Effect of a heated and cooled office chair on thermal comfort

Wilmer Pasut[1,*], Hui Zhang[1], Soazig Kaam[1], Ed Arens[1], Yongchao Zhai[1]

[1]Center for the Built Environment, University of California, Berkeley, CA

[*]*Corresponding email: wpasut@berkeley.edu*

Abstract

A heated/cooled chair was evaluated for its effect on thermal sensation and comfort. Thirty college students participated in 150 1.75-hour tests. Two heated/cooled chairs were placed in an environmental chamber resembling an office environment. The chamber temperatures were set at 16, 18, 25 and 29 °C (60.8, 64.4, 77, 84.2 °F). During the tests the subjects had full control of the chair surface temperature through a knob located on the desk. An additional 64 tests with sixteen subjects were conducted at the same four temperatures but with regular mesh or cushion chairs in order to provide reference results for comparison.

Subjective responses about thermal sensation, comfort, and temperature satisfaction were obtained at 20 minute intervals and eight times before, during, and after a break period. The chair's energy consumption was monitored continuously. The results show that the heated/cooled chair strongly influences the subjects' thermal sensation and comfort, providing thermal comfort under all tested conditions, both warm and cool. The average power draw is 27 Watts at 16ºC (60.8 °F), and 45.5 Watts at 29ºC ambient conditions (84.2 °F).

Keywords: Heated seat, Cooled seat, Thermal comfort, Personal comfort system, PCS, Thermal sensation.

Introduction

Thermal discomfort is one of the major complaints from occupants in offices (Huizenga at al. 2006), but as proven by several researchers (Melikov et al. 1998, Tsuzuki et al. 1999, Akimoto et al. 2003, Zhang et al. 2010), it is possible to reduce the dissatisfaction by using personal comfort systems (PCS). In the past, PCS systems have also been called task ambient conditioning (TAC) and personal environmental control (PEC). Zhang H. et al. (2010, 2011), Zhang and Zhao (2008), and Arens (2011) established that the use of PCS systems can broaden the acceptable ambient temperature range to 18-30 °C (64.4-86 °F). This implies that a building can be controlled with an extended thermostat deadband while still maintaining occupants' thermal comfort. Hoyt et al. (2009) studied the energy saving from extended setpoints compared with the typical range of 21.5-24 °C (71-75 °F). The saving is about 10% of total HVAC energy use for each degree Celsius increase or decrease in the setpoint (about 5% for each degree Fahrenheit).

A heated/cooled chair is a type of PCS that has been found to provide comfort. Watanabe et al. (2009) studied the influence of a ventilated chair incorporating two fans in the back and seat bottom to provide isothermal forced airflow for cooling. They found the chair enabled an acceptable ambient temperature of 30°C (86 °F). Kogawa et al. (2007) tested a ventilated chair in a real office. The chair had two air nozzles installed on the two armrests. It showed that the ventilated chair could keep occupants comfortable at 27ºC (80.6 °F). The chair cooled people up to 1 unit on the seven-point thermal sensation scale. Brooks and Parsons (1999) tested a car seat heated with encapsulated carbon fabric in cool environments. They reported improved overall thermal comfort when the ambient temperature was reduced below 20 °C (68 °F). Zhang et al. (2007) tested a car seat with surface that could be both heated and cooled. Their analysis indicated that the use of a heated/cooled seat would extend drivers' acceptable range of ambient temperatures 9.3 °C downwards and 6.4 °C upwards.

The purpose of this experiment was to test the effectiveness of a heated/cooled office chair at producing comfort in a realistic work environment with an expanded ambient temperature range.

Methods

The experiments were carried out at the Center for the Built Environment (CBE) at the University of California, Berkeley, between September 2011 and December 2011.

Heated/cooled office chair (named active chair). Two actively heated/cooled chairs, two regular cushion chairs and two mesh fabric chairs were used for the experiments. The active chairs are equipped with a thermoelectric device (TE) that can increase or reduce the seat and backrest surface temperatures

(Figure 1). The fabric that covers the chair has high conductivity to increase the heat exchange between the human body and seat surfaces. The heating and cooling power of the chair is controlled by a knob located on the desk (Figure 1). The measured power at maximum heating is 42 W, and 74 W at maximum cooling.

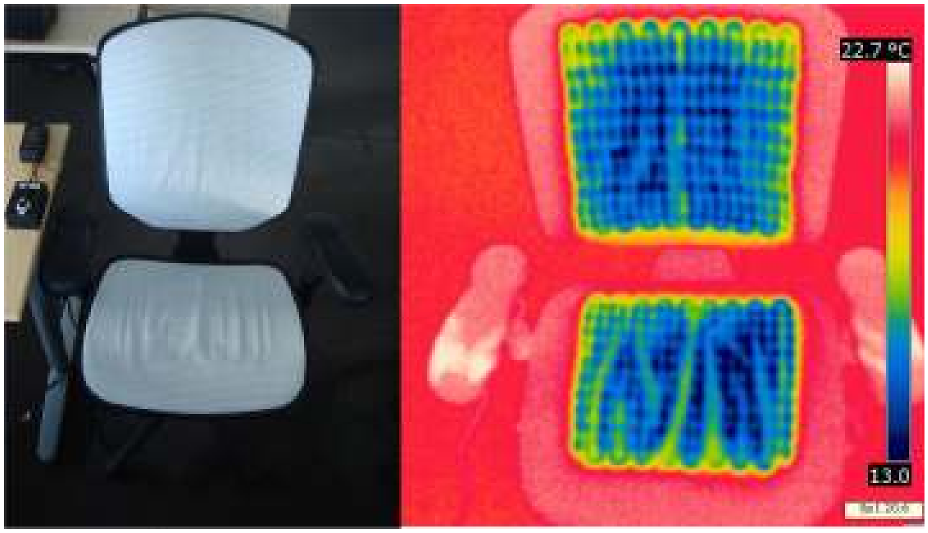

Figure 1. The active chair, control knob, and a picture of the chair with the IR camera.

Subjects and test conditions. The human subject tests obtained comfort responses and power consumption for winter (16, 18 °C) and summer (25, 29 °C) conditions. The relative humidity of the chamber was kept at 50% ±1%. The air velocity was less than 0.1 m/s (19.7 ft/min). Thirty subjects (16 females and 14 males) participated in each of the four test conditions using the active chair, for a total of 120 tests, plus an additional 30 tests at 29°C ambient temperature to study the effects of different chair pre-cooling levels. Also, tests were done with conventional chairs to provide reference conditions for comparison with the active chair. Sixteen subjects repeated the same test conditions with a commercial mesh chair (8 subjects) and a cushion chair (8 subjects), an additional 64 tests. Two workstations were installed in the Controlled Environmental Chamber at UC Berkeley so that two subjects could be tested at the same time. The chamber size is 5.5 x 5.5 m (18 x 18 ft), with windows on two sides, South and West. The windows are well shaded by fixed external shades. The temperature of the inner glass pane is controllable, and was kept isothermal with the interior. The room air temperature is controlled by 8 floor grill diffusers, and the air is exhausted through a 0.6 x 0.6 m (2 x 2 ft) ceiling return grill. Clothing was provided for the tests (0.5 clo for summer test conditions and 0.65 clo for winter test condition). During the tests the subjects were allowed to adjust the heating or cooling levels of the active chair using the control knob. They were asked to perform computer related activities during the tests, including their own assignments.

