Asian Climate-SDG Technology Innovation Hackathon for Next-generation (ACTION): Safeguarding Human Health in the Climate Crisis

Built Environment Technology Innovations for Enhancing Climate Change Adaptability and Human Health

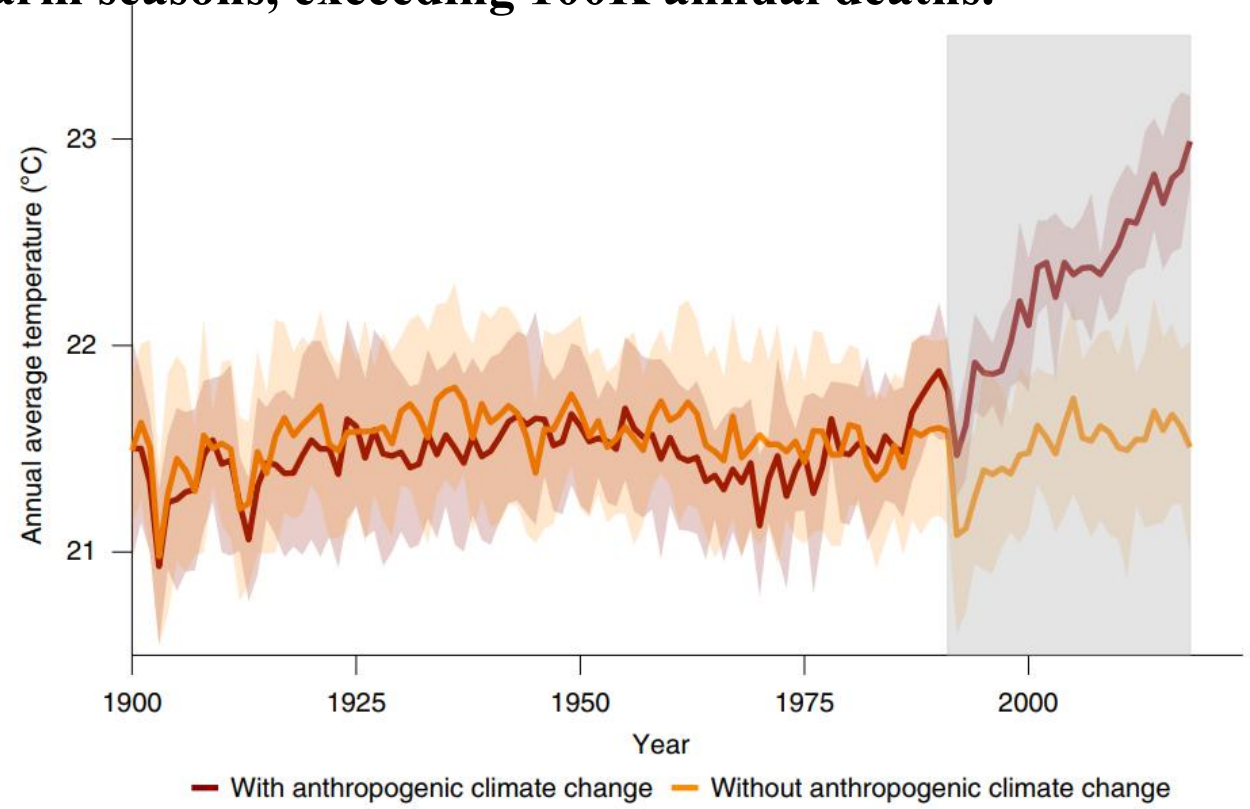
Prof. Borong LIN
Dr. Yang GENG

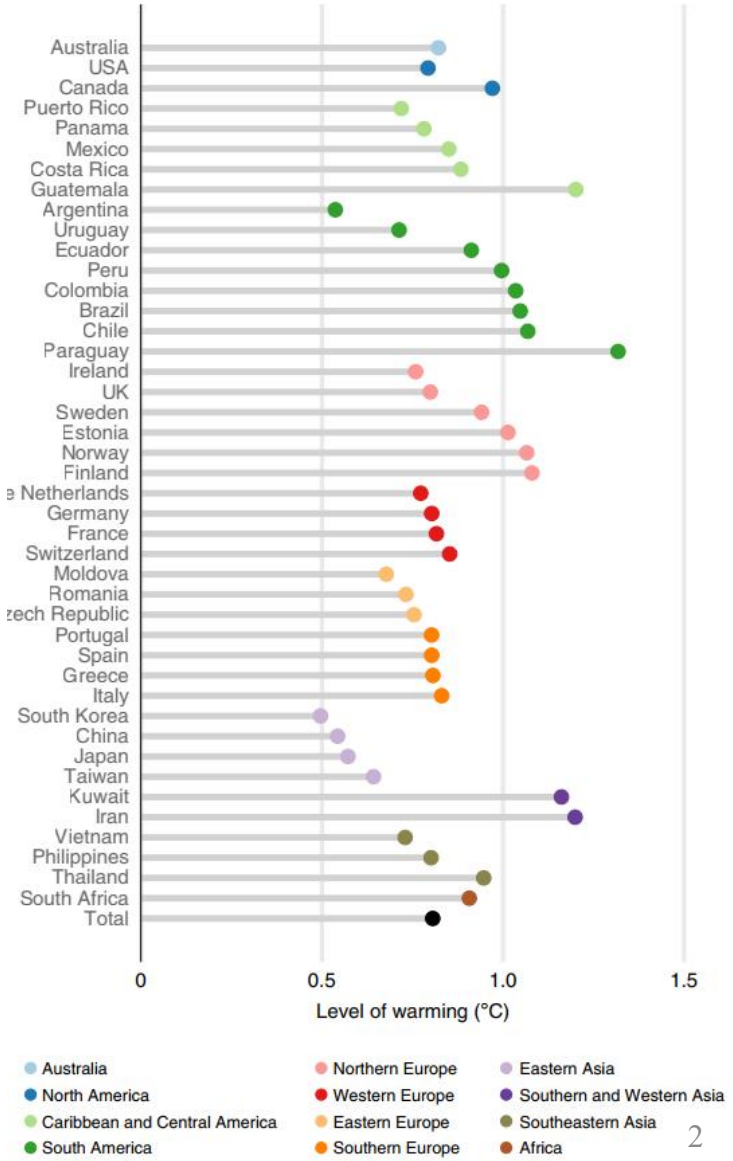
School of Architecture
Tsinghua University

June 19th, 2025

Current Status of Asian Climate Crisis
亚洲气候危机现状

- Global warming trends observed in all countries.
- Heat-related deaths occur rapidly after high-temperature exposure.
- Anthropogenic climate change causes ~0.6% of total deaths in warm seasons, exceeding 100K annual deaths.

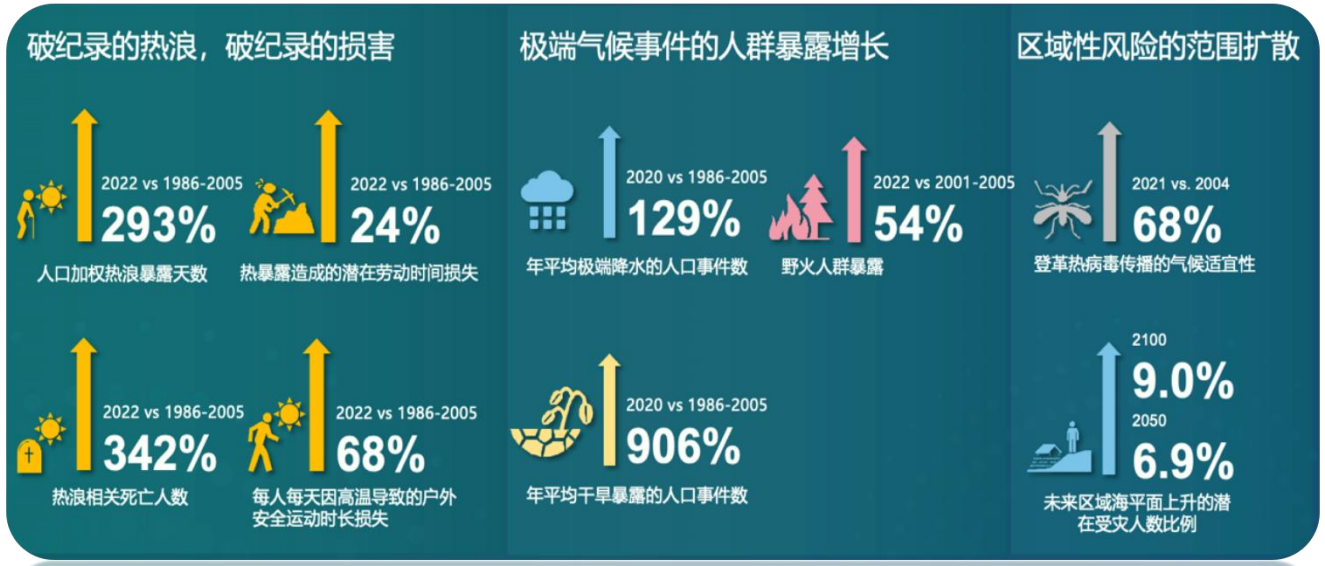


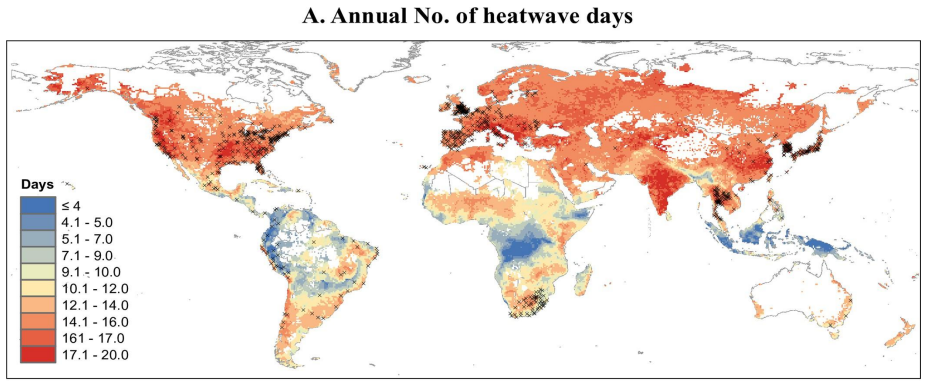


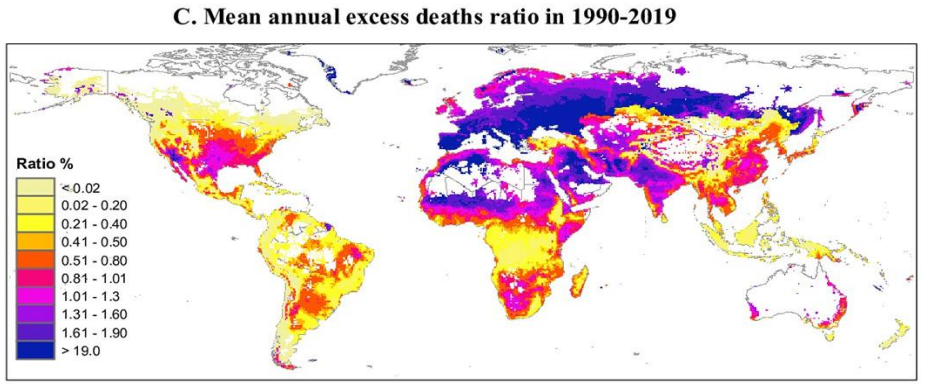
The burden of heat-related mortality attributable to recent human-induced climate change
https://www.nature.com/articles/s41558-021-01058-x#ref-CR14

