Mixed methods approach to understand occupants' acceptance and use of a personal ceiling fan

A field case study analysis

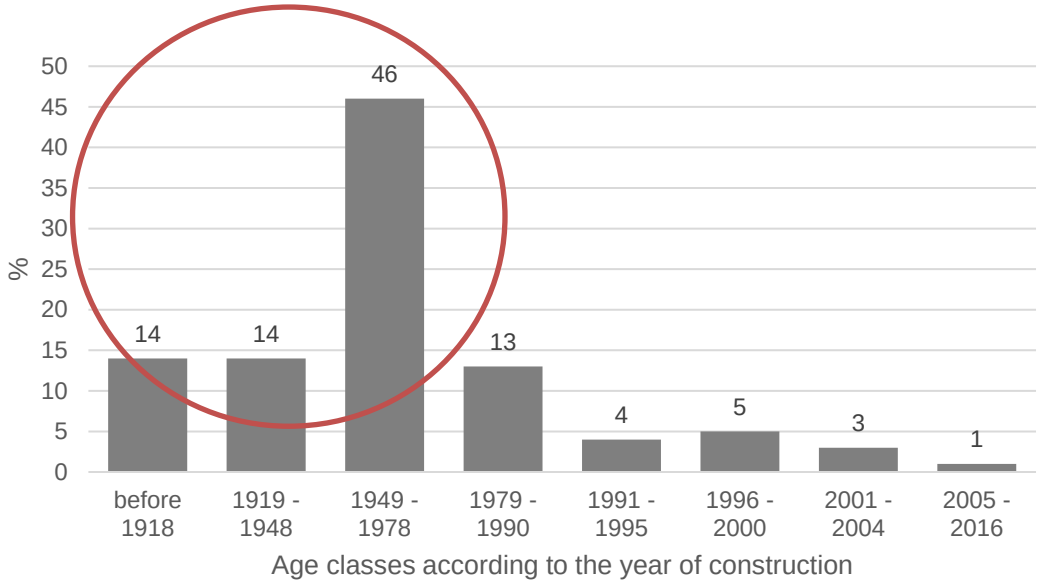
Romina Rissetto

Karlsruhe Institute of Technology (KIT)

Ways to climate-neutral buildings

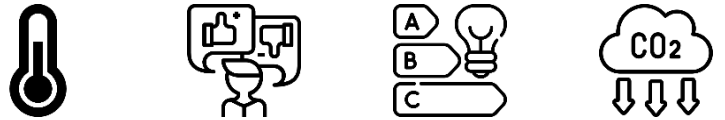
Efficiency improvements, combined with the slow adoption of renewable energy and minor behavioral changes, are insufficient to deliver on the 1.5°C target

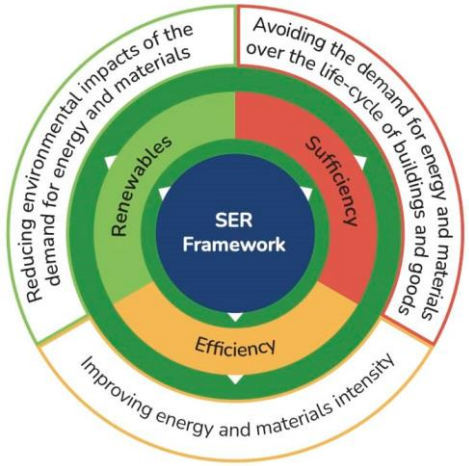
Germany: 80% of existing buildings (built before 1980) consume about 90% of the total energy in the building sector



Source: PtJ. destatis.

How to design buildings that provide **indoor environmental quality**, targeting occupants' **individual thermal preferences**, with only **little additional energy**, and are climate-friendly in terms of **minimal CO_2 emissions**?





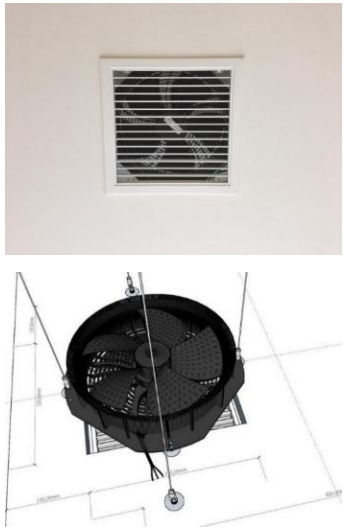
Sufficiency, efficiency, renewable (SER) framework for buildings. Saheb, Y. 2021. Buildings and Cities.

Project Deck-in-Vent: personal ceiling fans

Building retrofit to reduce heat loss and add on-site energy generation, but room temperatures above comfortable range still high!

Exterior of the district office building in Dillingen a. d. Donau, Germany.