Schedule for the tests. The tests took one hour and forty-five minutes. At the beginning of each test, the subjects sat for 15 minutes in a mesh chair to let their body to adapt to the chamber temperature. After this preconditioning time the subjects were asked to sit on the test chairs. The active chairs were pre-cooled/heated at an average power level. Upon sitting down, subjects had full control of the chair power to adjust the surface temperatures of the chair. The remaining part of the test was divided into two sessions by a ten-minute break. During the break period the subjects would stand, and in the middle of the break, they took 12 vertical steps on a 22cm tall step stool. This was to simulate a typical activity level when occupants are away from their desks in a real office. The survey questions automatically appeared on subjects' computer screen based on pre-set schedules (Figure 2).

Thirty pilot tests were conducted to verify whether pre-cooled/heated level affect the way subjects use the chair during the tests. Pilot tests results indicated that chair preconditioning level does not affect the way subjects use it during the test.

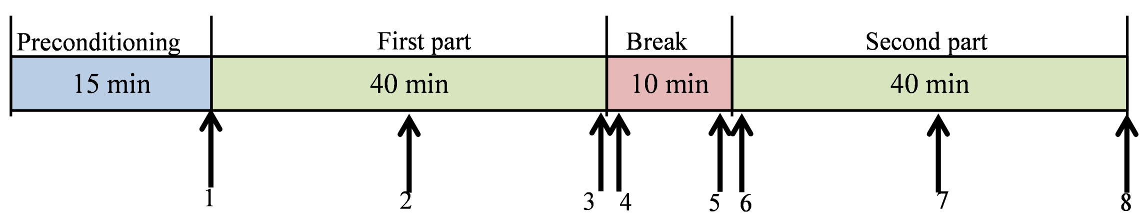

Figure 2 The test schedule. Arrows indicate times when the surveys are administrated.

Survey questions. The survey questionnaires included temperature satisfaction, thermal sensation, preferred thermal sensation and thermal comfort. The last three of these four questions were performed for the whole body, back region and gluteal region, to better understand the impacts of the two body parts involved in the heat exchange with the active chair on the whole body perception. Two survey question examples are shown in Figure 3. The scales are continuous.

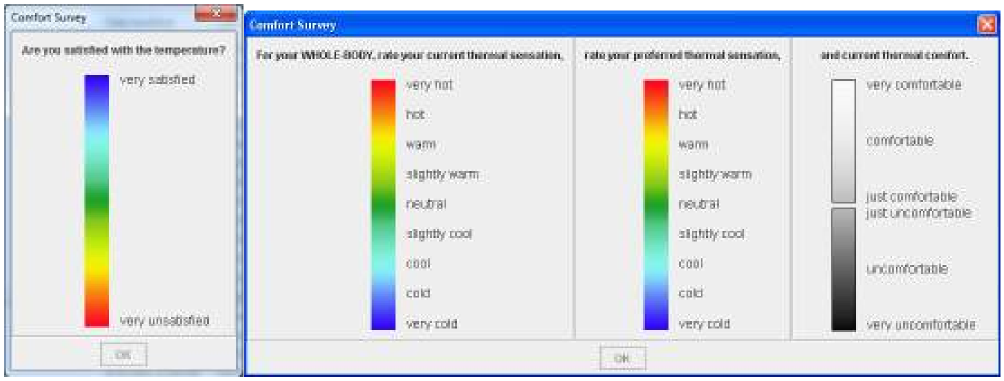

Figure3 Satisfaction, thermal sensation, preferred thermal sensation and thermal comfort surveys.

Following Zhang H. et al. (2010), we used a paired thermal sensation scale (as shown in the right image in Figure 3). The paired sensation scale gives more information than the thermal preference scale (want to be warmer, no change, cooler) by itself.

Subject training session carried out prior testing. All subjects attended a one-hour training session prior to testing. The training session served to get the subjects familiar with the test procedure, the active chair, and the survey questions.

Measurements. The back and gluteal skin temperatures were monitored at 20-second intervals, using Hobo dataloggers. Room air temperature and humidity were measured at 1.1 m height. The active chair energy usage was measured every minute.

Results

This paper focuses on both stable and transient conditions. For the stable conditions we analyzed subjects' responses to the number seven survey (see Figure 2).

Whole-body thermal satisfaction. In the following analysis, the mesh chair, cushion chair and active chair are abbreviated with three letters, M, C and A, respectively (Figure 4). Every graph has a triangle representing statistical significance of differences between chairs. The red line with an asterisk on the side indicates that the difference between the two chairs is statistically significant ($p<0.05$). The statistical analysis was performed with a non-parametric method called a permutation test, using the program NPC Test R10. For more details about the program and the non-parametric method refer to Pesarin (2010).

In Figure 4 the temperature satisfaction is presented for the four room temperatures. There is a significant difference between the active chair and both the cushion and mesh chairs, for the cold and cool conditions (16 °C and 18 °C), and for the hot condition (29°C). There is no significant difference for the neutral room temperature (25 °C). For all the four temperatures the median and the average vote with the active chair is above the line that divides 'satisfied' and 'unsatisfied'. The satisfaction level with the active chair at 29ºC is just above the line, suggesting that this temperature is near the feasible maximum for the cooled chair. Under cool (16ºC and 18ºC) and warm (29ºC) conditions, subjects with the cushion and mesh chairs were not satisfied.

