Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2635 – 2640

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Computational and field test analysis of thermal comfort performance of user-controlled thermal chair in an open plan office

Sally Shahzad[a]*, Ben Hughes[b], John Kaiser Calautit[b], Diana SNM Nasir[b],

[a]School of Engineering and Technology, University of Derby, Derby, DE22 3AW, UK
[b]Department of Mechanical Engineering, University of Sheffield, S10 2TN, UK

Abstract

In this study, a thermal chair prototype was developed that allowed personal control over the temperature settings of the back-rest and the seat. Limited research focuses on different methods to provide individual user control over the thermal environment. This is particularly difficult to achieve in an open plan office setting, where changing the temperature in one area directly influences the comfort and satisfaction of other occupants seated nearby. In this study, the application of the thermal chair was analysed using Computational Fluid Dynamics (CFD) and field-test analysis in an open plan office in Leeds, UK during winter. The results of the CFD model indicated an improvement in the local thermal comfort of the user. The CFD analysis provided detailed analysis of the thermal distribution around a siting manikin and was used to design and construct the thermal chair. The results of the field data survey indicated a great improvement in users' comfort (20%) and satisfaction (35%). This study concludes that local thermal control of the occupant improves their overall thermal comfort. It recommends further work to optimise the design of the thermal chair and to improve the modelling for better predictions.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Thermal Chair; comfort; open plan office; thermal control; Computational Fluid Dynamics (CFD)

1. Introduction

The research in the field of thermal comfort is mainly focused on what temperatures satisfy all in order to produce standards and guidelines [1]. Individual differences in perceiving the thermal environment are ignored [2,3]. Hitchings argues that 'instead of talking about what temperatures feel neutral in particular places when we have already accepted this to be dynamic, the ambition may now be to reveal which

---

* Corresponding author. Tel.: +44-784-648-8492 .
E-mail address: sally.shahzad@gmail.com .

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.761

techniques people are willing to employ to get through particular periods more sustainably' [4]. However, limited research is focused on different methods to provide individual user control over the thermal environment. This is particularly difficult to achieve in an open plan office setting, where changing the temperature in one area directly influences the comfort and satisfaction of other occupants seated nearby [3]. Furthermore, providing users with lower power devices to control their local thermal environment allows them to remain comfortable over a wider range of ambient temperatures. While, allowing the indoor temperature to vary by a few degrees can result in large energy savings because the space is conditioned less intensely and less often [5]. In this study, a thermal chair was designed, constructed and analysed that allows individual thermal control. The application of this thermal chair was analysed using CFD and field analysis.

2. Previous Related Work

There is a contradiction between literature and practice about providing user control over the thermal environment [6,7]. The literature suggests the use of thermal control for occupants to increase their comfort and satisfaction [5,8], because occupants use the actual and potential variations in room temperature [9]. In addition, thermal control is predicted as an important asset to the workplace in the future [10]. On the contrary, currently in practice, occupant control over the thermal environment is being replaced with centrally operated thermal systems [11] to simplify the management of thermal systems and to avoid users interfering with it [12]. University of Berkeley is leading the research on Personal Control Systems (PCS) [5,13-15]. Ventilated office chairs were reported as successful to cool and to improve user comfort in experimental chambers [16]. The successful use of heated and cooled chairs in the car industry were also reported [17]. Pasut et al. (2013) studied the application of a heated/cooled chair (active chair) in an experimental chamber [13]. They found that the use of the active chair improves occupants' comfort and satisfaction. They found that the heating impact of the chair is more effective and satisfying for users than the cooling impact. These studies mainly did not apply CFD analysis and real life situations.

3. Research Methodologies

This study investigated the application of CFD and field studies of thermal comfort to analyse the performance of a thermal chair used in an open plan office. A thermal chair was designed with separate temperature controls for the seat and back, as demonstrated in Fig. 1. The chair was incorporated with two heating elements pads that covers the seat and back rest areas (max 30W each pad).

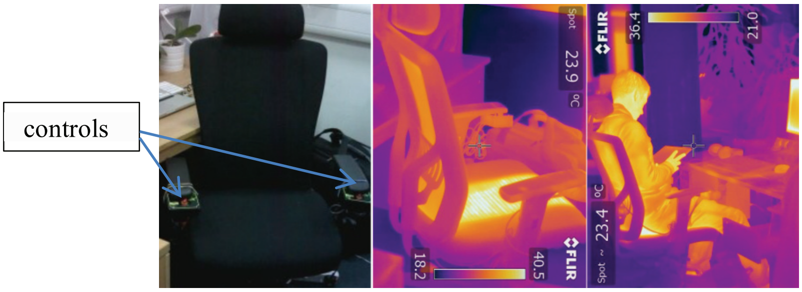


Fig. 1: Thermal chair: (left) design, (middle) thermal image of seat temperature (FLIR T660) and (right) in use

