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EBC Annex 69

Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings

EBC Webinar: The Science and Communication of Energy-Efficient Indoor Environments

10th November 2020

Yingxin Zhu
Tsinghua University
China

Richard de Dear
The University of Sydney
Australia

Background ——Low Energy Buildings

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- How to achieve low energy building?
  1. Appropriate indoor thermal environment
  2. Reasonable architecture design
  3. Low energy thermal environment control facilities

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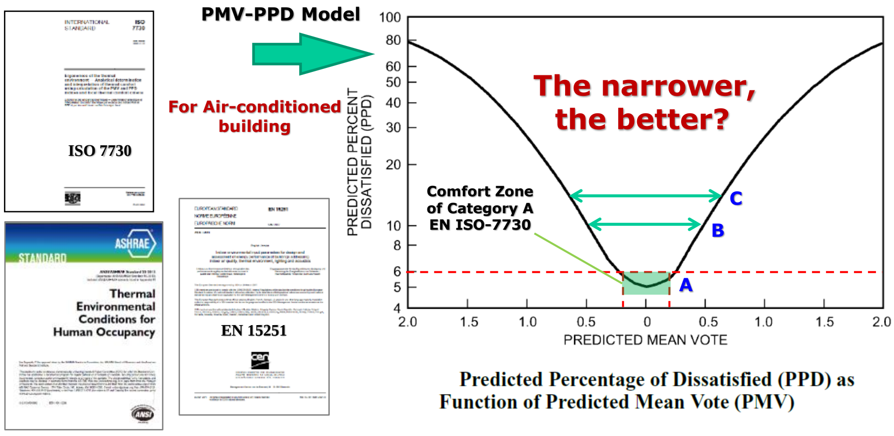
Why "Adaptive Thermal Comfort"?



Predicted Percentage of Dissatisfied (PPD) as Function of Predicted Mean Vote (PMV)

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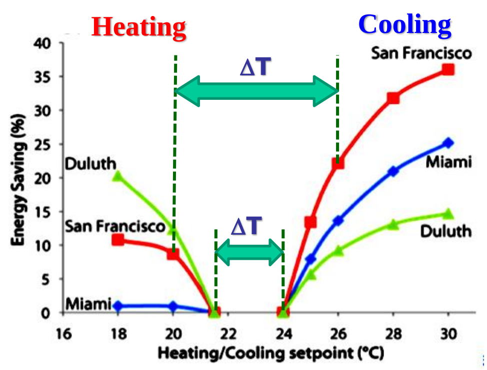
Energy Costs of Tight Temperature Control

As temperature control technologies have improved, dead-bands in buildings become narrower

We now rate buildings on their *thermal imperceptibility*.

However the amount of *HVAC energy demand* increases profoundly with such tight control.



Hoyt *et al*. (2009) "Energy savings from extended air temperature setpoints and reductions in room air mixing." International Conference on Environmental Ergonomics, Boston.

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1. Appropriate indoor thermal environment

Indoor thermal comfort standard and evaluation index are key point

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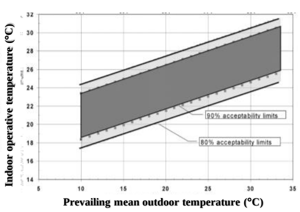
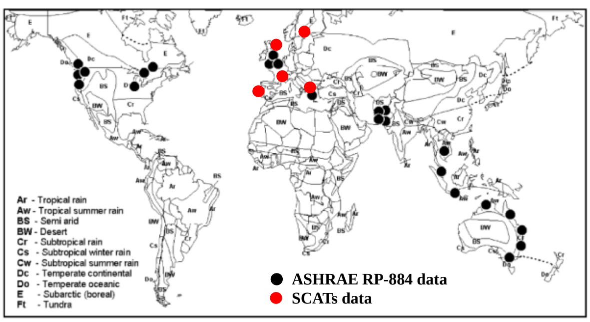
Adaptive thermal comfort model

Old databases: ASHRAE RP-884: 21000+ data from 4 continents
SCATs: 31000+ data from 5 European countries

