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Thermal comfort and perceived air quality of a PEC system

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SUMMARY

A personal environmental conditioning (PEC) system using air-jet cooling was evaluated for its thermal comfort, perceived air quality (PAQ), and eye comfort. The room surroundings and the air jets were both fixed at 28ºC and 50% RH. Two 4W fans directed room air toward the occupant's breathing zone from opposite sides. The premise was that facial air movement would both cool the occupant and disrupt potential PAQ in the body plume. Eighteen subjects participated in 90 3.5-hour tests. Comfort was assessed both at the workstation and during periodic breaks away from it. Comfort persisted throughout ten-minute standing/conversation breaks. After 15-minute step-climbing breaks had ensured discomfort, comfort resumed immediately upon the occupants' return. The influence of body plume on PAQ was examined using a plume-deflecting collar and a menthol scent applied at the waist. The collar significantly reduced the scent intensity, and the PEC air jets had the same effect.

IMPLICATIONS

PEC systems that do not require a cool air supply can be more easily implemented in buildings, are less expensive, and have very low energy use. By compensating for higher indoor temperatures, they can substantially reduce a building's cooling energy. This paper quantifies several practical issues related to their adoption.

KEYWORDS

Air movement cooling, absence from workstation, body thermal plume

INTRODUCTION

Various studies have found that Personal Environmental Control Systems (PECS) can deliver comfort and the perception of good air quality by providing air movement around the head or other parts of the body with very low energy input (Zhang at al. 2010, Melikov 2003, Amai et al. 2007, Sun et al. 2007). However, there remain practical questions about how PECS might be perceived by occupants over time in a real office environment, and also fundamental questions about how the air movement acts on the body to improve comfort and the perception of air quality (PAQ).

First, how long and to what extent would people feel comfortable when they are not under the direct influence of a PECS (e.g., when away at the copy machine, or exercising moderately as when climbing stairs), and how quickly can PECS restore comfort when people return to their workstations? Answers to these questions might impact the widespread adoption of PECS in practice. Second, is the known improvement in perceived air quality (PAQ) in the presence of air movement caused by a real air quality improvement or a psychological process? Real improvements might come either from the transport of fresh outside air to the breathing zone, or from the air movement stripping the bioeffluent-laden body plume from the breathing zone.

The objectives of the study were to determine: 1) the ability of this low-power PECS to provide comfort in warm environments, 2) occupants' comfort during absence from the PECS, for standing activity and a climbing activity producing a higher metabolic rate, 3) how quickly the PECS restores comfort after the occupants return, 4) air speed and body plume effects on PAQ, and 5) the relationships between PAQ, thermal sensation, and comfort.

METHODS

Tests were conducted in an environmental chamber from March through May 2009. 9 male and 9 female college students participated in one test per week for 5 weeks, for a total of 90 3.5-hour tests. Throughout the entire experiment, the room air temperatures were maintained at 28ºC, RH 50%. Subjects' skin temperatures were measured and they were surveyed for their subjective perceptions of thermal comfort, air quality, scent/body odor intensity, air movement preference, and others.

In each workstation, two 4" 4W muffin fans supply re-circulated room air through two nozzles toward opposite sides of the occupant's face. 4" and 2" diameter nozzles were tested. In some tests the air speed was controlled by the subjects using a slider on a computer screen. Liu (2011) presents the air flow profiles produced by the PEC system in this study.

Workstations were arranged so that two subjects could be tested simultaneously. The subjects wore standardized summer clothing, including cotton pants, short-sleeved cotton shirt, summer socks, and a pair of lightweight shoes (0.5 clo). Figure 1 shows the layout of the workstations and the clothing that subjects wore. The configurations tested were listed in Table 1.

Figure 1. Experimental setup

Table 1. Tested configurations

air speed at cheek (m/s)	0 ('no PEC'), 0.6, 1.0
nozzle diameter (inches)	2, 4
number of nozzles:	1, 2

72 tests took 3.5 hours, with 3 one-hour test phases of separate PEC configurations, and a 10-minute break time between each one-hour phase. The order of the PEC configurations in each phase was randomly alternated and balanced. The subjects were surveyed in the beginning, middle, and end of each phase. The last survey (at the 60th minute) is used to analyze the stable condition. The first survey is used for analyzing how comfort is restored after absence from PEC.

The survey questionnaires regarding thermal sensation, comfort, and PAQ appeared automatically on the subject's computer screen at scheduled times.

