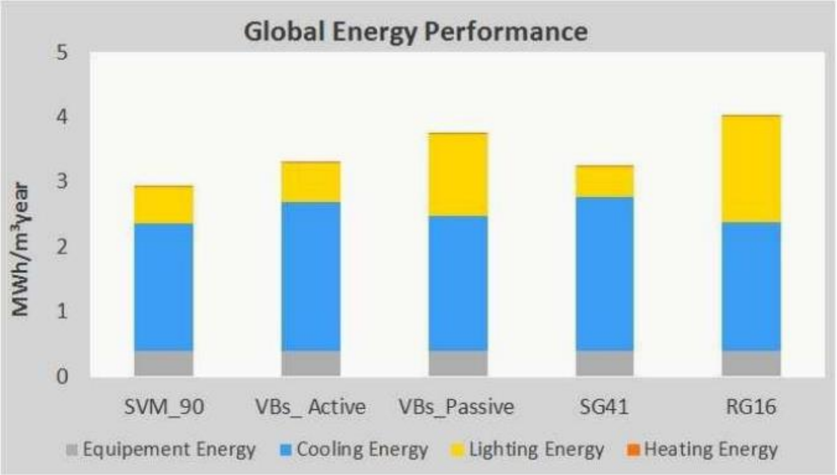




1. Building envelope improvement — Shading and ventilation

- An adaptive shading and daylighting system—SVM (Shape-Variable Mashrabiya)
- Consisting of three identical opaque backscattering shields, and able to move relative to each other so as to switch between in the shading and lighting





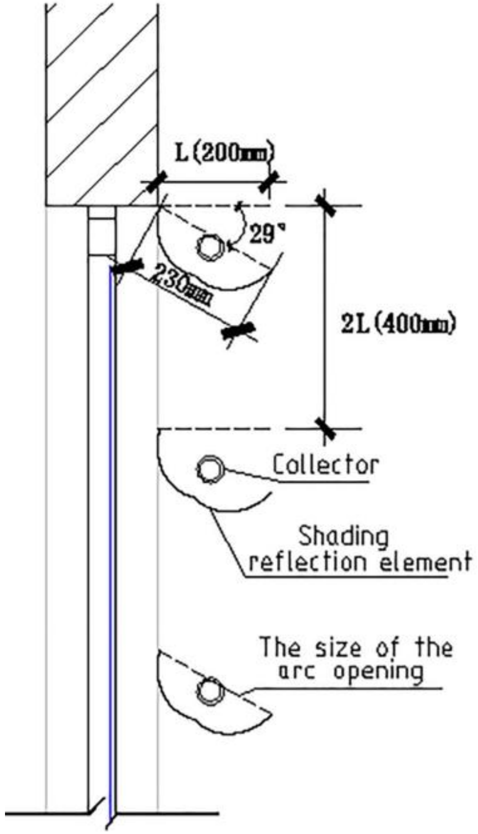
Images of the SVM: opened (left) and closed (right) configurations.

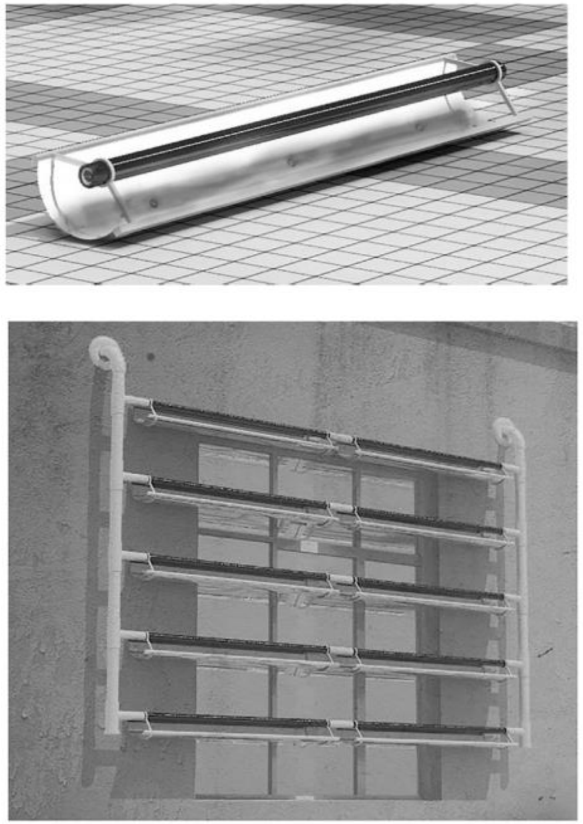
Combines the advantages of building shading and lighting

- SVM is able to effectively block the solar radiation in the presence of direct sunlight, thus avoiding overheating of building spaces and minimizing glare issues. when direct radiation is absent, the SVM allows important skylight penetration while restoring some view to the outside.
- A high amount of direct sunlight is transformed into diffuse light providing more visual comfort to the users.

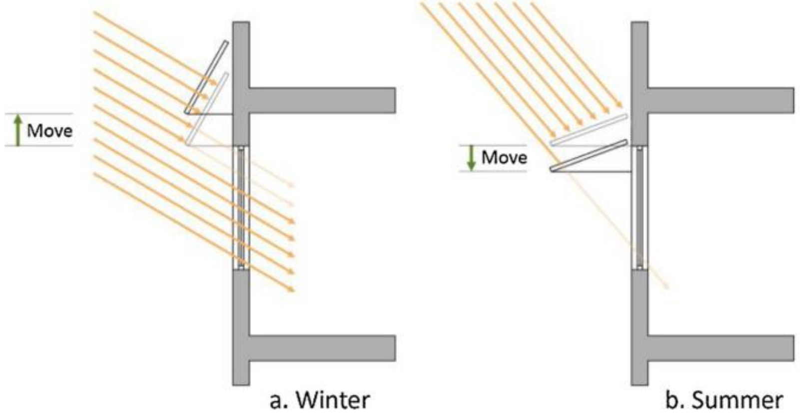
1. Building envelope improvement — Shading and ventilation

- Sun shading device integrated with solar energy collector and photovoltaic panel
- Using the characteristics of solar radiation and dry in extreme environments, building shading is combined with solar energy collection to control shading, while using solar energy and photovoltaic power generation

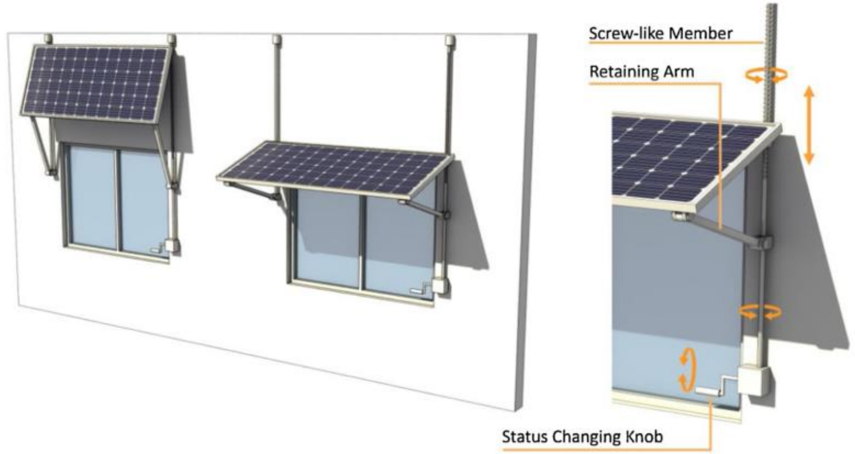




Involute shading collector elements and installation diagram

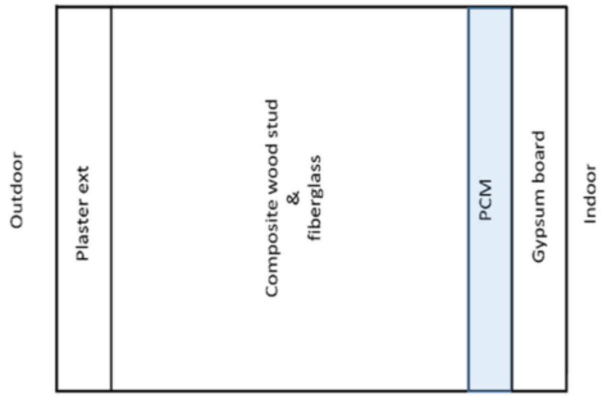


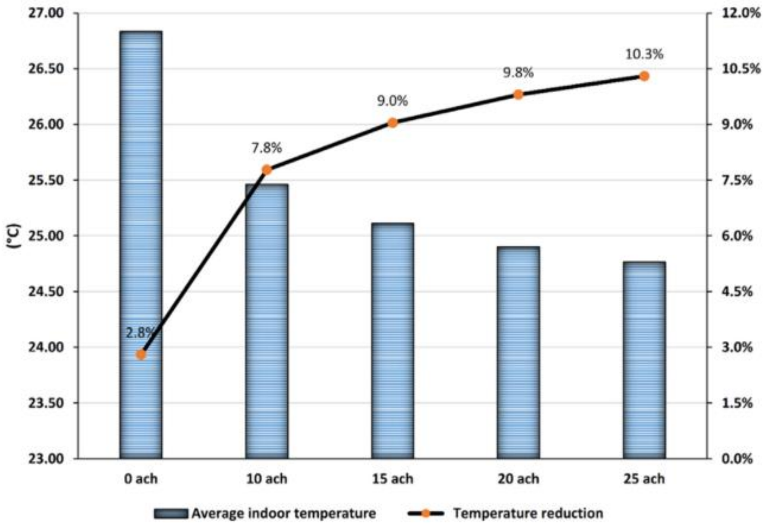
Using PV panels as movable shading device in winter and summer

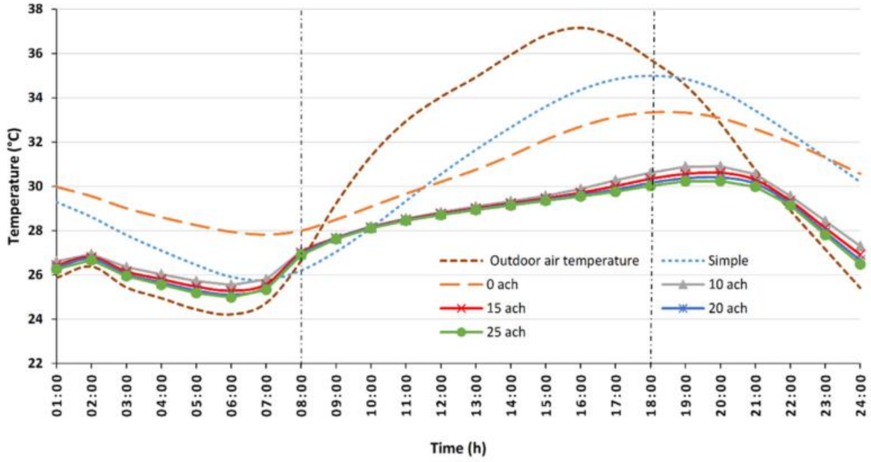


1. Building envelope improvement — Shading and ventilation

- Phase change materials assisted night purge ventilation
- This method uses the cool of the night to release the warmth stored in the thermal mass during the day.