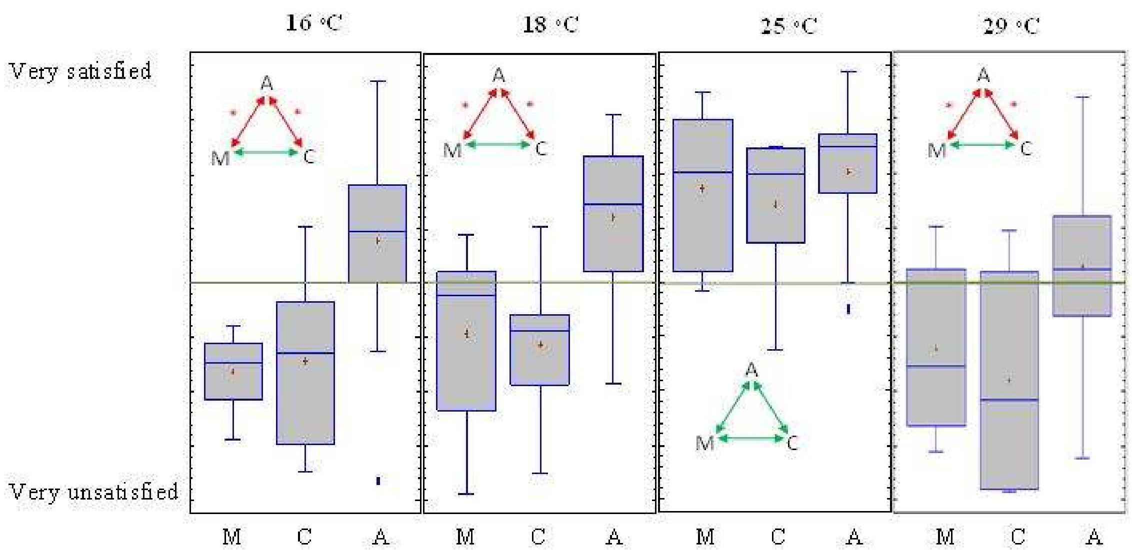

Figure 4 Whole-body thermal satisfaction

Whole-body thermal sensation. Thermal sensation for the four conditions is reported in Figure 5. As can be seen, the active chair keeps the average thermal sensation close to the neutral line. Again there is no statistical difference among the tests at 25°C. There is no statistical difference between the mesh chair and cushion chair for all 4 tested conditions. It seems that using a mesh chair does not provide any advantage in a hot environment or any disadvantage in a cold environment.

From Figure 5 it is also possible to notice that the distributions for the active chair (labeled with the A) are very similar under the four different conditions. We performed a non-parametric test to verify if the four distributions are different. The analysis indicates that there is no statistically significant difference for thermal sensation among the four thermal configurations if the active chair is used. This means that the active chair keeps the user's thermal sensation constant over the range of temperatures analyzed in this study.

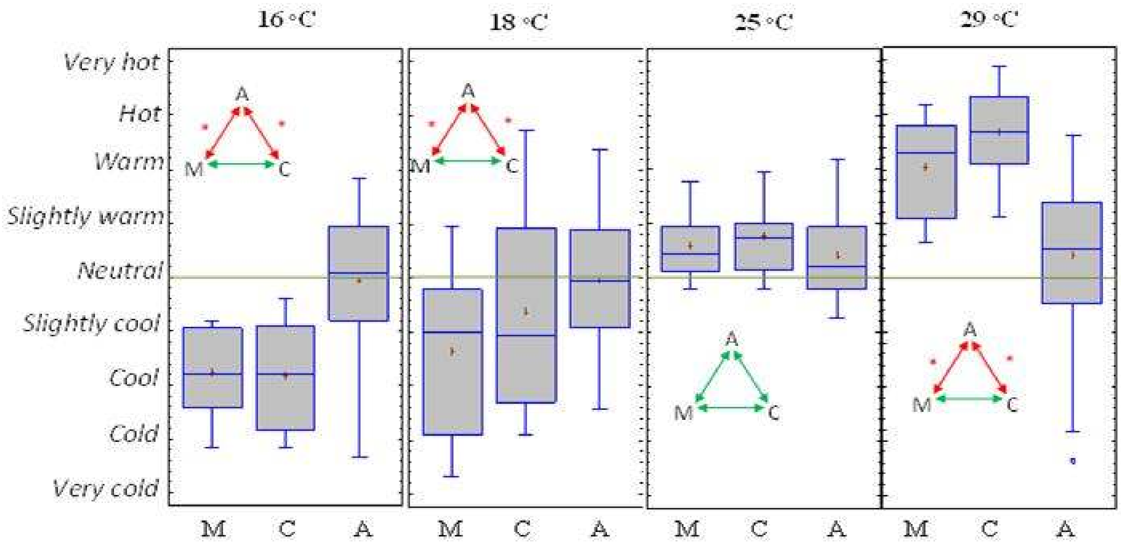

Figure 5 Whole-body thermal sensation

Whole-body preferred thermal sensation. There is only one significant difference in terms of preferred thermal sensation, between the active and cushion chairs at 18 °C. For all the other cases there is no significant difference between three types of chairs. In general, people's preferred sensations were around neutral, but we did see that subjects preferred to have a slightly warmer sensation for the mesh air at 16ºC temperature and a slightly cooler sensation for the cushion chair at 29ºC temperature (Figure 6), with both differences statistically significant.

Humphreys (2004) first used the paired scale for "preferred" thermal sensation and "thermal sensation". Humphreys and Hancock (2007) showed that there is a relationship between "desired" thermal sensation and "thermal sensation". From our results appears as if the use of the active chair fails to follow the expected correlation shown by Humphreys. This can be seen for the results at 16 °C presented in Figures 5 and 6. For this environmental condition the distributions for the whole-body "thermal sensation" are very different between active chair and mesh and cushion chairs (Figure 5), but there are no statistical differences for the whole-body "preferred" thermal sensation distributions between the three different chairs (Figure 6), as would be expected if there were a relation between "thermal sensation" and "preferred" thermal sensation. The same can be said for the 29 °C environment.

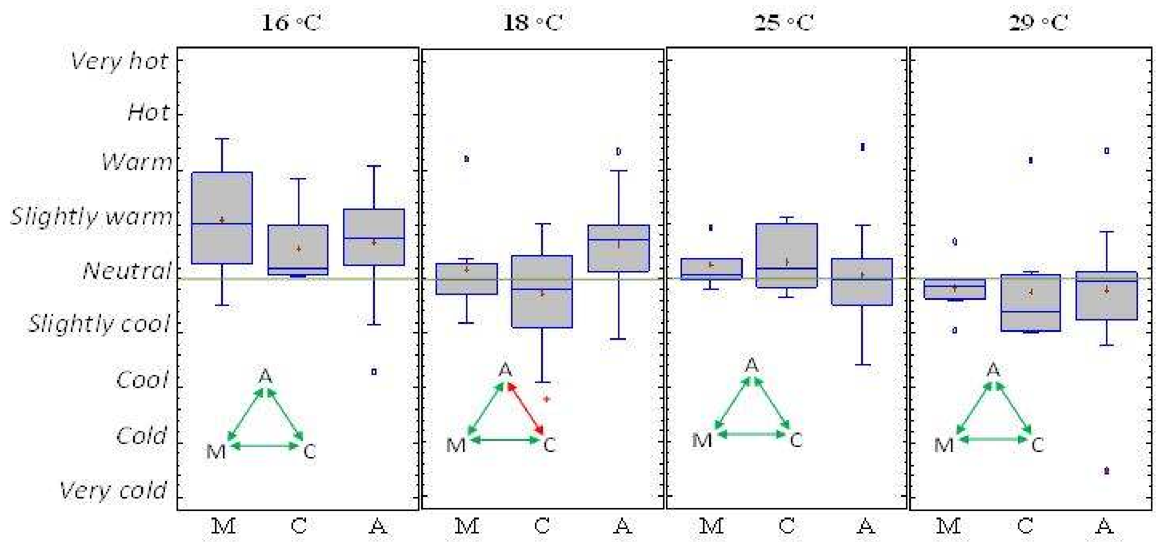

Figure 6 Whole body preferred thermal sensation.