Development and demonstration of personal ceiling fans integrated in an acoustic panel



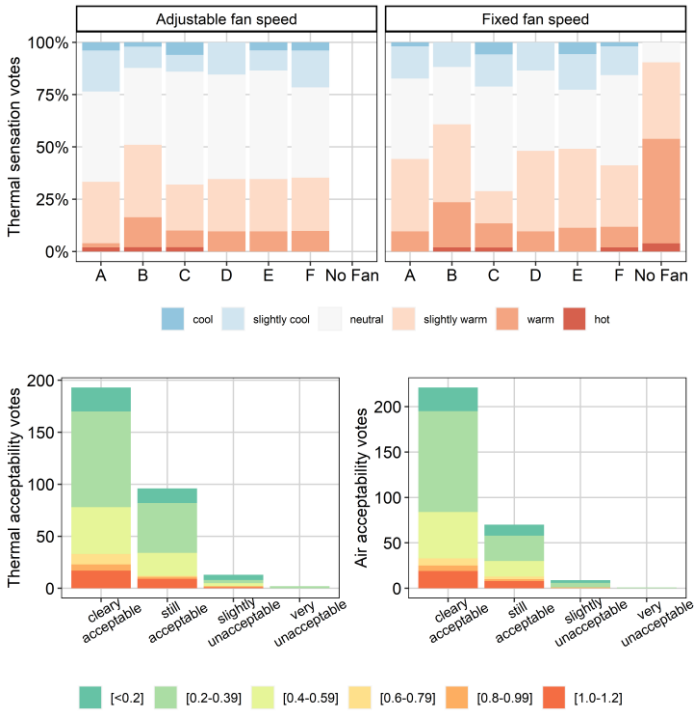
Detail of the integrated fan: view from below (left, upper) and from above (left, bottom). Shared office room with two integrated ceiling fans (right).

Can personal ceiling fans provide occupants with **thermal satisfaction**?

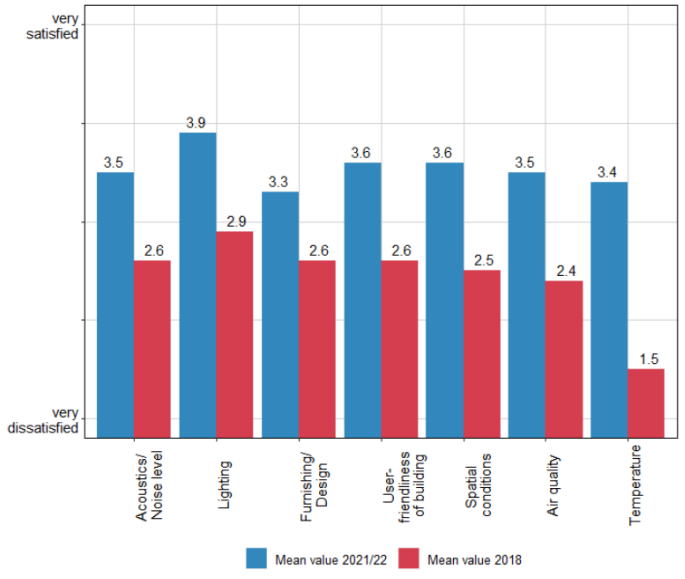
What is the **cost-benefit** ratio?

What do occupants **expect** from building systems and how does that relate to IEQ and fan satisfaction?

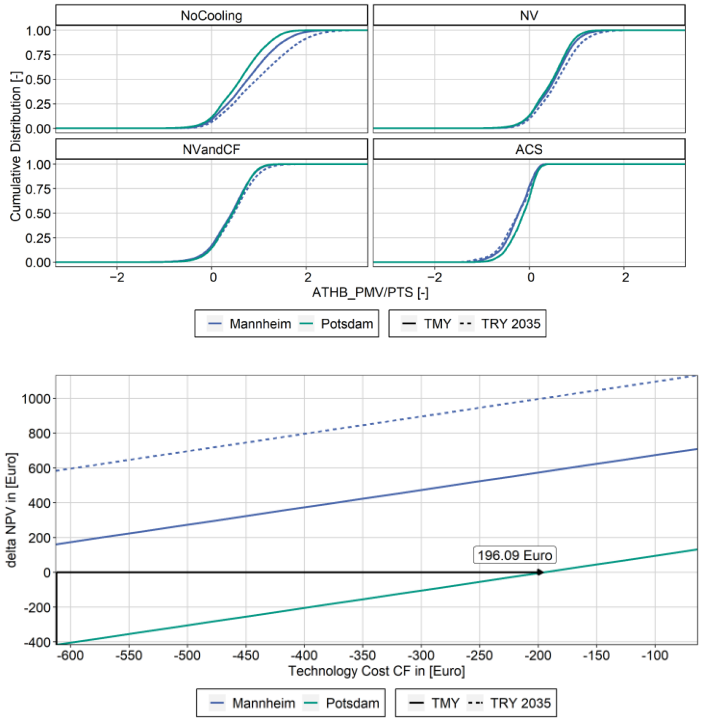
Cooling effect, satisfaction, cost-comfort evaluation



Percentage of thermal sensation votes for different fan configuration (A – F) and no-fan condition, according to control possibility (top). Thermal and air velocity acceptability votes binned according to air velocity (bottom). Rissetto et al. 2021. Energy and Buildings.



Occupant satisfaction with individual comfort parameters in 2018 (before renovation) and in 2021/22 (after renovation). Source: Project Final Report (in review).



