Resilient Cooling of Buildings: Principles and System Examples

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Introduction

- We spend 90% of our lives indoors
- Indoor Environmental Quality (IEQ) is critical
- Buildings are built for people, not to save energy
- Comfort, health, and productivity should be achieved with the lowest possible energy use + renewables
- HVAC systems -> IEQ, energy, sustainability, and resilience
- Resilience to extreme events (future weather, heat waves, power outages, …)

Resilience

Current Projects – IEA EBC

IEA-EBC

International Energy Agency's Energy in Buildings and Communities Programme

ANNEX **80** **Resilient Cooling of Buildings**

Status	Ongoing (2018 - 2023)
Website	annex80.iea-ebc.org

ANNEX **87** **Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems**

Status	Ongoing (2021 - 2026)
Website	annex87.iea-ebc.org

https://www.iea-ebc.org/projects/ongoing

Introduction to Resilience: IEA EBC Annex 80

- Goal: "to assess and communicate solutions of resilient cooling and overheating protection"
- Resilient cooling
    - Low energy and low carbon
    - Strengthen the ability of individuals and/or community to withstand and prevent impacts of disruptive events
- Focus on heatwaves and power outages
- Development of definitions, KPIs, future weather files (typical meteorological years and years with heat waves) and a dynamic simulation guideline

Qualitative assessment of resilient cooling strategies

Characteristics of Resilient Cooling

Absorptive Capacity	The ability to absorb the impact of disruptive events
Adaptive Capacity	The ability to adjust to disruptions, especially in cases where the absorptive capacity is exceeded
Restorative Capacity	The ability to return to the normal operation after a disruptive event
Recovery Speed	The speed of the restorative process

Zhang et al. (2021) Resilient cooling strategies – A critical review and qualitative assessment. Energy & Buildings.

Qualitative KPIs for resilient cooling

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Resilient cooling strategies – A critical review and qualitative assessment

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ABSTRACT

The global effects of climate change will increase the frequency and intensity of extreme events such as heatwaves and power outages, which have consequences for buildings and their cooling systems. Buildings and their cooling systems should be designed and operated to be resilient under such events to protect occupants from potentially dangerous indoor thermal conditions.

This study performed a critical review on the state-of-the-art of cooling strategies, with special atten-

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Dynamic Simulation Guideline: Version 2

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DENMARK

IEA EBC Annex 80 - Dynamic simulation guideline for the performance testing of resilient cooling strategies: Version 2

Zhang, Chen; Kazanci, Ongun Berk; Attia, Shady; Levinson, Ronnen; Lee, Sang Hoon; Holzer, Peter; Rahif, Ramin; Salvati, Agnese; Machard, Anaïs; Pourabdollahtootkaboni, Mamak ; Gaur, Abhishek ; Olesen, Bjarne; Heiselberg, Per

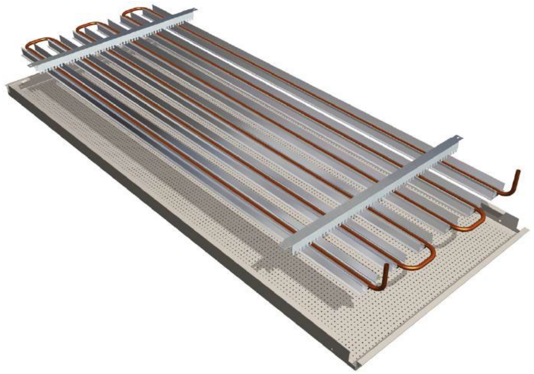
https://vbn.aau.dk/files/514931326/Dynamic_simulation_guideline_DCE_report_No.306.pdf