- **ASHRAE Std. 55**
- **EN 15251**

For Free-running building

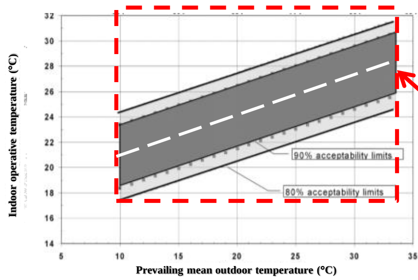




Shortages: Quality of original data was ragged; Format and information were not unified; Lack of data from many important climate zones

Adaptive thermal comfort model: Problems and Challenges

- Although the adaptive effect has been recognized widely by researchers, but the mechanism has not been yet included in the model — partially due to the imperfection of old database

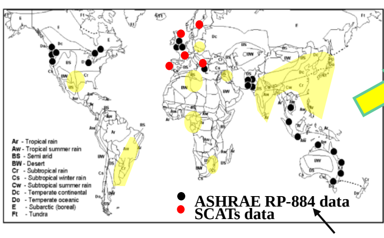


$$T_{comf} = 0.31 T_{out,m} + 17.8$$

How physiological adaption, psychological adaption, occupants' behavior work along with thermal balance?

What we have done

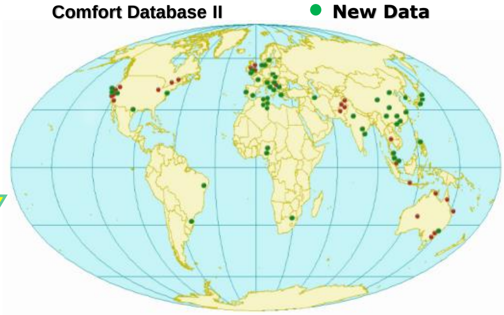
First step: thermal comfort database



ASHRAE Global Thermal Comfort Database I

ASHRAE Global Thermal Comfort Database II

● Old Data
● New Data



6 Continents, 22 Countries, 55 cities; >180,000 new data Denmark, Iran, Japan, USA, Nigeria, China, Phillipines, Singapore, Australia, India, Slovakia, Italy, Tunisia, South Africa, UK, weden, Portugal, Greece, France, Brazil, Korea

The adaptive thermal comfort model with mechanism—— SET based model

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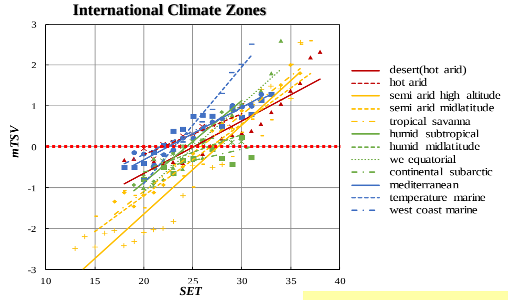
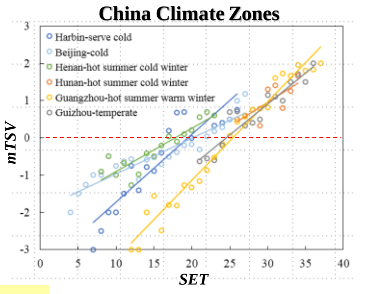
Tsinghua Univ.: PTS model (Predicted Thermal Sensation)

$PTS = f(t_a, RH, v_a, MRT, Met, clo, \text{indoor/outdoor thermal experience, psychological adaption})$





Data source: ASHRAE Global Thermal Comfort Database I
Number of samples: 20693

The slope and intercept reflect different thermal adaptation levels.

Data source: ASHRAE Global Thermal Comfort Database II
Number of samples: 5043

The adaptive thermal comfort model with mechanism—— PMV based model

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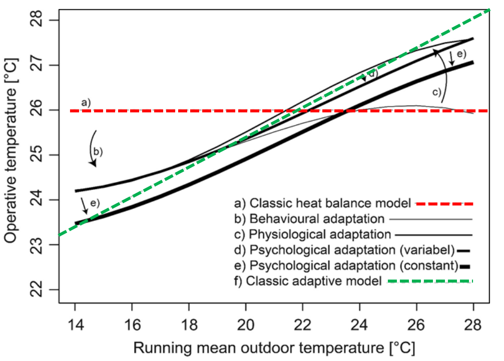

Marcel Schweiker & Andreas Wagner, 2015

What thermal comfort index/model should be used for mixed-mode building?