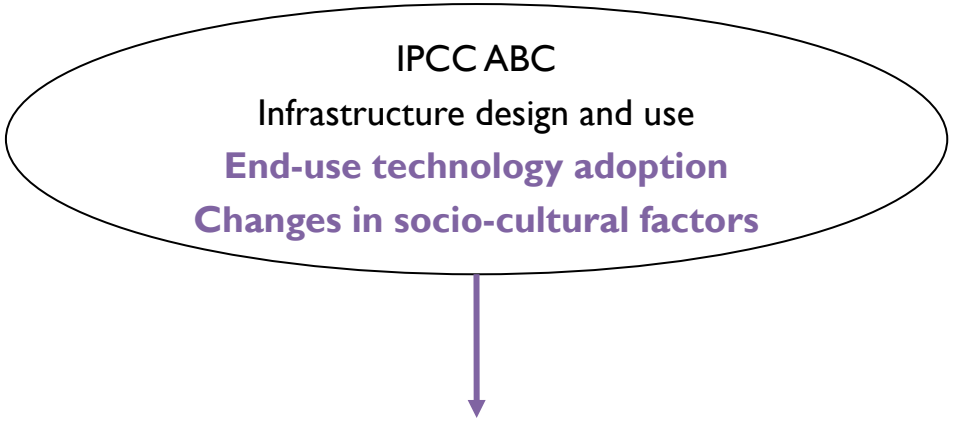
Cumulative PMV (ACS) and PTS (NoCooling, NV, NVandCF) values for all climate scenarios (top). Delta Net Present Value and investment cost for the ceiling fan for different climatic scenarios (bottom). Knudsen et al. 2023. Buildings.

Experimental studies on thermal satisfaction in climate chamber at KIT

Longitudinal comfort survey in the Dillingen district office

Simulation study with monitoring data

Technology acceptance: knowledge, expectations

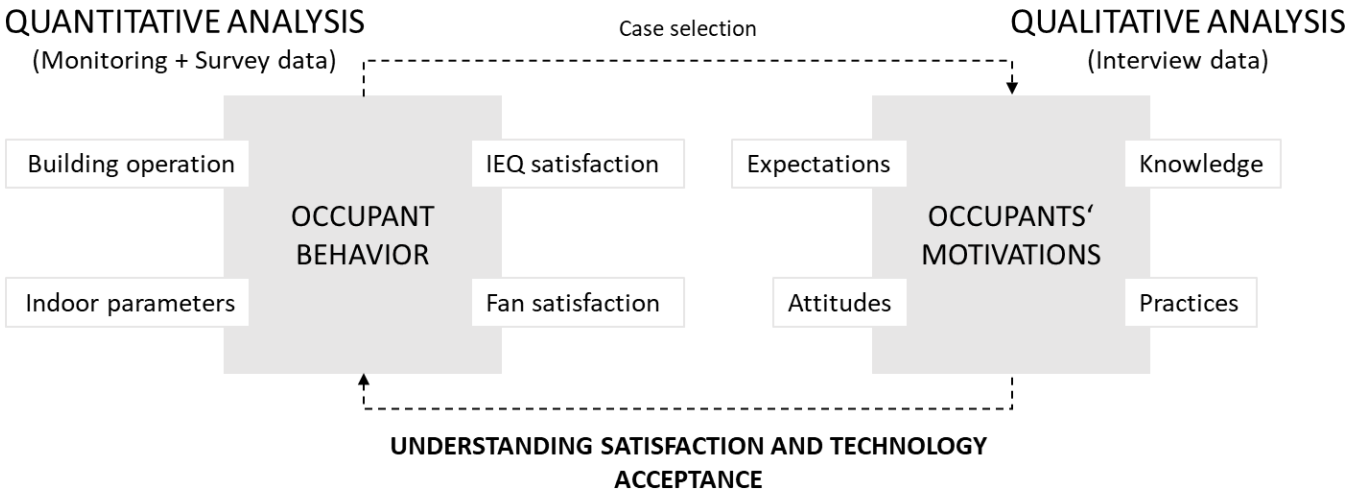


- Limited commercially available PECS.
- Simply having access to personal controls does not guarantee comfort.
- Increased energy consumption if systems are not operated properly.

Effect of occupants' motivations, expectations and level of knowledge on their acceptance and use of PECS and IEQ satisfaction in non-residential buildings.

- To what extent do different **motivations and expectations** for choosing a **cooling strategy** have an impact on the use and satisfaction with the PCF?
- To what extent do more positive expectations and a **higher level of knowledge** about the PCF and the building design affect the use of and satisfaction with the PCF and IEQ?

Mixed methods approach



Data collection

Monitoring/Survey campaigns

- 1 year monitoring data, 93 office rooms
- 5 questionnaires before and after retrofit
- Survey comparison through ID

Employee interviews

- Case selection: most different cases
- 10 volunteer employees
- Card sorting: cooling strategies, decision factors
- Semi-structured interviews: 5 thematic blocks

Concepts for the card sorting (in German).