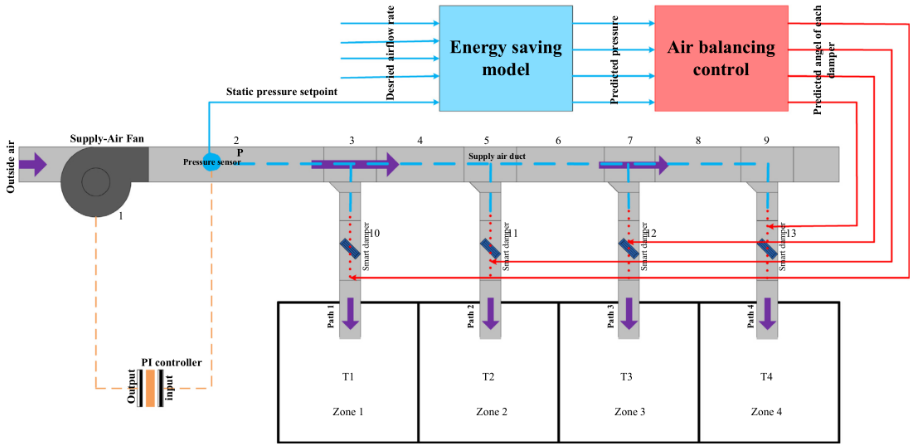


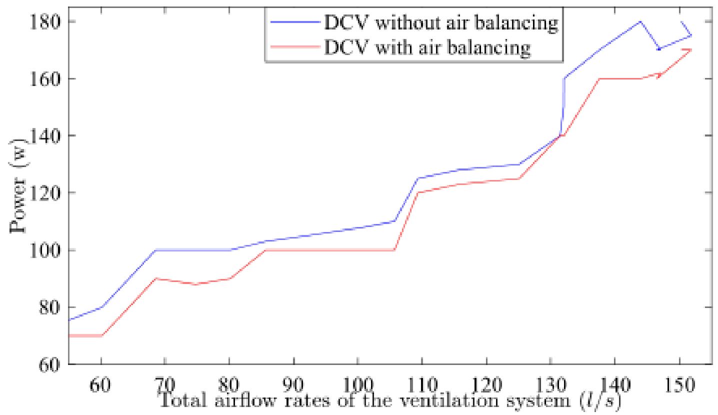
PCM+Night purge ventilation

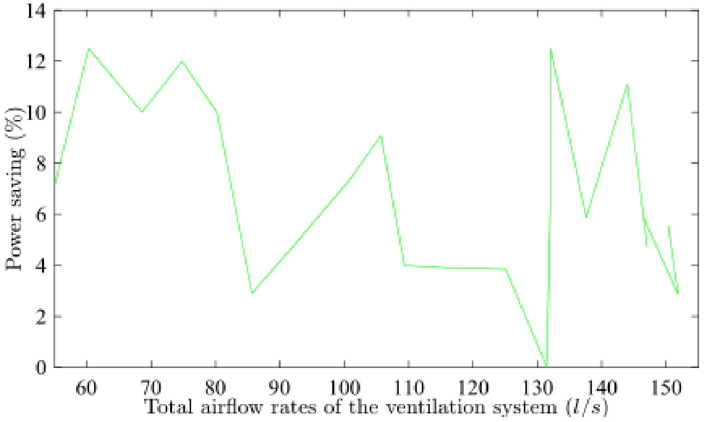
- the low mass and high energy storage capacity of PCMs augment the thermal inertia of buildings
- night ventilation removes the heat stored in the building during the day

1. Building envelope improvement — Shading and ventilation

- **Demand controlled ventilation strategy with data-driven model and air balancing control**
- **The ventilation strategy consists of two steps: system model construction and air balancing control**







Based on data-driven model and air balancing control

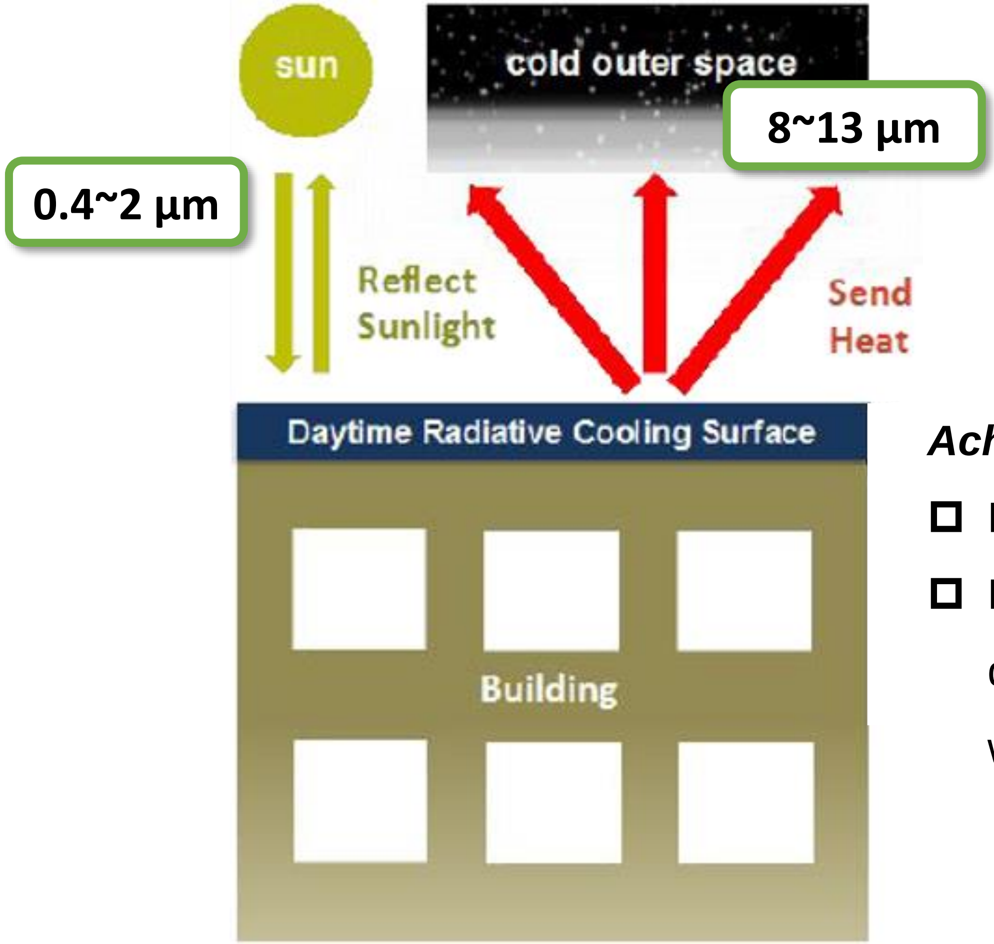
- Use data for training to optimize building ventilation performance
- The ventilation control strategy effectively solves the problem of over-ventilation and under-ventilation of the ventilation system, and achieves energy saving of fan power

1. Building envelope improvement — Radiative cooling

- ☐ **Radiative cooling: Inspired by nature**
- ☐ **Applied in buildings: passive cooling, heat dissipation to outer space**


Frost on vehicles


n leaves

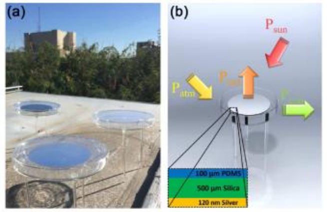


Achieve passive cooling in daytime

- ☐ High solar reflectance
- ☐ Enhance the radiation and heat dissipation through the atmospheric window

1. Building envelope improvement — Radiative cooling

- **Daytime radiative cooling: Great progress has been made in materials innovation**



Catalanotti et al, Solar Energy 17, (1975)
- 1st Study
- But only limited to nighttime radiative cooling

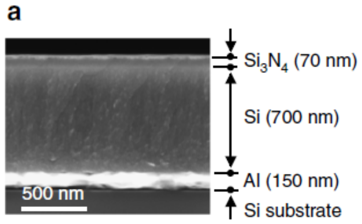
Raman et al, Nature 515, (2014)
- Photonic radiative cooler
- Non-vacuum

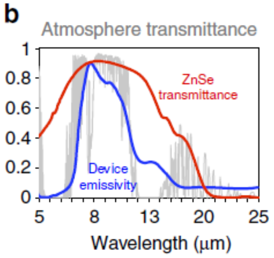
Chen et al, Nature Communications 7, (2016)
- Photonic radiative cooler
- Vacuum