- Mixed-mode building=Free running + Air-conditioning
- In many Asia countries, most buildings are mixed-mode buildings
- **We found that thermal adaptation is also present in mixed-mode buildings**
- Adaptive opportunities：
  - Natural ventilation, shading, solar radiation, change cloth, drink cold/hot drinks……
  - Electric fan, air-conditioner, personal comfort system(PCS)

2. Reasonable Architecture Design

Not always high insulation and air tight are reasonable

A Mixed-mode office building, Shenzhen, China, subtropical climate

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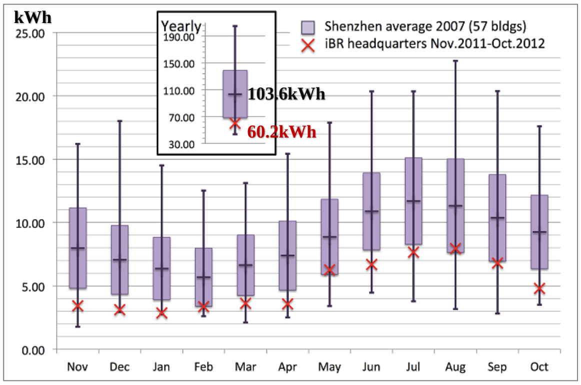
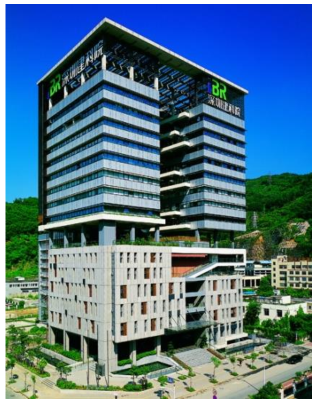
Strategy: open spaces, natural ventilation, local controlled AC, 60% energy consumption





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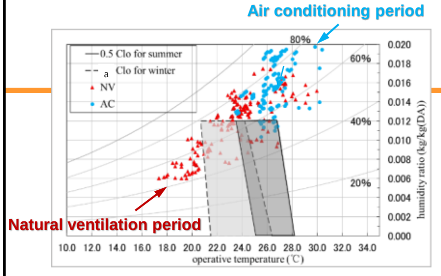

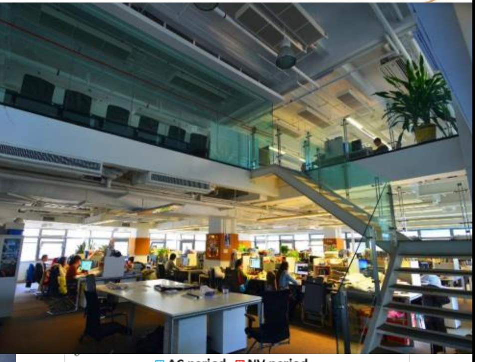

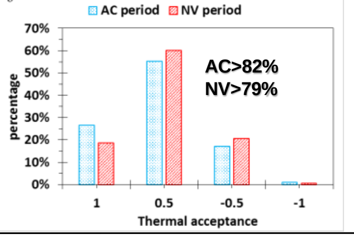

Office building in Guian, China
Free-running building, Moderate climate

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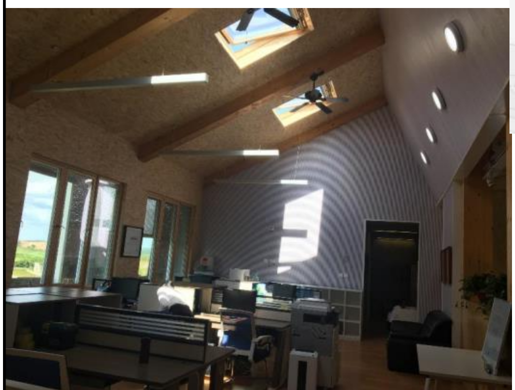
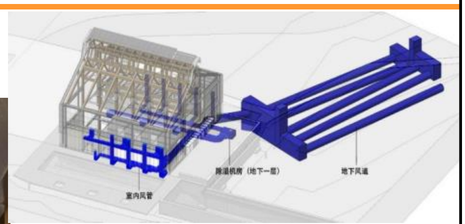
Ceiling fans and underground duct





