AIVC workshop 2026: Climate Change, Ventilation and Resilience

Personal Environmental Control Systems: Occupant-system interactions and impact on cognitive performance

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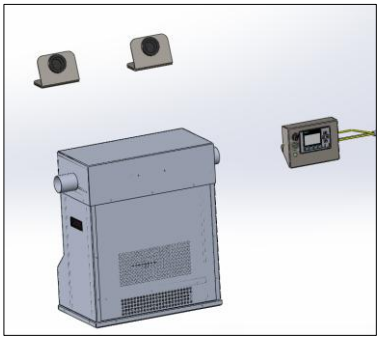
Motivation

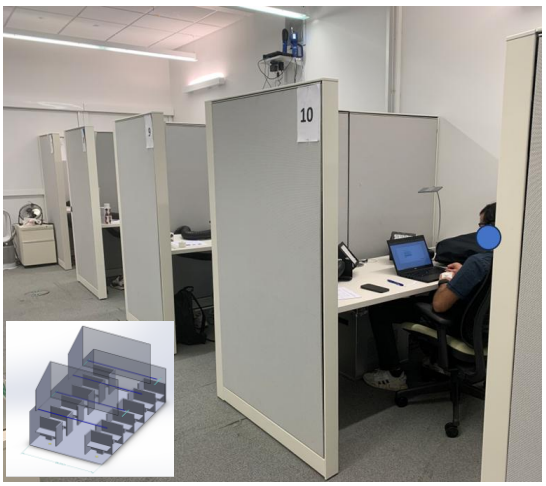
- 1) Why personal environmental control?
  - **Give "what you want"** instead of "one size fits all";
  - **Energy efficient** delivery of IEQ (~28% of annual energy savings [1]) "use it only when/where it is needed";
  - **Shift peak load** with thermal storage (our PECS, μX [2] developed via DOE-ARPA E project);
- 2) Why focusing on occupant interactions and perceptions?
  - **Lack of user-experience data**, a barrier for commercialization;
  - **Lack of data on** how user **interactions** affect PECS operation, IEQ, and occupants' perception and performance.



[1] Beverly Guo, Zhaozhou Meng, Jensen Zhang, Micro Environmental Control System (μX), Part 1 Building Energy Modeling and Simulations, E+ Simulation Results for 7 Cities – Annual Percentage Savings, 20160415
[2] Edward A Bogucz, Micro-Environmental Control System (Final Report), https://doi.org/10.2172/1867683

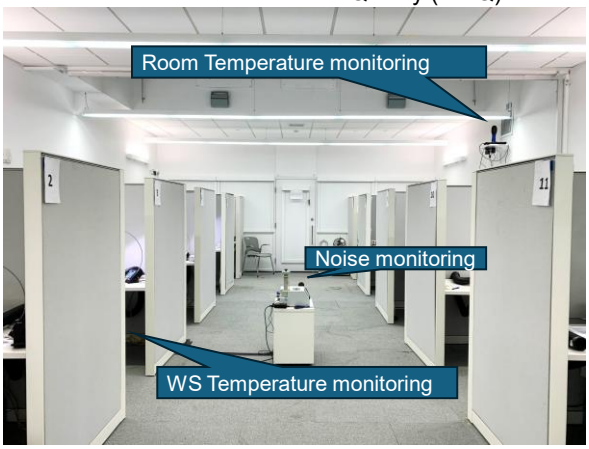
Objectives and Scope

- How people use PECS (μX)?
  - **Does people choose to use μX during** different temperature conditions?
  - If they use it, **when?** Under what temperature?
  - **How people use it?** What's the PECS settings they choose?
- What's the impact of PECS?
  - Physical
  - Physiological
  - Psychological
  - Cognitive performance