Current Status of Asian Climate Crisis
亚洲气候危机现状

- ***Death:*** **1990-2019 saw over 153K heatwave deaths globally, half in Asia (India, China, Russia top 3).**
- ***Social labor:*** **2022 heatwaves caused 38.3billion work-hour losses, up 20% in 20 years.**
- ***Economy:*** **2022 heatwave cost $313.5billion (1.91% of GDP) due to labor productivity loss.**
- ***Energy:*** **Prolonged heatwaves surged summer AC demand, while concurrent drought reduced hydropower supply, triggering power supply crises.**







Global, regional, and national burden of heatwave-related mortality from 1990 to 2019: A three-stage modelling study | PLOS Medicine

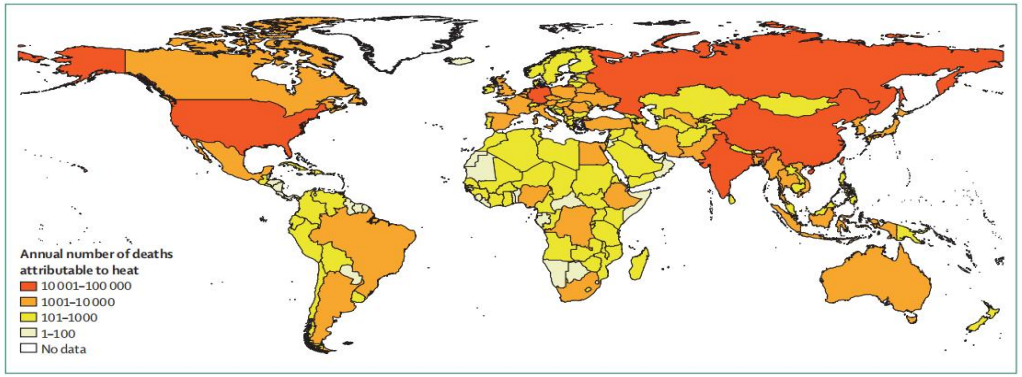
《柳叶刀人群健康与气候变化倒计时中国报告（2023年）》

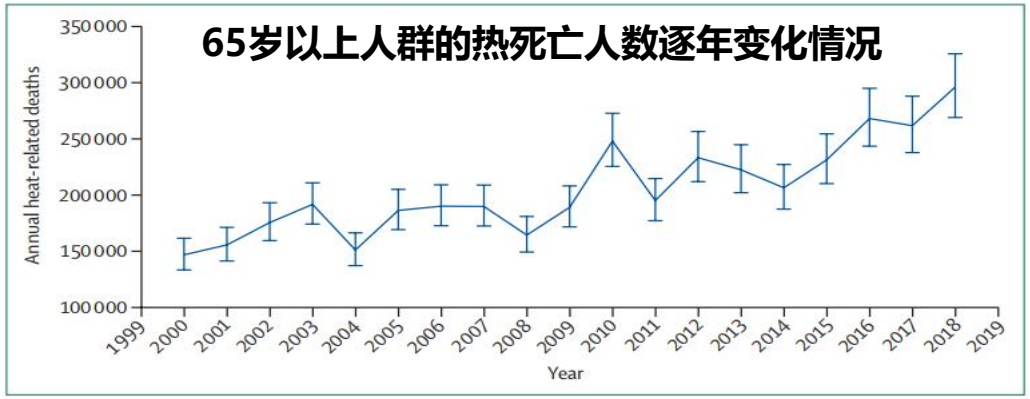
The thermal health issues caused by environment are increasingly severe

热环境导致的热健康问题日益严峻

- Vulnerable groups face rising heat-related disease incidence.
- Heatwave exposure days increased by
  - 3.1 billion person-days (old people over-65s).
  - 626 million person-days (children under 1).

65岁以上人群的热死亡人数的全球分布





	Billions of work hours lost in 2000 (n=199·0)	Billions of work hours lost in 2019 (n=302·4)	Work hours lost per person in 2019
Global	199·0	302·4 (100·0%)	52·7
India	75·0	118·3 (39·1%)	111·2
China	33·4	28·3 (9·4%)	24·5
Bangladesh	13·3	18·2 (6·0%)	148·0
Pakistan	9·5	17·0 (5·6%)	116·2
Indonesia	10·7	15·0 (5·0%)	71·8
Vietnam	7·7	12·5 (4·1%)	160·3
Thailand	6·3	9·7 (3·2%)	164·4
Nigeria	4·3	9·4 (3·1%)	66·7
Philippines	3·5	5·8 (1·9%)	71·4
Brazil	2·8	4·0 (1·3%)	23·3
Cambodia	1·7	2·2 (0·7%)	202·2
USA	1·2	2·0 (0·7%)	7·1
Mexico	0·9	1·7 (0·6%)	17·4
Rest of the world	28·7	58·3 (19·3%)	27·5

Data are n or n (%). For these estimates, all agricultural and construction work was assumed to be in the shade or indoors—the lower bounds of potential work hours lost. Work hours lost per person were estimated for the population older than 15 years.

Table 1: **Potential heat-related work hours lost**

N. Watts, et al., The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises, The Lancet, 397 (2021) 129-170.
《柳叶刀人群健康与气候变化倒计时中国报告（2023年）》

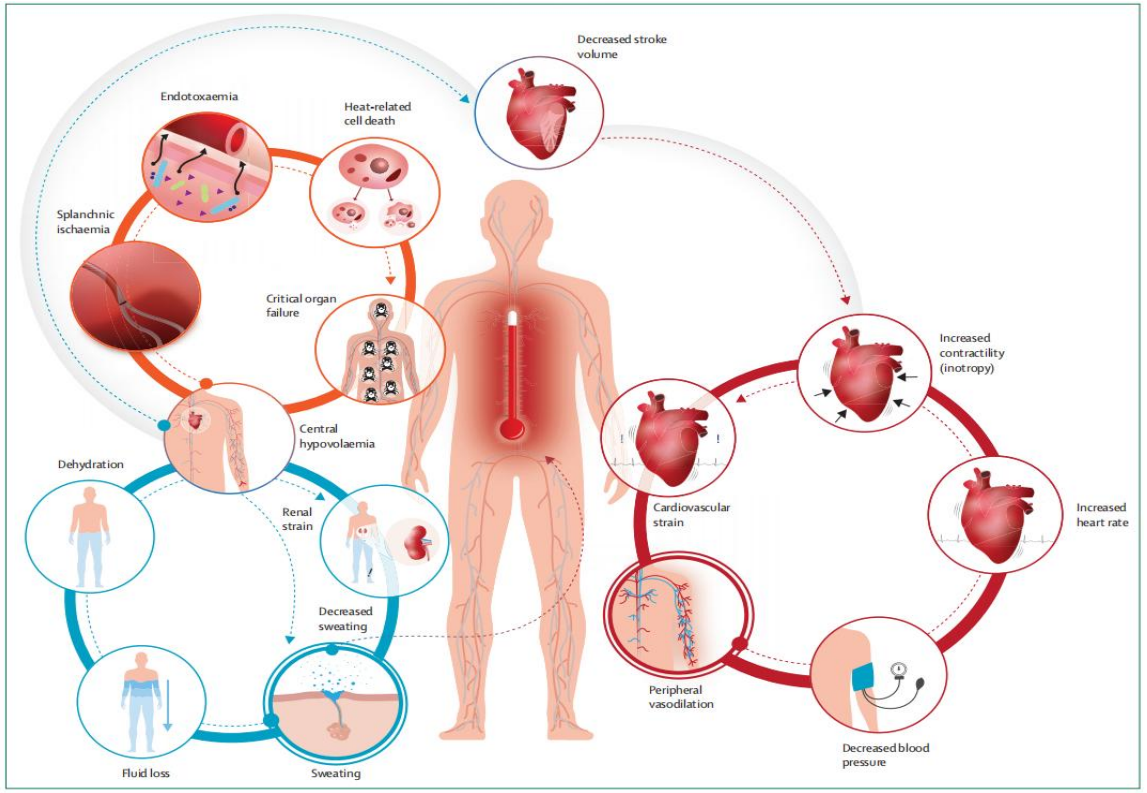
The thermal health issues caused by environment are increasingly severe

热环境导致的热健康问题日益严峻

清華大學 Tsinghua University

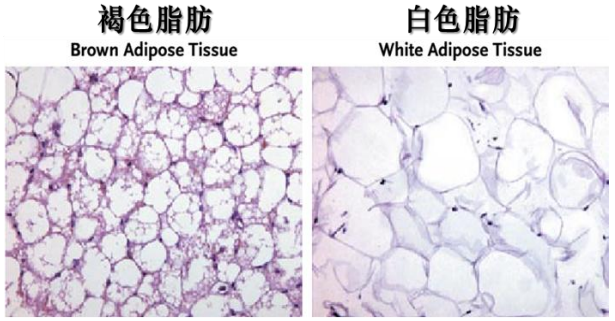
Hot Health paper published in the Lancet (2021):

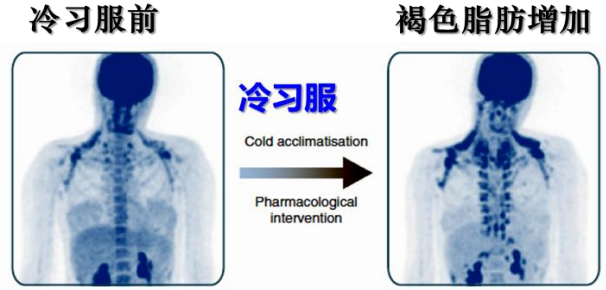
"Reveals the mechanism among thermal environment, human physiological response, and human health."