- Disruption Scenarios
- Future Weather Files
- Load Settings
- KPIs

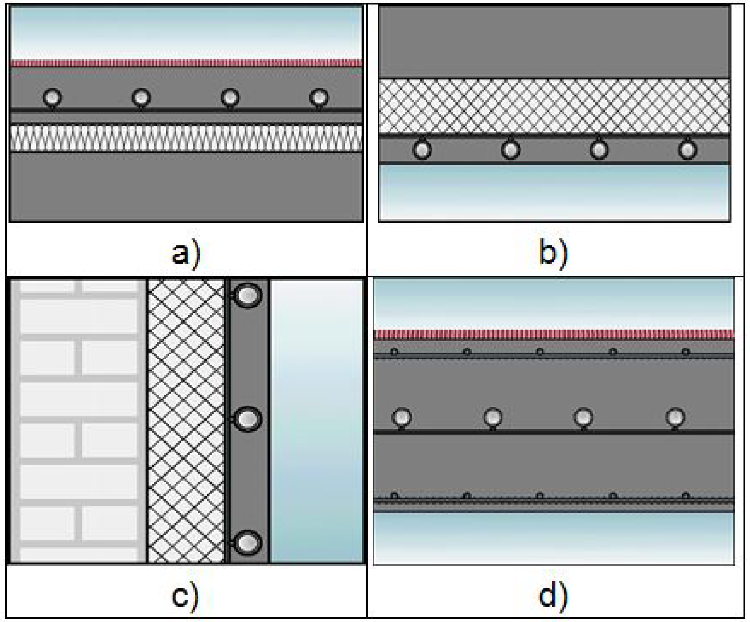
Radiant heating and cooling systems

Radiant heating and cooling systems

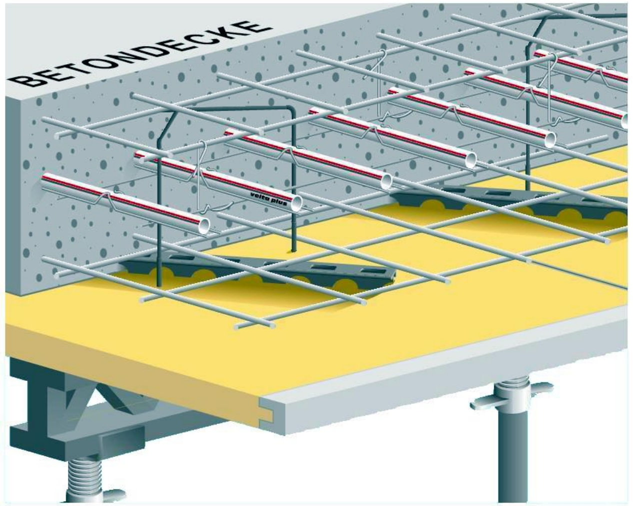
- Low temperature heating and high temperature cooling
- Heat emission or removal by radiation and convection (more than half by radiation) – mostly water-based
- Three main types
  - radiant heating and cooling panels
  - pipes isolated from the main building structure (radiant surface systems)
  - pipes embedded in the main building structure (TABS)



Examples of a radiant ceiling panel (Source: Swegon)



a) Floor, b) Ceiling, c) Wall, d) TABS (Source: Olesen et al. 2000)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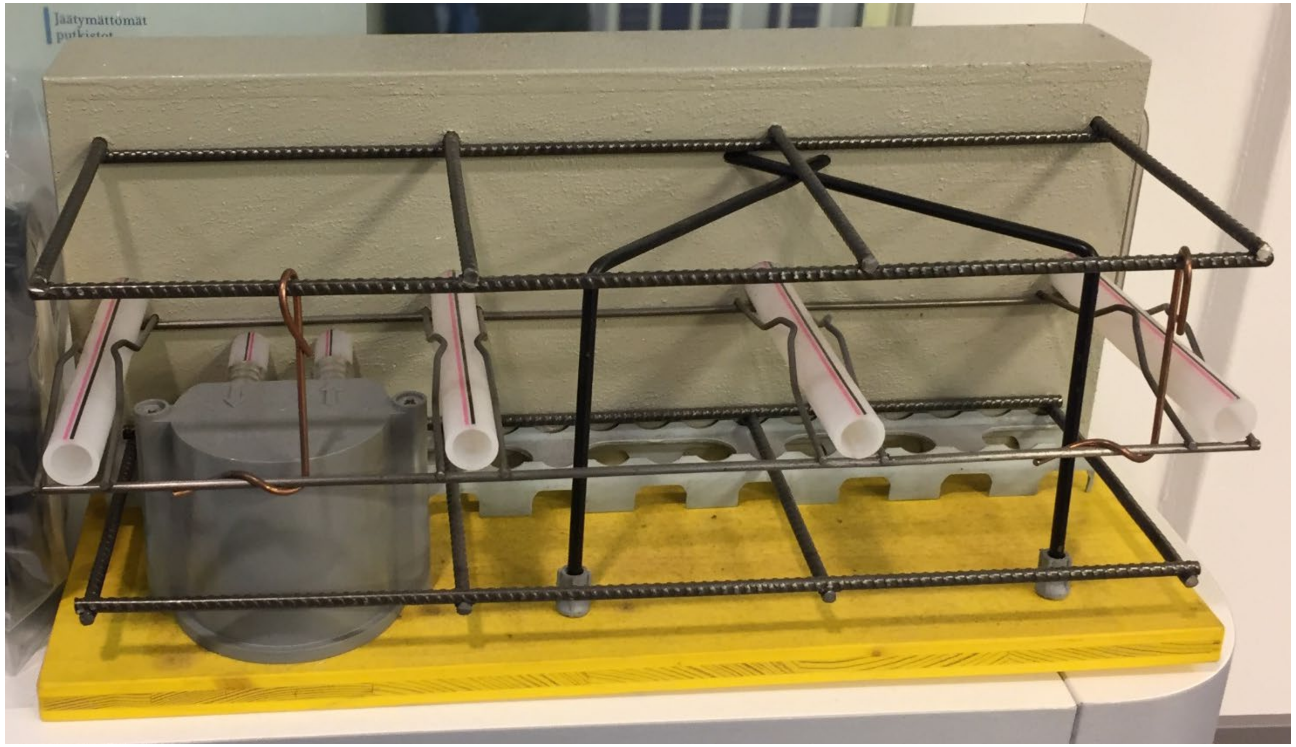
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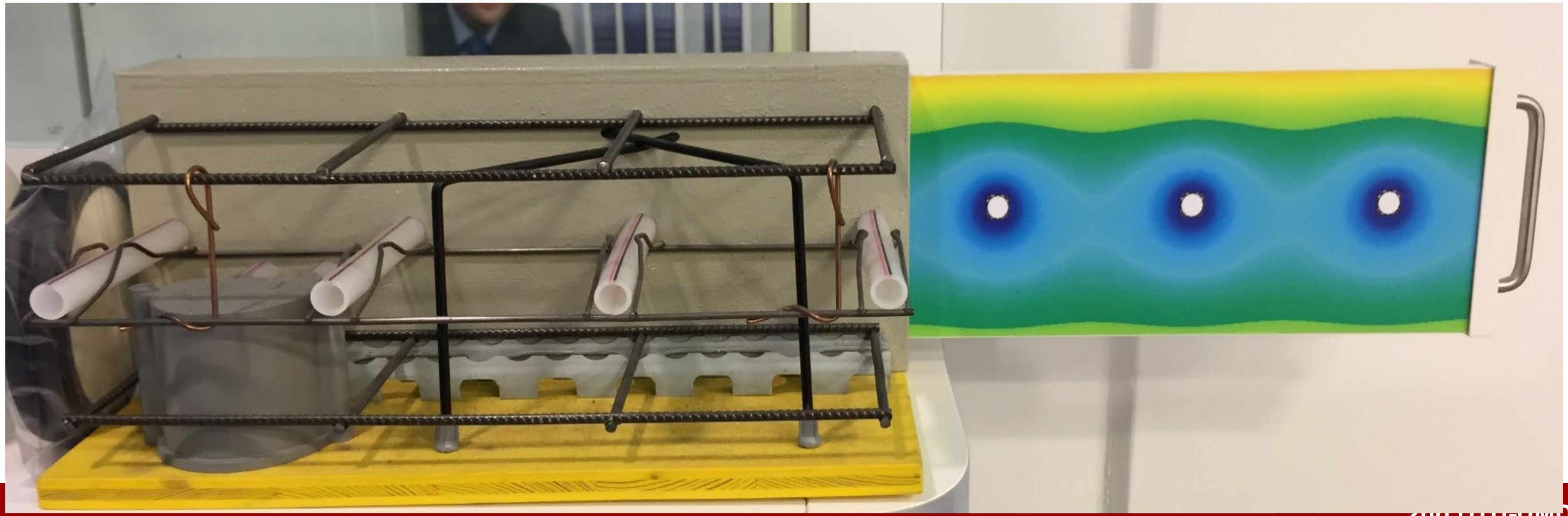