Absence at a low activity level. During the 10-minute break periods, the PEC systems were turned off and the subjects were asked to leave their workstations. They were encouraged to stretch their bodies and to involve in conversation with each other and with the researcher in charge of the test (Figure 2a). At the end of the 10-minute break, before resuming the next PEC test configuration, they answered a set of questions about thermal comfort and PAQ.

Absence with high metabolic exertion. In 18 tests, 15-minute breaks were used. Both at the beginning and end of a 15-minute break, the subjects climbed a step 40 times (Figure 2b), corresponding to climbing and down 5 stories. At the end of the break, they answered the survey questions. Then they sat in the workstation with the PECS on, and repeated the survey immediately. They were then surveyed again five and fifteen minutes later.

Body odor/scent intensity tests. In the 18 tests with high-exertion breaks, subjects did not perceive an increase body odor after exertion. To examine the mechanism of body odor transported in the body's thermal plume, a cough-relief patch containing menthol, camphor, and eucalyptus oils was placed on the abdomen skin to add a perceptible scent (Figure 3). The subjects were surveyed about the scent intensity under three conditions: with and without a collar to deflect the body plume away from the nose, and then with the PEC providing air movement.

The scent test took 1 hour. After 15 minutes in the chamber, we applied the menthol patch to the subject. Each configuration lasted five minutes interchanging the order of the collar while adding the PEC (0.6 m/s) at the end. Five minutes later, they answered a survey about scent intensity and PAQ.

a. scent intensity question   b. scent   c. with collar   d. no collar

Figure 3. Scent test

RESULTS

1. Whole-body thermal sensation and comfort with the PEC system

Whole-body thermal sensation and comfort are presented in Figure 4. The X axis represents the test configurations listed in Table 1. Without PEC, thermal sensation is close to 'warm'. At the low velocity setting (0.6 m/s at the breathing/cheek region) there is a slight but insignificant cooling effect. All the other configurations are between 'slightly warm' and 'neutral', and the differences are significant ($p<0.05$).

Comfort is improved by PECS from 'just uncomfortable' (the negative value for 'no PEC') to a range of comfortable values for all other configurations. It is interesting that although the thermal sensation cooled slightly and insignificantly under low air movement (0.6 m/s), comfort is significantly improved under the same condition. At the higher air movements, comfort is above 1 on the comfort scale. The highest comfort values are for the 2x4" nozzle configurations (both 1 m/s and user-controlled). Comfort is better for the 2x 4" than the 2x2" configurations, and user control does not provide an advantage for either size. The comfort for the two nozzles is significantly better than the comfort for the single nozzle.

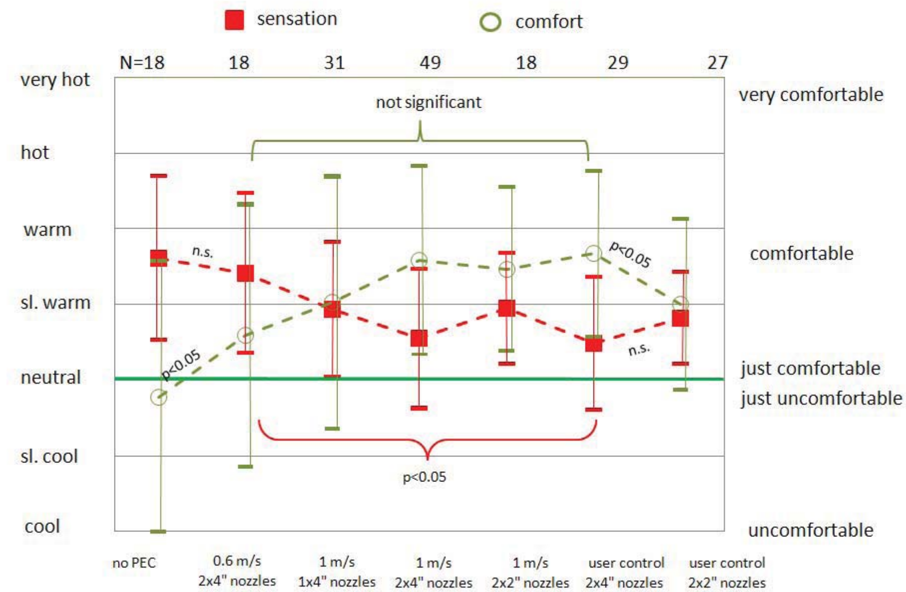


Figure 4. Whole-body thermal sensation and comfort (bar represents ± SD, n.s. represents not significant)

2. Comfort during and after break periods

After the 10 min break, subjects' sensations are between slightly warm and warm (Figure 5). Thermal comfort is reduced 1 scale unit (Figure 5), but is still on the comfortable side. Once the PECS is applied, comfort is immediately restored to above 1.