Data analysis

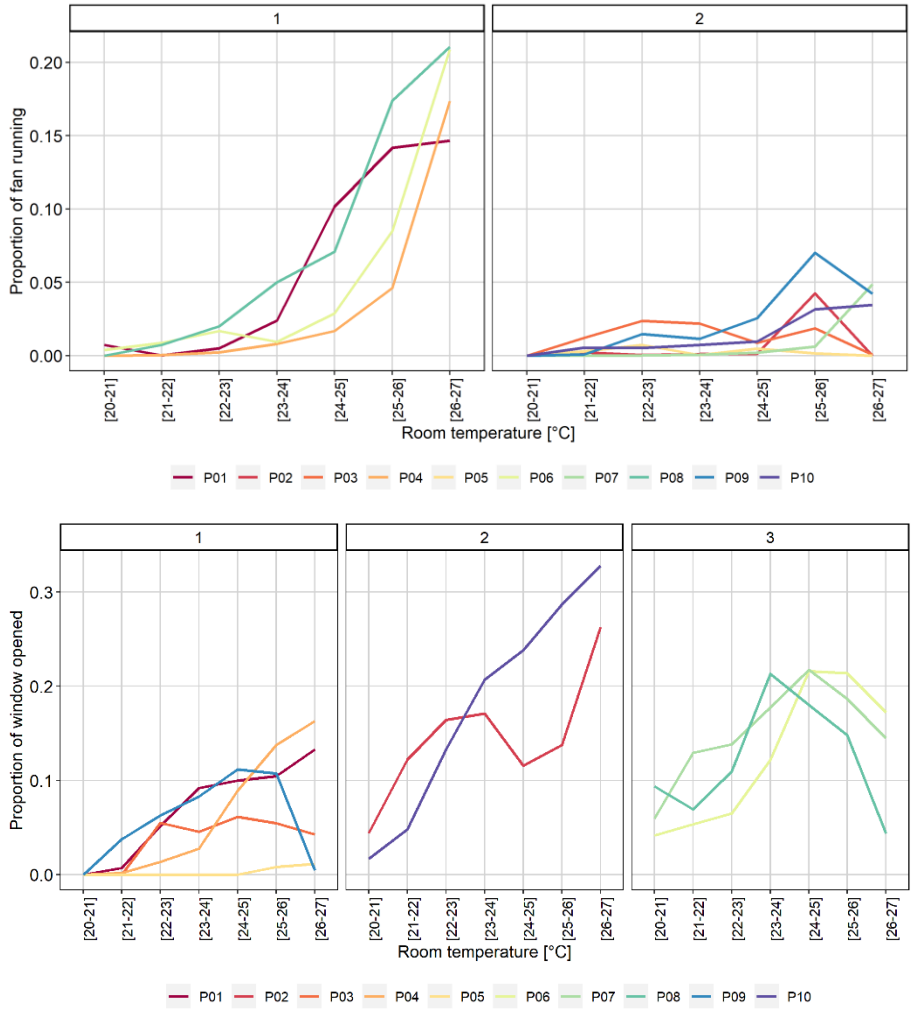
Quantitative

- Clustering analysis: ceiling fan and window usage patterns.

Qualitative

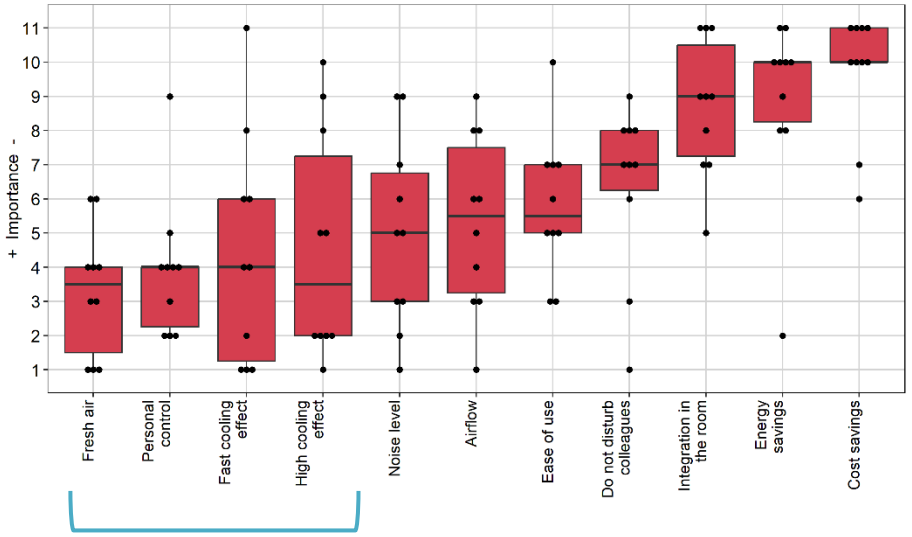
- Direct content analysis: transcription, categorization and coding; coding scheme with deductive codes

