Technical University of Denmark

Effects of Exposure to Carbon Dioxide and Human Bioeffluents on Cognitive Performance

Zhang, Xiaojing; Wargocki, Pawel; Lian, Zhiwei

Published in:
The 9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) joint with the 3rd International Conference on Building Energy and Environment (COBEE), 12-15 July 2015, Tianjin, China

Link to article, DOI:
10.1016/j.proeng.2015.08.1040

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Zhang, X., Wargocki, P., & Lian, Z. (2015). Effects of Exposure to Carbon Dioxide and Human Bioeffluents on Cognitive Performance. In The 9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) joint with the 3rd International Conference on Building Energy and Environment (COBEE), 12-15 July 2015, Tianjin, China (Vol. 121, pp. 138-142). Elsevier Science. (Procedia Engineering). DOI: 10.1016/j.proeng.2015.08.1040

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 121 (2015) 138 – 142

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Effects of Exposure to Carbon Dioxide and Human Bioeffluents on Cognitive Performance

Xiaojing Zhang[a], Pawel Wargocki[b], Zhiwei Lian[a, *]

[a]*School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, China*
[b]*International Centre for Indoor Environment and Energy, Technical University of Denmark, Copenhagen, Denmark*

Abstract

The purpose of this study was to examine whether exposures to CO_2 in the range of 500 ppm to 3,000 ppm with and without bioeffluents influence cognitive performance. Twenty-five subjects were exposed in the climate chamber for 255 minutes. Cognitive performance was examined by multiple tasks including proof-reading, addition, subtraction, text typing, neurobehavioral tests, Tsai-Partington task, and d2 attention task. Subjective ratings of comfort and experienced acute health symptoms were collected, physiological responses of subjects were monitored and the saliva samples were collected to analyze stress biomarkers. The results show that during exposure to bioeffluents with CO_2 reaching 3,000 ppm speed of addition was significantly reduced, subjects responded significantly quicker in redirection task and completed significantly less correct links in Tsai-partington test, which may imply that arousal (stress level) was an underlying mechanism.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: Carbon dioxide; Human bioeffluents; Cognitive performance

1. Introduction

Recent studies suggest that exposure to pure carbon dioxide (CO_2) (without bioeffluents) at concentrations of 2,500 ppm to 4,000 ppm can have respectively negative effects on decision making performance[1] and the performance of proof-reading[2]. If confirmed by other experimenters, these results suggest that the strategy for designing ventilation rates in densely populated spaces, where these CO_2 levels are likely, may have to be revised.

* Corresponding author. Tel.: +86-021-34204263; fax: +86-021-34204263.
E-mail address: zwlian@sjtu.edu.cn

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.08.1040

The purpose of this study was to examine the potential effects of low to moderate CO_2 levels on human performance and extend the scope of previous work by examining the effects during exposures to CO_2 with human bioeffluents. The results of subjective responses have been reported earlier by Zhang et al. [3]. The present paper focuses on the effects on cognitive performance.

2. Methods

The experiment was carried out in a 3.6 × 2.5 × 2.5 m stainless steel chamber (30 m^3 volume with recirculation ducts) (Fig. 1), which was described in detail by Albrechtsen [4]. The construction minimizes the emissions and sorption of pollutants and ensures that the chamber volume is tightly sealed. The chamber has its own system for supplying and conditioning outdoor air, in which the ducting is also made of stainless steel. Immediately prior to the present experiments, the chamber and the plenum were thoroughly cleaned with 'neutral' cleaning agents and 'baked' for one week at 40°C to reduce any potential residual pollution adsorbed on the surfaces in contact with chamber air. There were six workstations in the chamber for the subjects and the experimenter, each consisting of a table, a chair, a laptop PC and a desk lamp.