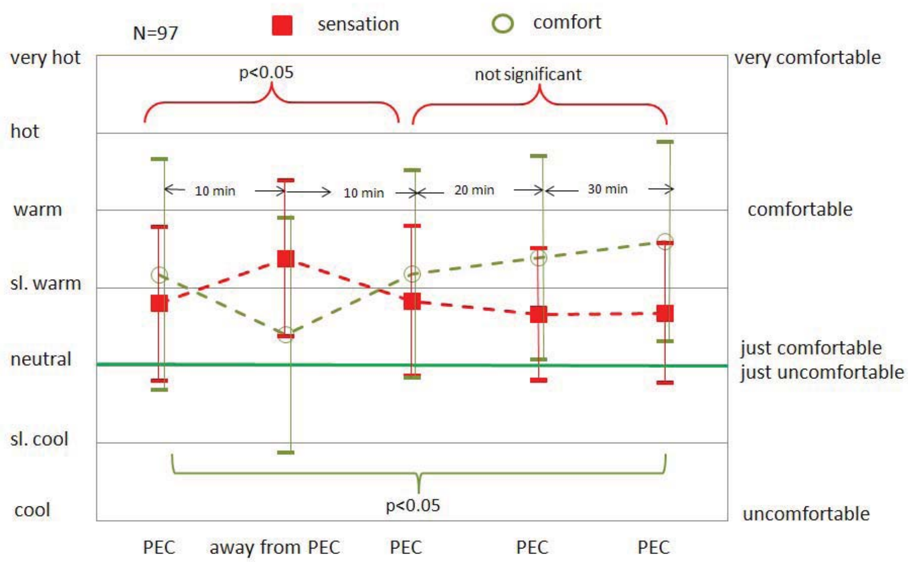


Figure 5. Thermal sensation after the 10-minute break

After the 15 minute break in which the subjects twice did 40 steps in the ambient condition of 28ºC, subjects are warm (sensation between warm and hot) and uncomfortable (Figure 6). Right after the PEC is applied, the sensation is close to be slightly warm and comfort goes up

1.5 scale units and is above zero. The two subsequent surveys show continued cooler thermal sensation and improvement to comfort.

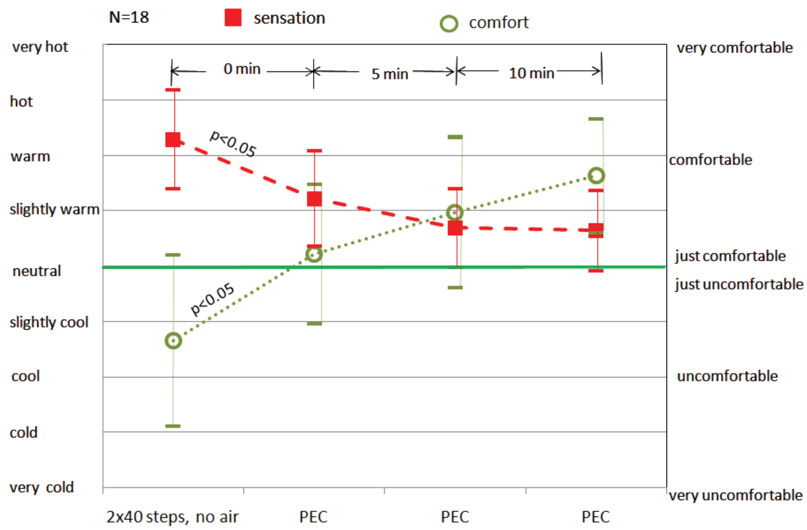
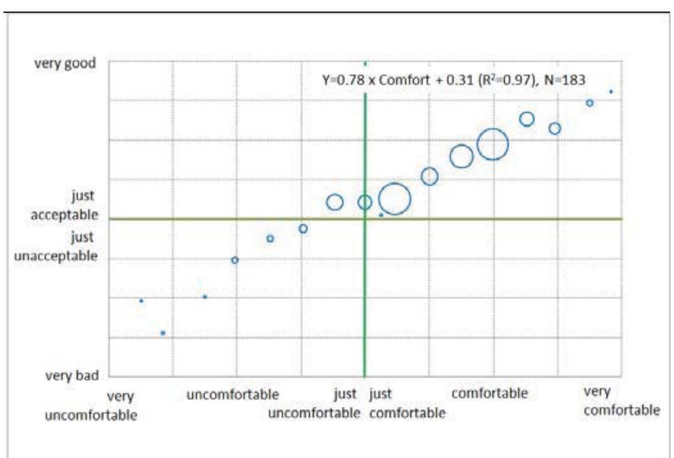


Figure 6. Sensation and comfort after exercise in the 15 minute break.

