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Exploring Indoor Thermal environment and cognitive performance in a short-term occupancy setting

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ABSTRACT

It is general knowledge that the thermal comfort strongly influences people's wellbeing, health, and productivity. Many studies point to a significant relationship between working performance and indoor thermal conditions. This contribution presents the results of a related large scale experiment with a group of architectural students. Participants were separated in two groups, placed in two identical rooms (seated at tables), and shown a brief video lecture. One of the test rooms was heated, the other one was cool. After watching the video, participants were asked to work on a test involving a few multiple choice and open questions. The test cells were monitored with regard to temperature, relative humidity and CO_2 concentration. We discuss the test performance of the two groups of participants in the context of the corresponding indoor climate conditions.

KEYWORDS: cognitive performance, indoor climate, short-term occupancy

1 INTRODUCTION

This contribution deals with the cognitive performance of participants in a short-term occupancy context involving two distinct indoor climate conditions. Participants were seated in two spatially similar but differentially tempered test cells, were shown a video lecture about building physics, and were asked to work on a test. During the experiment, indoor conditions in the test cells were monitored. The experiment was conducted in May 2012 with nearly 200 participants. The objective was to explore potential relationships between prevailing indoor climate conditions and participants' test performance.

2 BACKGROUND

Indoor thermal comfort is seen as important for health, satisfaction, and productivity of occupants. Sensharma et al. (1998) highlight the importance of research with regard to productivity implications of indoor environment. Tanabe et al. (2007) focus on the influence of the temperature on productivity. While no direct interdependency between temperature and work performance could be found, it was suggested that most participants in warmer settings complained about mental fatigue and that a higher cerebral blood flow was required to perform tasks. Seppänen et al. (2005) state that the work performance decreases by 2% per degree room temperature increase above 25°C. They also suggested that lower temperatures tend to have a negative effect on manual work. Their recommendation for the optimal indoor working space temperature is 22°C (corresponding to observed productivity peak). Kostiainen et al. (2011) suggested that temperature influences people's rating of the indoor air quality and their satisfaction with the working space. Recently, the responsible executive of an internationally active company suggested that the office spaces of the company's headquarter would be cooled down to 15°C to increase productivity and keep meetings short (ORF 2013, GUARDIAN 2013). In contrast, Hedge (2004) suggests that the optimal indoor temperature for office spaces is around 25°C (highest concentration on work-related issues, least typing mistakes). In Austria, indoor temperatures in offices need to be between 19 and 25 °C (AStV 1998).

3 METHODOLOGY

Two test cells (mockup offices as shown in Figure 1) with identical dimensions (3 by 4 m, height = 2.5 m), construction, and furniture (two tables, six seats, a flat screen) were used for the experiment. Test cell A was equipped with an electrical radiator for heating, whereas test cell B had an A/C-Unit for cooling. Figure 1 shows a schematic illustration of the two test cells, while Figure 2 depicts the interior of a test cell.

Participants were 181 architecture students of the Vienna University of Technology. They were randomly divided into groups of 12 people (six in test cell A and six in test cell B). However, an effort was made to have roughly the same number of male and female participants in each group. Figure 3 depicts the total number of male and female participants allocated to the two test cells. After watching a video lecture, the participants were requested to work on a brief test. Note that the thermal resistance of the participants' clothing was determined based on observation and was found to be (in clo units) about 0.6 ± 0.15.

Participants watched a 22-minute video lecture (shown simultaneously in both test cells) including basic topics in building physics pertaining to measurements of temperature, relative humidity, CO2-concentrations, solar radiation and wind speed, use of the Pettenkofer's diagram of CO_2-concentration (Pettenkofer 1858) and necessary fresh air provision, including a simple calculation example. Subsequent to the video screening, participants took a test including seven questions (3 multiple choice and four open questions) pertaining to various issues in building diagnostics, indoor air quality, and thermal comfort. Each group spent about 40 minutes in the cells (video lecture, test).

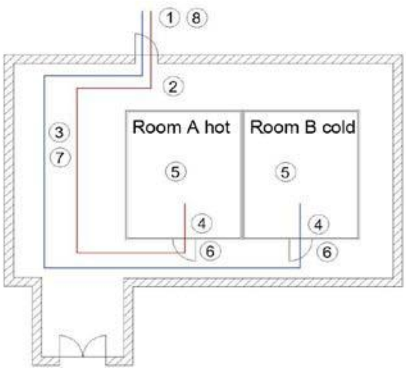

Figure 1: Schematic plan of the test cells A (heated) and B (cooled)


Figure 2: Interior of a test cell

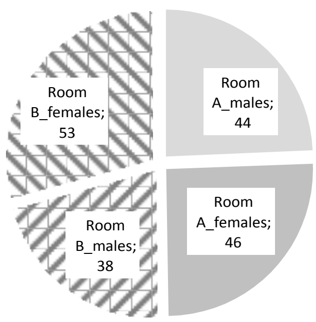

Figure 3: Allocation of participants to test cells A and B

Both test cells were equipped with sensors for temperature, relative humidity and CO_2-concentration. Values were recorded continuously throughout the experiments (1-minute intervals).

As mentioned before, test cell A was heated with an electrical radiator and test cell B was cooled with an A/C-Unit. The aimed set-point temperature for test cell A was 25 °C and for test cell B 17°C. The actually prevailing temperatures in the two cells are summarized in Table 1.