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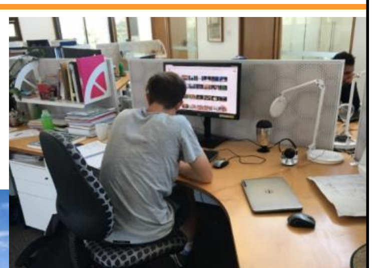
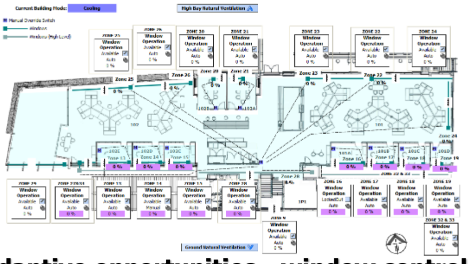
Office building, Wollongong, Australia

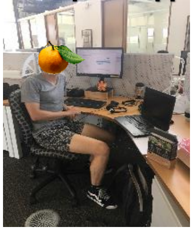
Maritime climate zone
Mixed-mode building

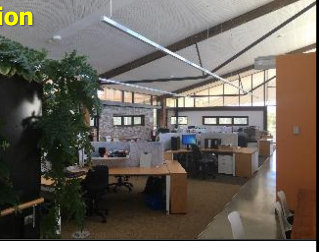


Type of building: mixed-mode, net zero energy



Adaptive opportunities：window control, PCS, natural ventilation





Office building, mixed-mode, Ahmedabad, India. Hot climate

- **Adaptive opportunities:** Personal fans, window openings, clothing
- **Electrcity:** 56.99 kWh/m^{2}a, with equipment load
  37.87 kWh/m^{2}a, without equipment load

3. Low energy thermal environment control facilities

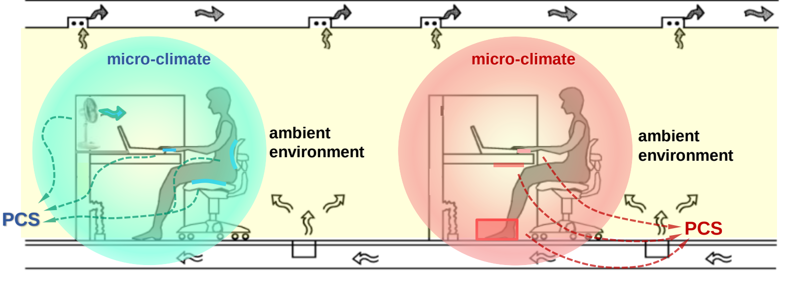
PCS: Personal Comfort System

Concept of PCS

Personal Comfort Systems

Referring to devices (and their combinations) that provide **personal environmental control** of the thermal and air quality conditions **directly surrounding the occupant**.

They may also be referred as Personal Environment Control (PEC) systems, Personal Ventilation (PV), Personal Climatization Systems (PCS), Individually Controlled Systems (ICS), Task-Ambient Conditioning (TAC) ,etc., in existing literatures with different emphasis.



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PCS concept

Personal Comfort Systems

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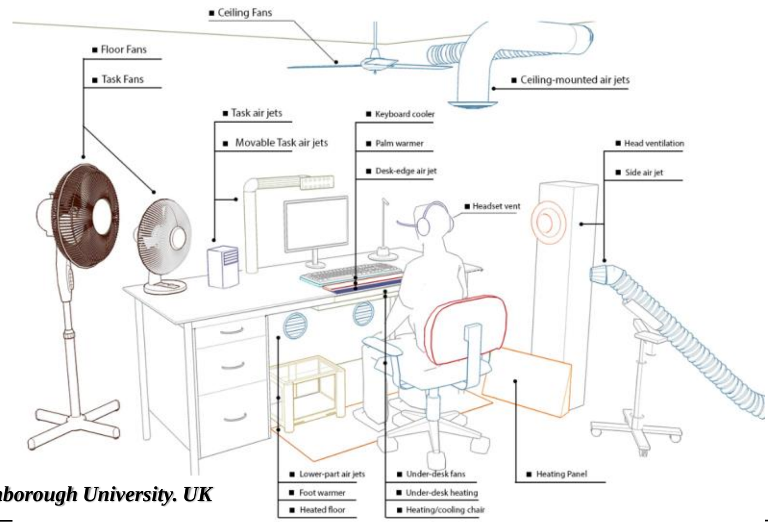