3. Perceived air quality (PAQ)

Perceived air quality is significantly improved by air movement at 28ºC. Without air movement, the PAQ was just unacceptable, but under all PEC configurations it was fully acceptable. This finding is similar to that of a previous PECS test (Arens et al. 2008). Thermal comfort determines PAQ rather than air temperature, as seen in Figure 7.



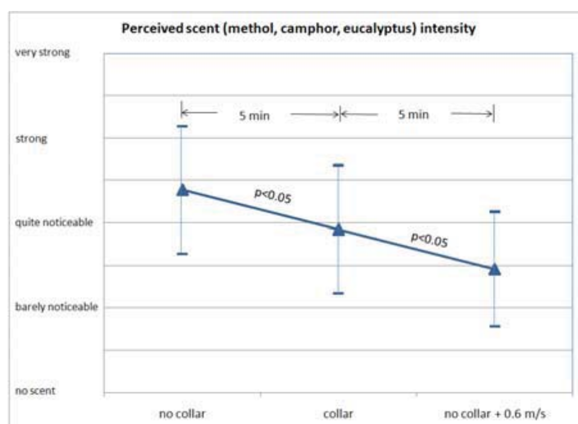


Figure 7. PAQ vs. thermal comfort (circle size represents the number of votes)

Figure 8. Sent intensity between collar, no collar, and air movement

Adding the menthol patch, significant differences are found for the scent intensity between the no collar configuration, the with-collar configuration, and the no-collar-with-low-air-movement at the breathing zone (Figure 8). The collar acts to reduce the scent intensity over no collar, and air movement reduced it more than the collar.

CONCLUSIONS

For thermal comfort questions:

- The low-power task-ambient conditioning system provides high levels of occupant comfort in a warm 28ºC (82.4ºF) environment.
- Comfort was maintained during the 10-minute break periods between PEC tests, in which subjects stood and engaged in conversation.
- PEC restores comfort immediately after a 15-minute period in which discomfort was induced by two intensive metabolic step exercises.

For PAQ questions:

- Air speed significantly improves PAQ, even at the lower speed of 0.6 m/s.
- Wearing a plume-deflecting collar significantly reduced the menthol scent intensity.
- PAQ and comfort are well correlated, with better PAQ at higher levels of comfort.

Throughout the tests, eye discomfort was not reported.

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REFERENCES

Amai, H., Tanabe, S., Akimoto, T., Genma T. 2007. Thermal sensation and comfort with different task conditioning systems. *Building and Environment* 42 (12), 3955 - 3964.

Arens, E., Zhang, H., Kim, D, Buchberger, E., Bauman, F., Huizenga, C., Higuchi, H. 2008. Impact of a task-ambient ventilation system on perceived air quality. *Indoor Air* 2008, August 17 - 22, Copenhagen.

Fang, L., Clausen G, Fanger, PO. 1998. Impact of temperature and humidity on the perception of indoor air quality during immediate and longer whole-body exposure. *Indoor Air* 1998; 8: 276 - 284.

Liu, C., Higuchi H., Arens E., Zhang H. 2011. Study of a Personal Environmental Control System Using Opposing Airstreams. *Indoor Air 2011*, Texes, April 8 – 11, 2011.

Melikov, AK. 2003. Personalized ventilation. *Indoor Air* 2004; 14: 157 - 167.

Sun, W., Tham KW., Zhou, W., Gong, N. 2007. Thermal performance of a personalized ventilation air terminal device at two different turbulence intensities. *Building and Environment* 42 (12), 3974 - 3983.

Zhang, H., Arens E., Abbaszadeh Fard S., Huizenga C., Paliaga G., Brager G., Zagreus L., 2007. Air movement preferences observed in office buildings. *International Journal of Biometeorology,* 51: 349 - 360.

Zhang, H., Arens E., Kim D., Buchberger E., Bauman F., and Huizenga C. 2009. Comfort, Perceived Air Quality, and Work Performance in a Low-Power Task-Ambient Conditioning System. *Building and Environment* 45(1), 29 - 39.