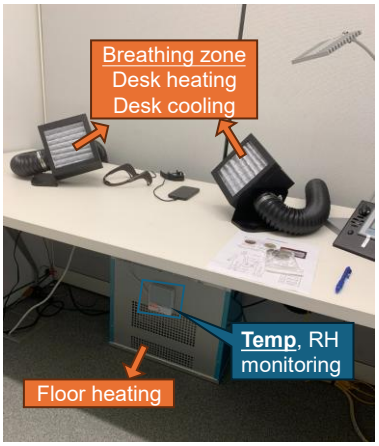


Approach – 1: Environmental control & monitoring

- Ambient environment
- Total Indoor Environmental Quality (TIEQ) Lab



- Personal environment
- μX



The full study involved 224 participants across four IAQ conditions; results presented here are from **28 participants tested under low VOC low PM2.5 (LVLP) in summer, with thermal condition as the sole variable**.

Approach – 2: User actions and responses

1) **User adjustments:** clothing, PECS's operation (on/off, heating/cooling mode, fan speed);
2) **Physiological signals** (skin temperatures, heart rates, heart rate variability, brain waves, EDA-electrodermal activity, sleep quality, steps, exercise type & duration, calorie);
3) **Perceived IEQ** (thermal, IAQ, noise, odor);
4) **Cognitive performance** (memory, motor execution, learning, math, perception, attention, creativity, decision making).
5) **Sitting positions:** already pre-adjusted

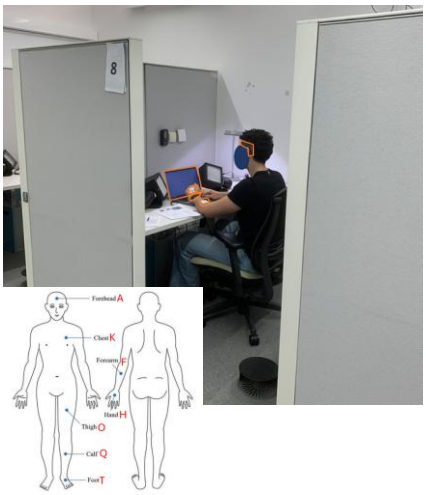
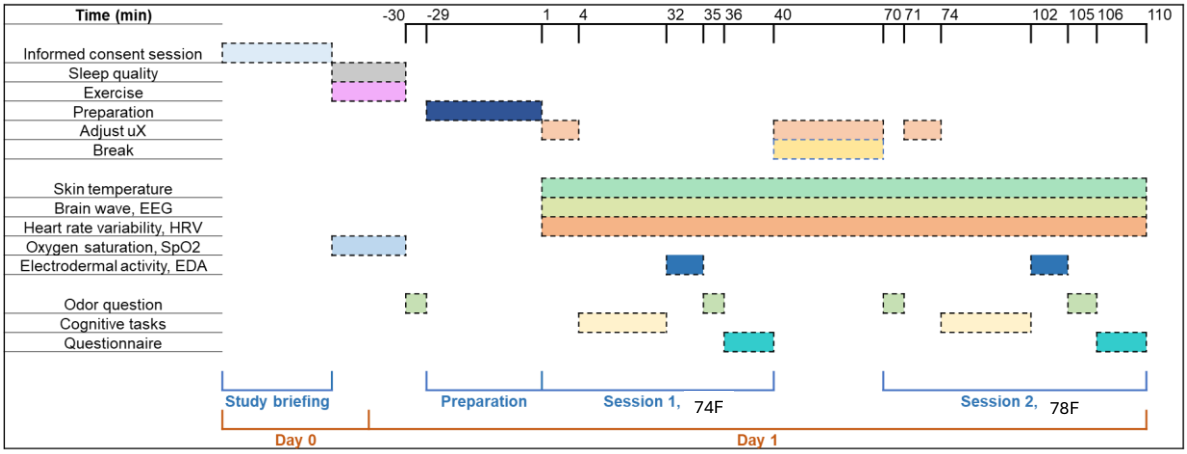