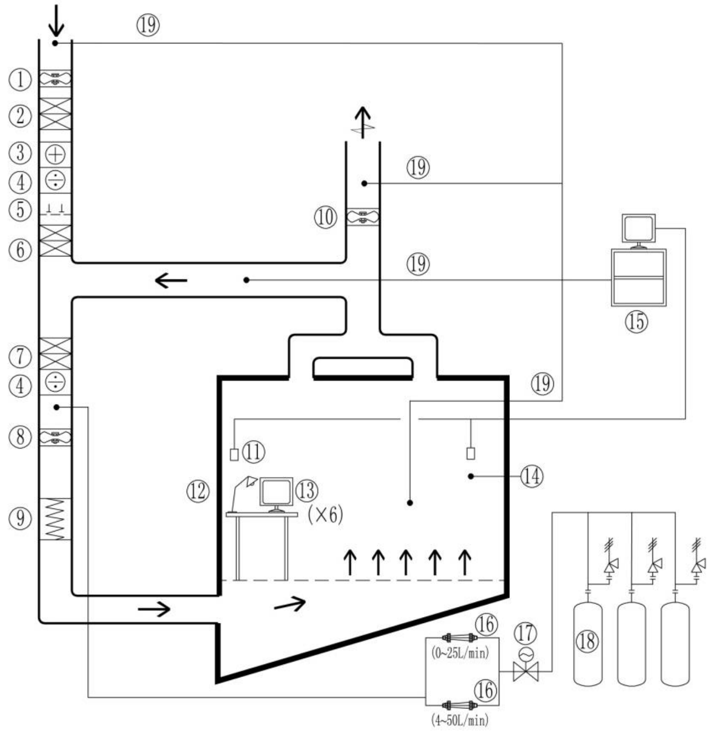

Fig. 1. Schematic figure of the chamber, where the experiments were carried out: ① supply fan, ② two stage filter G3/F7, ③ heating coil, ④ cooling coil, ⑤ dampers, ⑥ filter box for charcoal filters (empty), ⑦ filter box (empty), ⑧ recirculating fan, ⑨ electric heating coil, ⑩ exhaust fan, ⑪ HOBO logger (temperature & relative humidity sensor) with CO2 sensor, ⑫ desk lamp, ⑬ laptop, ⑭ temperature and humidity sensor of the chamber control system, ⑮ multi-gas analyzer, ⑯ flowmeters, ⑰ pressure regulator, ⑱ CO2 gas cylinders (30L), ⑲ sampling point

In three of the five exposures examined in the present experiments the outdoor air supply rate was high enough to remove bioeffluents, creating a reference condition with CO_2 at 500 ppm (referred to as B500), while chemically pure CO_2 was added to the supply air to create exposure conditions of 1,000 ppm or 3,000 ppm (referred to as P1000 and P3000). In two other conditions, the outdoor air supply rate was restricted (reduced) to allow the bioeffluent CO_2 level to reach 1,000 ppm or 3,000 ppm (referred to as M1000 and M3000), thereby ensuring that other bioeffluents reached concentrations corresponding to those in the occupied rooms with CO_2 at these levels. Table 1 shows that the resulting levels of CO_2 in the chamber originated from 3 different sources: from the cylinders, from the outdoor air itself, and from the occupants, in descending order of magnitude. Temperature and noise level were kept constant during the exposures, however, due to the lack of a dehumidifier, the relative humidity (RH) increased by a few % at M3000.

Table 1. Planned conditions for different exposures

Condition	Outdoor air supply rate to the chamber (m^3/h) / (l/s per person)	CO_2 transported with outdoor air (l/min)	Pure CO_2 dosed from cylinders (l/min)	Metabolic CO_2 generated by people in the chamber (l/min)	CO_2 level in the chamber (outdoor level at 350 ppm)	Temperature RH Noise level
B500	720 / 33.3	4.2	-	1.9	500	
P1000	720 / 33.3	4.2	6	1.9	1000	24°C
P3000	720 / 33.3	4.2	30	1.9	3000	30%
M1000	155 / 7.2	0.9	-	1.9	1000	45 dB(A)
M3000	38 / 1.8	0.2	-	1.9	3000	

Twenty-five subjects were exposed in climate chamber for 255 minutes in groups of five persons at a time in a Latin-square design. Cognitive performance was examined by the test battery (TB) including multiple tasks resembling office work (proof-reading test, addition, subtraction and text typing) as well as by neurobehavioral tests (redirection, grammatical reasoning, Stroop and Stroop with feedback), Tsai-Partington test and d2 attention test. In parallel the subjective ratings of comfort and acute health symptoms were collected, physiological responses (PM) were monitored and saliva samples were collected to analyze levels of stress biomarkers: α-amylase and cortisol. Fig. 2 shows in details the experimental procedure during each exposure.