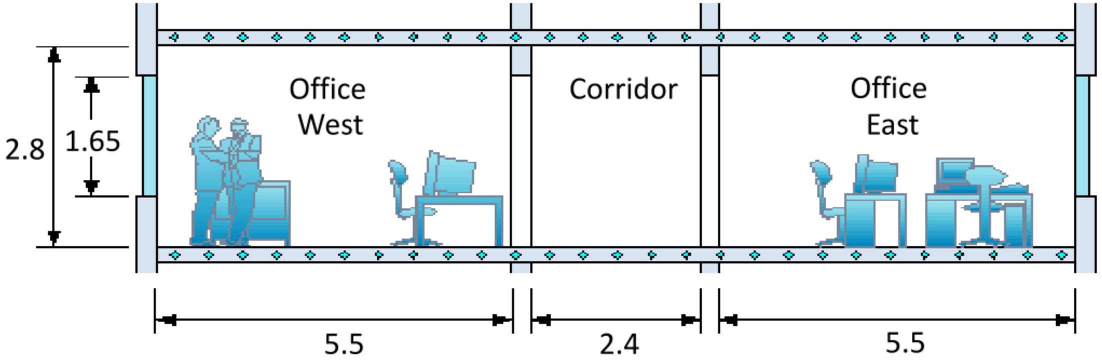
Radiant heating and cooling systems

- Floor, walls and ceiling can be used; large surface area for heat exchange
- Supply water temperatures
    - Heating: 25 – 35° C
    - Cooling: 16 – 23° C

Resilience benefits of radiant cooling

- Radiant cooling, by activation of thermal mass
  - Possibility to absorb heat gains over a longer period (also pre-cooling)
  - Integration of renewable energy resources
  - Transferring peak loads to off-peak hours, and peak load reductions (peak shaving and peak shifting)
  - Possibility of intermittent operation to help the grid