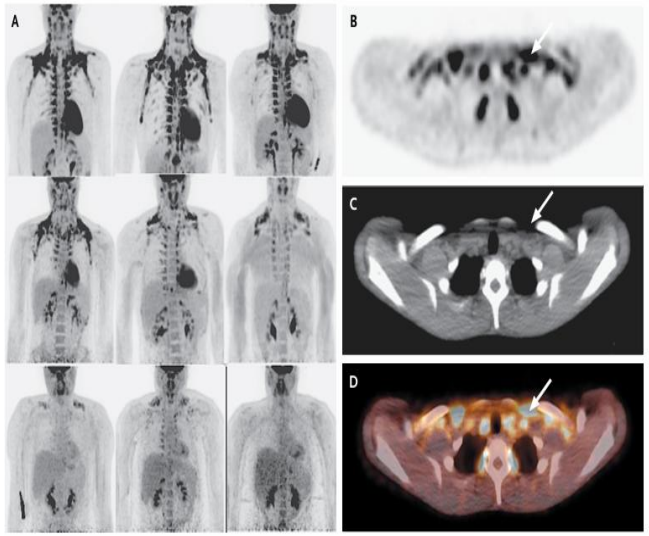


Pro. Wouter van Marken Lichtenbel from the Netherlands:

"Thermal environment affects human endocrine and metabolic systems."





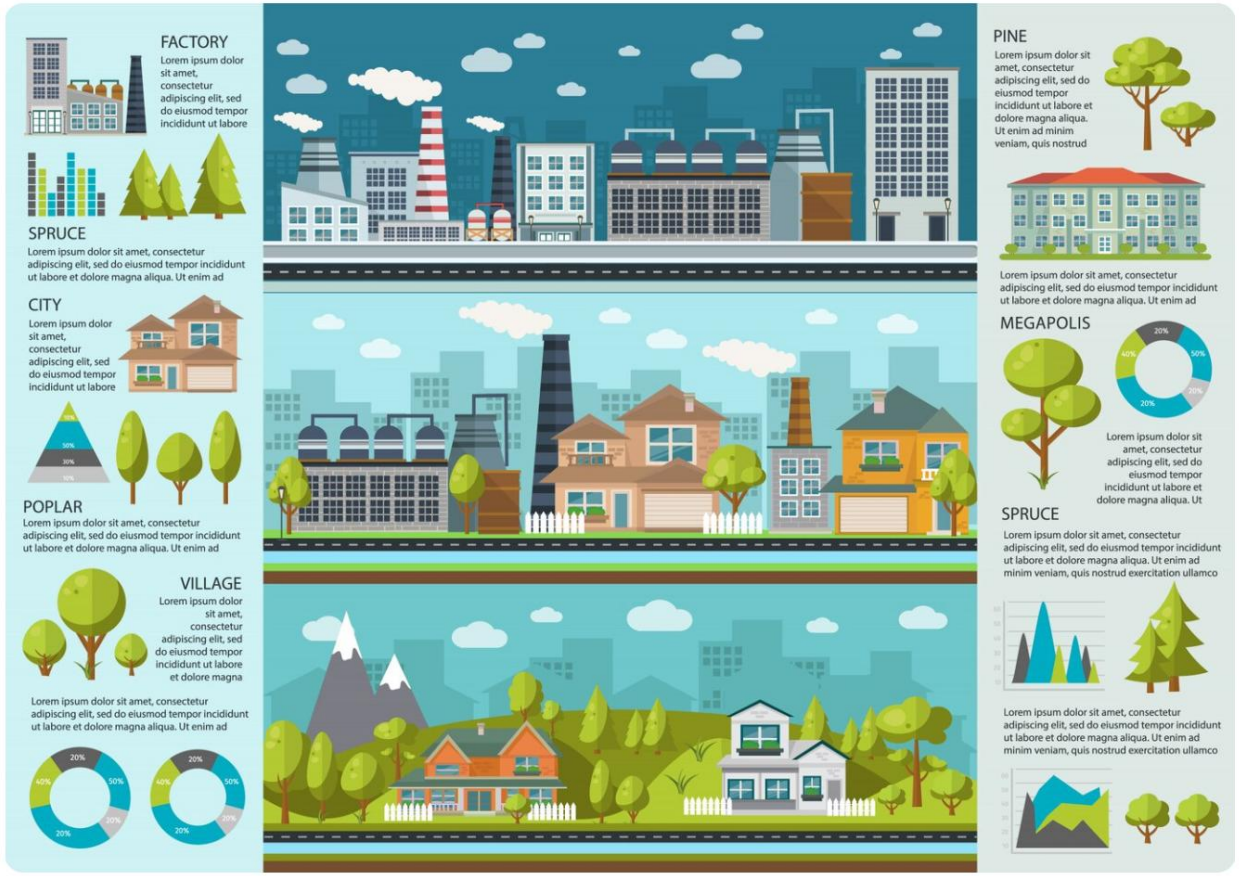


热健康的生理学威胁

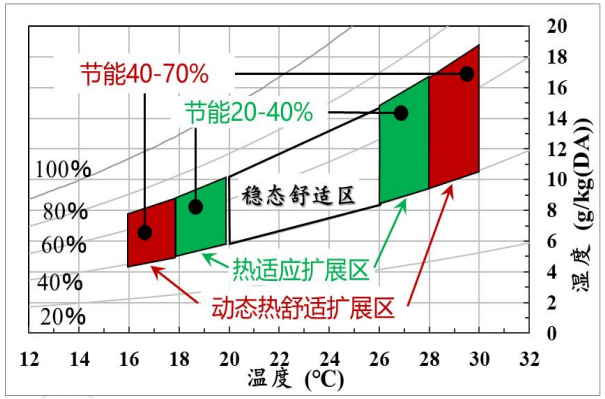
1. K.L. Ebi, A. Capon, P. Berry, C. Broderick, R. de Dear, G, Hot weather and heat extremes: health risks, The Lancet, 398 (2021) 698-708.
2. O. Jay, A. Capon, P. Berry, C. Broderick, R. de Dear, G, Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities, The Lancet, 398 (2021) 709-724.
3. W. Lichtenbelt, et al. The future of brown adipose tissues in the treatment of type 2 diabetes, Diabetologia, 2015, 58 (8) :1704-1707e
4. W. Lichtenbelt, et al. Cold-Activated Brown Adipose Tissue in Healthy Men. The New England Journal of Medicine, 2009, 360(15): 1500–1508.

The building sector plays an important role
建筑领域的重要性

Buildings are major sources of greenhouse gas emissions and a cause of climate crisis.



Humans spend 90% of time indoors, making healthy & efficient building thermal environments vital for thermal health.

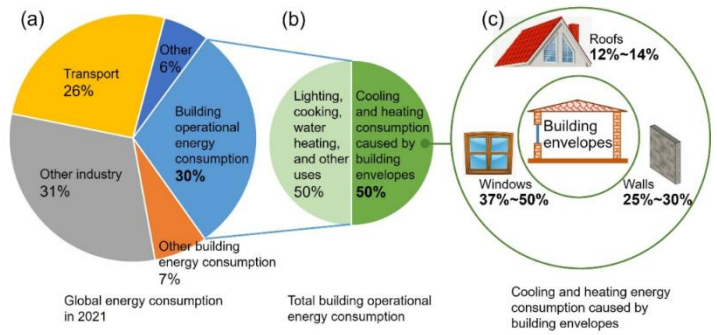


The inadequacies of traditional building systems
传统建筑系统的不足

静态围护结构—Ⓢ动态气候的矛盾

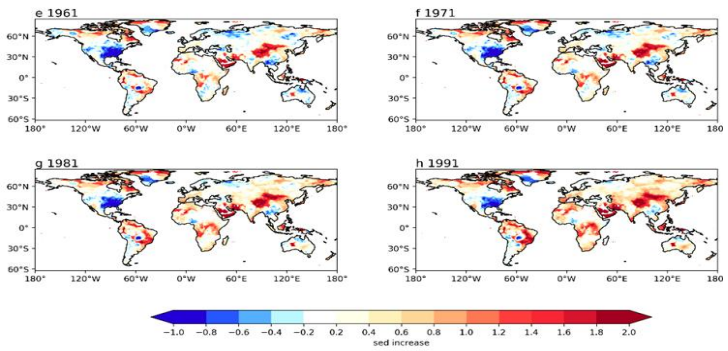
Contradiction：

Static building envelopes —



BUT

Dynamic climate ∿



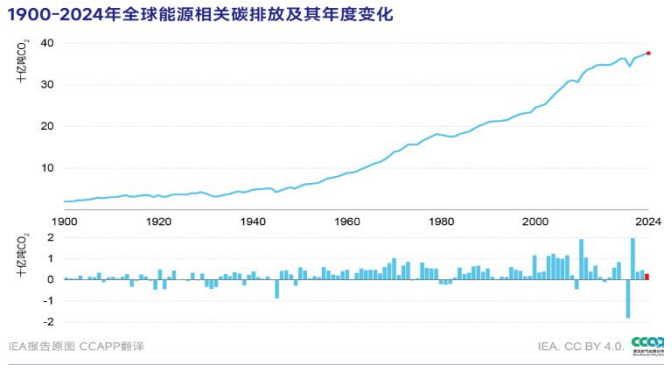
空调普及率↑与碳排放↑的能耗困境

Dilemma：

Air-conditioning popularity ↑

BUT

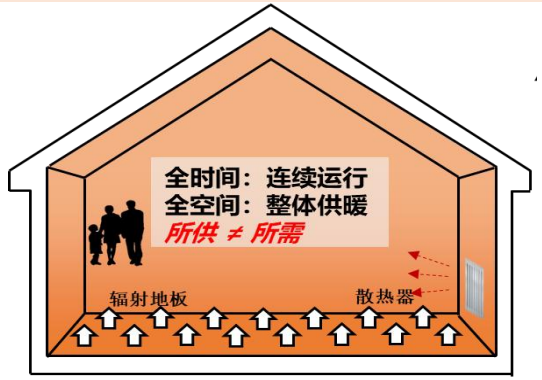
Carbon emissions ↑



全空间环境营造→能源浪费

Waste：

Overall supply ○



BUT

Local demand

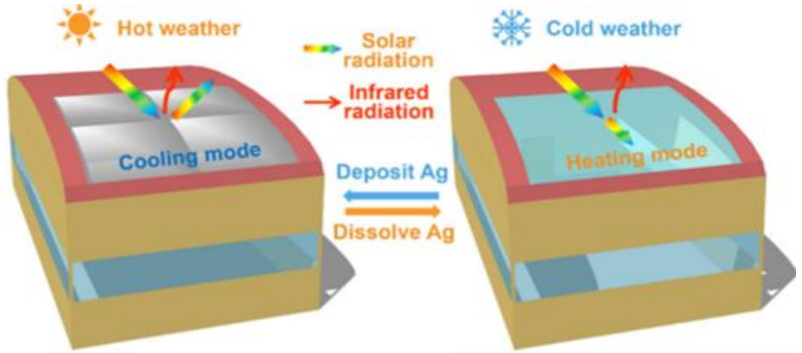
The demand for future technological R&D in the building sector
气候危机/热风险对建筑侧未来技术研发的需求