Figure: Participant at the workstation during the experiment

Experimental Design & Test Schedule

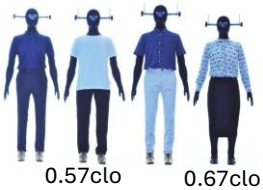
Case	Day	Time	Session	Ambient temperature
Informed consent session	Day 0	6:00 PM to 7:00 PM		
Formal test	Day 1	9:30 AM to 12:00 PM	Session 1	74F (23.3°C)
			Session 2	78F (25.6°C)

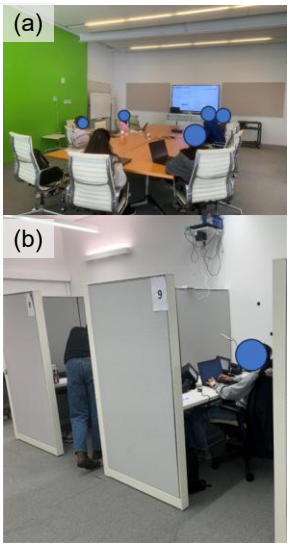


Participants

A total of 28 participants were recruited for the summer testing phase, which examined performance under varying temperature conditions. Among them, 20 were provided with the μX system, while 8 were not.

- Pre-test briefing, practice operating μX
- Sleeping quality of the night before testing day
- Ages, mean age = 24.8 ± 3.5 years
- BIM, 22.8 ± 3.2 kg/m^2
- Gender, 10 female, 18 male
- Clothing, prespecified
- Testing period
- Compensation, $50 for each participants
- Approved by the Institutional Review Board at Syracuse University.





Photos on the right - Pre-test briefing: (a) experimental procedure explanation; (b) μX interface introduction.

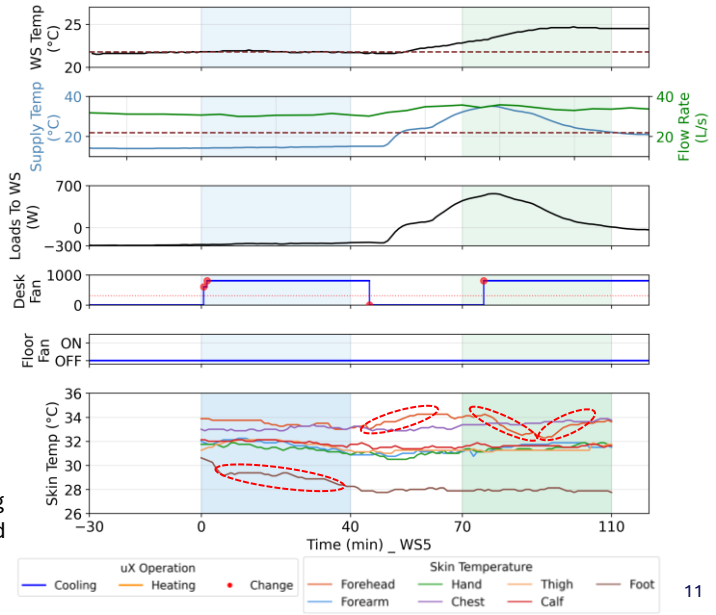
WS5: μX Operation & Skin Temperature

❑ **μX interaction & skin temperature:**

- Turned on desk cooling → increased fan speed → forehead and foot temperature decrease → after ~40min, turned off desk cooling
- Room supply air temperature and flow rate increase → heat load to workstation increase→ forehead temperature increase → turn on the desk cooling again → forehead temperature decrease