Thermal Comfort – a simulation study



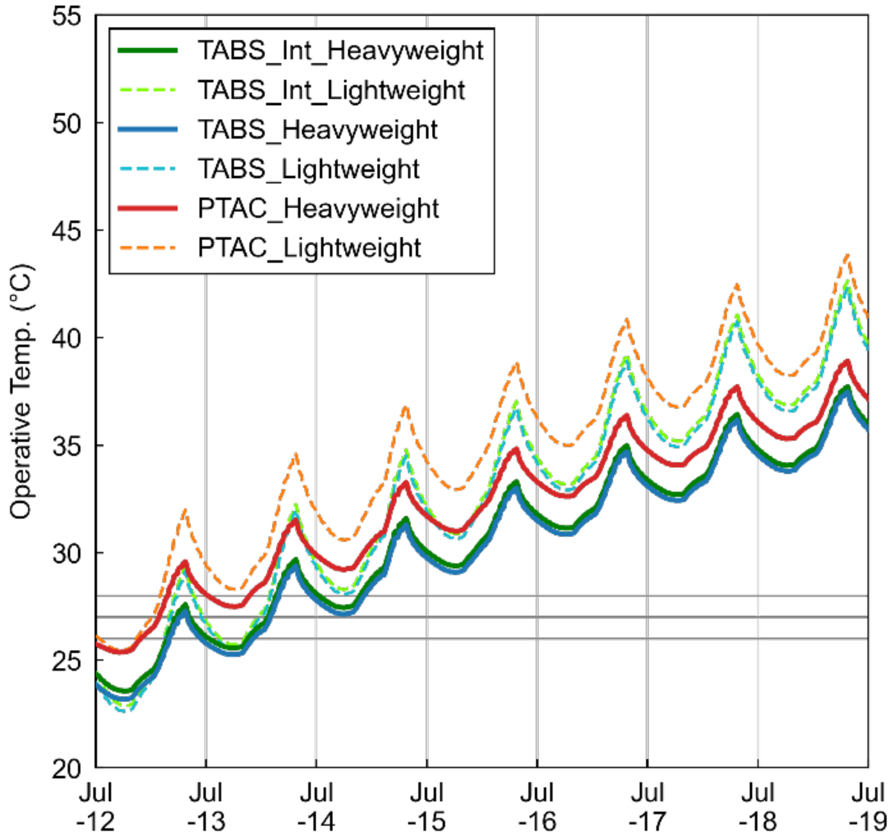
Room width = 3.6 m, window portion of the external wall = 30%

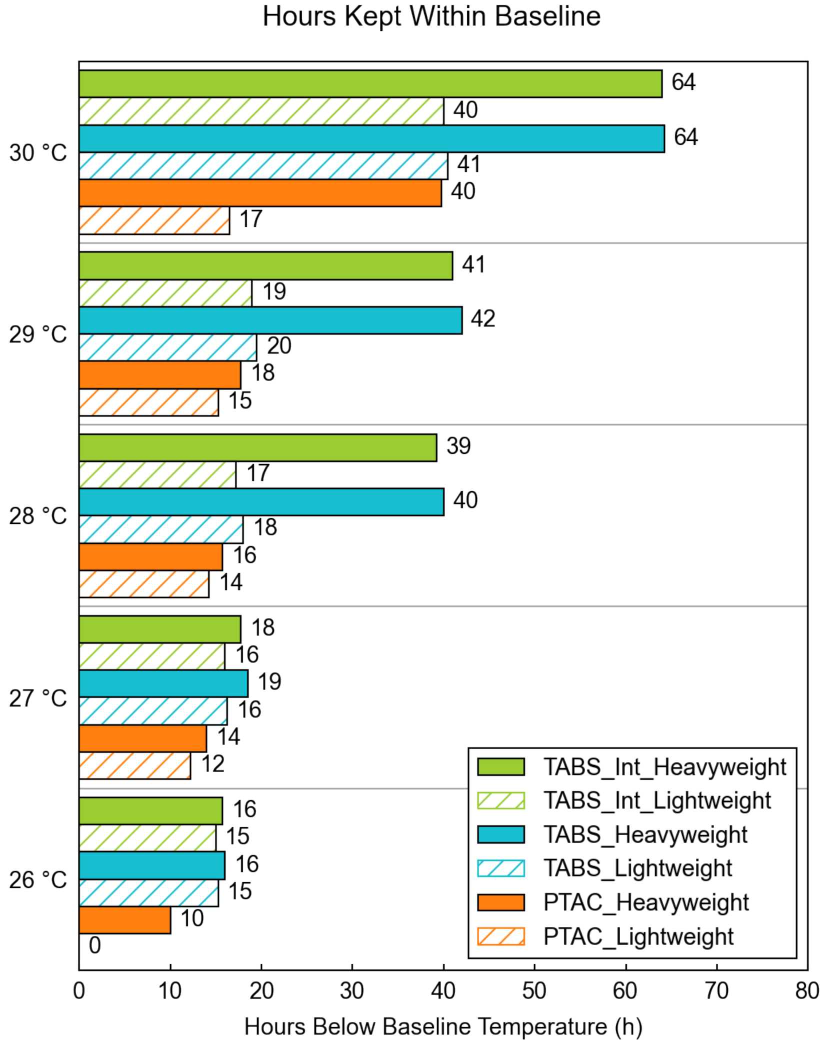
Construction	Heavyweight & Lightweight
Location	Copenhagen, Denmark
Floor Area	Office: 19.8 m^2 (5.5 x 3.6 m) each Corridor: 8.6 m^2 (2.4 x 3.6 m)
Systems	Packaged Terminal Air Conditioner (PTAC) Thermally Active Building System (TABS); 24 h & Intermittent operation
Scenarios	Heatwaves, with/without power outages