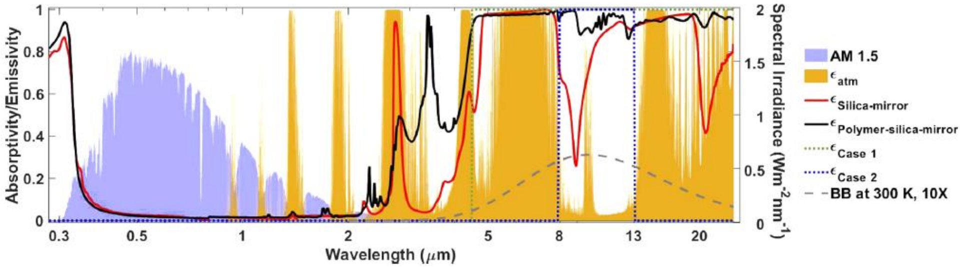
Zhai et al, Science 355, (2017)
- Polymer radiative cooler
- Hybrid metamaterial

Kou et al, ACS Photonics 4, (2017)
- Polymer radiative cooler
- Bilayer of SiO_2 and PDMS, backed by Ag reflector

Performance Enhanced



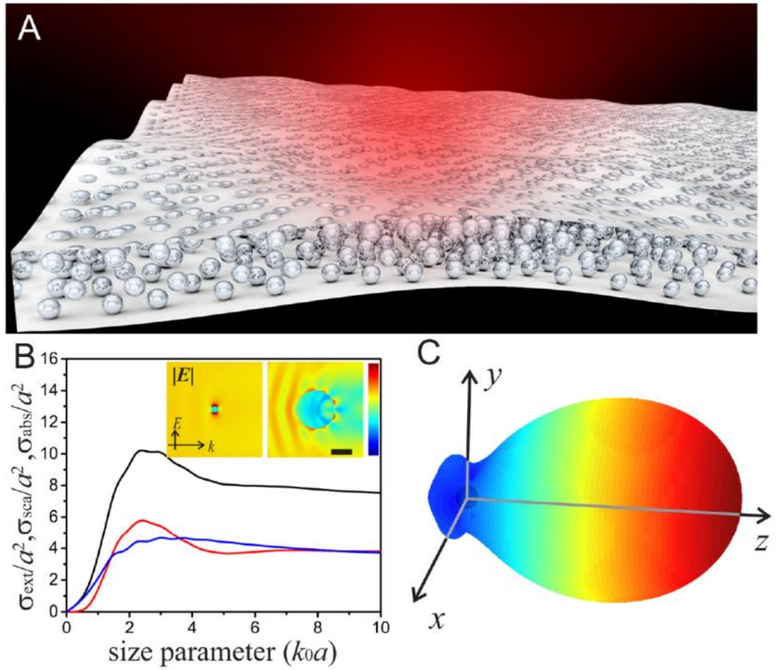


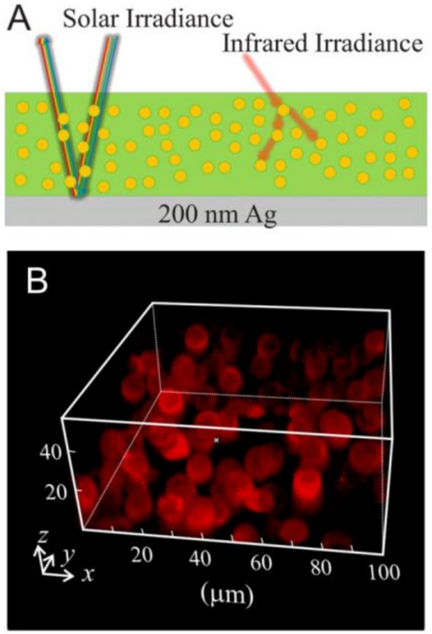


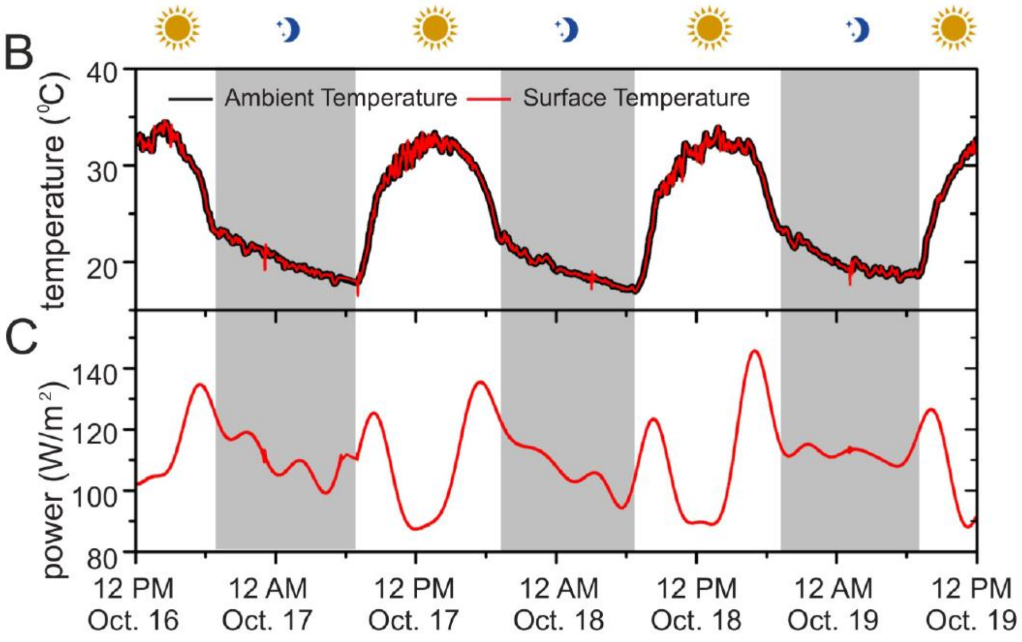
香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

1. Building envelope improvement — Radiative cooling

- Novel material： Polymer radiation material (University of Colorado)
- Infrared emissivity greater than 0.93
- When the material is backed with silver coating, the noon radiation cooling power of the material reaches 93W/㎡ under direct sunlight,





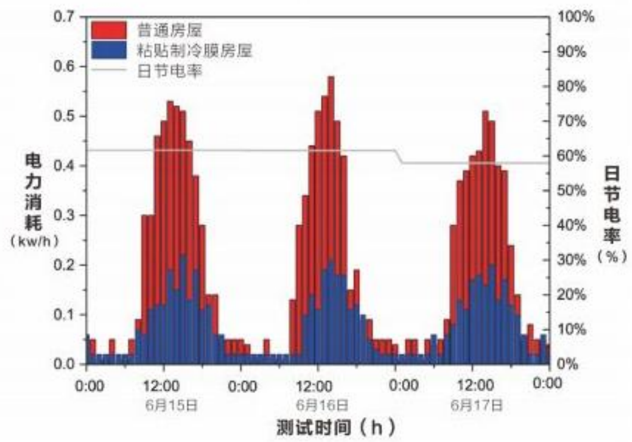


1. Building envelope improvement — Radiative cooling

- Polymer radiation material
  - Mass production has been carried out, and the material is flexible and can be wound
  - Mixed metamaterial film：width 300mm，thickness 50μm
  - Industrial production： 1 roll (5m long) / minute

1. Building envelope improvement — Radiative cooling

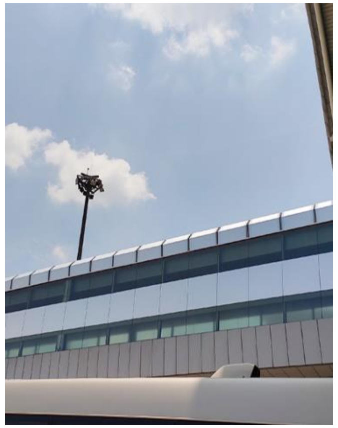
- The polymer radiation material has achieved mass production
- Applied in airport terminal



产品参数 Product Parameters

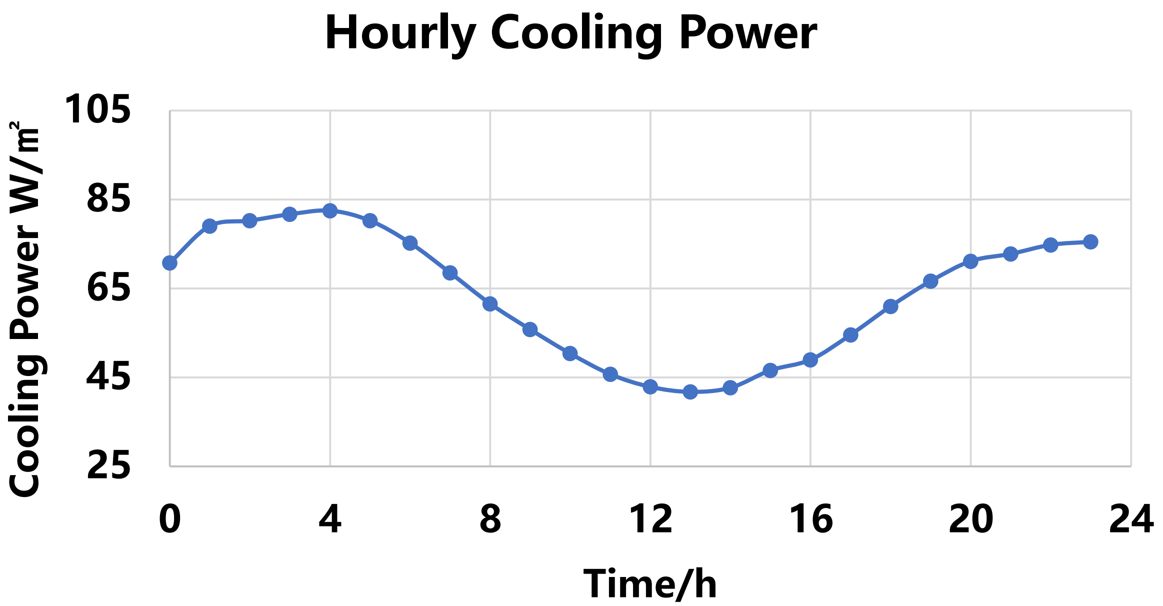
降温效果	检测方法	技术参数
成品宽幅	GB/T 13542.2-2009	1225mm（可定制）
热反射率	Q/RL 001-2019	大于90%
制冷功率	Q/RL 001-2019	100-150[W/m2]
大气窗口辐射率	Q/RL 001-2019	大于90%
成品长度	GB/T 6673-2001	50m（可定制）
成品厚度	GB/T 6673-2001	150 -200μm