Whole-body thermal comfort. The use of the active chair strongly influenced and improved thermal comfort for the 16, 18 and 29°C temperatures (see Figure 7). The increases are statistically significant between the active chair and the mesh and cushion chairs. With the active chair, the thermal comfort median and average are comfortable at these temperatures, while for other two chairs, they are uncomfortable. For the environment at 18 °C with the active chair, the entire population except one subject (3% of the population) is comfortable. The comfort levels are much higher in cool environments (16 and 18ºC) than in the hot environment (29ºC).

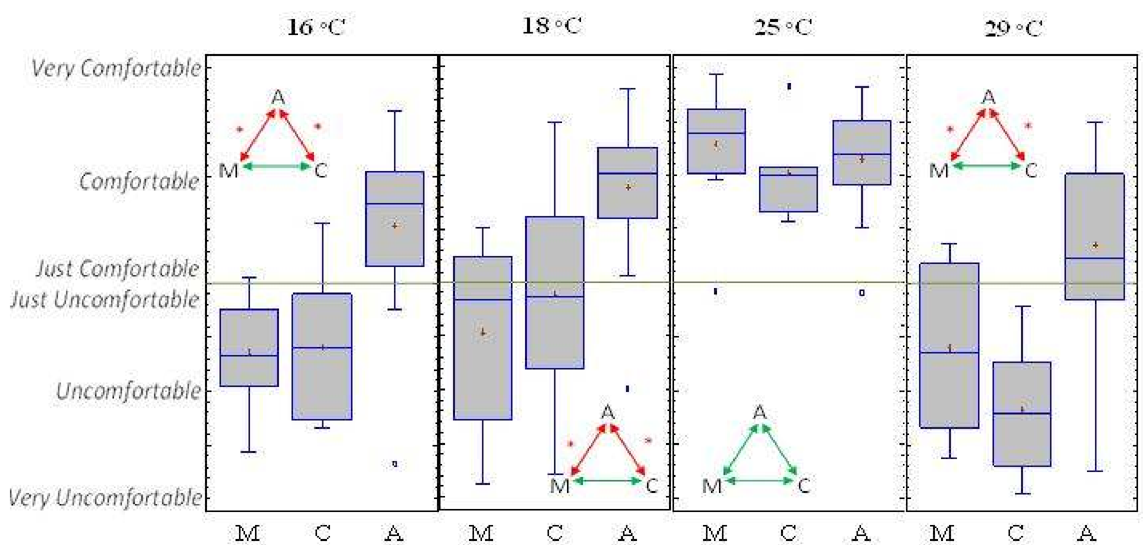

Figure 7 Whole body thermal comfort.

No significant difference was registered in whole-body thermal comfort for the three chairs in the 25 °C environment. Also in this case the active chair does not confer any advantage or disadvantage. No statistical differences are seen for the mesh and cushion chairs in any of the environments.

Others body parts. The survey questionnaires included questions for those body parts in direct contact with the chair. Questions about thermal comfort, thermal sensation and preferred thermal sensation were asked for the back and gluteal regions. The results are presented in Figures 8 to 13, following the scheme of the previous the charts.