清華大學 Tsinghua University

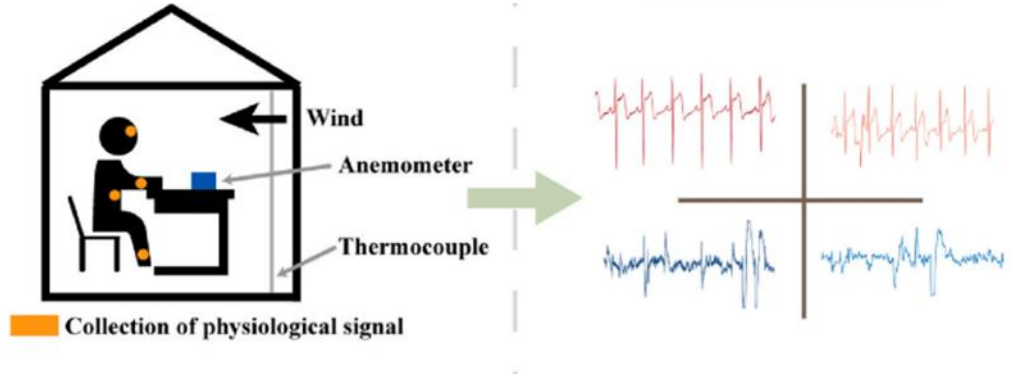
Contradiction：	*Dilemma：*	*Waste：*
Static building envelopes	Air-conditioning popularity ↑	Overall supply
BUT	**BUT**	**BUT**
Dynamic climate	Carbon emissions ↑	Local demand

Technical Needs for Buildings to Address Climate Change & Heat Risks:

Dynamic response capability



Human-centered precise regulation



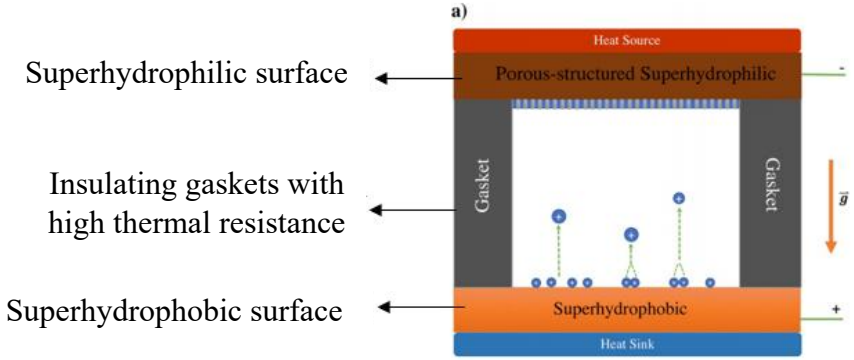
Our Team's Technical Explorations——

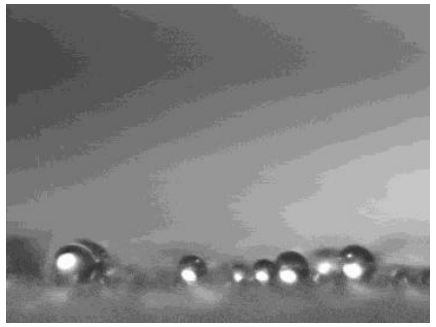
- New technology for non-transparent building envelopes: thermal diode roofs
- New technology for transparent building envelopes: smart windows
- New technology for local built environment: radiant-convective workstation terminals

Non-transparent building envelopes: thermal diode roofs
建筑非透光围护结构新技术-热二极管屋顶

- **Implementation method: Jumping-droplet thermal diode**

- Innovative working mechanism with excellent unidirectional heat transfer capability

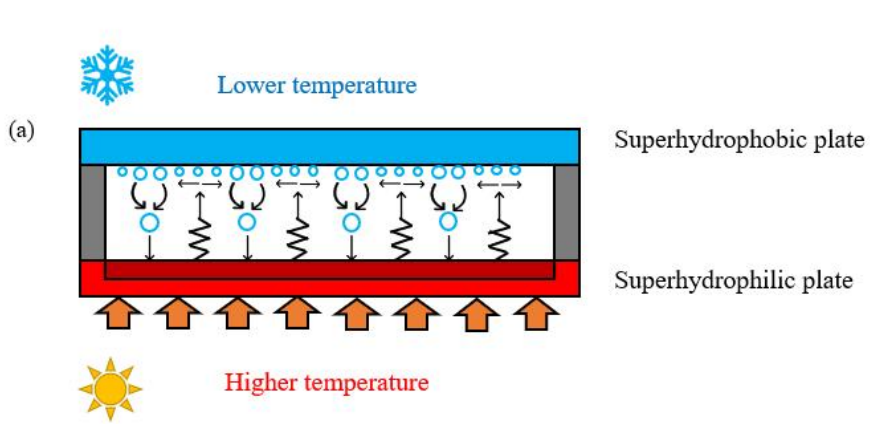




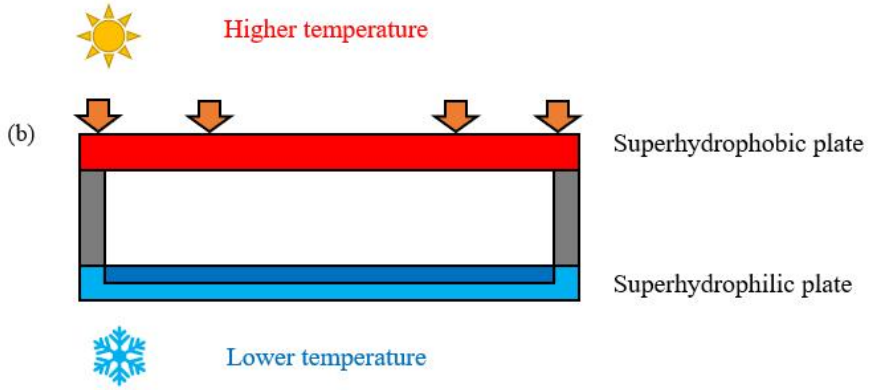
$$\eta = \frac{k_f - k_r}{k_r}$$

k_f— forward， W/m·K

k_r— reverse， W/m·K



Forward Mode (a) ： For heat removal



Reverse mode (b) ： For thermal insulation

Differences in working modes

Passive insulation and heat dissipation in buildings

Forward mode: Water evaporates for phase change heat transfer, condenses on the upper side
Reverse mode: No internal phase change heat transfer, only ineffective thermal conductivity

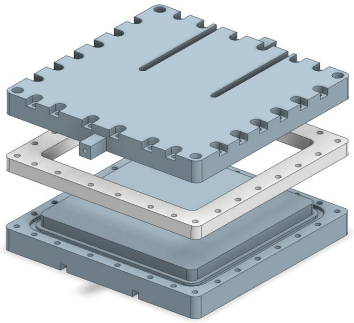
Non-transparent building envelopes: thermal diode roofs

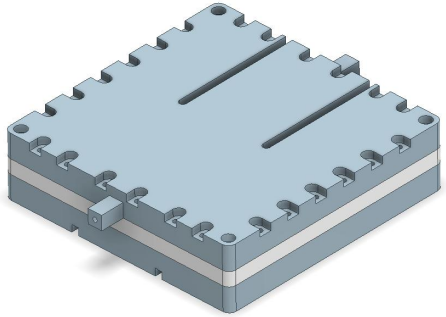
建筑非透光围护结构新技术-热二极管屋顶

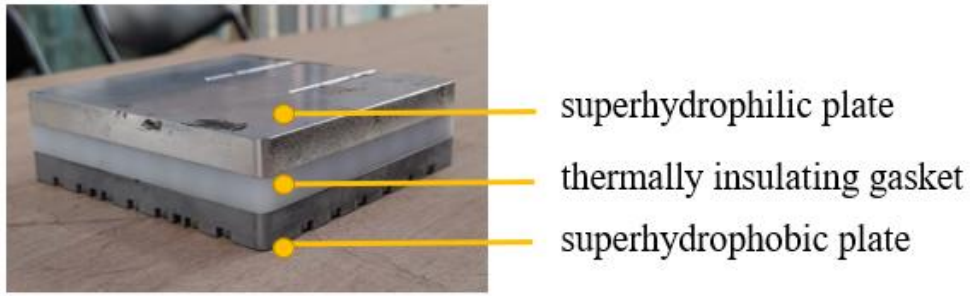
- **Fabrication of the novel thermal diode**

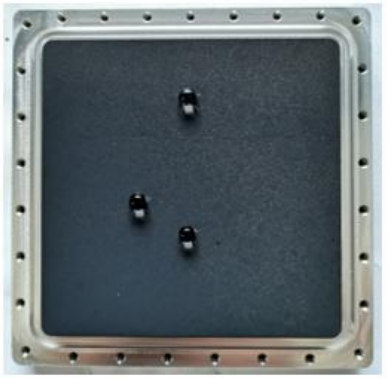
  - The thermal diodes manufactured mainly consist of **aluminum and copper plates**