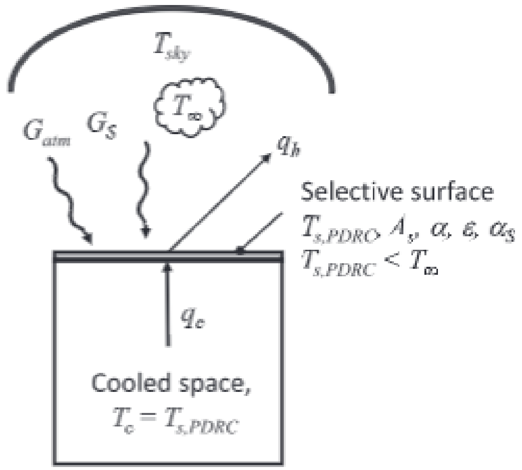
备注：以上为典型值，不作为质量承诺。



1. Building envelope improvement — Radiative cooling

- The polymer radiation: theoretic sustainability analysis
- In summer condition (building size 6.9*4.2*3.5m)
- Suitable for extremely hot environments

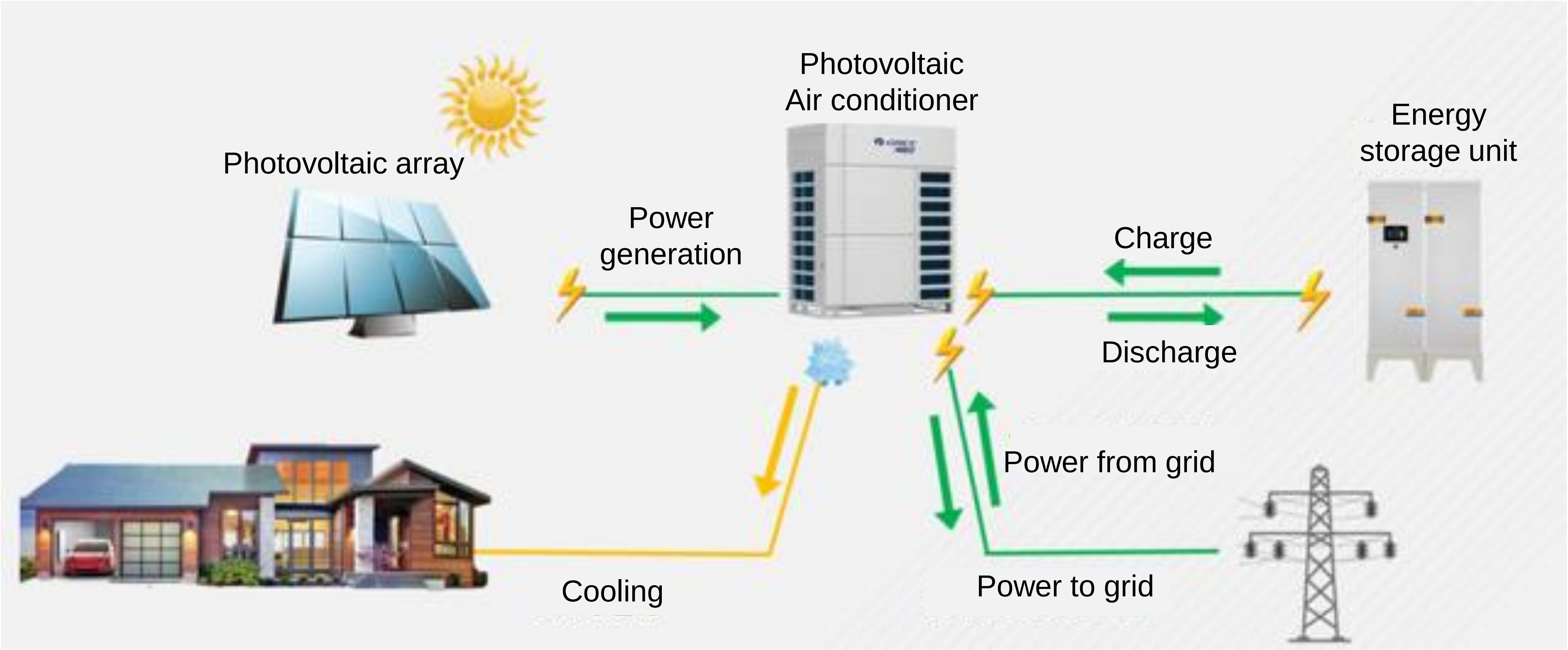




- Outdoor air velocity 2m/s
- Clear sky and cloudless
- Cooling power > **42W/m²**

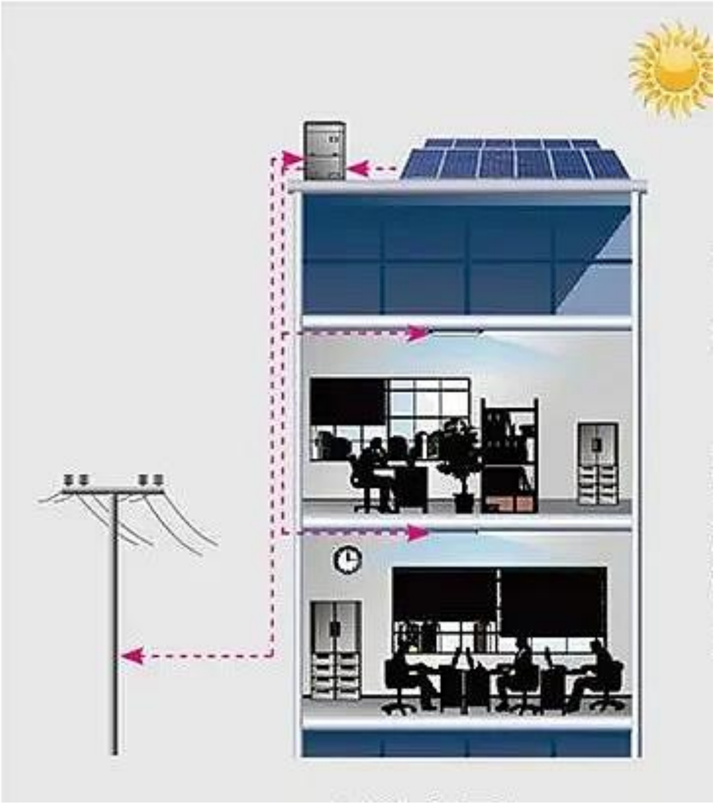
2. Utilization of natural environment — Solar Energy

- Solar energy: Reliable renewable energy in extreme environments
- Photovoltaic Air conditioner: utilization of solar energy
- Flexible and efficient; Energy saving and low carbon



2. Utilization of natural environment — Solar Energy

- Photovoltaic Air conditioner: could achieve Net zero energy consumption and zero carbon (designed and manufactured by Gree)
- Won the Global Quality Innovation Award



2. Utilization of natural environment — Solar Energy

Sustainable (Zero carbon) case: Photovoltaic Air conditioner


Phoenix (U.S.A)


Hospital (Pakistan)


Warehouse (Saudi Arabia)