Ziqiao Li. Loughborough University. UK

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The heated/cooled chair

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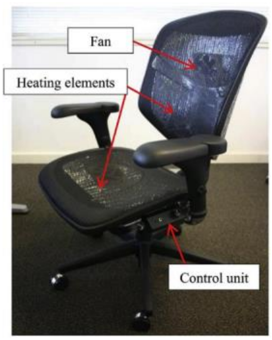
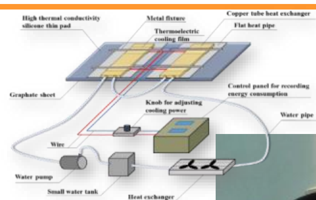


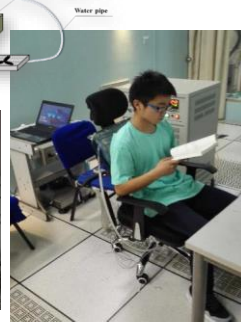
Mesh PCS chair

- battery-powered
- seat and back separately controlled
- four levels of heating or cooling
- total maximum power is 14 W for heating and 3.6 W for cooling

UC Berkeley

Ed. Arens & Hui Zhang





Semiconductor refrigeration Contacted cooling chair

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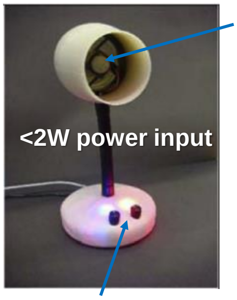
Desk fan



Infrared occupancy sensor

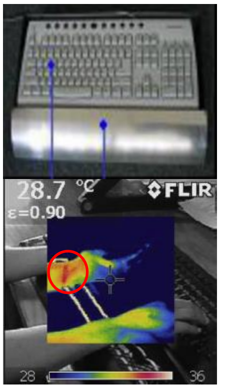
Knob for level control
Red for foot-warmer
Blue for fan

Foot-warmer

Heated Insloe

- 2.4W for both insole together;
- wirelessly charged

Wrist-pad



Maximum input power is 7 W for heating and 2.4 W for cooling

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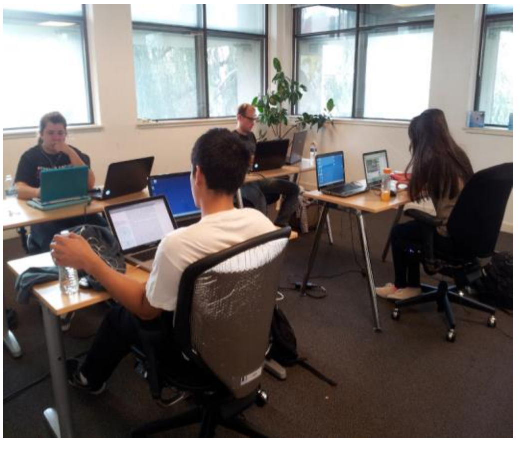
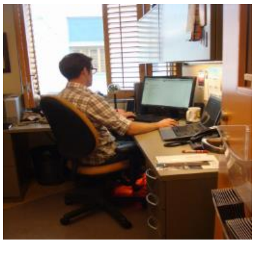
Scenario for using PCS





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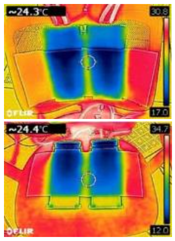
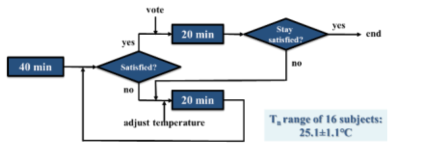
- Contact cooling chair, surface temperature demand is 25~28°C
- Subject can keep thermal neutral when ambient T=30°C



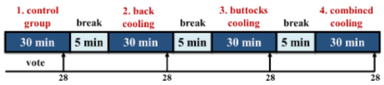
Chair for back & buttocks cooling by Peltier effect

Contact cooling Chair

EXP.0 Find the neutral ambient temperature of each subject



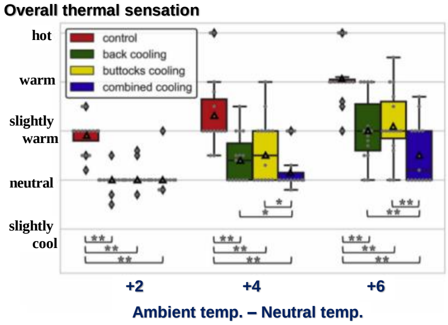
EXP.1-3 Local cooling is available and adjustable, when ambient temperature is 2,4,6℃ higher than neutral respectively.