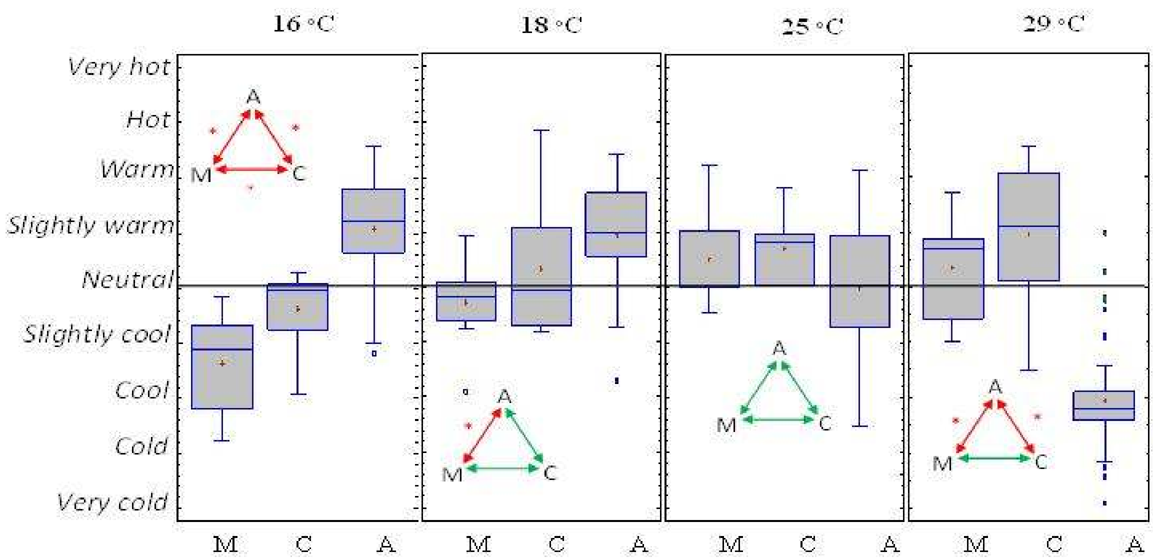

Figure 8 Back thermal sensation

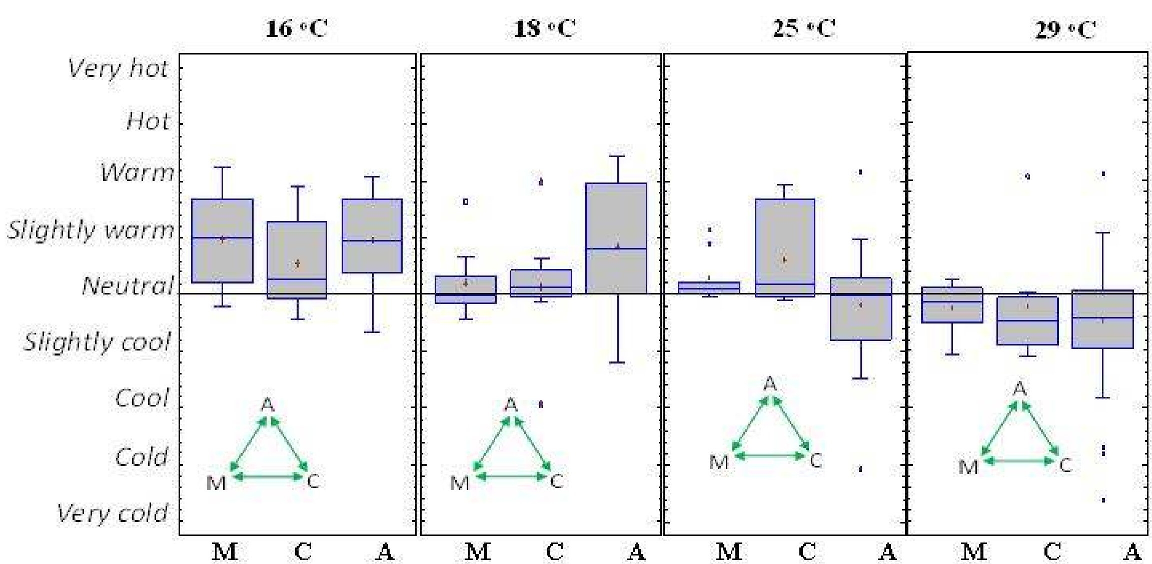

Figure 9 Back preferred thermal sensation

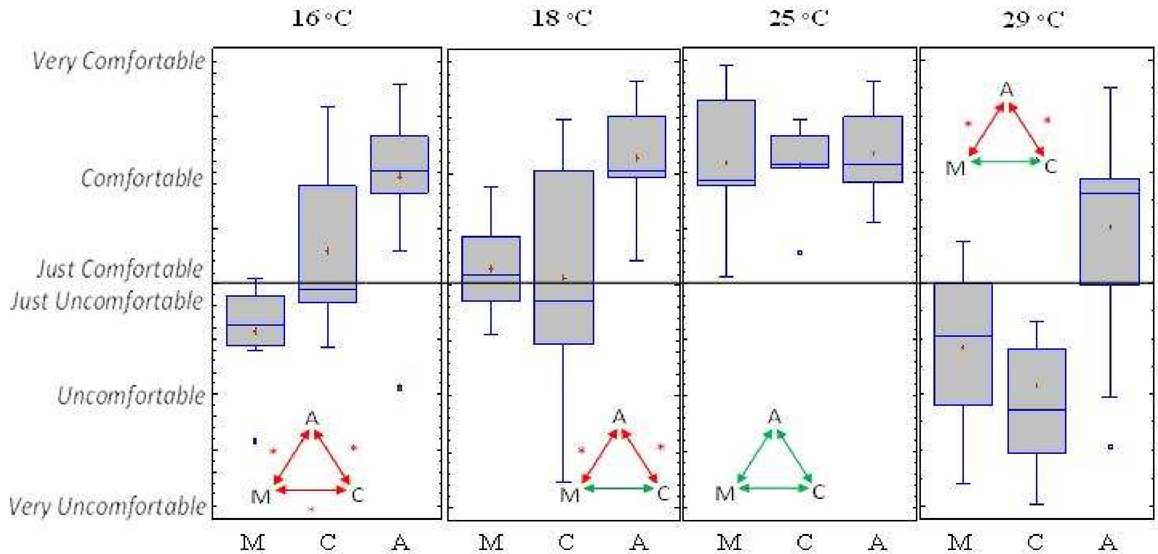

Figure 10 Back thermal comfort

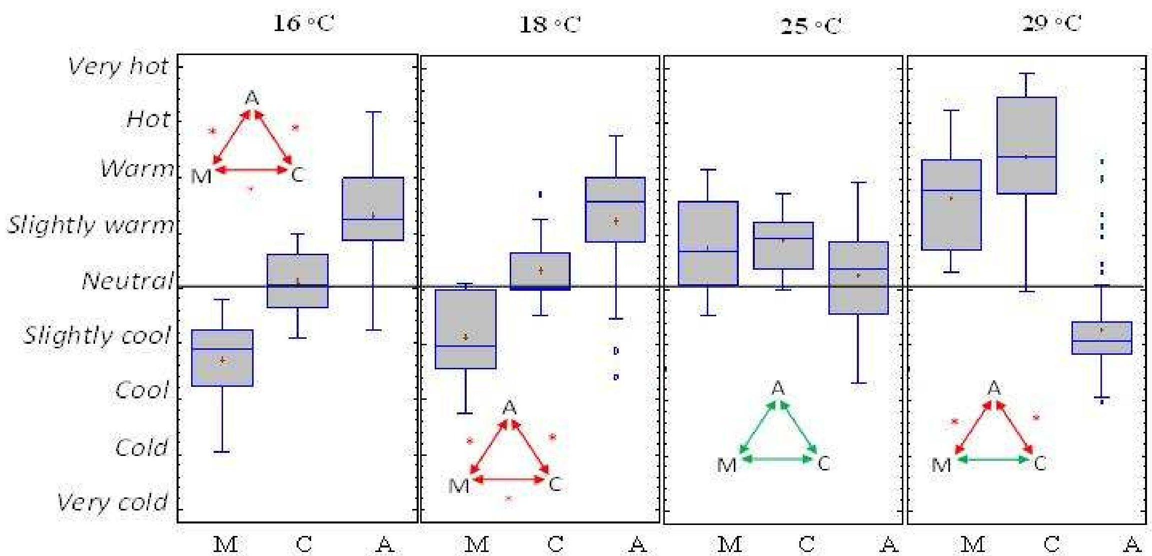

Figure 11 Gluteal region thermal sensation

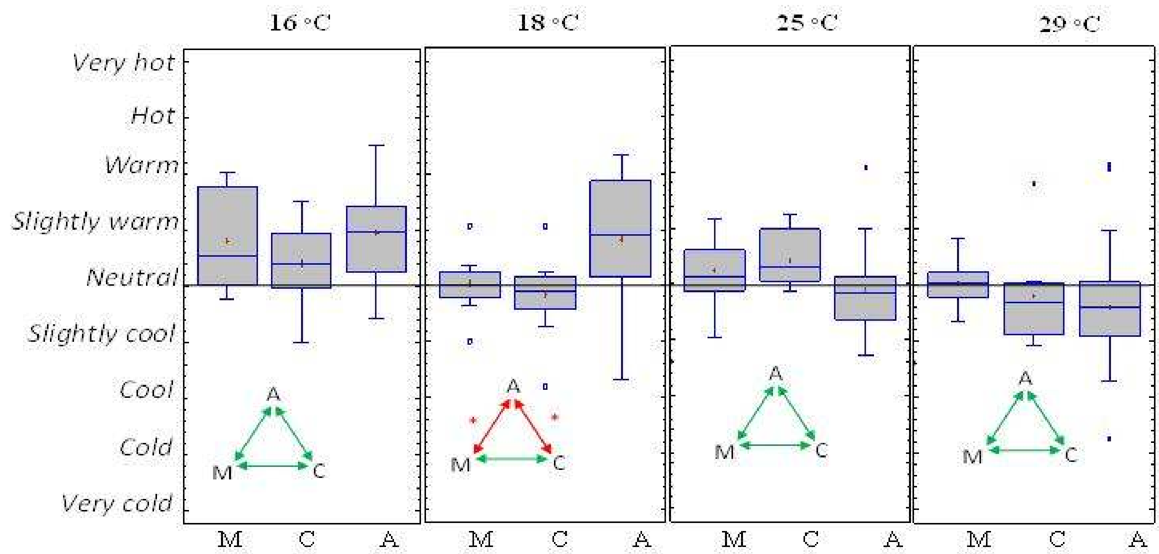

Figure 12 Gluteal region preferred thermal sensation

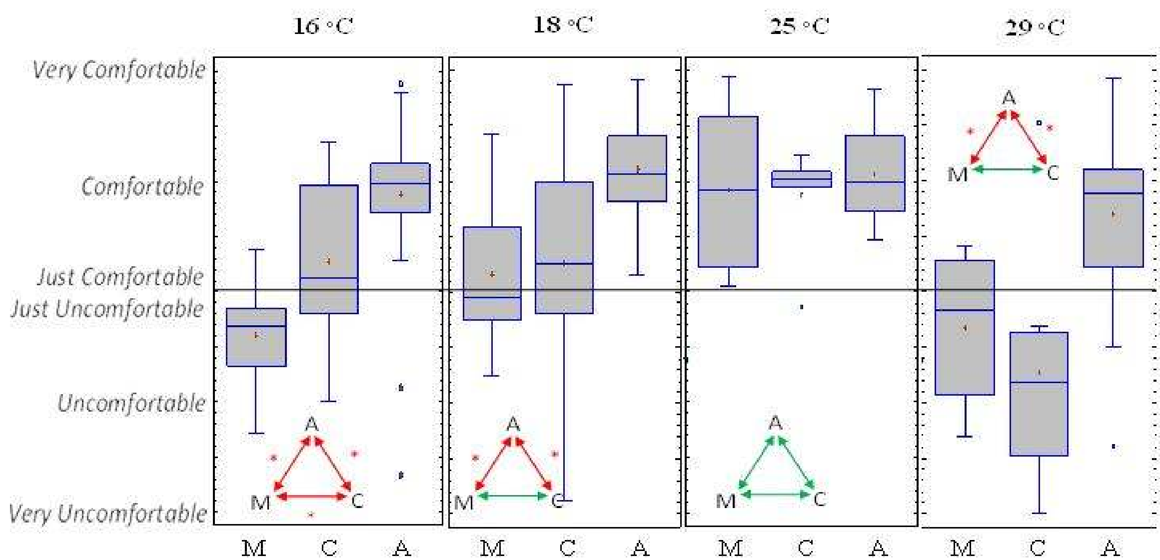

Figure 13 Gluteal region thermal comfort

Under neutral condition (25 °C) using the active chair affects neither thermal sensation nor thermal comfort.

The graphs indicate a difference in thermal comfort and perceived thermal sensation between mesh and cushion chairs for the test at 16 °C. This phenomenon was not recorded for the whole body. For the configuration at 29 °C, the statistical analysis between mesh and cushion chair never produced a p value lower than 0.05, but always very close to it. For the two body parts considered in this analysis it seems that the cushion chair performs better under colder conditions than the mesh chair; again this result is not reflected by the statistical analysis of the whole body.

Transients. In Figures 14 and 15, temperature satisfaction, grouped by survey number as shown in Figure 2, is reported for 16°C and 29°C ambient conditions respectively. Surveys four and five (highlighted in green), are the surveys performed during the break. The reduction in temperature satisfaction during the break, when subjects had to stand up and take twelve steps, is clearly visible from the figures.