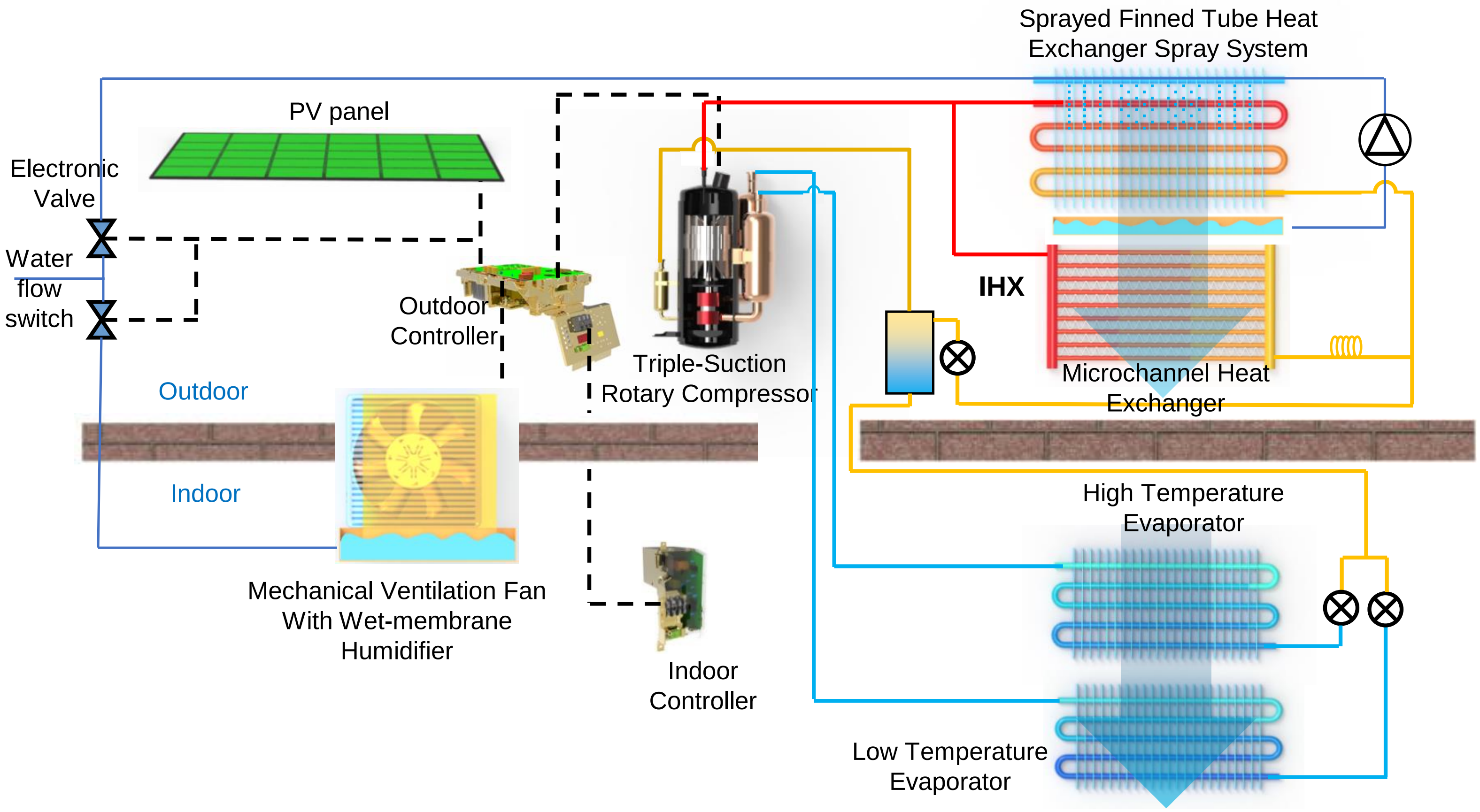

Factory


Office building


School

3. Higher efficient equipment and system — UEAC

- **An *Ultra-Efficient Air Conditioner* for cooling: energy saving for extreme environments**



High performance systems and components

- Dual evaporators and condensers
- cascade-heat-transfer refrigeration cycle

Natural energy utilization

- Fresh air evaporative cooling and ventilation
- Evaporative cooling of unit

Low carbon and renewable energy

- Photovoltaic direct-drive technology
- Low GWP refrigerant R152a

Ultra-Efficient Air Conditioner Integrated with Evaporative Cooling Fresh Air and Photovoltaic

Especially suitable for Tropical monsoon and Tropical savanna climate

3. Higher efficient equipment and system — UEAC

The Research & Development path

GREE
+
清華大學 Tsinghua University

Sponsor:
RMI ENERGY. TRANSFORMED.
DEPARTMENT OF SCIENCE & TECHNOLOGY
Ministry of Science and Technology
Government of India
सत्यमेव जयते
MISSION INNOVATION
accelerating the clean energy revolution

Preliminary stage

2018.11 Competition start

2019.6 Registration deadline

2019.8 Detailed Technical

2019.10 Announcement of Finalists

2019.10-2020.8 Prototype Development

Participant Engagement for final stage

2020.10 Field Testing

2020.12 Lab Testing

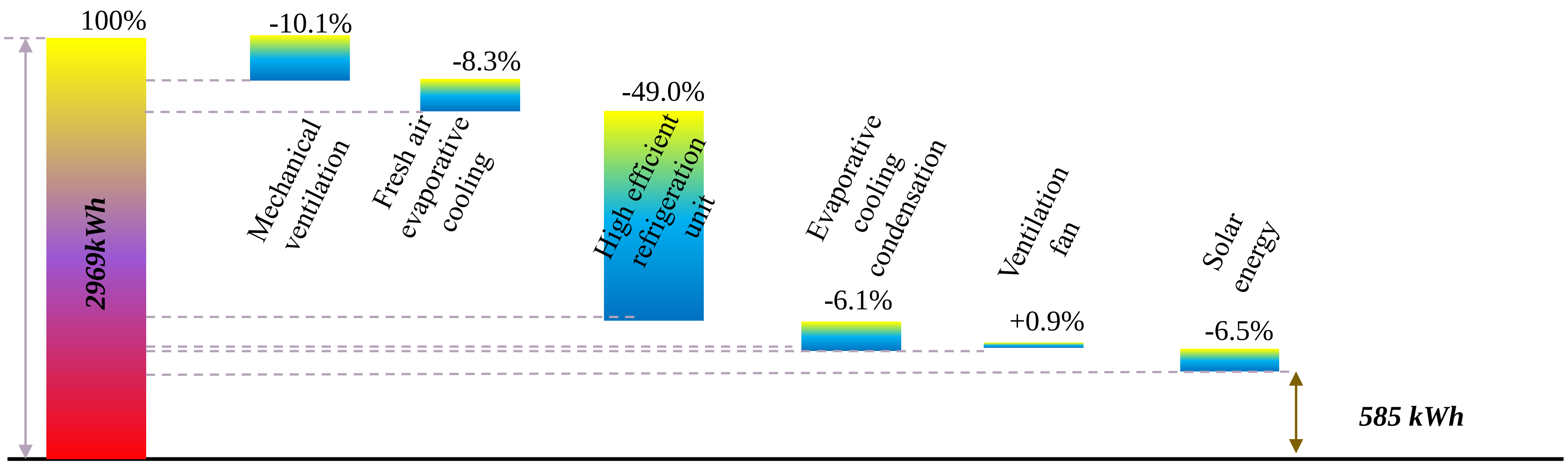
2021.2 SEER test

2021.4 Grand Award Ceremony

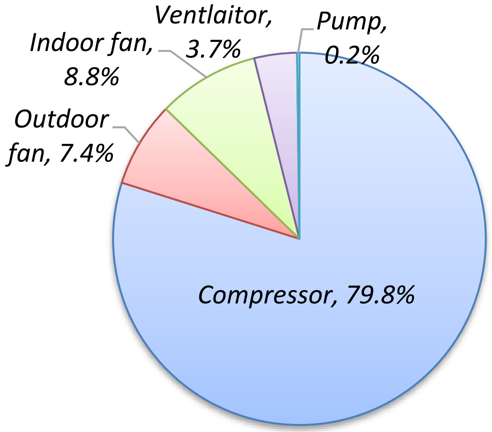
Final stage

3. Higher efficient equipment and system — UEAC

Simulation results



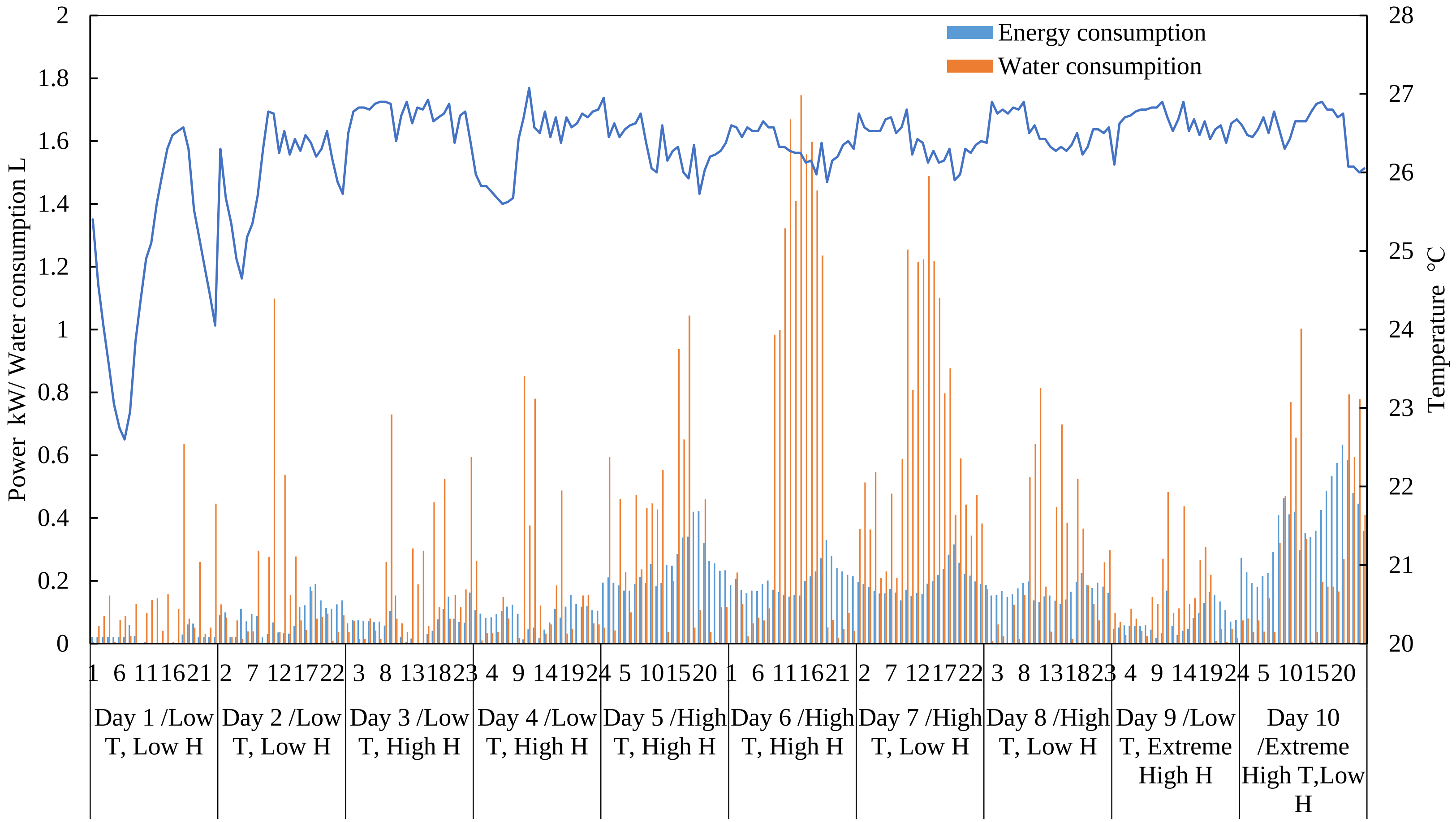
Energy saving rate of different methods



- Annual total power consumption reduced to **585 kWh**
- Compressor energy consumption accounts for **79.8%**
- Fans energy consumption accounts for **20.0%**