Cooling strategies and decision factors



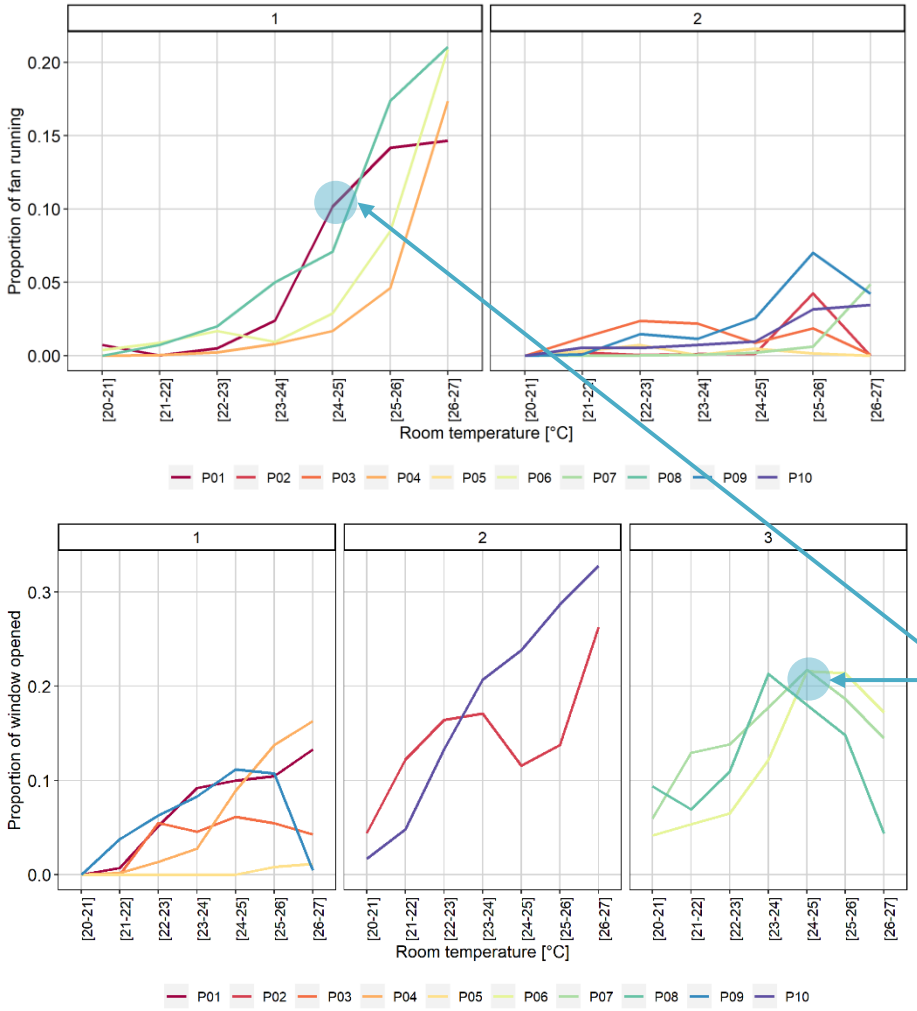
Proportion of ceiling fan running (above) and window opened (below) for each temperature bin grouped according to cluster number.

Boxplot of decision factors by importance. Black dots represent the individual votes.



Most important factor when choosing a cooling strategy

Cooling strategies and decision factors

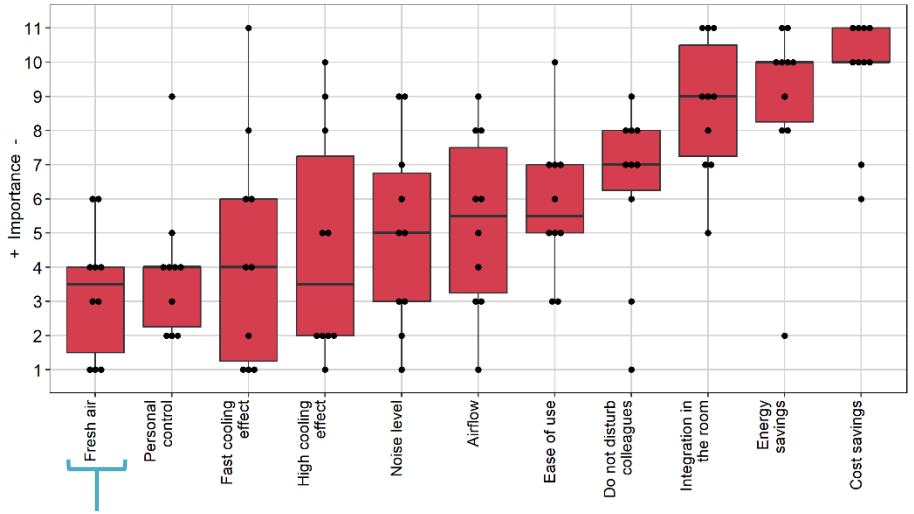


Proportion of ceiling fan running (above) and window opened (below) for each temperature bin grouped according to cluster number.

Higher probability of window opening than turning on PCF (up to 26°C)

Preference for windows opening instead of turning on PCF

Boxplot of decision factors by importance. Black dots represent the individual voices.