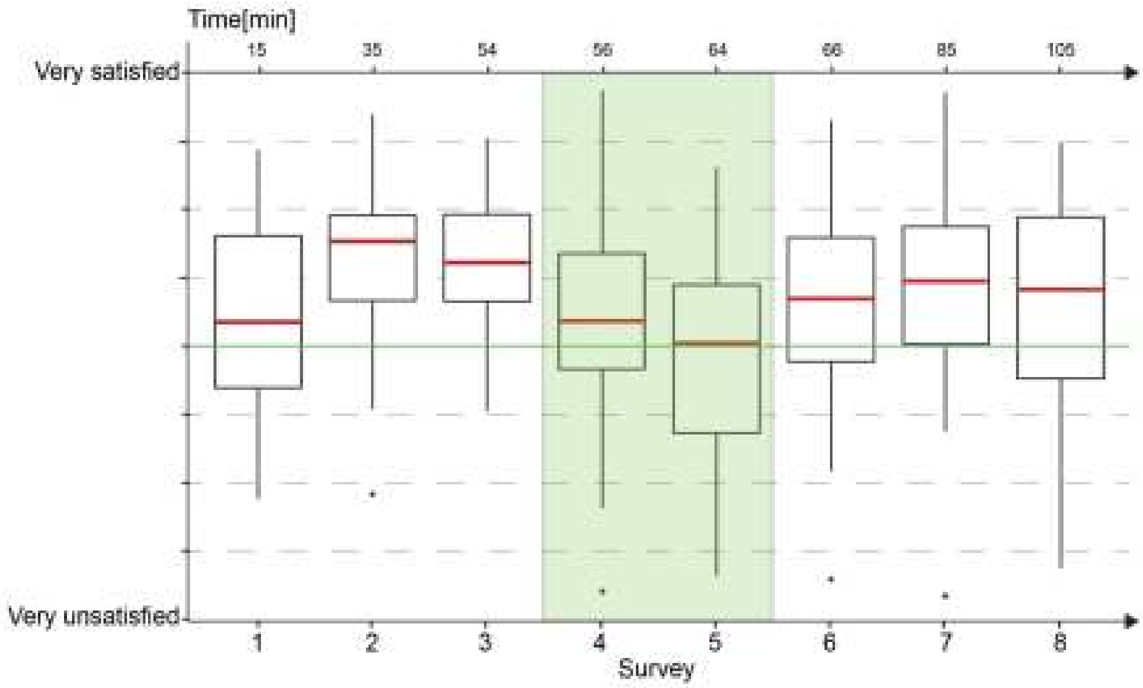

Figure 14 Temperature satisfaction, 16 °C

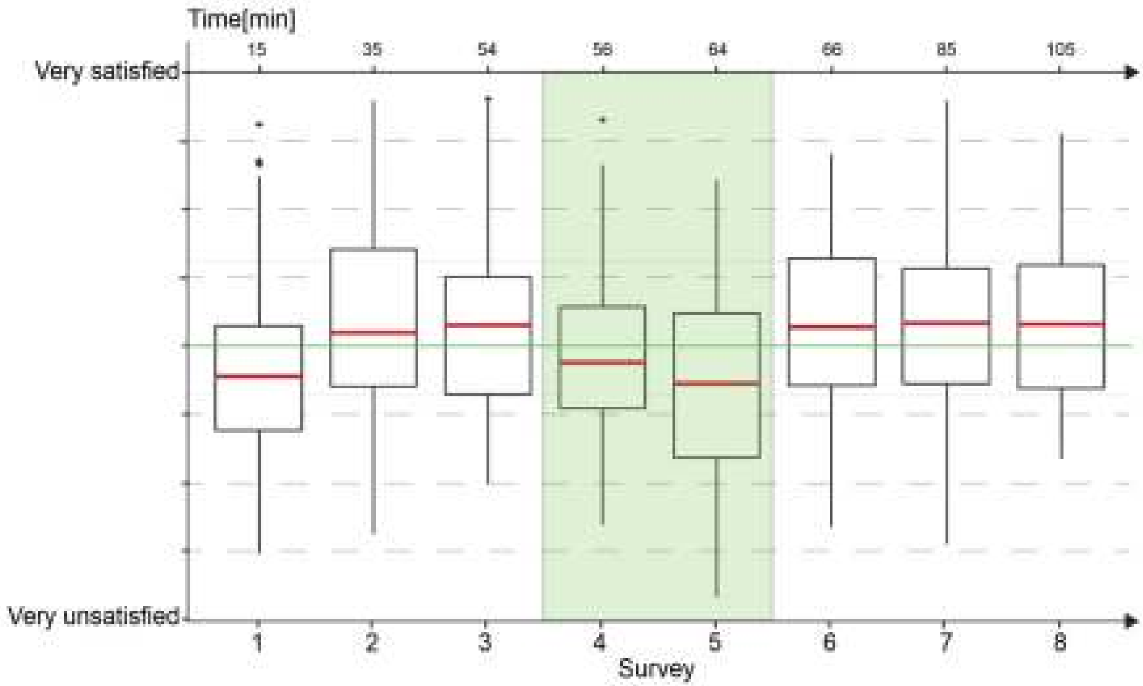

Figure 15 Temperature satisfaction, 29 °C

The active chair has an instantaneous effect on temperature satisfaction, as it can be noticed comparing survey 5 taken standing at the end of the break, and survey 6 taken one minute after the break, with the subjects in the chair again.

Energy consumption. As described above, subjects had freedom to adjust the power levels of the active chair, and the energy consumption was monitored every minute. The average energy consumption under stable conditions (last 10 minutes of every test) is reported in Table 1. The energy use in warm environments (29°C) is about double the amount used in cool environments (16 and 18°C).

Table 1. Average energy consumption under different room temperatures

Temperatures, °C (°F)	16 (60.8)	18 (64.4)	25 (77)	29 (84.2)
Average Energy Consumption [W]	27	23.5	16.5	45.5

Gender. No gender differences are shown based on the statistical analysis of the results. Energy consumptions for male and female at 29°C and 16°C conditions are reported in Figure 16. There is no statistical difference for the energy consumption (meaning the active chair surface temperature) between male and female. The distributions for 29 °C conditions are wider than for 16 °C for both genders, indicating large variations in the selected surface temperatures.

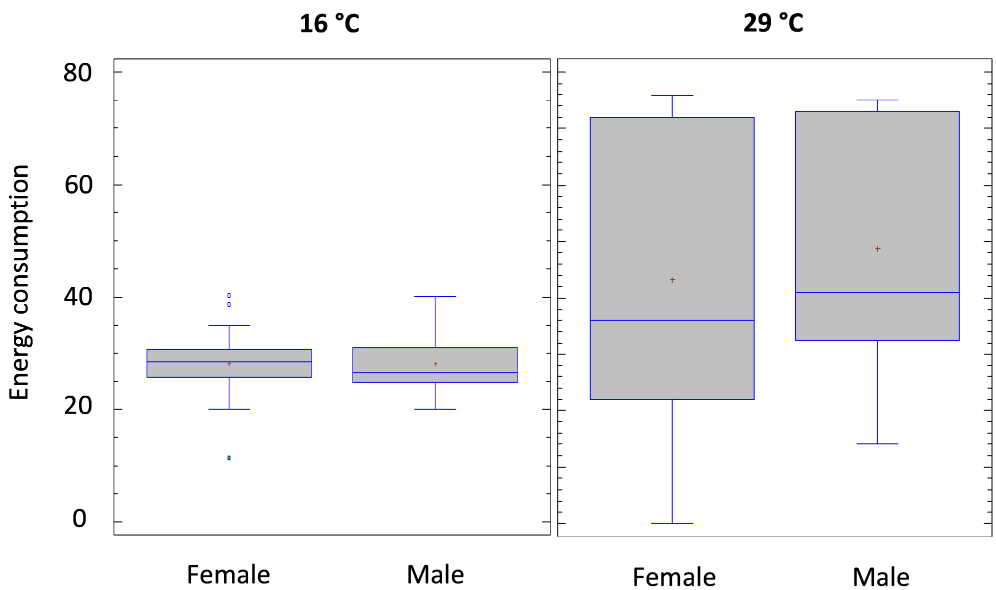

Figure 16 Chair energy consumption for male and female at 16°C and 29 °C

Discussion

1. The active chair performs better in a cold environment than in a hot environment. This result is in line with the findings of Zhang (2007).

2. With the active chair the average comfort levels were on the comfortable side of the scale (Figure 7), satisfying 80% of the subjects at 16 °C ambient temperature, but only 63% were satisfied at 29°C. Still, this is a big improvement compared to the mesh and cushion chairs, which satisfied only 25% of subjects.

   Zhang (2003) defined the "most influential group" of local body parts affecting thermal comfort as the back, chest, and pelvis. She showed that sensation from these body parts has a dominant impact on overall sensation. The active chair affects thermal sensation for two of the three body parts in this most-influential group. This explains the strong influence that the active chair has on increasing or reducing whole-body thermal sensation towards neutral.

3. It is interesting to notice that the use of the active chair shows a wider standard deviation for 29 C° (Figure 4, 5, 7). That might indicate that people have different feelings regarding the cooled seat. On exit surveys that we performed at the end of the tests, some subjects expressed their dissatisfaction

with the chair in cooling mode. The chair has the potential to cool down their bodies, but they did not like the feeling of a cold chair in a warm environment. Based on this result a more gentle system to cool down the back and bottom of the body might be advised. Another good indication for this phenomenon is the energy consumption distributions in Figure 16. The distributions for 29 °C condition are wider then for 16 °C. The feeling of a cold surface in touch with the body is so different among the subjects that some used the chair at full power and others did not use it at all. On the other hand everybody seemed to like the sensation of a warm surface in a cold environment.