3.1. Computational Fluid Dynamics (CFD) modelling

The basic assumptions for the CFD simulation include a three-dimensional, fully turbulent, and incompressible flow. The CFD code was used with the Finite Volume Method (FVM) approach and the

Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) velocity-pressure coupling algorithm with the second order upwind discretisation. The standard k-e transport model was employed [18]. The geometry (Fig. 2) was created using CAD software and then imported into ANSYS to create a computational model. In this study a sitting manikin was used to analyse the impact of the thermal chair on the prediction of airflow velocity and temperature field. It should be noted that the manikin in the study was non-thermal and only intended to replicate the physical shape of the person. Hence, the effect of the heat released by the manikin on the surrounding airflow field (thermal buoyancy flow) is not simulated, which will have overall impact on the thermal comfort predictions. The study by [19] details the impact of simplified methods on thermal airflow fields in the vicinity of surfaces. Fig. 2 shows the geometry of the thermal chair with the manikin (1.8m standing height) inside the computational domain (4.8m width x 3.8m length x 3m height). One side of the computational domain was set as velocity inlet (set at 0.1 m/s and 23˚C) and the opposite wall as pressure outlet. Two configurations for heating were simulated; (a) office chair with heated seat (heat flux: 40 W/m2) and back rest (heat flux: 40 W/m2) and (b) 250mm diameter underfloor air jets (set at 0.2 m/s and 25˚C).

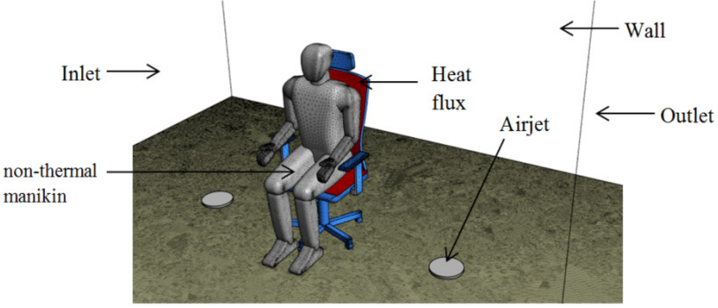


Fig. 2: Computational domain for the analysis of office thermal chair with non-thermal manikin model.

Due to the complexity of the model, a non-uniform mesh was applied to volume and surfaces of the computational domain [20,21]. The generated computational mesh is shown in Fig. 1. The grid was modified and refined according to the critical areas of interests in the simulation. The size of the mesh element was extended smoothly to resolve the areas with high gradient mesh and to improve the accuracy of the results. The computational mesh was based on a sensitivity analysis which was performed by conducting additional simulations with same domain and boundary conditions but with various grid sizes. Fig. 2 summarises the set boundary conditions.

3.2. Field studies of thermal comfort

The thermal chair was tested in November 2014 by 45 individuals (30 males and 15 females mainly between 20 to 50 years old) in the real context of an office, where mainly sedentary activities took place. This was a mechanically ventilated open plan office in the University of Leeds. Respondents' views and thermal environmental conditions were recorded before and after using the chair for a duration of an hour during the working hours. The ASHRAE seven-point scale thermal sensation, comfort and satisfaction were used. Environmental measurements were applied instantly at the workstation level simultaneous with the occupant responding to the questionnaire.

4. Analysis

Fig. 3 compares the predicted thermal distribution around the manikin with heated office chair and normal chair. As observed, the thermal chair (Fig. 3 left) heated the seat and back rest areas between 25-35˚C. While for the case of the space heated with underfloor air jets, the temperature around the manikin range between 23-24˚C. Table 1 summarises the predicted comfort levels in the vicinity of the manikin surfaces. Based on the PMV predictions, improved comfort levels were observed for the back area and upper legs area. The seat area went from -0.42 (neutral) to 0.78 (slightly warm) when the chair was heated, Hence, there should be separate controls for the seat and backrest area and this was implemented in the design of the chair used in the field tests. In addition, a significant improvement is predicted in the thigh/upper legs area.