Li et al., 2015; Olesen and Dossi, 2004; Kazanci et al., 2022

Maintaining comfort conditions

Heat Wave + Power Outage Starts



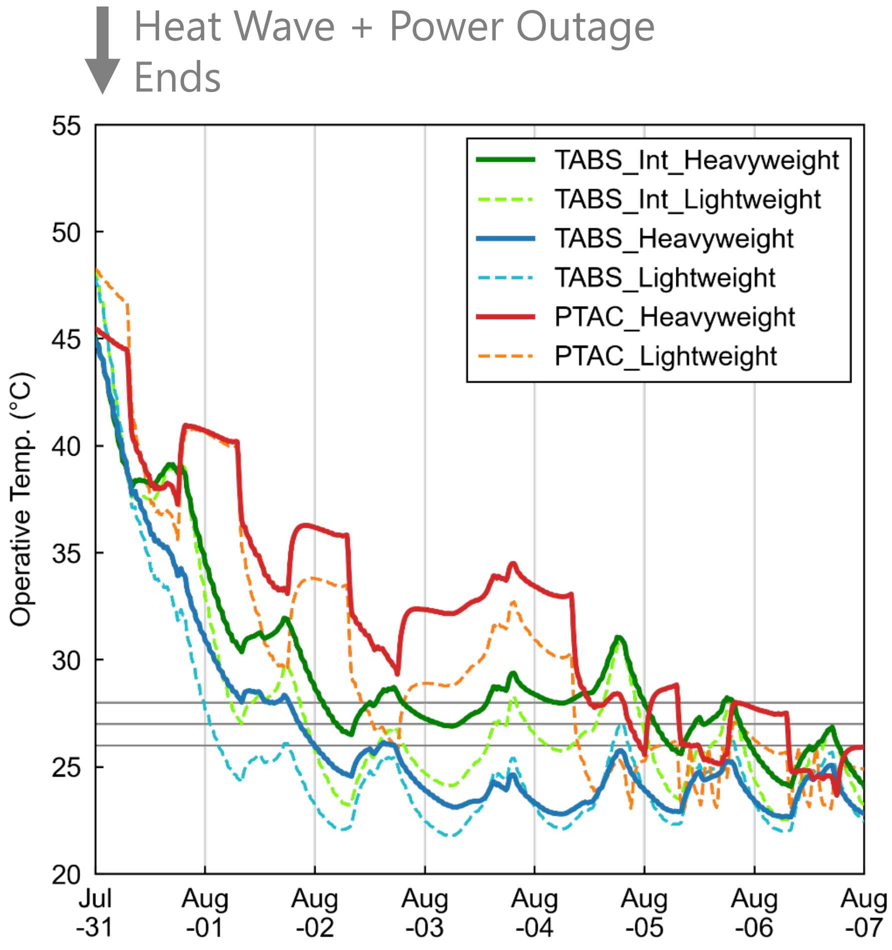


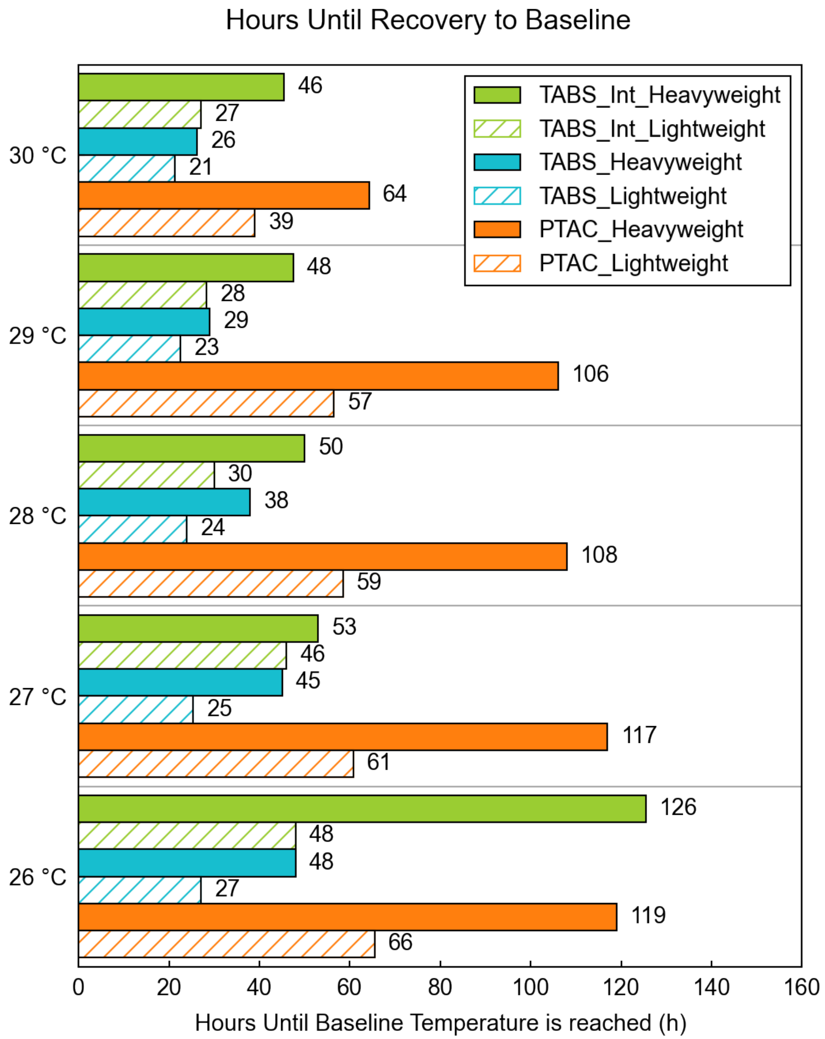
Scenario:

Power outage during the whole duration of a heatwave

Note: ISO 17772-1 (2017)
Temp. range for cooling season
Category II: 23.0 – 26.0 °C
Category III: 22.0 – 27.0°C
Category IV: 21.0 – 28.0 °C

Recovering to comfort conditions





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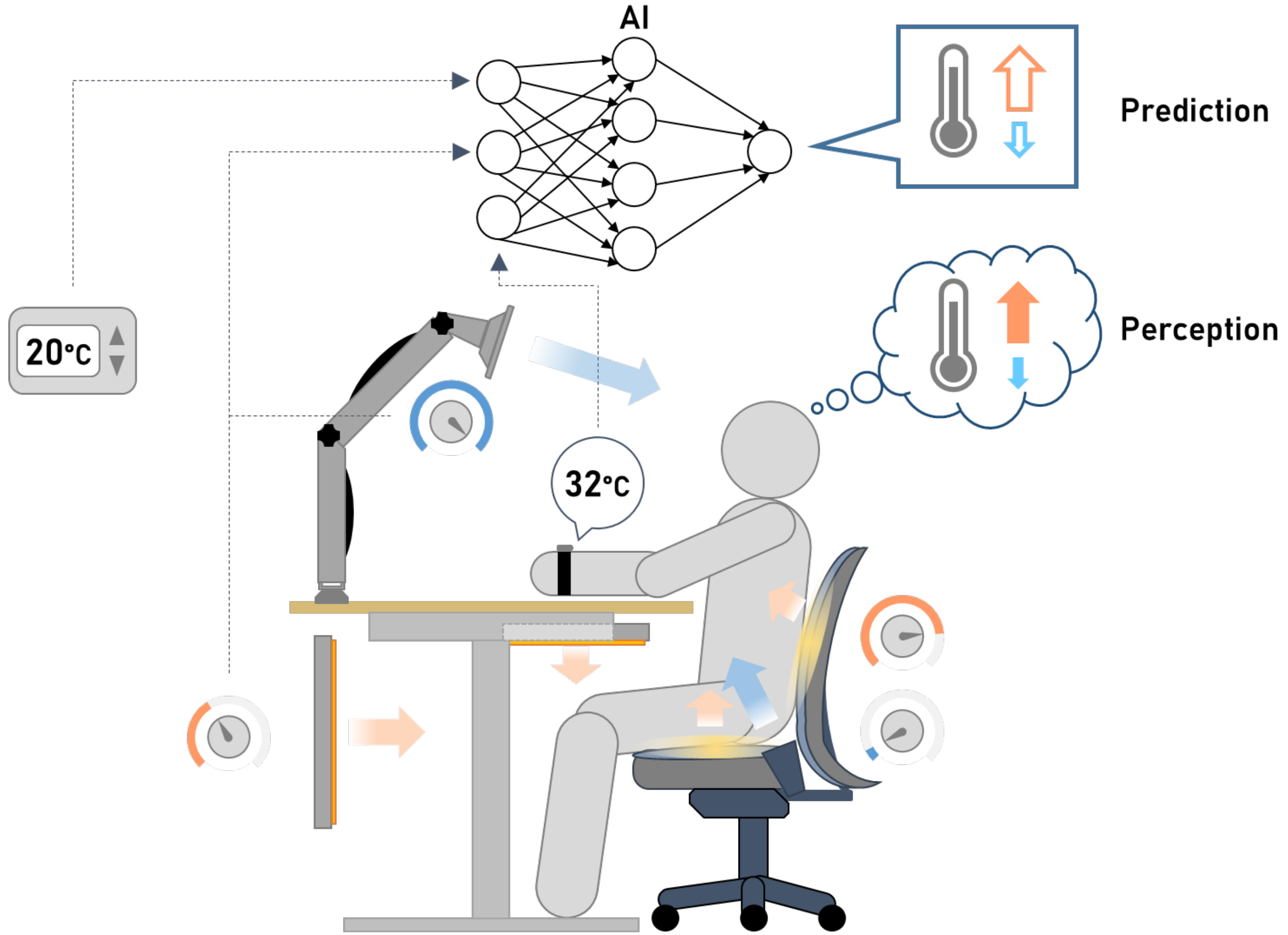
From addressing a group of people to individuals

Introduction

- Personalized environmental control systems (PECS)
- PECS intend to condition the immediate surroundings of the occupants, creating a ”personalized” space
- Provide individual control over indoor environmental quality (IEQ) factors
  - Heating / Cooling
  - Ventilation
  - Lighting
  - Acoustics
- Personalized control (user-controlled, automatic control)

Personalized Environmental Control Systems (PECS)



PECS Studies (1979)

- Madsen and Saxhof
  An unconventional method for reduction of the energy consumption for heating of buildings