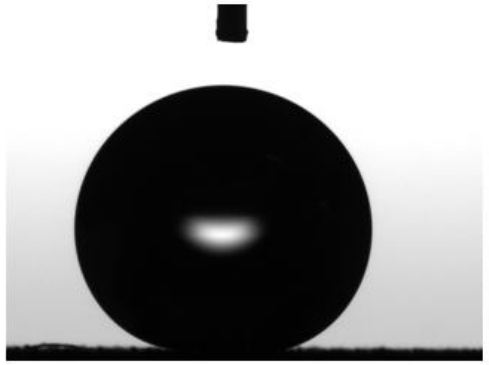
  - Manufacturing mainly includes **superhydrophilic surface and superhydrophobic surface**

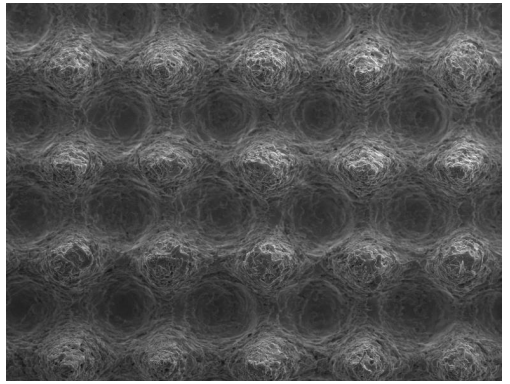










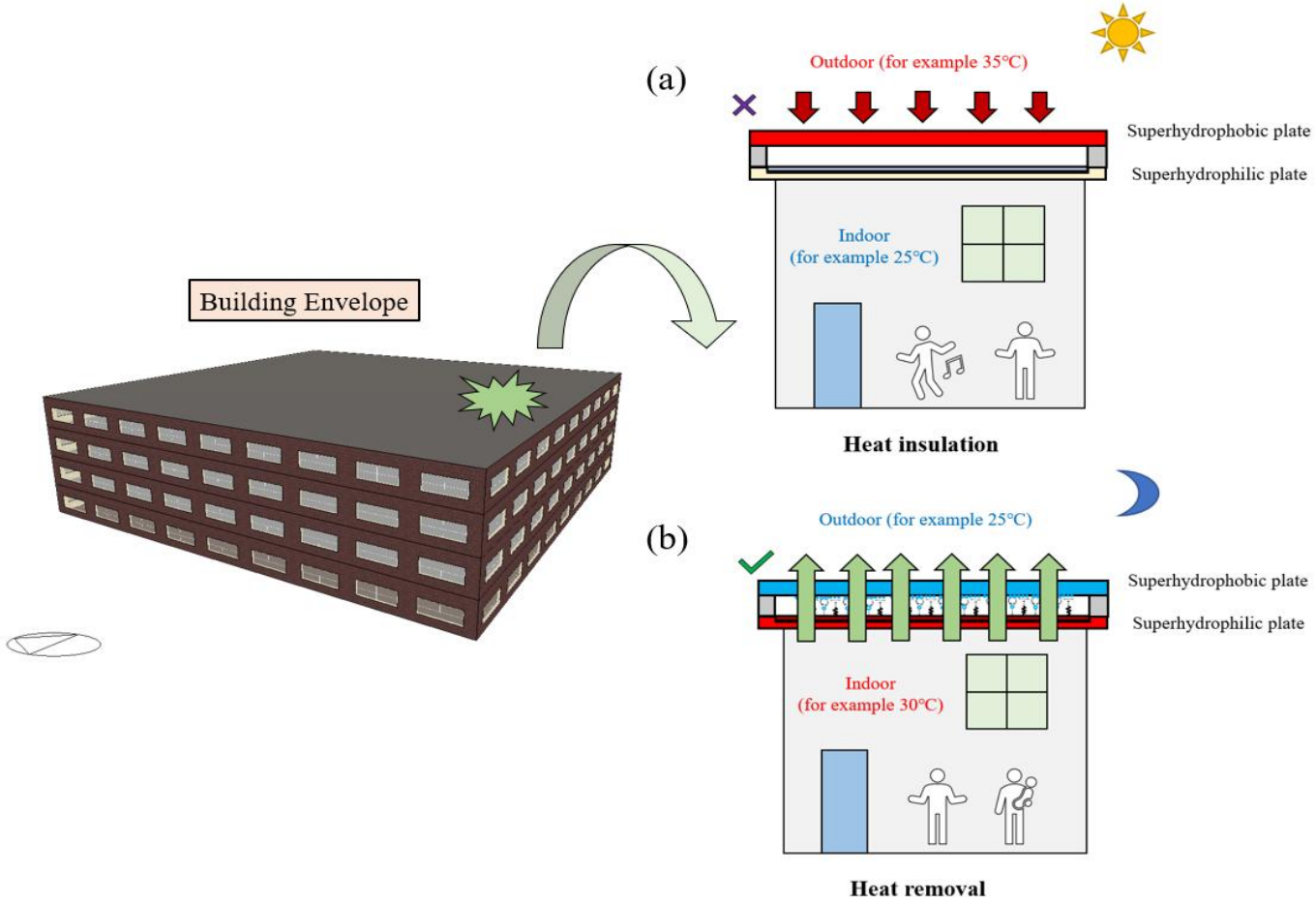


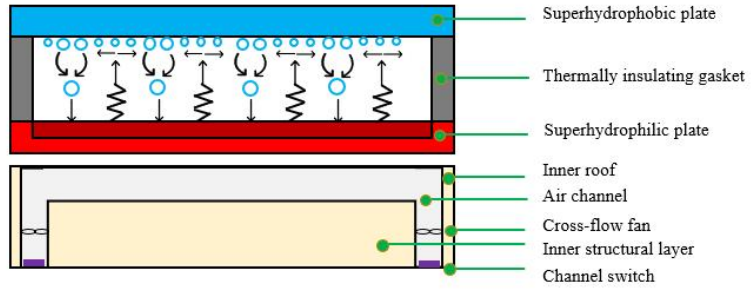
Laser fabricated groove structure 50μm + low surface energy coating-CA 160°-RA 7°

Non-transparent building envelopes: thermal diode roofs

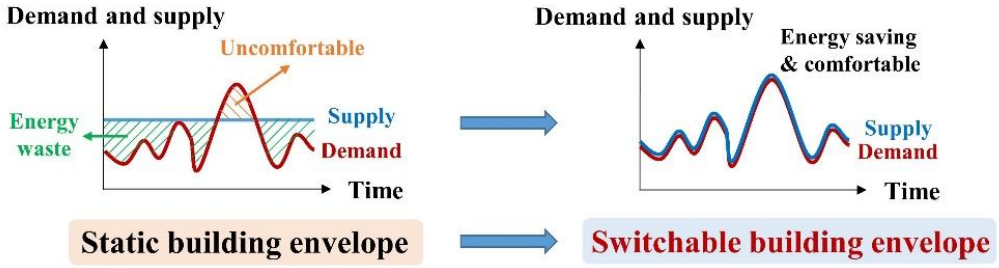
建筑非透光围护结构新技术-热二极管屋顶

- **Jumping droplet thermal diodes combined with building envelope**
  - Application in the field of **building envelope to achieve passive energy saving**
  - Initially used on **building roofs** to **insulate heat during the day and passively exhaust heat at night**





Jumping droplet thermal diodes combined with building roofs, **dynamically adjustable**