3. Higher efficient equipment and system — UEAC

10-day lab test

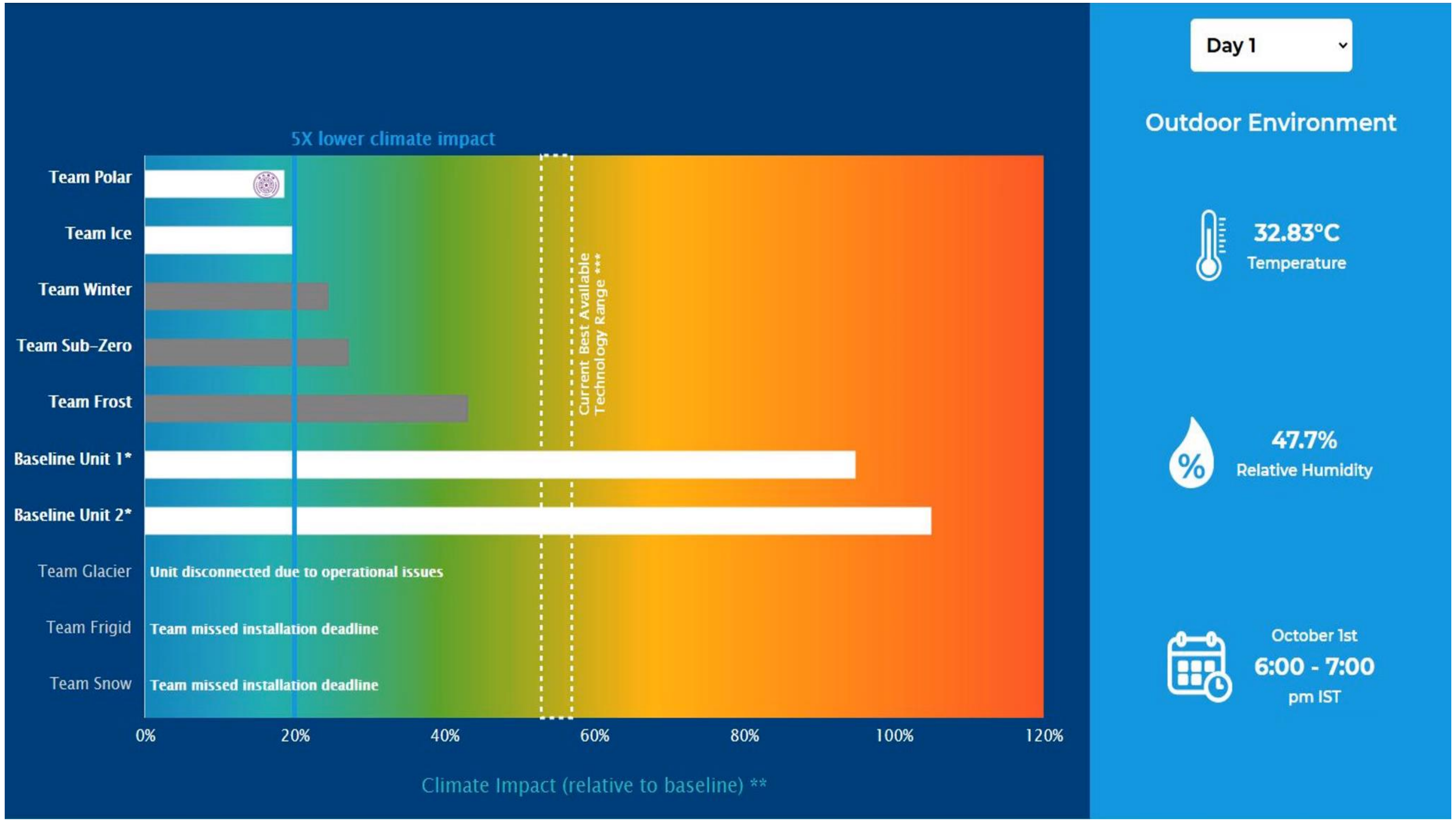


- Typical 10-day lab-simulated year-round performance test
- Converted annual power consumption: **739 kWh**
- Reduced annual power consumption: **84.3%**
- Reduced carbon emissions: **85.7%**

3. Higher efficient equipment and system — UEAC

Field test

- A field test in an actual south-facing residential apartment
- The test period lasted 31 days, from October 1st to 31st
- Independent ventilator operation hours accounted for **38.4%**
- Electricity savings reached **89.8%**



3. Higher efficient equipment and system — UEAC

The Global Cooling Prize – Grand Winner

April 30, 2021

Beijing National Convention Center

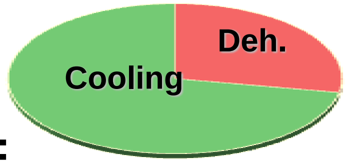
Reported by CCTV News (China Central Television)

3. Higher efficient equipment and system — THIC

- *Temperature and Humidity Independent Control*
- Eliminating sensible heat load and latent heat load independently
- Improving system COP by utilizing high temperature cold source

Conventional

$E = \dfrac{\text{[pie]}}{COP_{sys(\sim 7℃)}}$

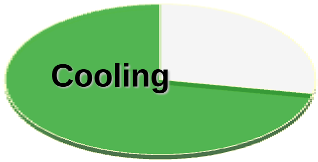


Low temperature cold source

Improving COP_{sys}: >30%!

THIC

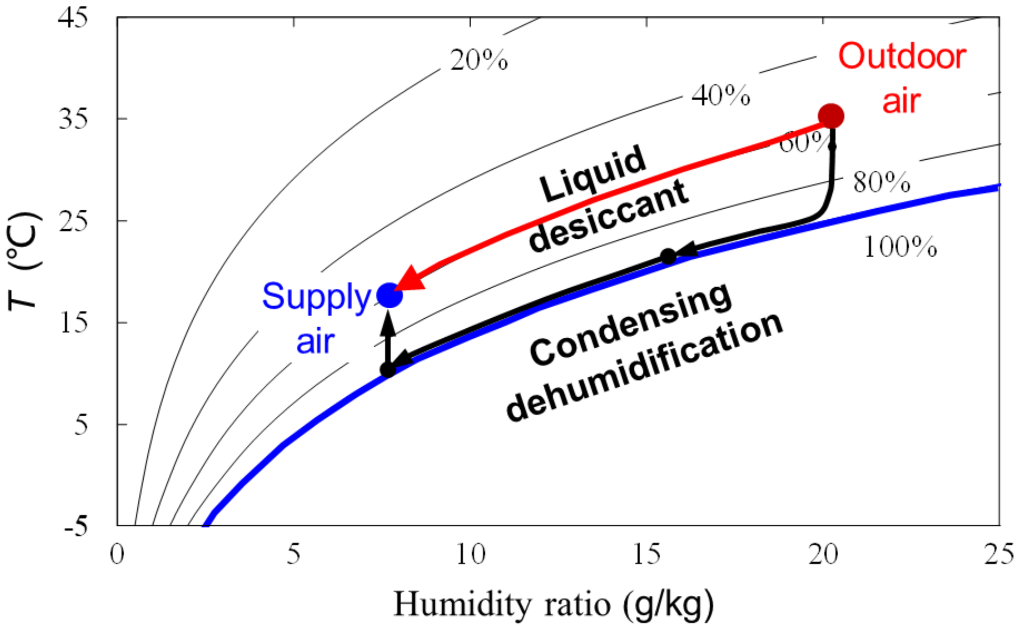
$E = \dfrac{\text{[pie]}}{COP_{sys(\sim 16℃)}} + \dfrac{\text{[pie]}}{COP_{Deh}}$

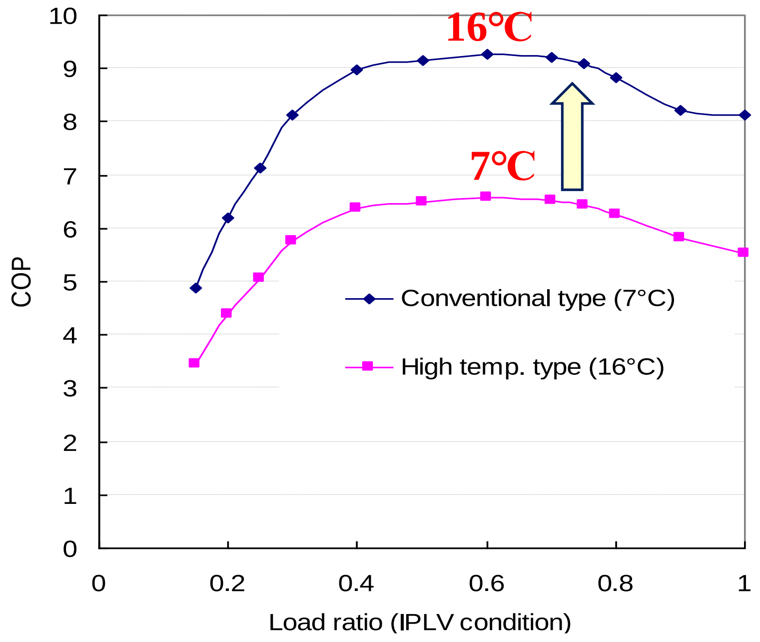


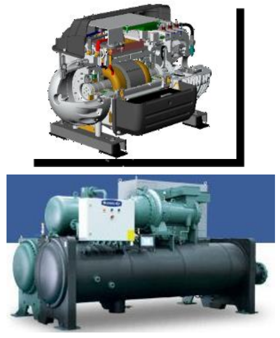
High temperature cold source

3. Higher efficient equipment and system — THIC

- ***T**emperature and **H**umidity **I**ndependent **C**ontrol*
- **Latent heat load：by liquid desiccant**
- **Sensible heat load: improving system efficiency by decreasing the demand for low temperature cold source**