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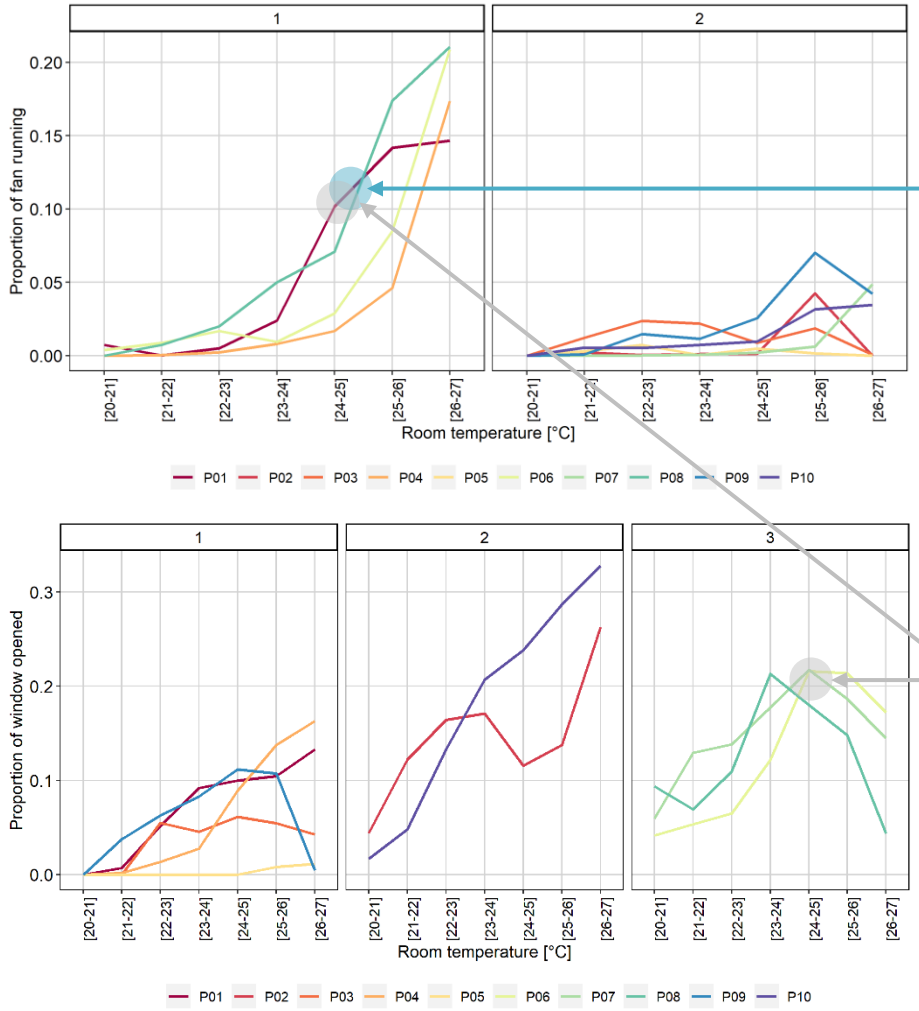

Proportion of ceiling fan running (above) and window opened (below) for each temperature bin grouped according to cluster number.

Higher probability of turning on PCF at higher indoor temperatures

Employees satisfied with PCF control

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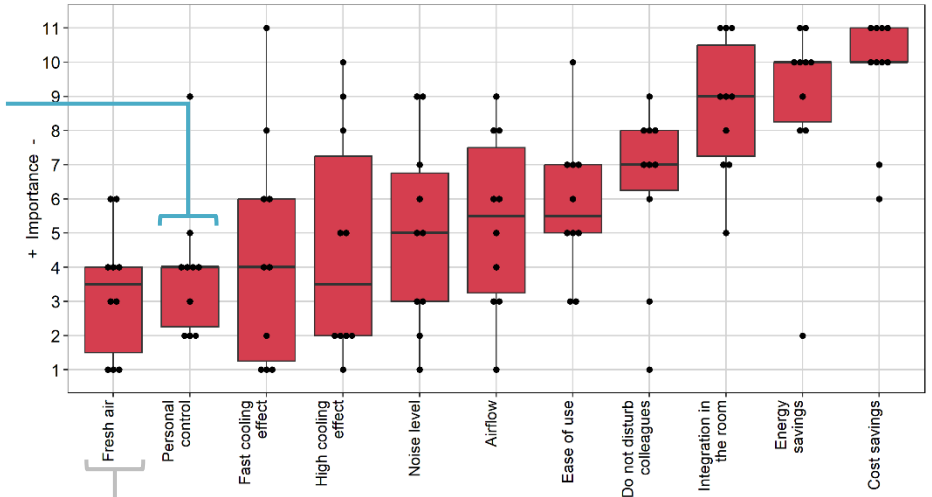

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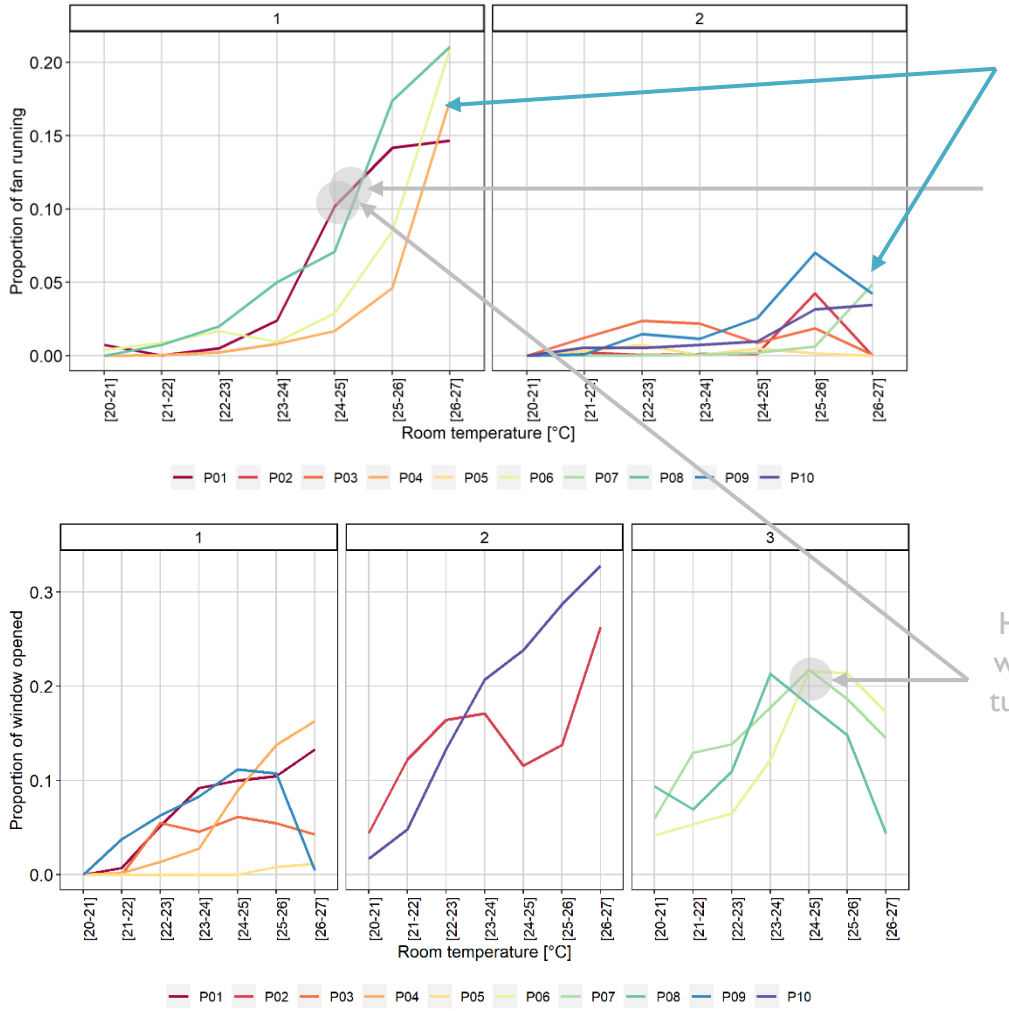