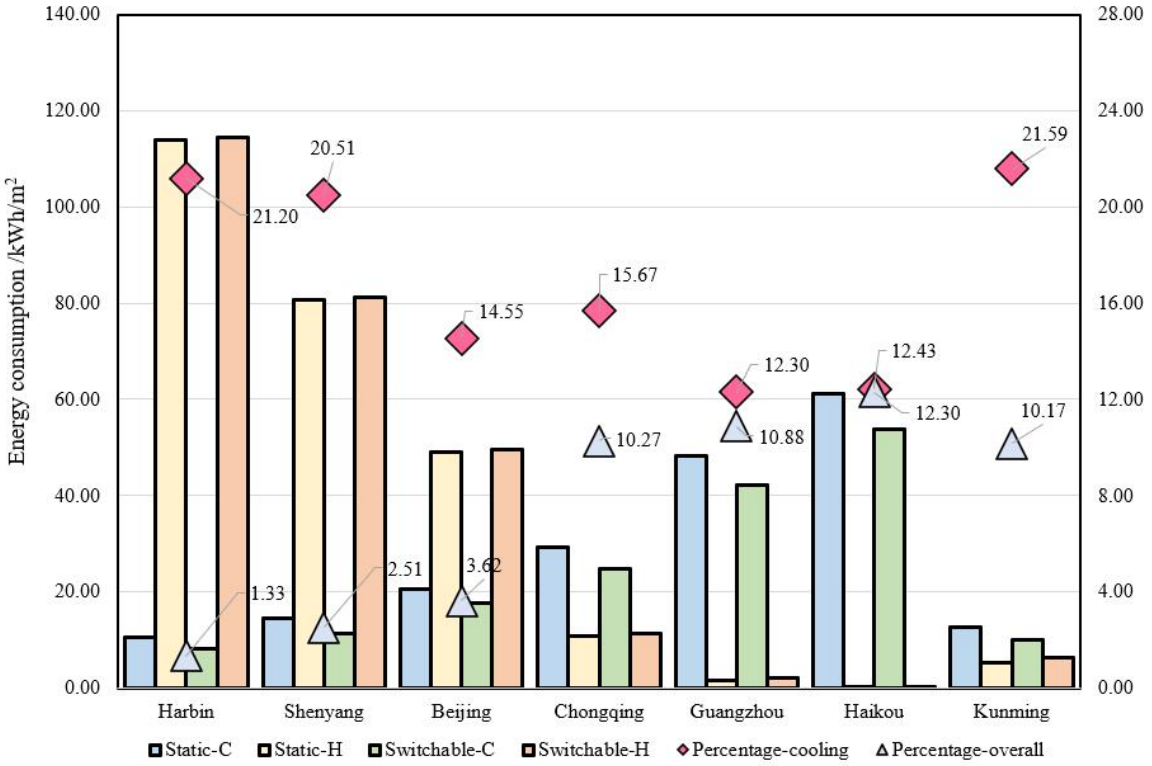


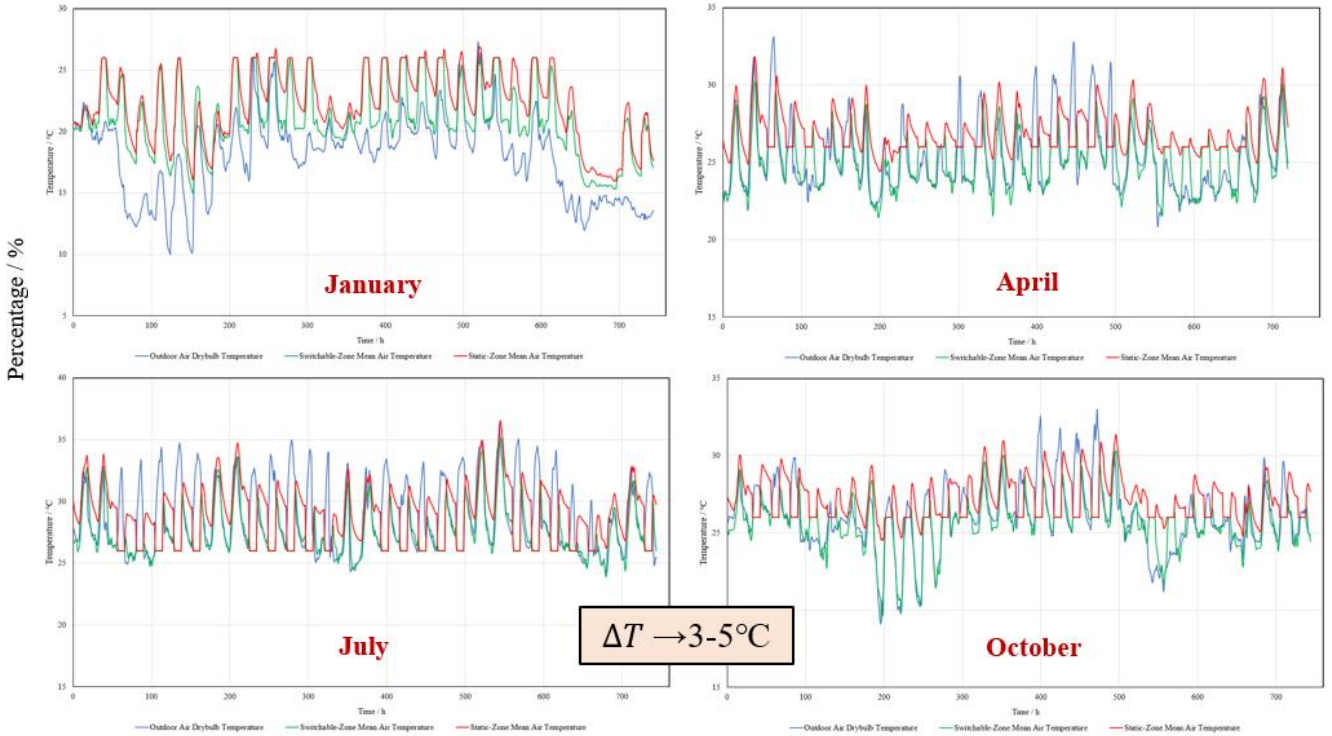
Non-transparent building envelopes: thermal diode roofs
建筑非透光围护结构新技术-热二极管屋顶

Tsinghua University

- **Simulation results of energy consumption in different climate zones**

  - **Seven Chinese cities in seven climate zones** were selected for simulation with CDD10 from high to low





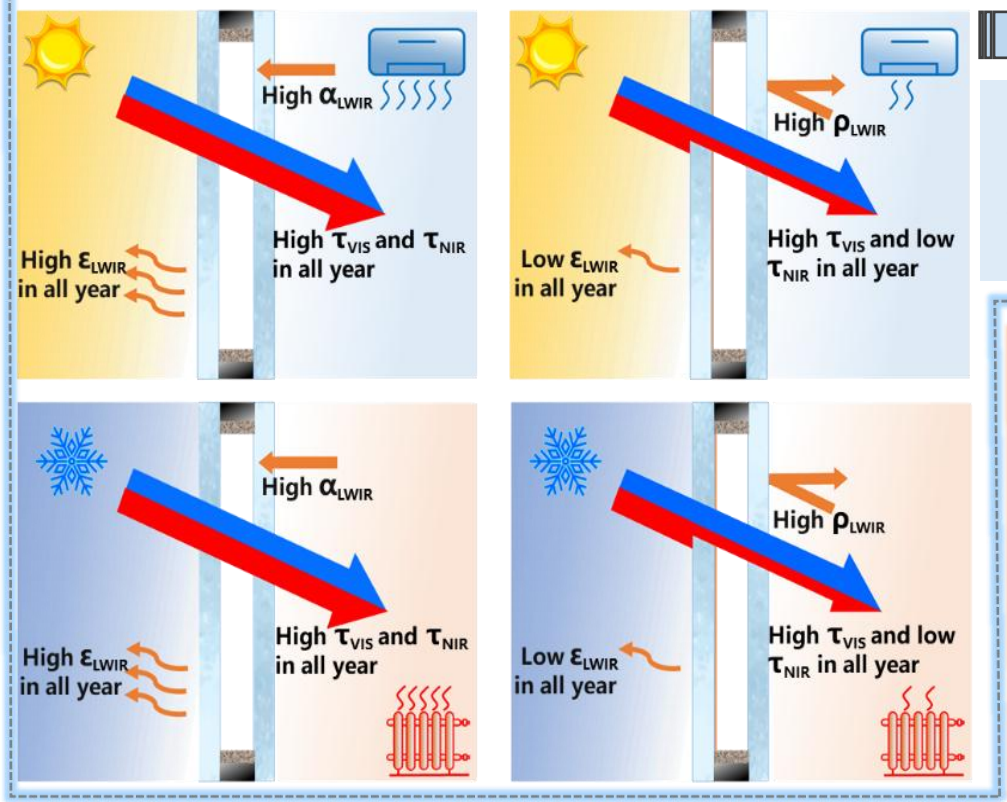
➢ The building envelope has a certain energy saving potential in terms of **cooling energy consumption, which reaches 12.30-21.59%**

➢ **The passive temperature difference is 3-5℃**

Non-transparent building envelopes: smart windows
建筑非透光围护结构新技术-智能窗

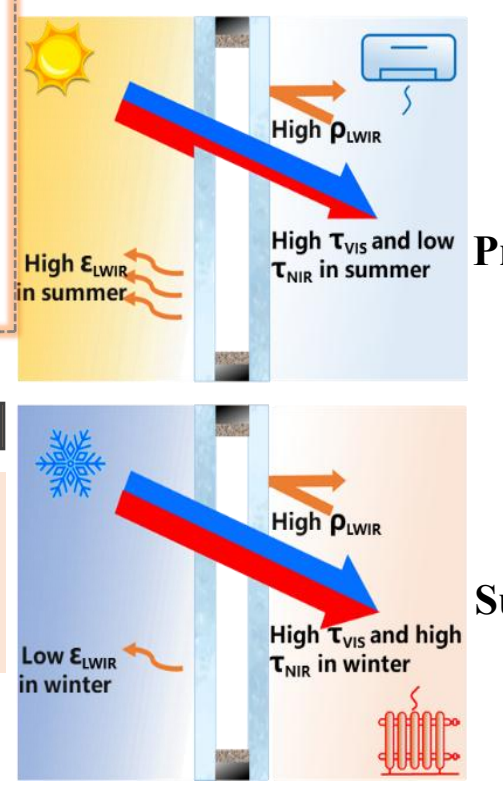
Adjustable smart windows: composed of dimming material and glass and other substrates, their solar radiation transmittance can be actively/passively adjusted

Traditional static transparent envelopes:



Limitations:
Overheating in summer or insufficient passive heating in winter

Smart windows:



Summer:
Guaranteed VIS
Shield NIR
Promotes radiative cooling

Winter:
Guaranteed VIS
Transmits NIR
Suppresses radiative cooling

Advantages:
Maximizing the energy-saving benefits throughout the year

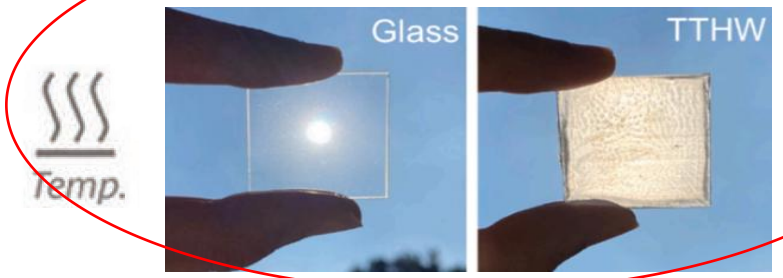
Smart window- Adaptive regulation achieves global energy-saving benefits