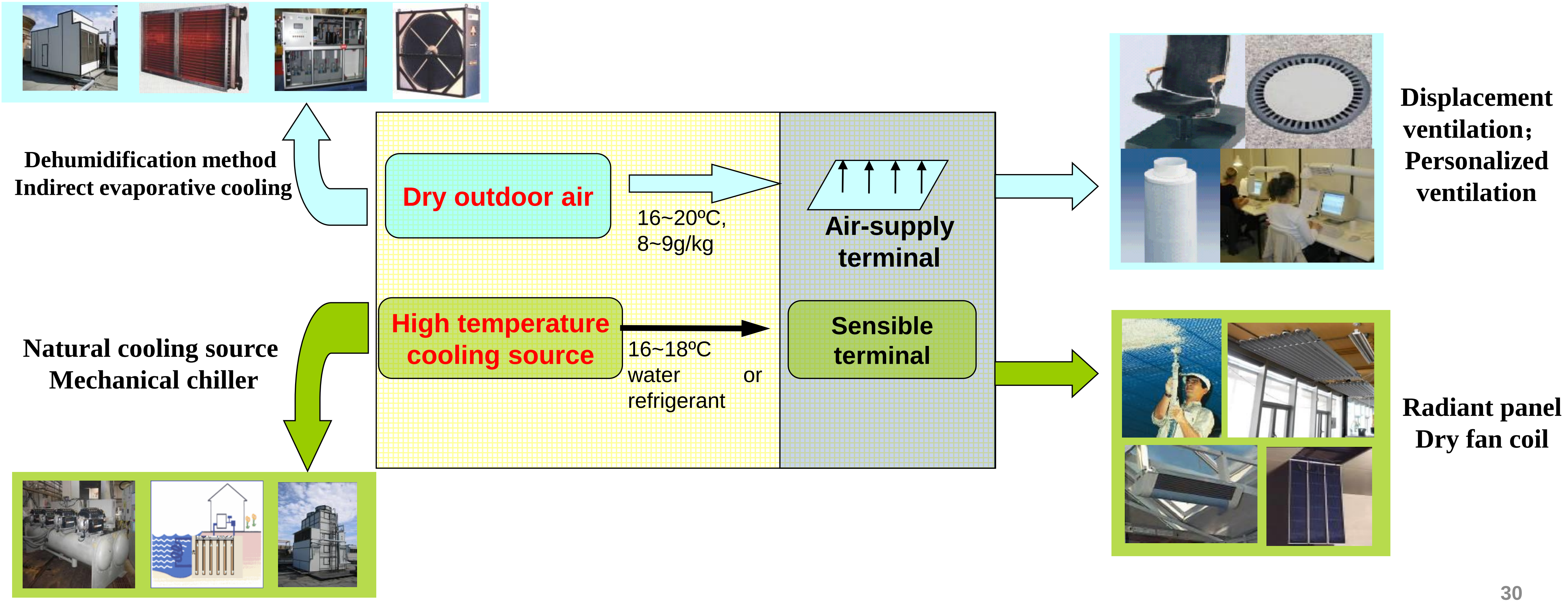


***COP* increase >35%**

Centrifugal water chiller (tested results)

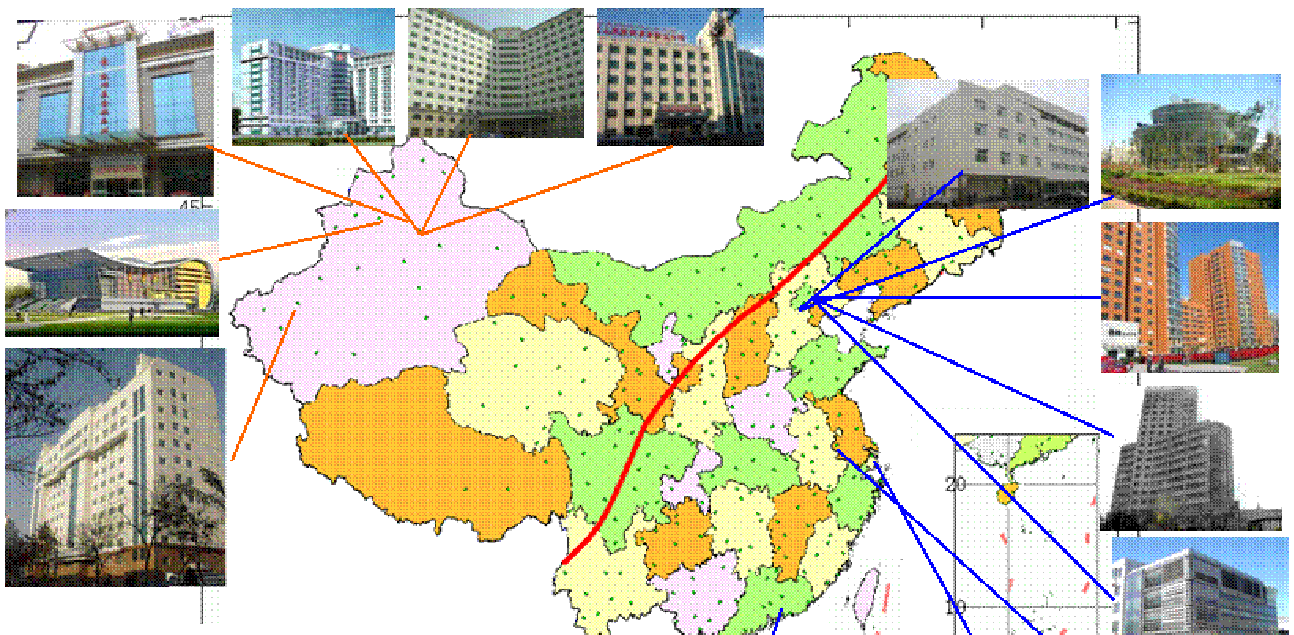
3. Higher efficient equipment and system — THIC

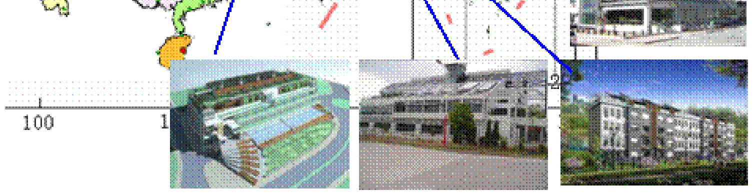
- *Temperature and Humidity Independent Control*
- Especially suitable for extreme environment



3. Higher efficient equipment and system — THIC

- ***T**emperature and **H**umidity **I**ndependent **C**ontrol*
- **Application: different climate regions and building types**





THIC system applications:

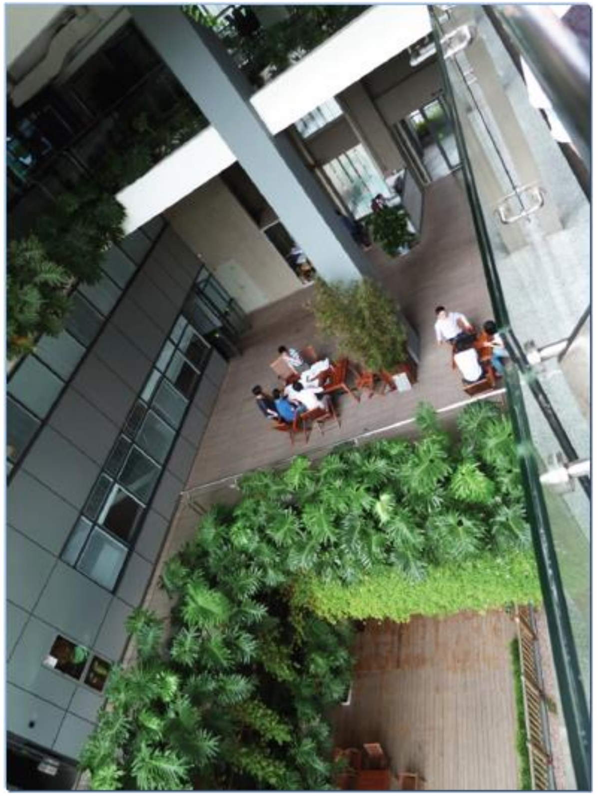
- **20 million m^2 of buildings in recent 5 years**

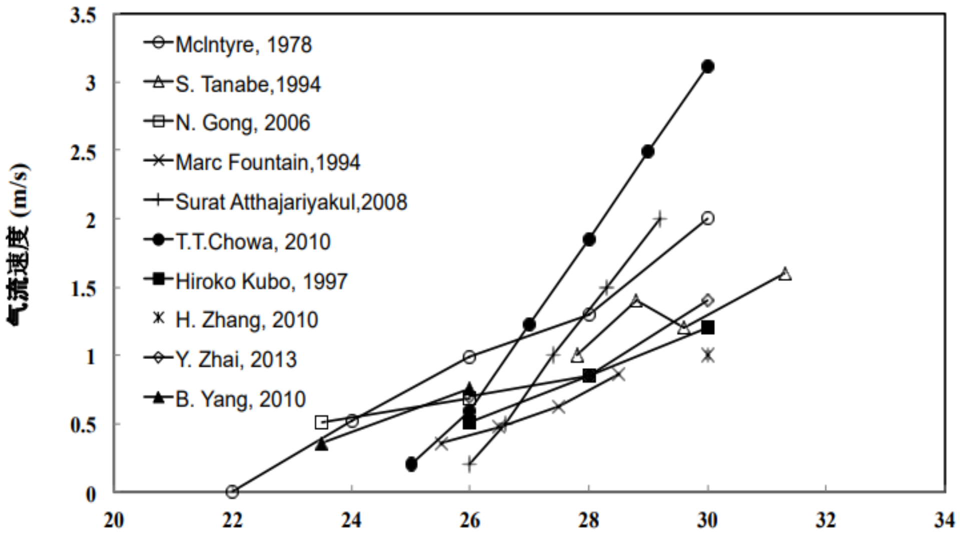
4. Thermal adaptation theory and application