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Different fan usage patterns

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Association with AC

Employees *uncomfortable* with thermal conditions in room

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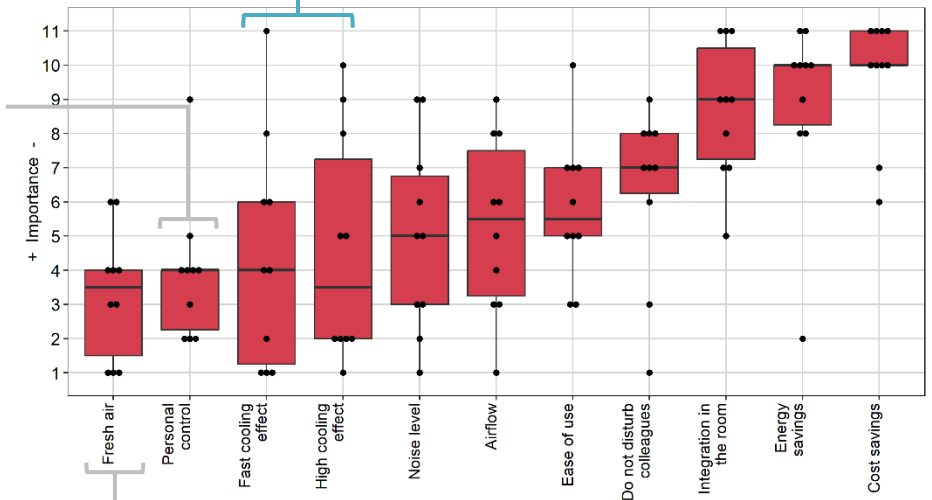

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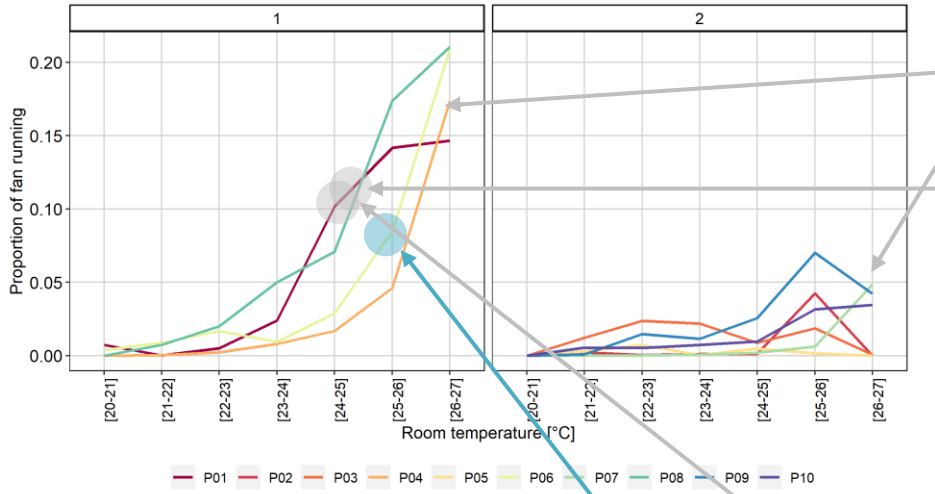