智能窗-自适应调节可实现全球节能效益

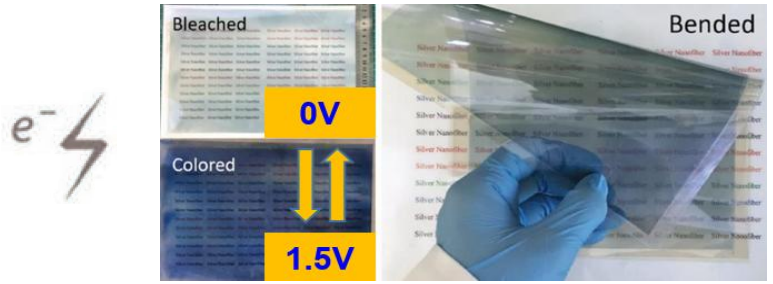
Tsinghua University

Many types of smart window-related technologies

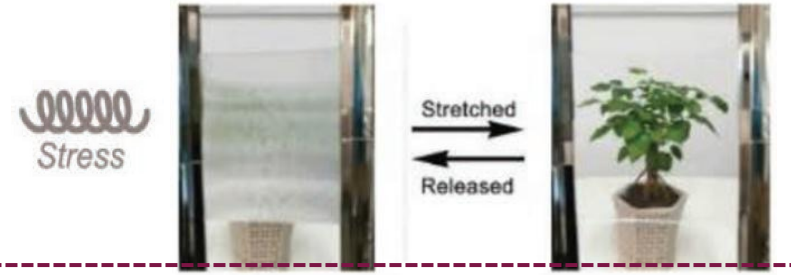
Thermochromic smart window



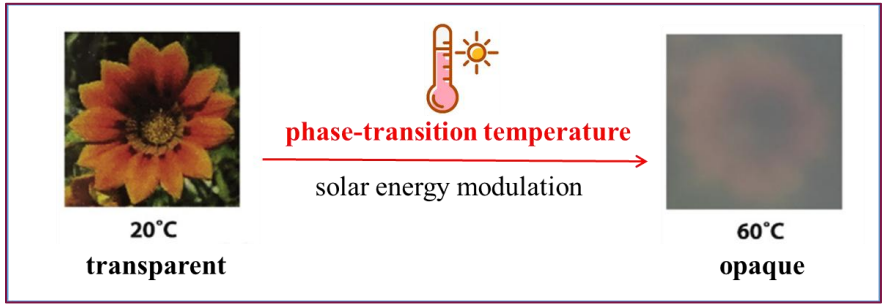
Electrochromic smart window



Mechanochromic smart window



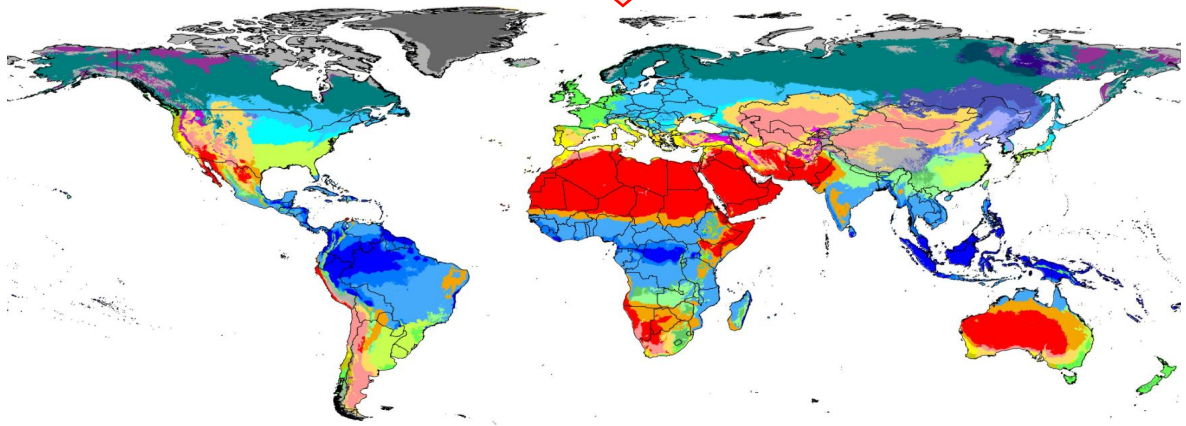
Thermochromic smart window



Outdoor Weather Changes

Climate adaptation
Completely passive

Window status changes



Produce certain energy-saving effects in various climate zones.

Smart window- Efficient light-thermal control

智能窗-高效光热调控营造舒适健康的室内环境

Outdoor

Energy performance

Facade

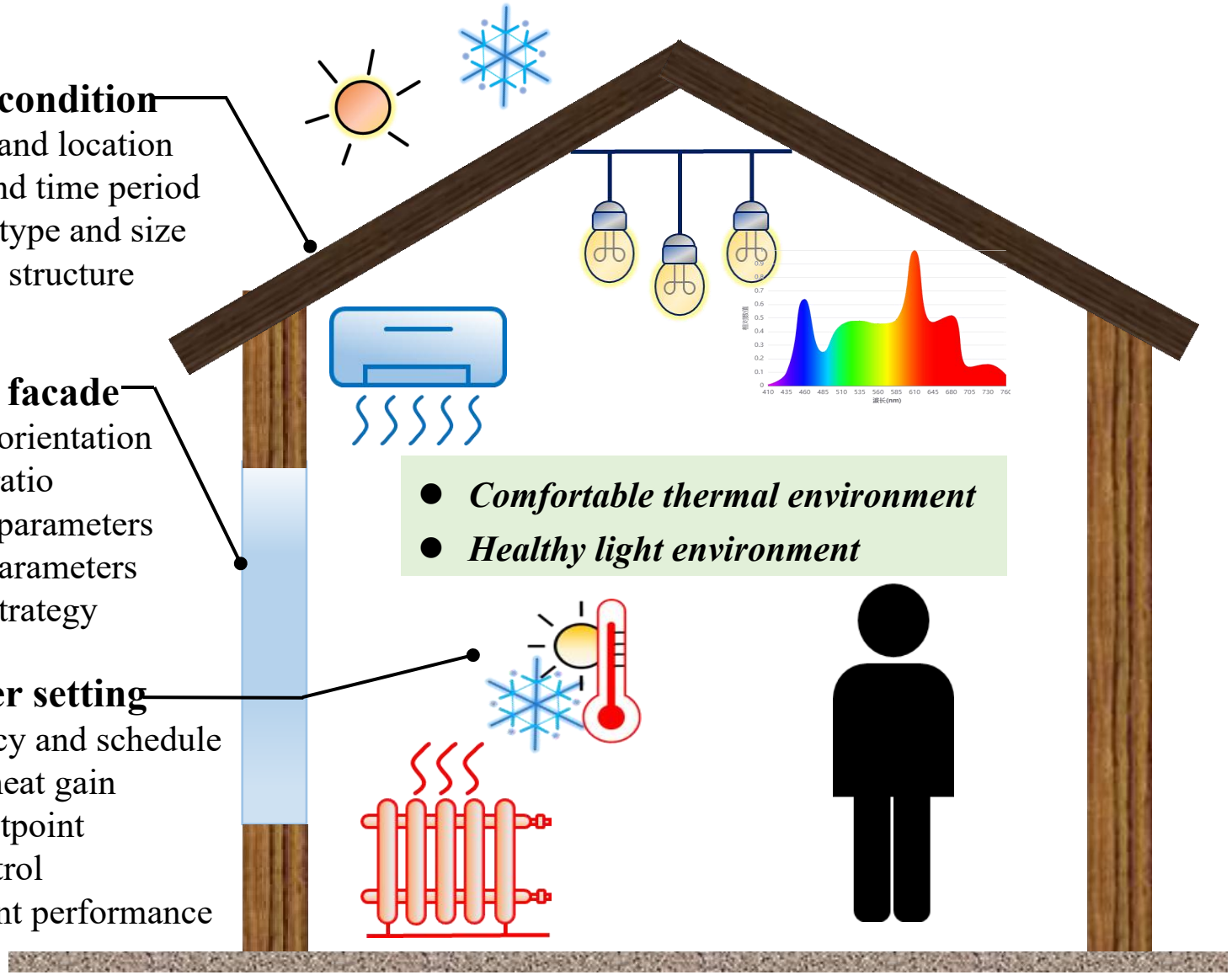
Environmental performance

Indoor

Building condition
- Climatic and location
- Season and time period
- Building type and size
- Envelope structure

Adaptive facade
- Window orientation
- Glazing ratio
- Thermal parameters
- Optical parameters
- Control strategy

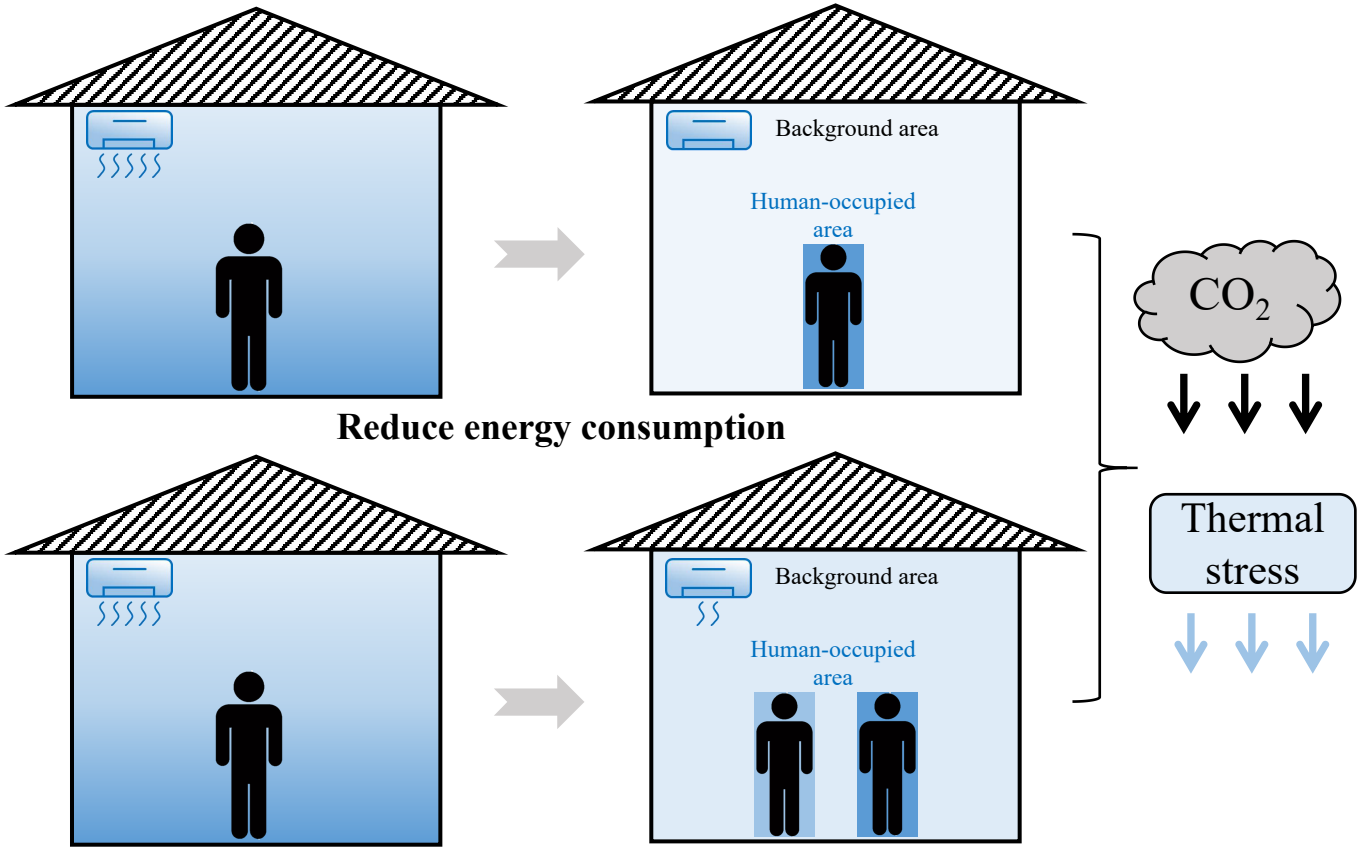
Parameter setting
- Occupancy and schedule
- Internal heat gain
- HVAC setpoint
- User control
- Equipment performance