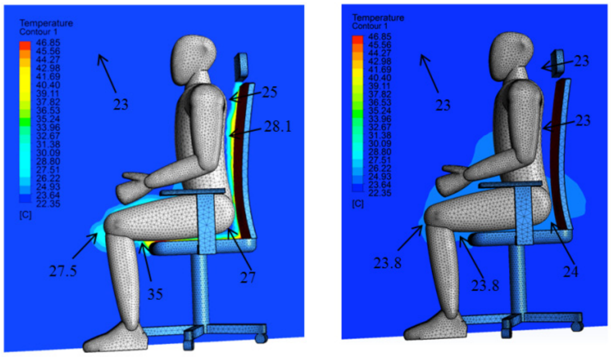


Fig. 3: Cross-sectional contour showing temperature distribution around manikin (left) thermal chair (right) underfloor air jet

Table 1: Predicted Mean Vote and thermal comfort levels in the vicinity of the manikin surfaces

Body parts	With thermal chair in use		Without thermal chair	
	PMV	**PPD (%)**	**PMV**	**PPD (%)**
Head	-0.67 (slightly cool)	14	-0.62 (slightly cool)	13
Back/Back rest area	0.40 (neutral)	8	-0.59 (slightly cool)	12
Seat area	0.78 (slightly warm)	18	-0.42 (neutral)	9
Thigh/Upper Legs	0.20 (neutral)	6	-0.51 (slightly cool)	10

Thermal comfort levels calculated using PMV method with set values for humidity (30%), metabolic rate (1 met), clothing (0.7)

Field studies of thermal comfort were applied before and after using the thermal chair and Users' views were compared. They had much higher comfort level after using the chair, as presented in Fig. 4, the number of comfortable and very comfortable occupants changed from 57% to 77%. The thermal sensation bar chart shows that slightly warm or neutral before the experiment, while after using the chair majority of them felt slightly warm or warm. The number of occupants feeling a neutral thermal sensation dropped from 32% to only 9%, while their comfort level and satisfaction increased. Their satisfaction increased from 45% to 80%, as illustrated in Fig. 5. Majority of the occupants set the temperature of both the seat and the back between 29 to 35°C, which was close to the range predicted by the CFD analysis. 43% reported to desire no change in the temperature and 39% preferred slightly warmer temperature. This suggested that occupants preferred to feel slightly warm to warm. 82% of the occupants expressed their satisfaction level as "satisfied" or "very satisfied" regarding the performance of the thermal chair, as demonstrated in Fig. 5.

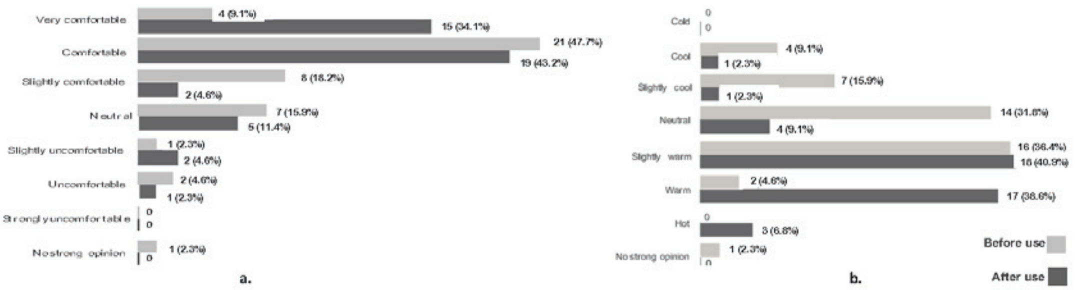


Fig. 4. a. Users' views of their comfort and b. thermal sensation before and after using the thermal chair

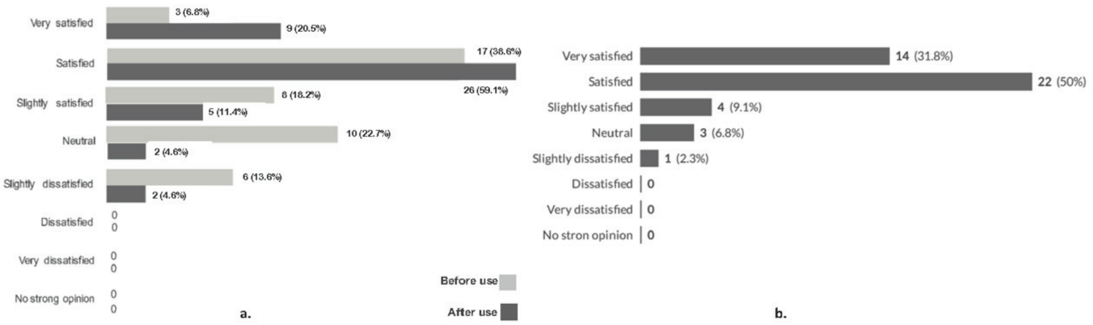


Fig. 5: a. Users' overall satisfaction with the thermal environment and b. their satisfaction using the thermal chair