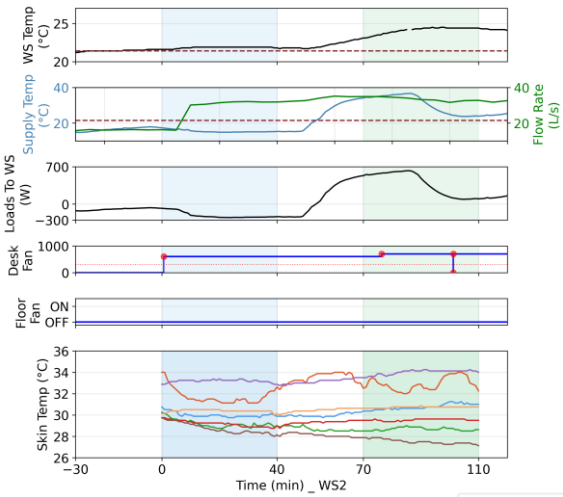
❑ **Skin temperature & heart rate:**

- Heart rate remained stable (~80–90 bpm) throughout both sessions, indicating the thermal conditions did not induce significant cardiovascular stress in participants.
- The forehead temperature recovery during Session 2 was likely driven by the elevated workstation temperature (~25°C) rather than thermoregulatory responses.

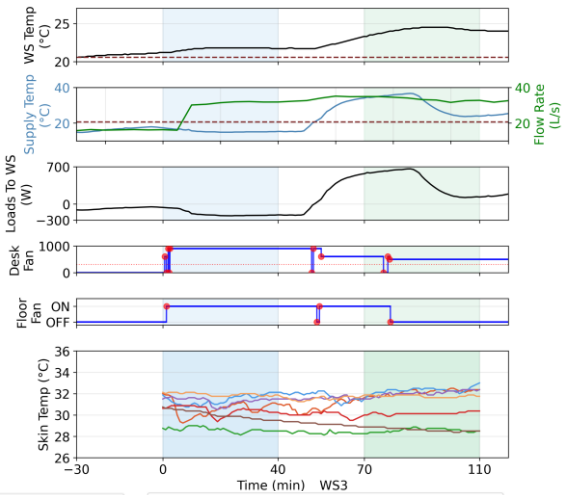


WS2 & WS3: μX Operation & Skin Temperatures

- Most body segments warmed (forehead+1.2°C, chest+0.8°C, calf +0.35°C, thigh+0.33°C) in Session2 → Participants choose to increase desk fan speed



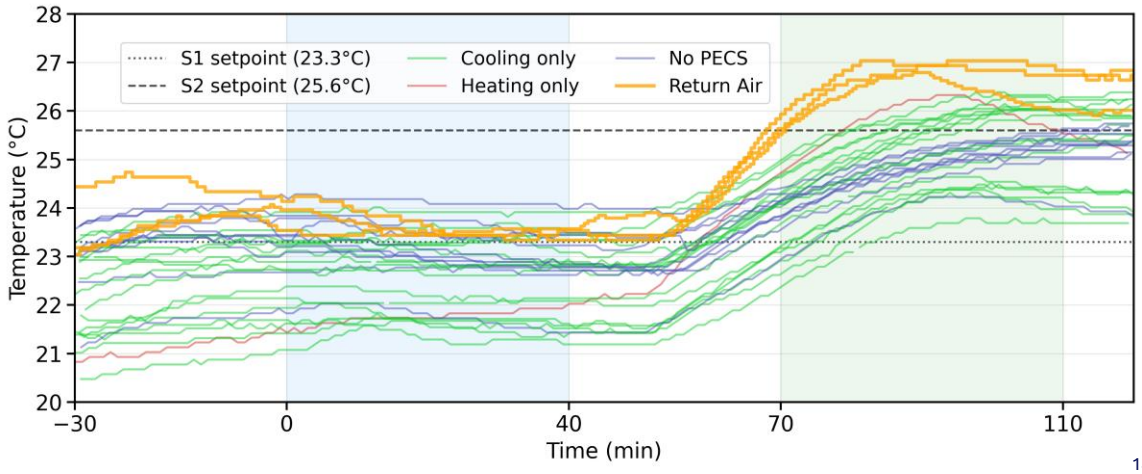
- Upper body warmed (forehead +1.5°C) due to strong room HVAC (i.e., ambient) heating, while floor fan enhanced convective cooling on lower extremities (foot −1.4°C) → high heat sensitivity