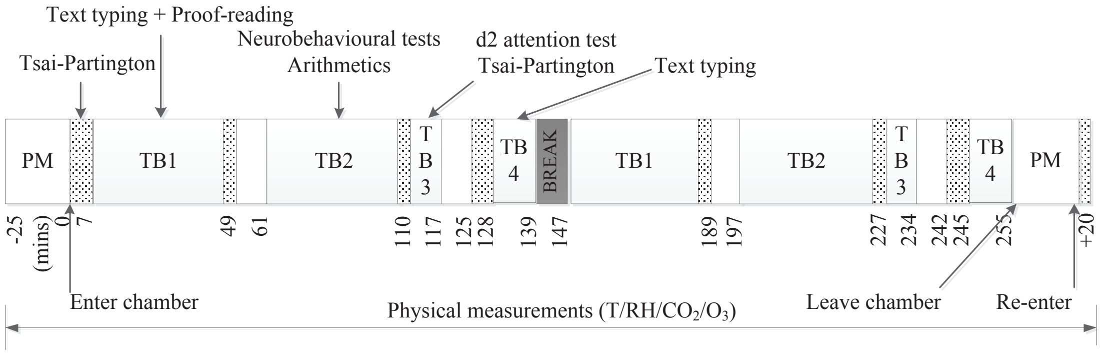

Fig. 2. Experimental procedure

The effects of exposures on different outcomes were analysed using a mixed ANOVA model; the significance level was set to 0.1 for random effects and to 0.05 for fixed effects. Experimental conditions (*c*), time at which different assessments were made during the day (*t*), condition×time interaction (*ct*), order of exposure of conditions (*o*) and gender (*g*) were included as fixed factors. Subjects (*S*), groups (*Gr*), subject×condition interaction (*SC*) and subject×time interaction (*ST*) were included as random factors in the model. Since the levels of time do not reflect the actual time, but rather the order of the repeated measurements during a day, time is included as a fixed factor not as a covariate. With the design of experiments, a specific exposure condition was always following a specific other exposure condition except if the condition was given on Monday. This caused that subject×condition (*SC*) interaction was confounded with the subject×order of exposure (*SO*) interaction in the statistical model. These interactions will consequently be referred to as simply *SC*. In addition to mixed ANOVA model, Page trend test was used for these outcomes that changed monotonically with CO_2 levels with significance level set to 0.05.

3. Results and discussion

Among the many tests examining the cognitive performance of subjects there were only few for which the performance differed significantly between conditions. These were addition (P=0.023), redirection (P=0.015) and Tsai-Partington test (P<0.001).

Speed at which subjects added units was lower for different conditions compared with B500, the difference reaching statistical significance at M3000 (Fig. 3). Analysis of variance showed that % of errors committed was also different between different conditions (P=0.049) but it was not possible to determine, at which conditions the difference was statistically significant through post-hoc tests. Raw data showed highest % of errors at B500 and M3000.