4. The non-uniform environment created by the active chair modifies the correlation between "thermal sensation" and "preferred" thermal sensation. The effect of active chair on thermal sensation is significant, and its magnitude is visible in Figure 5. However, despite the influence on thermal sensation, there is no difference for the preferred thermal sensation among the three chairs. A possible explanation could be that in a non-uniform environment the "preferred" thermal sensation is not led by the whole body "thermal sensation", but it is more likely led by the thermal sensation of the most uncomfortable body part (i.e. feet in a cold environment or face in warm environment). We cannot clearly prove what affects the preferred thermal sensation in a non-uniform environment, but we can say that it is not related with the whole body thermal sensation, at least for the two extreme conditions, 16 °C and 29 °C.
5. Using the active chair does not give any benefits under neutral conditions (25 °C). This is true for the whole body as well as for single body parts.
6. The maximum chair energy consumption for cold condition (27W) is relatively low if compared with that of typical personal heaters, which are about 1000-1500W. This has a good potential for energy savings in buildings where this device (or other PCS devices) could be used. The potential energy saving related with a lower winter temperature set point (Hoyt et al. 2009) greatly overcomes the energy consumption of the chair.
7. Although the differences of thermal sensation and comfort between cushion chair and mesh chair for the back and gluteal region are statistically significant (Figure 8, 10 and 11, 13), there are no differences for the whole body thermal sensation and comfort (Figure 5 and 7). Under cold conditions

using a cushion chair instead of a mesh chair does not overcome cool or warm thermal sensations of other body parts like chest, feet and hands.

8. There is no any statistically significant difference in the way males and females use the active chair (Figure 16). Also, for all the questions covered by the survey we did not encounter any difference between males and females.

Conclusions

1. The active chair maintains subjects' thermal sensation around neutral under the tested conditions between 16 and 29°C.
2. The active chair maintains comfort at tested conditions. The improvements in comfort with the active chair are statistically significant at 16, 18, and 29°C, compared to the mesh and the cushion chairs.
3. The comfort levels in heating mode at 16 and 18°C room air temperatures are higher than with in cooling mode at 29°C room air temperature. The heated chair in cool environments appears more effective than the cooled chair in a hot environment.
4. The non-uniform thermal environment created by the chair does not support the previously observed correlation between whole body thermal sensation and preferred thermal sensation.
5. Under neutral temperature conditions (25 °C) there is no improvement resulting from the use of the active chair.
6. There is no statistical difference between the cushion and mesh chairs for any tested room temperature.
7. The average energy use of the active chair is 27W in heating mode and 45W in cooling mode.
8. The active chair can re-establish satisfaction within one minute after a break away from the chair, in which the subject stands and performs a light metabolic activity task.
9. There is no difference in the way females and males use this PCS device.

Acknowledgment

The authors are grateful to Trempronics, Inc. for financial and technical support, and to the Center for the Built Environment, UC Berkeley..

References

Akimoto, T., S. Lee, N. Iesaki, T. Yokota, J. Hayashi and S. Tanabe. 2003. Impact of non-isothermal task conditioning system on thermal comfort. *Proceedings of Healthy Buildings '03, Singapore,* 776-782.

Arens E., H. Zhang, W. Pasut, A. Warneke, F. Bauman and H. Higuchi. 2011. Thermal comfort and perceived air quality of a PEC system. *Proceedings of Indoor Air '11, Austin, Texas.*

Brooks J. and K. Parsons. 1999. An ergonomics investigation into human thermal comfort using an automobile seat heated with encapsulated carbonized fabric (ECF). *Ergonomics,* 42, 661-673.

Fanger P.O. 1970. Thermal Comfort. *Copenhagen: Danish Technical Press.*

Griffiths I.D. 1990. Thermal comfort in buildings with passive solar features: field studies. *Report to the commission of the European communities ENS3S-090-UK. Department of Psychology, University of Surrey, GU2 5XH, UK, 1990,* pp 123.

Hoyt T., H.L. Kwang, H. Zhang, E. Arens and T. Webster. 2009. Energy savings from extended air temperature setpoints and reductions in room air mixing. *Proceedings of International Conference on Environmental Ergonomics, August 2-7, Boston.*

Huizenga C., S. Abbaszadeh, L. Zagreus and E. Arens. 2006. Air Quality and Thermal Comfort in Office Buildings. Results of a Large Indoor Environmental Quality Survey. *Proceedings of Healthy Buildings '06, Lisbon, Portugal,* 3: 393-397.

Humphreys M.A. 2004. Do people like to feel 'neutral'? Response to the ASHRAE scale of subjective warmth in relation to thermal preference, indoor and outdoor temperature. *ASHRAE Transactions*, 110 (2): 569–577.

Humphreys M.A. and M. Hancock. 2007. Do people like to feel 'neutral'? Exploring the variation of the desired thermal sensation on the ASHRAE scale. *Energy and Buildings*, 39: 867-874.

Kogawa Y., T. Nobe and A. Onga. 2007. Practical Investigation of Cool Chair in Warm Offices. *Proceedings of Clima '07, Helsinki, Finland*.

Melikov A., G. Langkilde and L.W. Rasmussen. 1998. Human response to local heating for use in connection with low enthalpy ventilation. *Proceedings of RoomVent '98, Stockholm, Sweden*, 315-321.

Pesarin F., and L. Salmaso 2010. *Permutation Tests for Complex Data: Theory, Application and Software.* Wiley.

Tsuzuki K., E. Arens, F. Bauman and D. Wyon. 1999. Individual thermal comfort control with desk-mounted and floor-mounted task/ambient conditioning (TAC) systems. *Proceeding of Indoor Air '99, Edinburg, Scotland,* 2: 368-373.

Watanabe S., T. Shimomura and H. Miyazaki. 2009. Thermal evaluation of a chair with fans as an individually controlled system. *Building and Environment,* 44: 1392-1398.

Zhang H., E. Arens, D. Kim, E. Buchberger, F. Bauman and C. Huizenga. 2010. Comfort, perceived air quality, and work performance in a low-power task-ambient conditioning system. *Building and Environment,* 45: 29-39.

Zhang Y. and R. Zhao. 2008. Overall thermal sensation, acceptability and comfort. *Building and Environment*, 43: 44-50.

Zhang H., E. Arens and W. Pasut. 2011. Air temperature thresholds for indoor comfort and perceived air quality. *Building Research and Information*, 39: 134-144.

Zhang Y.F., D. Wyon, L. Fang and A. Melikov. 2007. The influence of heated or cooled seats on the acceptable ambient temperature range. *Ergonomics*, 50: 586-600.

Zhang H. 2003. Human Thermal Sensation and Comfort in Transient and Non-Uniform Thermal Environments. Fall 2003, Ph.D. dissertation, University of California Berkeley.