➢ **Inter-individual baseline differences are large**

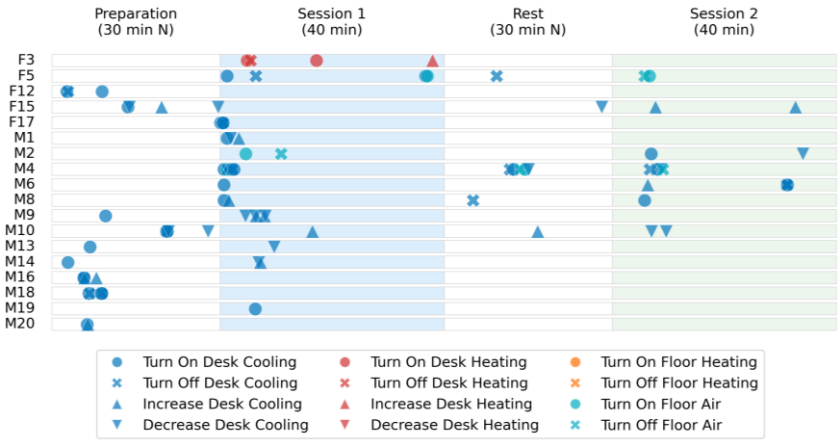
Results-1: Air Temperatures in the cubicles

- Room temperature was controlled based on the room return air temperature.
- Workstation temperatures were measured at the return of the PECS (μX). They do not reflect the local cooling.
- **Desk cooling primarily affects localized thermal comfort** → WS temperature profiles are similar across all PECS usage categories with similar pattern as the room return air temperature.



Results-2: User Interactions With the PECS

- 20 participants was provided with the PECS, among them, 18 (90%) chose to use PECS.
- 17 participants responded by activating **desk cooling** under summer conditions.
- Nine participants activated cooling during preparation, indicating **immediate thermal discomfort**.
- Five participants made behavioral changes during the rest period, which coincided with the transient temperature phase.
- Interactions decreased notably in Session 2 despite rising temperatures
- One participant (F3) chose heating instead of cooling → Felt cool/neutral at start (from the survey data).

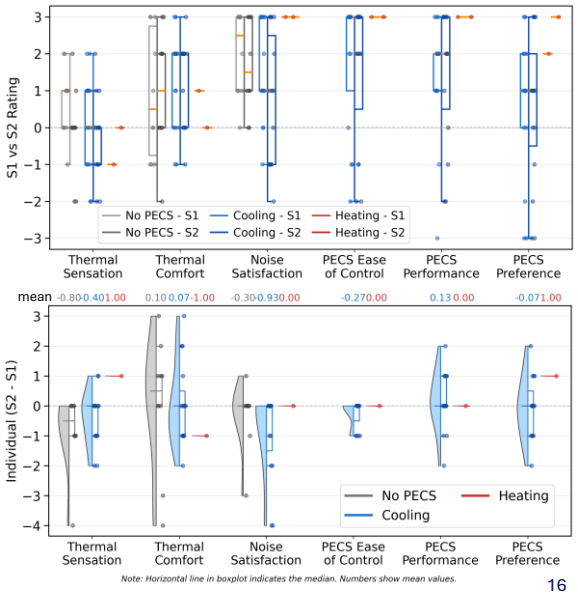


Note: N represents normalized

➢ PECS interactions decreased in Rest and S2, possibly due to **established preferences from earlier sessions**, **short-term thermal adaptation**, or **diminished thermal alliesthesia over time**. → same as the TSV, comfort vote

Results-4: Perceived IEQ

- All questions use a **7-point scale**, with 0 indicating a neutral response. A score of 3 corresponds to Hot / Positive / Clearly Clean / Clearly Acceptable / Very Satisfied.
- **Thermal sensation**
  - PECS desk cooling maintained thermal neutrality despite of the increase of room air temperature.
  - With PECS, participants perceived a cooler thermal environment compared to those without PECS.
  - Most participants reported the same thermal sensation in both test sessions (74 & 78 F room air, respectively).
  - ➢ **Varied outcomes correlated with the PECS operation**
- **Thermal comfort**
  - PECS users reported consistently higher thermal comfort than non-users in both sessions.
  - ➢ **PECS restored thermal comfort for most people**
- **Noise**
  - Cooling group, median = 1 in both sessions. Although lower than the No PECS group, the rating remains positive, indicating that fan noise was noticeable but still acceptable to most participants.
  - ➢ **Neutral or satisfied for most people, but less satisfaction in Session 2, due to PECS operation**