- The Ceiling fans are widely used in many countries
  - Reduce indoor thermal stress & improved thermal comfort
  - Reduce energy consumption 30% by increasing indoor air velocity and setting temperature
  - Improve indoor air temperature stratification for tall space heated buildings

4. Thermal adaptation theory and application

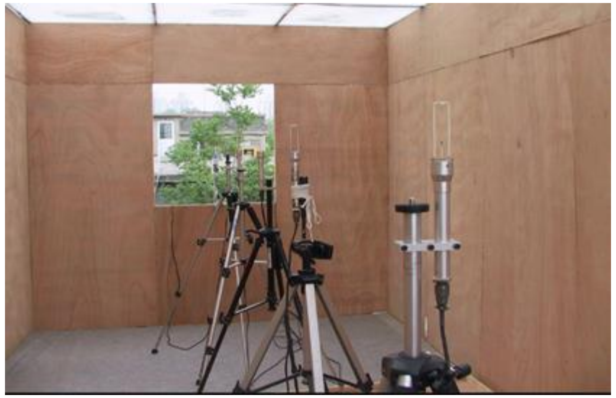
- Human shows higher thermal comfort in under a natural draft condition
- The comfortable ambient temperature of naturally ventilated buildings is significantly higher than the design temperature of air conditioning

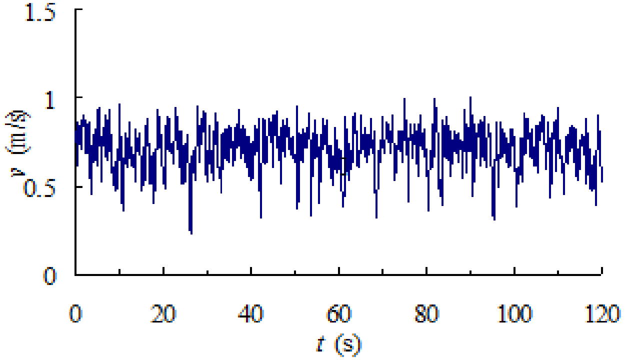




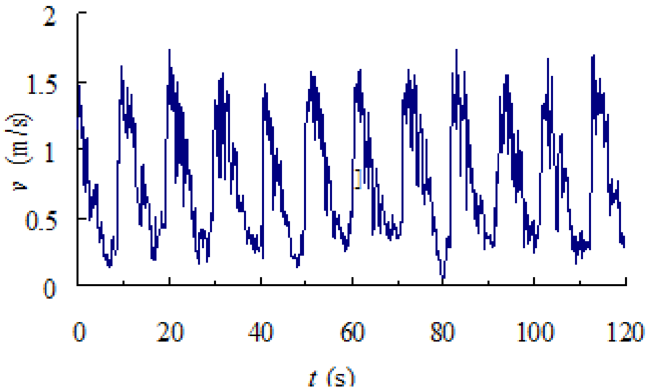
4. Thermal adaptation theory and application

- Collecting natural wind characteristics
- Establishing the frequency of natural wind

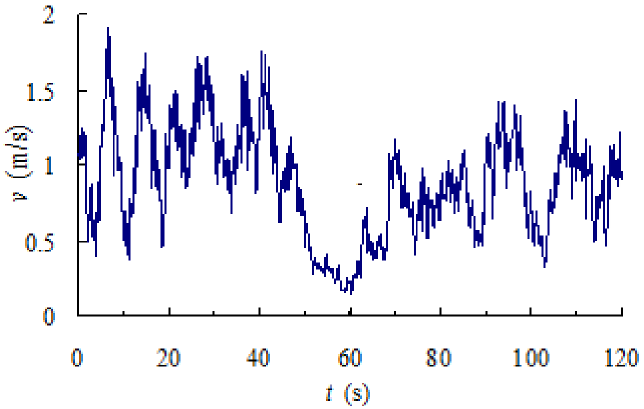




Mechanical ventilation



Sinusoidal ventilation

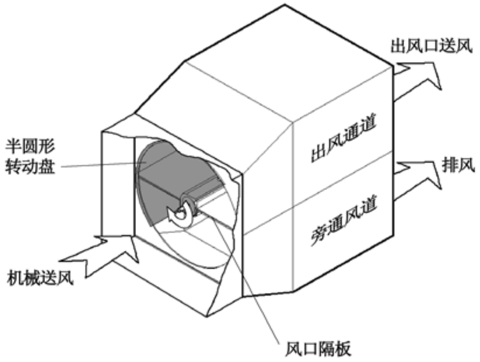


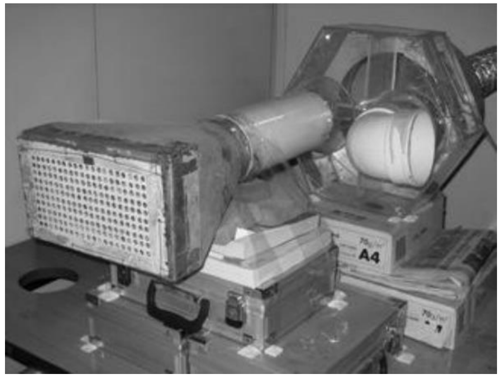
Naturalistic ventilation

4. Thermal adaptation theory and application

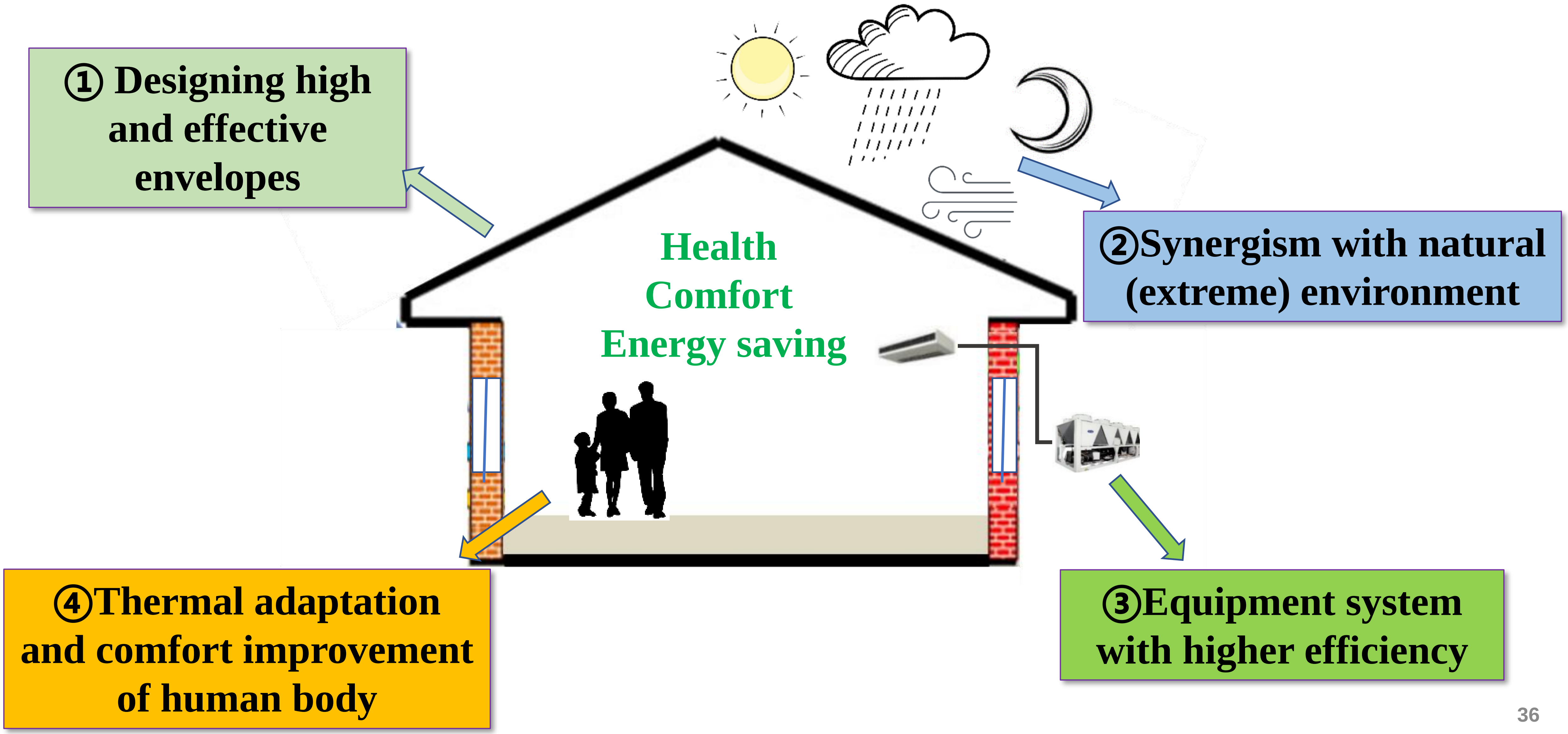
- Developing mechanical ventilation fans: imitating natural wind
- Suitable for buildings in extreme environment
  - Reducing the set temperature of the air conditioning system
  - Reducing energy demand and carbon emissions
  - Improving the health and thermal comfort







Summary: design sustainable buildings in extreme environments with this 4 strategies



Thanks for listening!