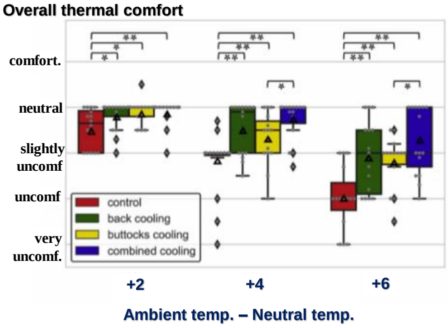


Hecheng Yang et al. Study on the local and overall thermal perceptions under nonuniform thermal exposure using a cooling chair. Building and Environment. 176 (2020) 106864. (online)

Overall effect in comfort lift

- Local cooling can significantly reduce overall thermal sensation and improve overall thermal comfort. The corrective power can be 2~4°C, e.g. 28~30°C ⇒ 26°C (neutral)
- Back cooling is slightly more effective than cooling on buttocks. Combined cooling shows the best effect.





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Wearable PCSs

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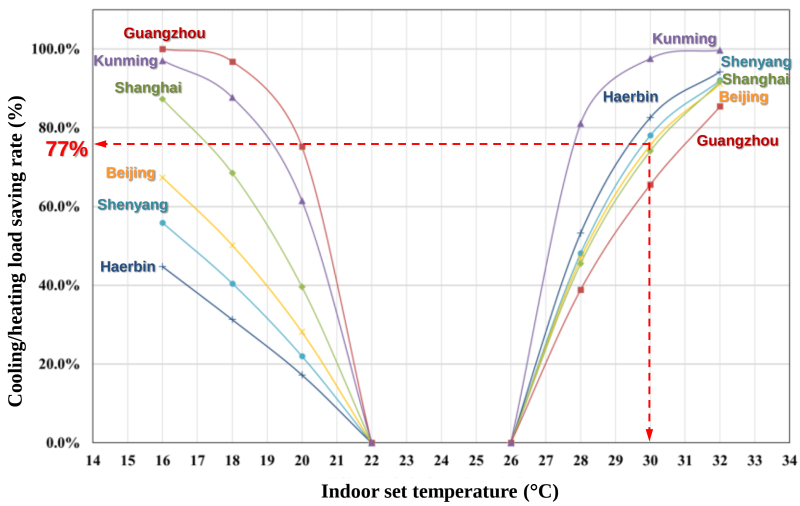
Beijing:
T_{set} 26°C ⇒ 30°C, cooling load 77%⇓

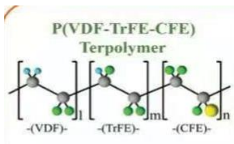


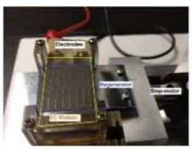
Energy saving potential of PCS

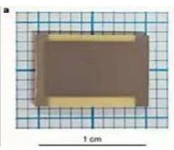
- Electricity consumption for cooling in Beijing office building is about 40 kWh/m²a, 77% energy saving means it ⇒ 9.2 kWh/m²a
- Electricity consumption of the fan of cooling chair (UCB) is 3.6 W/chair, ~0.6 kWh/m²a

Pasut W, Zhang H, Arens E, Zhai YC. Energy-efficient comfort with a heated/cooled chair: Results from human subject tests. Build Environ. 2015;84:10-21.

- For contact cooling chair, electrocaloric effect is a very promising micro refrigeration approach, COP⇒10.0







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Thanks for your attention!

Operating Agents:

Yingxin Zhu
Tsinghua University
China

Richard de Dear
The University of Sydney
Australia

Secretary:

Bin Cao
Tsinghua University
China