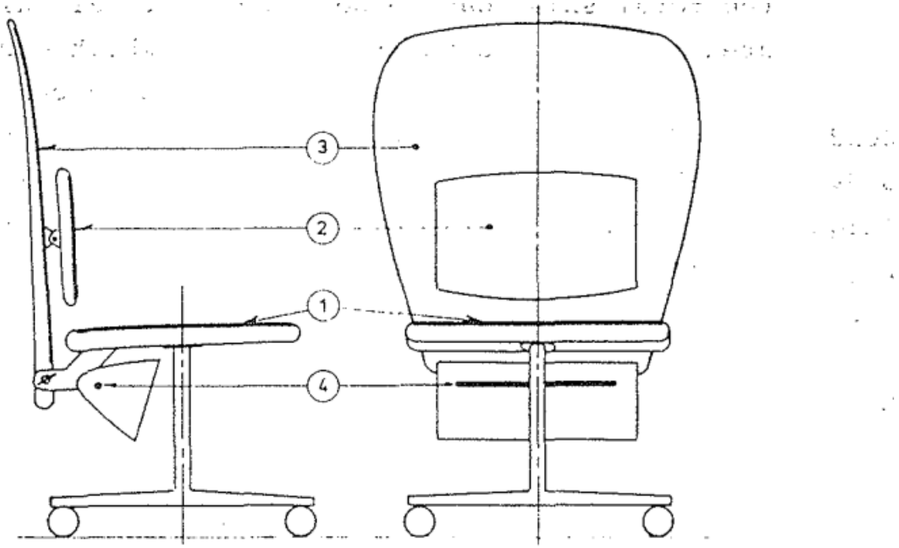
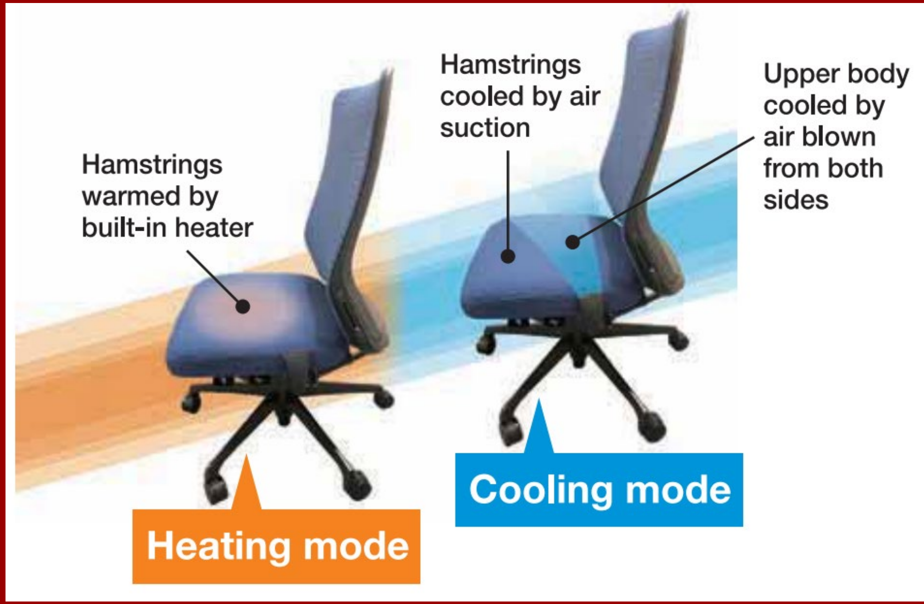


Fig. 6. Principle shetch for a heated chair. Each of the four elements can be controlled separately to a wanted effect.

1. heating element in seat.
2. heating element in back
3. radiation heating element behind the back
4. radiation heating element for legs and feet