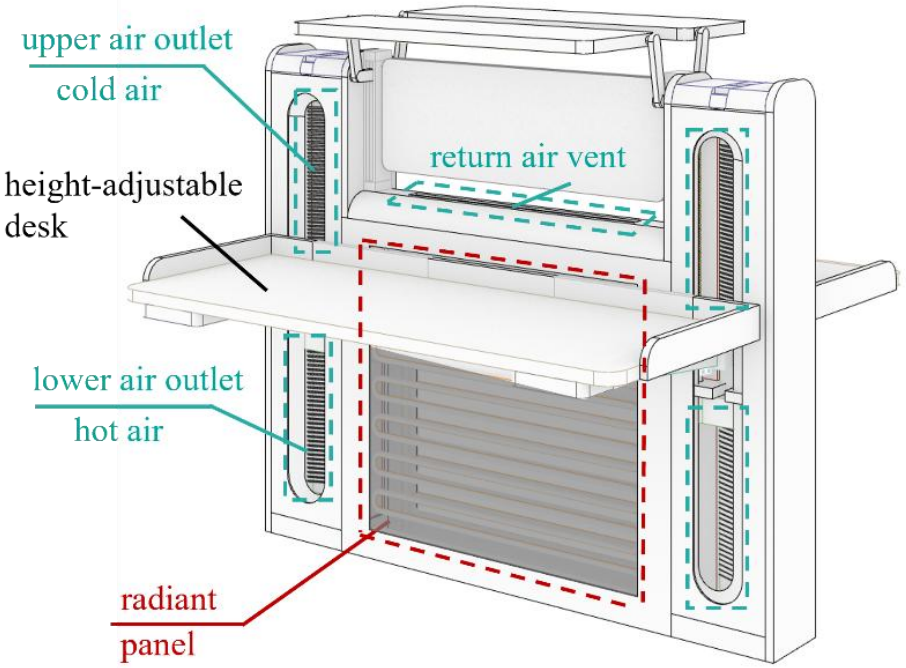
Radiant-Convective Workstation Terminals-Technical principle
辐射对流工位末端-技术原理

Radiant-convective workstation terminal: creates localized environmental conditions to meet personalized comfort needs, shaping a **customized micro-environment** to cope with climate change

"Partial-time, localized spaces" Concept



Radiant-convective workstation terminal



Convective -Rapid response

Radiant -Comfort

Precise thermal regulation enhances individual thermal comfort

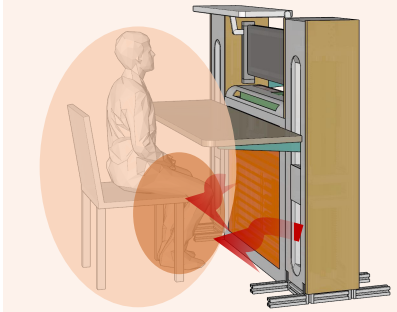
辐射对流工位末端-精准热调控提升个体热舒适

Tsinghua University

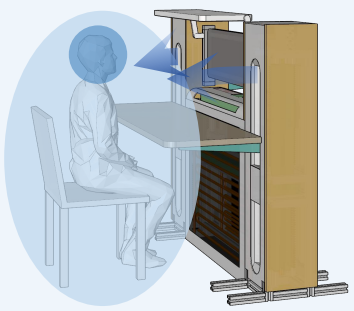
The terminal creates a comfortable thermal environment that promotes heat health

Terminal usage pattern

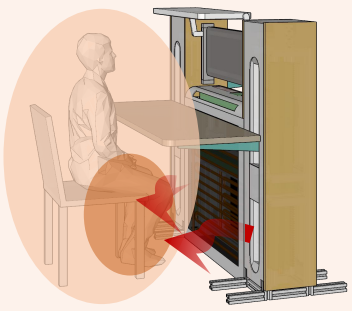
Heating



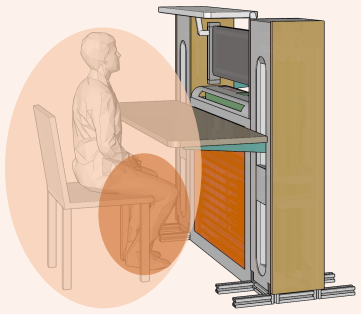
Cooling



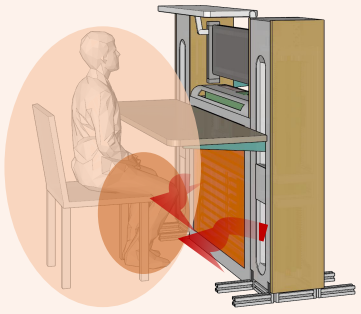
Convection mode



Radiation mode

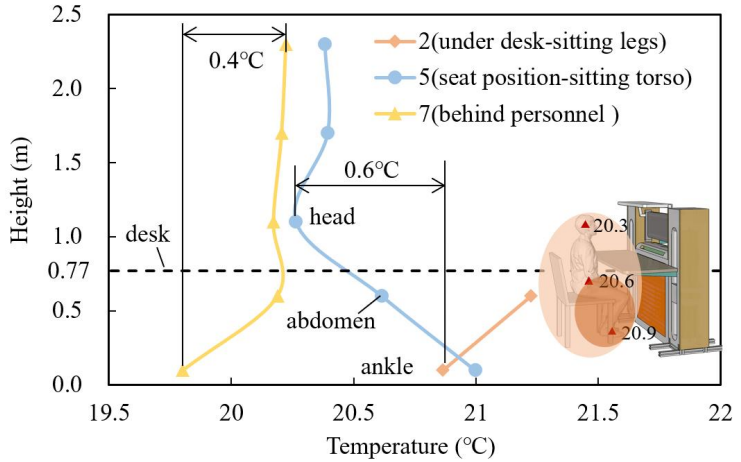


Combined mode

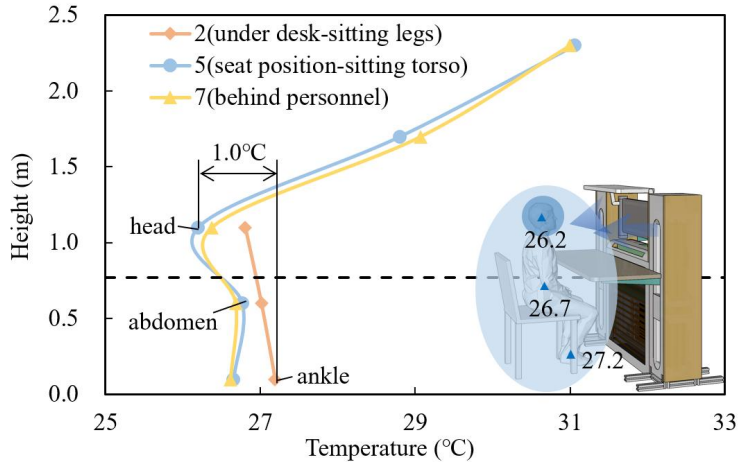


Thermal Performance

Heating



Cooling

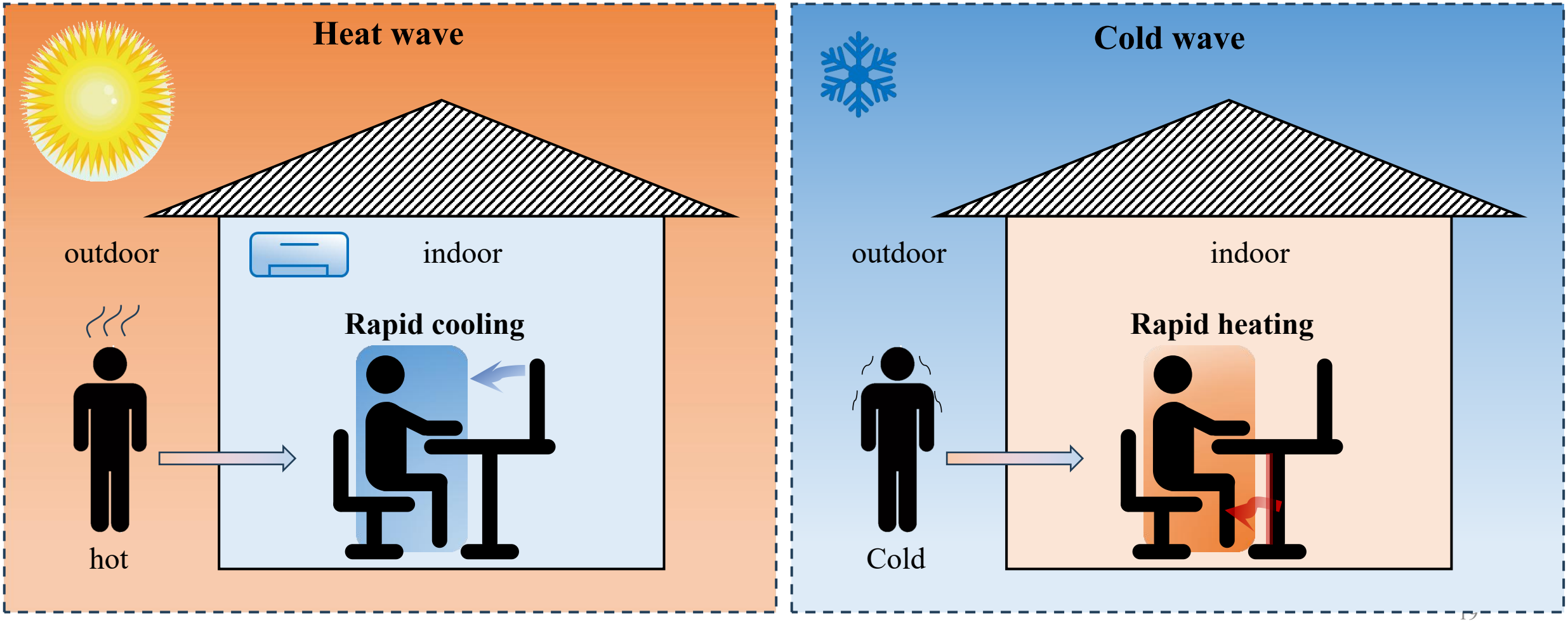


Copes with extreme climates to safeguard personnel thermal health

辐射对流工位末端-应对极端气候保障人员热健康

Tsinghua University

During extreme climate events, a thermally neutral environment is maintained to mitigate thermal stress, particularly benefiting vulnerable populations such as the elderly and those with chronic conditions.



Thank You!

Prof. Borong LIN
Dr. Yang GENG

School of Architecture
Tsinghua University

June 19th, 2025