5. Discussion, Conclusion and Future Works

The CFD analysis showed an increase in the local thermal comfort (slightly cool to neutral for the back and neutral to slightly warm for the seat). The results showed the importance of using detailed CFD analysis to evaluate the performance of the thermal chair. The CFD analysis showed that separate control is necessary to further optimise the comfort levels. The overall thermal comfort of the person was predicted quite close before (i.e -0.56 slightly cool) and after using the chair (i.e. -0.08 neutral). The results of the field study suggested much higher comfort and satisfaction after using the thermal chair, as the overall user comfort was improved by 20% and satisfaction by 35%. It also indicated that users reported to feel slightly warm to warm at their back and the seat, which was in line with the temperature settings they used on the chair. This suggested that occupants preferred to feel slightly warm or warm and not necessarily neutral in order to feel comfortable. This study recommends the requirement to improve the CFD modelling and analysis according to accurate modelling of human models and to consider other thermal sensations for comfort (e.g. slightly warm or warm). Furthermore, it is proposed that a change in local temperature of body parts (e.g. seat or back) improves overall thermal comfort of the occupant. Finally, the design of the chair will be improved to include heating and possibly cooling for other body parts as well as sensors for energy efficiency.

Acknowledgements

The authors gratefully acknowledge the contribution of the occupants of the case study building.

References

[1] ANSI/ASHRAE Standard 55-2013. Thermal Environmental Conditions for Human Occupancy.

[2] Van Meel, J. 2000. The European Office. Rotterdam.

[3] Shahzad, S. 2014. Individual Thermal Control in the Workplace. University of Edinburgh.

[4] Hitchings, R. 2009. Studying Thermal Comfort in Context. BRI-37.

[5] Arens, E., Humphreys, M. A., De Dear, R. & Zhang, H. 2010. Are 'Class A' Temperatue Requirements Realistic or Desirable? Building and Environment, 45, 4-10.

[6] Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B., Calautit, J. K. 2016. Energy and comfort in contemporary open plan and traditional personal offices. Applied Energy.

[7] Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B., Calautit, J. K. 2016. Related Symptoms, Energy, and Thermal Control in the Workplace: Personal and Open Plan Offices. Sustainability Journal: 8: 331.

[8] Wagner, A., Gossauer, E., Moosmann, C. 2007. Thermal Comfort and Workplace Occupant Satisfaction. Energy and Building-39.

[9] Baker, N. & Standeven, M. 1995. A Behavioural Approach to Thermal Comfort Assessment. International Journal of Solar Energy, 19, 21-35.

[10] Leaman, A. 1996. User Satisfaction. Building Evaluation Techniques. McGraw.

[11] Bordass, B., Bromley, K. , Leaman, A. 1993. User and Occupant Controls in Office Buildings. BUS.

[12] Roaf, S., Horsley, A. , Gupa, R. 2004. Closing the Loop. RIBA.

[13] Pasut, W., Zhang, H., Kaam, S., Arens, E. 2013. Effect of a Heated and Cooled Office Chair on Thermal Comfort. UC Berkeley.

[14] Pigman, M. 2014. The Impact of Cooling Strategy and Personal Control on Thermal Comfort. UC Berkeley.

[15] Pasut, W., Zhang, H., Arens, E., Zhai, Y. 2015. Energy Efficient Comfort with a Heated/Cooled Chair: Results from Human Subject Test. Building and Environment: 84: 10-21.

[16] Watanabe, S., Shimomura. T., Miyazaki, H. 2009. Thermal Evaluation of a Chair with Fans as an Individually Controlled System. Building and Environment-44.

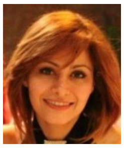
[17] Parkhurst, G., Parnaby, R. 2008. Growth in Mobile Air-Conditioning. BRI-36.

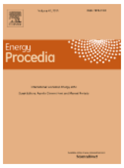
[18] Launder, B.E. and Spalding, D.B. (1974) The numerical computation of turbulent flows, Computer Methods in Applied Mechanics and Engineering, 3, 269–289.

[19] Yan, Y., Li, X., Yang, L., Tu, J. 2016. Evaluation of manikin simplification methods for CFD simulations in occupied indoor environments. Energy and Buildings, 127, 611-626

[20] Calautit, J.K., O'Connor, D., Sofotasiou, P., Hughes, B.R. 2015. CFD Simulation and Optimisation of a Low Energy Ventilation and Cooling System. Computation, 3, 128-149.

[21] Calautit, J.K., Hughes, B.R., Shahzad, S. 2015. CFD and wind tunnel study of the performance of a uni-directional wind catcher with heat transfer devices. Renewable Energy, 83, 85-99.





Biography

Sally is a lecturer in the University of Derby, her research interest is thermal-comfort. She was a Postdoctoral Research Fellow in the University of Leeds and completed her PhD in Architecture in the University of Edinburgh, where she was a co-editor of the EAR Journal and received the Edinburgh-Award twice.