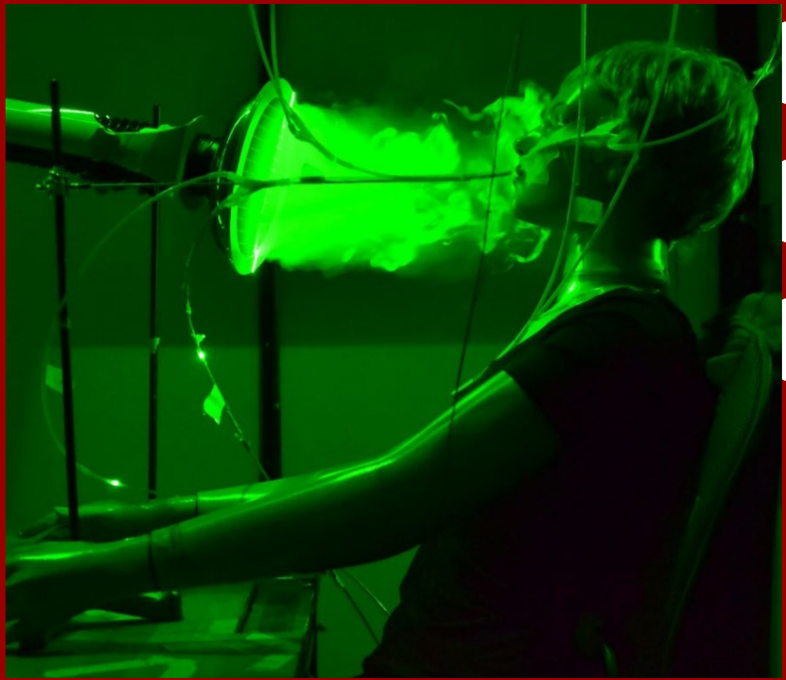
PECS Examples



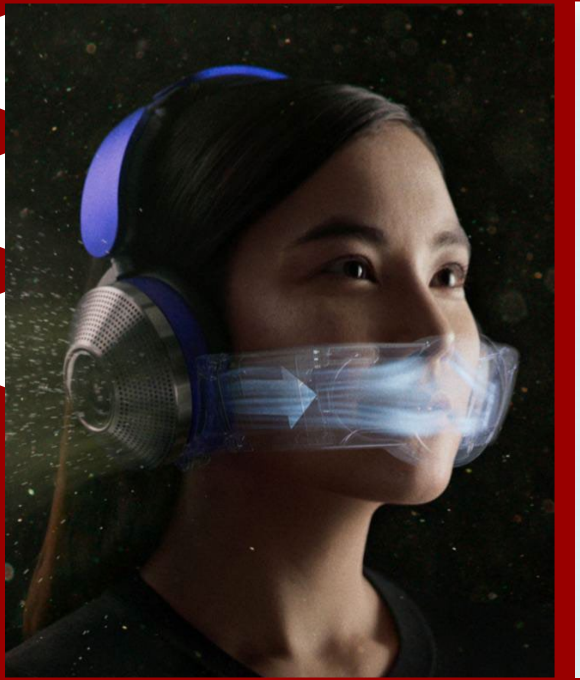
https://www.daidan.co.jp/sustainability/pdf/2020/daidan_report2020_all_eng.pdf

http://abee.or.jp/designaward/past/16/docs/06.pdf

Melikov 2016



Bivolarova et al., 2017



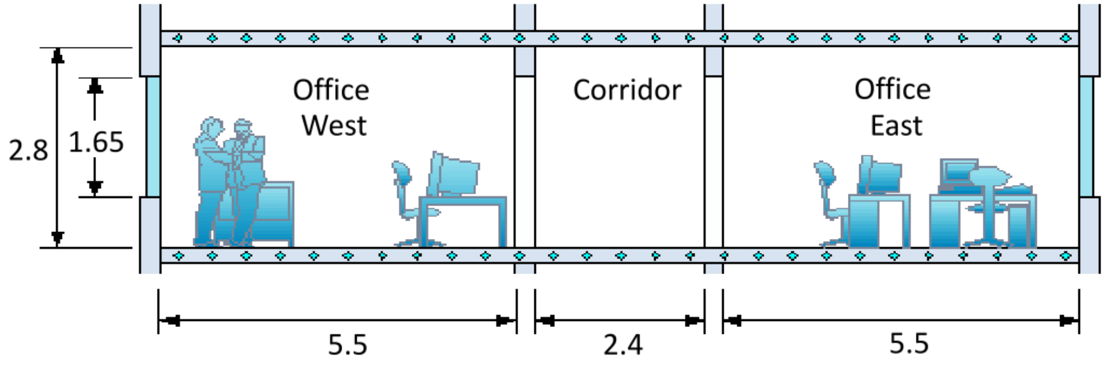
https://www.dyson.com/wearables/dyson-
zone-air-purifying-

https://www.coolingpost.com/news-
headlines/fujitsu-develops-personal-cooler/

Resilience benefits of PECS

- PECS, by creating a personalized/localized space
  - Temperature setpoint relaxation
  - Higher room temperatures are acceptable
  - Personalized spaces can be occupied longer, and sooner after the heat wave or power outage
  - Wearables can provide extended benefits outdoors and transition spaces

Thermal Comfort – a simulation study



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Simplified evaluation of PECS by altered comfort limits:

- Veselý and Zeiler (2014): up to 30 °C
- He et al. (2017): up to 32 °C
- ISO 17772-1:2017
  Table H.4 – Indoor operative temperature correction applicable for buildings equipped with fans or personal systems providing building occupants with personal control over air speed at occupant level

Average air speed [m/s]	Operative temperature correction [°C]
0.6	1.2
0.9	1.8
1.2	2.2

Resilience benefits of PECS

- Extended temperature ranges for PECS (based on standards and literature)
- Hours below baseline temperature at the beginning of heatwave/power outage and hours until baseline after heatwave/power outage

Baseline Temperature (°C)	Hours maintained below baseline temperature (h)	Hours until baseline temperature is reached (h)
26	0 – 16	27 – 126
27	12 – 19	25 – 117
28	14 – 40	24 – 108
29	15 – 42	23 – 106
30	17 – 64	21 – 64

Concluding remarks

Concluding remarks

- Buildings are built for people -> always focus on people
- Resilience – future-proofing: New criteria to be integrated into the design and operation
- Radiant systems and PECS have several benefits compared to traditional systems
- They are also resilient solutions during heat waves and power outages
- Need to develop an approach for considering building, systems, and occupants simultaneously
- Future: building-attached -> building-detached -> occupant-attached

Thank you for your attention

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