Results-5: Cognitive Task Performance

- Most participants did not show consistent pattern **across the 7 metrics** in the performance difference between 74 F and 78 F.
- A few individuals showed **nearly consistent trends**
  - M18 (Cooling) improved in 5 of 7 metrics
  - F21 (No PECS) declined in 6 of 7 metrics
- Motor Execution and Divergent Thinking remained stable across both sessions and groups → no negative impact from PECS operation.
- Using PECS cooling improved Attention compared to No PECS → localized cooling may support sustained attentional focus, though individual variability is large.
- With PECS cooling, the performance difference between 74 and 78 F room air conditions for females (F5, F12, F15, F17) was generally smaller than that of males.

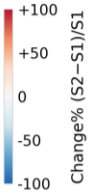
➢ Overall, PECS cooling did not negatively affect cognitive performance across the seven metrics despite the increase in room temperature.

No PECS (n=9)

	Math	Attention	Perception	Learning, Memory	Working, Memory	Motor Execution	Divergent Thinking
F11	150	17	-16	-10	-7	-1	
F21	-33	-2	-3	0	-5	-2	7
F25	43	17	-1	0	5	-0	4
F26	0	2	0	-10	-29	-0	15
F27	44	17	12	12	25	0	-2
M22	112	10	4	25	-21	-1	5
M23	17	8	-4	14	5	1	-2
M24	8	26	40	-25	2	0	8
M28	9	6	8	-33	39	-1	8

Cooling (n=17)

F12	100	15	-12	-10	4	-0	-13
F15	30	13	20	14	-30	-0	6
F17	13	1	-4	0	-4	0	-0
F5	-5	1	4	11	-12	0	-1
M1	21	48	8	0	-7	-1	10
M10	140	19	5	25	-12	0	-3
M13	-14	18	8	-14	-30	-1	12
M14	25	12	-19	11	4	0	1
M16	0	23	-12	0	124	7	-18
M18	333	36	48	25	46	-0	-10
M19	9	23	11	-10	-8	-1	6
M2	-38	7	14	-11	25	-0	4
M20	0	35	-1	43	-0	-0	-2
M4	-8	25	3	20	48	-0	-6
M6	23	25	7	0	-10	-4	-2
M8	-4	4	11	0	19	-0	-4
M9	-23	4	-2	29	52	0	1



Summary and Conclusions

- **User interactions with PECS**
  - Most subjects chose to use the PECS at the beginning even when the room temperature was 74F (23.3C), and fewer chose to adjust PECS further when the room temperature was increased to 78F (25.6C), suggesting that **both availability and perceived thermal condition played a role in participants' behavior in using the PECS.**
  - Variation in individual user adjustments to PECS operation were also observed.
- **Physiological responses**
  - When room air temperature increased from 74F to 78F, the **forehead temperature exhibited oscillatory pattern** (rising, dropping, then rising again), while the **hand temperature exhibited more variable responses**, indicating **complex combined effects** of room air temperature (cooling load increase), local cooling, and thermoregulatory mechanisms.
- **Perceived IEQ**
  - There were no significant difference in perceived thermal comfort between 74F and 78F room air conditions, indicating that the PECSs were able to achieve **local** thermal comfort. The noise level was generally acceptable, but less so at 78 F room air condition, suggesting additional effect from thermal condition.
- **Impact on performance**
  - PECS allowed individuals to moderate their thermal exposure, resulting **no decline between 74F and 78 F**. PECS group outperformed No PECS group in attention, perception, learning, and motor execution.
  - Differential effects on cognitive versus motor tasks indicates the complex task-dependent relationships between environment and performance.

Questions

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