Indoor environmental quality (IEQ) and energy performance evaluation of PECS

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SUMMARY

Most current environmental control systems installed in buildings aim to create a uniform IEQ, disregarding the large interpersonal and intrapersonal variability in occupants' thermal, visual, acoustics & air quality requirements. By creating occupant micro-environments that respond to individual preferences, and relaxing the surrounding space, personalized environmental control systems (PECS) can satisfy all occupants with relatively low-energy input. The performance of PECS on improving IEQ and energy use has been widely studied in different spaces using different simulation and modeling techniques, experimental methods, and field studies. Key performance indicators (KPIs) were subsequently used to quantify this performance and benchmark it with respect to conventional systems.

KEYWORDS

Personalized environmental control systems, indoor environmental quality, energy, performance evaluation methods

1 PECS PERFORMANCE

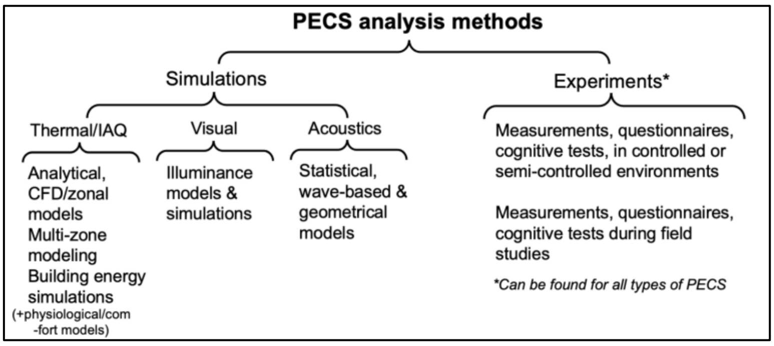
1.1 Analysis methods

Up until recent times, PECS performance evaluation methods could be classified into two major categories (Figure 1): **(i)** digital simulations that differ depending on the type of micro-environment targeted by the PECS (i.e., thermal, IAQ, acoustic, visual) or study objectives and **(ii)** experimental methods that are commonly used by all types of PECS. Combinations of simulations with select-experiments for validation of numerical prediction is also common.

Experimental techniques consist of deploying a fully functioning PECS in controlled or semi-controlled environments (e.g., climatic chamber) with either human subjects or test mannequins. Experiments also include field tests in occupied case study buildings (Kaczmarczyk, 2004; Melikov, 2007). Performance of PECS was evaluated via objective measurements of physiological (e.g., segmental skin temperature, heart rate, pupil size) and room parameters (e.g., air velocity, sound pressure) and through subjective satisfaction assessment collected from participants (e.g., questionnaires, cognitive tests, sick building syndrome, self-assessed productivity).

With every increasing hardware/software capability, computer simulation tools and modeling techniques have been widely and successfully applied to PECS research. For example, thermal/IAQ PECS (coupled to physiological comfort models) have been modeled using simplified mathematical analysis and theoretical formulations with adequate assumptions (Al Assaad 2018) or computational fluid dynamics (CFD) when more information is required about air distribution patterns as well as thermal/concentration fields in specific locations. Building energy simulations tools (e.g., EnergyPlus, IDA-ICE) are commonly used to assess the year-round energy use and potential savings for thermal/IAQ and visual PECS (Schiavon 2009). Despite the potential of digital simulation environments, they lack in their ability to simulate inter and intra individual differences between occupants and their dynamic interaction with the building.

Figure 1: Overview of PECS performance evaluation methods



1.2 Key performance indicators (KPIs)

For each PECS type (Figure 1), further subcategorization is possible. For example, thermal/IAQ PECS can be divided based on their function (heating, cooling and/or ventilation). Under this umbrella, multiple PECS exist with multiple design variations. For each type of PECS and for each evaluation method, different evaluation indices can be found. The conditions between studies were also different rendering difficult PECS comparison. Table 1 displays a summary of the main KPIs used to analyze PECS performance in simulations, experiments, or both. Common indicators found between all types of PECS include human subjective IEQ satisfaction votes often used in experimental studies

This shows the need for a universal method or standardized procedure to test and evaluate PECS performance which will be one of the main objectives of the newly formed international project "IEA EBC Annex 87 – PECS". These procedures should include ventilation/thermal resilience performance of PECS and its environmental impact (i.e., carbon footprint).

Table 1: Summary of main KPIs used in †simulations, *experiments, °both (Shinoda 2023)

Thermal comfort[1]	Visual comfort	Acoustic comfort	Air quality	Energy
Overall/Local Thermal sensation, comfort (**votes**, predicted from models)°	Room/local visual sensation, comfort **votes***	Equivalent Sound pressure levels°	Ventilation effectiveness°	Corrective energy, corrective power*
Draught index°	Gaze, eye movement, pupil size*	Daily noise exposure level	Personal exposure effectiveness°	Energy savings, energy demand°
Segmental/Equivalent skin temperature°	Luminance, luminance ratio°	**Acceptability** of system*	Intake fraction°	Power usage°
Segmental/Mean heat losses (sensible, latent) °	Daylight factor, daylight autonomy°	Speech **annoyance**, ability to concentrate*	Pollutant exposure reduction°	Heating/Cooling load°
Air temperature & velocity distribution°	Glare index°	**Perceived** privacy*	**Perceived** air quality*	Device-level COP*

[1]*Excluding heat stress related indices*

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