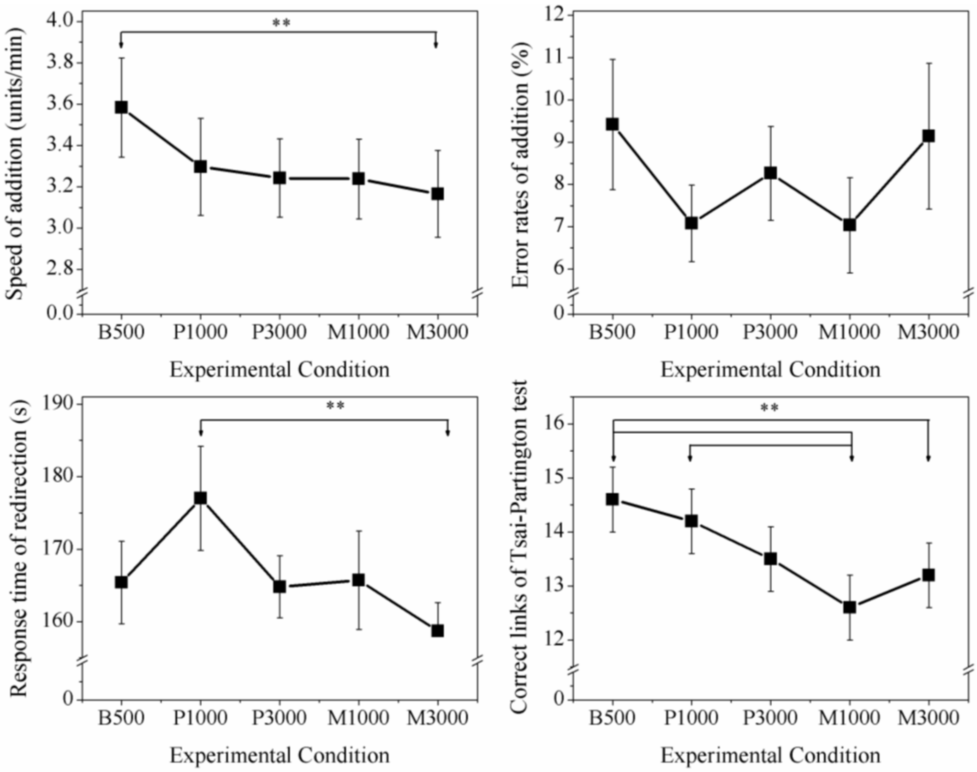

Fig. 3. Significant effects of exposure to CO2 and human bioeffluents on cognitive performance

Subjects responded significantly quicker in redirection test at M3000 compared with B500 (Fig. 3). No effects were observed on % errors.

The results of Tsai-Partington test showed the number of correct links made by the subjects was lower for different conditions compared with B500, the difference reaching statistical significance at M1000 (Fig. 3). The performance of Tsai-Partington test depends on the level of stress and is improved (more links are made) at lower stress and large attention field [5]. Thus this result suggests that the arousal of subjects was higher at elevated CO_2 levels. Poor performance on Tsai-Partington test at elevated CO_2 levels (especially with bioeffluents) may explain also why speed in addition was lower but response quicker in redirection. This is because the performance of different tasks depends on arousal level and the nature of the task [6]: High arousal being likely to decrease the high mental performance like addition and to increase the performance of tasks requiring attention and quick response like redirection.

Analysis of variance showed also that the difference in performance of two tasks between conditions approached statistical significance. These were performance of proof-reading (P=0.062) and text-typing (P=0.053). Speed, at which proof-reading was performed, was varying across different conditions and was the lowest at M3000 while the highest at P3000; there were no effects on errors or false positives. Page test showed that speed increased systematically between B500, P1000 and P3000 ($P<0.05$). The systematic effect was also seen in reduction of speed between B500, M1000 and M3000 but this trend did not reach formal statistical significance. In text typing there were very small differences between number of characters typed by the subjects at different conditions and it was not possible to determine with the post hoc tests which conditions differed mostly. The error rates of text typing have not yet been analyzed.

4. Conclusions

Present results suggest that only exposures to bioeffluents when CO_2 reached 3,000 ppm significantly affected performance of some cognitive tasks. Increased arousal level at this exposure can be used to explain the observed results.

Acknowledgements

This work is supported by Bjarne Saxhof Foundation, and the 12th Five Plan National Science and Technology Support Project of China (No. 2012BAJ02B05).

References

[1] U. Satish, M.J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, W.J. Fisk, Is CO_2 an indoor pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance, Environ. Health Persp. 120 (2012) 1671-1705.
[2] L. Kajtár and L. Herczeg, Influence of carbon-dioxide concentration on human well-being and intensity of mental work, Q. J. Hungari. Meteor. Serv. 116 (2012) 145-169.
[3] X.J. Zhang, P. Wargocki, Z.W. Lian, Effects of exposure to carbon dioxide and human bioeffluents on human subjective responses, in: Healthy Buildings Europe 2015, 2015.
[4] O. Albrechtsen, Twin climatic chambers to study sick and healthy buildings, in: Healthy Buildings '88, 1988, Vol.3, pp. 25-30.
[5] H. J. Eysenck and R. A. Willett, Cue utilization as a function of drive: An experimental study, Perceptual and motor skills. 15 (1962) 229-230.
[6] E. Duffy, The psychological significance of the concept of arousal or activation, Psychol Rev. 64 (1957) 265-275.