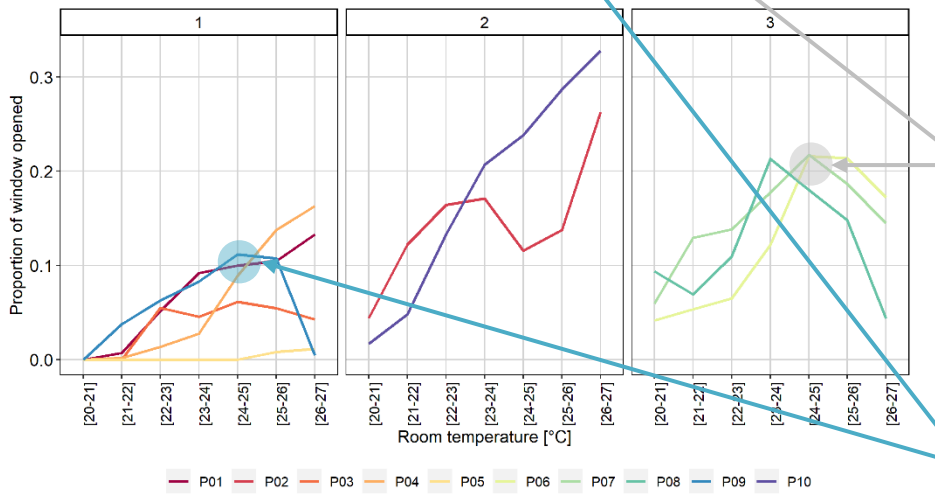

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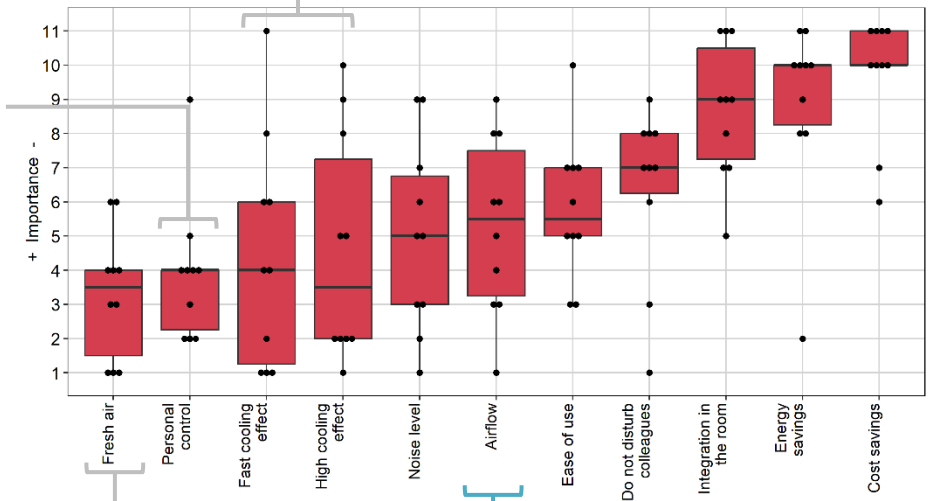

Higher probability of window opening than turning on PCF (up to 26°C)

Preference for windows opening instead of turning on PCF

Similar probability of window opening up to 24°C; similar PCF usage

Association with fresh air; airflow coming from the fan *very strong*

Information, knowledge and expectations

Involvement and communication about retrofit → More positive expectations of building renovation → Greater perceived control, and IEQ satisfaction

*"Yes, so roughly. I **knew then already**, from the realities, and that, with the new windows and this facade, a lot has really been done."* *"I already **had the hope** that it would bring something. And that has **also come true**."*

*"(…) now we have **possibilities**, so more is not possible."* *"**Operation** has become **easier**."* *"The high **cooling effect** has gotten **better** due to the fan."* *"It has brought quite a lot; the **climate** in the office is **much better**. "*

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Successful communication of PCF features → Greater satisfaction with PCF characteristics

*"(…) have a very **pleasant effect on the room acoustics**.."* *"the **fans are not loud**."* *"[airflow] So from the side and the front. That's kind of a breeze."*

↓ Contrary effect when communication fails

*"a bit technical, [controlling the speed] that's a **problem** (...) so the setting is a bit, **needing to get used** to."*

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Operating principle of PCF → Higher satisfaction with PCF → Contrary effect when knowledge is lacking

*"(…) we don't have any active cooling here, that is, **no subcooling of the air**, but rather this **chill effect**, and that ensures that you then **feel somehow comfortable**."*

*"I always feel it's not enough, even if the **fans cools down the heat or just cools down the air**, the window has to be open too."*

Different patterns of use

Final remarks

- To what extent do different motivations and expectations for choosing a cooling strategy have an impact on the use and satisfaction with the PCF?

- PCF provided **personal control** and ensured **high perceived indoor air quality**.
- **Diversity** of control responded to individual cooling **expectations and preferences**; failure affected IEQ satisfaction, but not PCF use.
- **High/fast cooling effect** not most relevant aspect, but employees had **modest expectations** of existing building.

- To what extent do more positive expectations and a higher level of knowledge about the PCF and the building design affect the use of and satisfaction with the PCF and IEQ?

- **Knowledge** of principles and operation, could increase occupants' **IEQ satisfaction.**
- **Communication** of building design, could set **more positive expectations** but does not necessarily correlate with occupant behavior and interactions.

Observations of physical conditions and occupant behavior in post-occupancy evaluation

Effective communication of PECS characteristics in the context of the building design and interaction with HVAC systems, particularly in building retrofit.

Aligning occupant expectations with building design, and providing personal control of various adaptive strategies.

Thank you!

Karlsruher Institut für Technologie

Questions?

Romina Rissetto

romina-rissetto
romina.rissetto@kit.edu

Building Science and Techonology (bst), Karlsruhe Institute of Technology (KIT)