Table 1: Average, maximum, and minimum temperatures during the experiment in test cell A and B

Test Cell	Maximum [°C]	Minimum [°C]	Average [°C]
A	29.9	22.5	26.8
B	21.4	15.1	17.3

4 RESULTS & DISCUSSION

Figures 4 and 5 include box plots of the temperature and CO_2 concentration in test cells A and B during the experiment. This data highlights the significant difference in the air temperature of the two test cells. The CO_2 concentration levels were, however, closer.

Figure 6 shows the general results of the test (percentage of participants who answered questions Q1 to Q7 correctly). Note that participants doing the test in cell A performed slightly better than those in cell B.

Figure 7 includes boxplots of participants' performance on the test (number of correctly answered questions). The same information is included in Figure 11 in terms of cumulative distribution functions depicting percentage of correctly answered test questions. These Figures highlight the clear difference in the overall performance of the participants in cells A and B. Students in test cell A showed, in average, a better performance: The median performance in cell A was 4 out of 7 possible points as opposed to 3 out of 7 in cell B. In cell A nearly 60% of the participants reached 3 or more points, as opposed to 50% in B. These results suggest that the cognitive performance of the participants as assessed via a test during a short-term occupancy situation was slightly better in the test cell with the higher temperature.

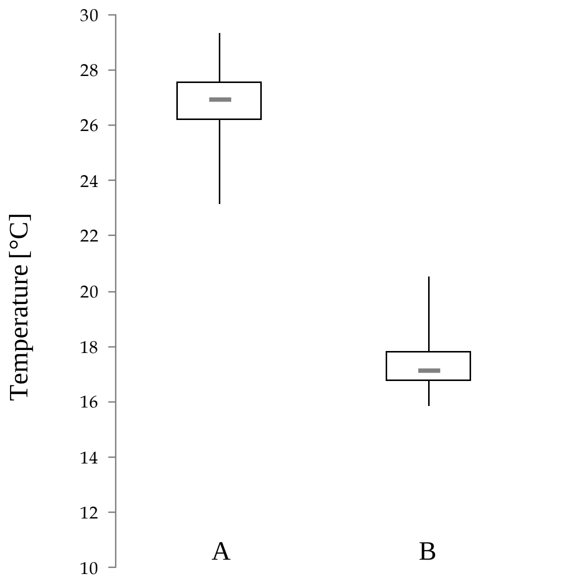

Figure 4: Boxplot of temperature inside cells A and B

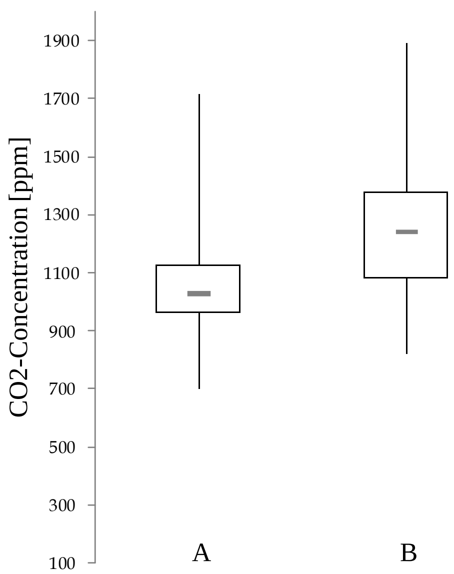

Figure 5: Boxplot of CO_2 concentration inside cells A and B

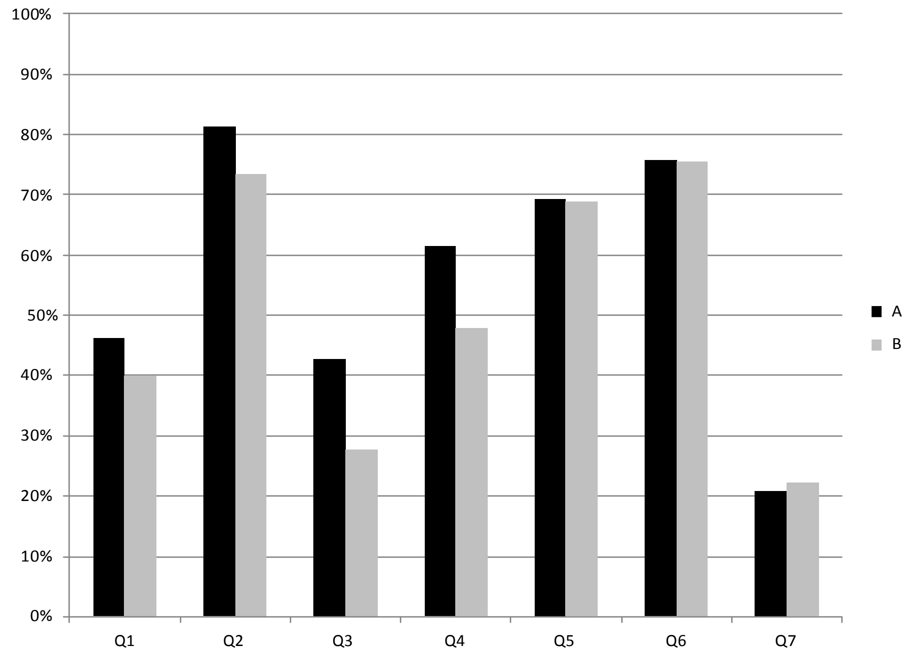

Figure 6: Percentage of participants who correctly answered questions Q1 to Q7 (black bars: cell A; grey bars: cell B).

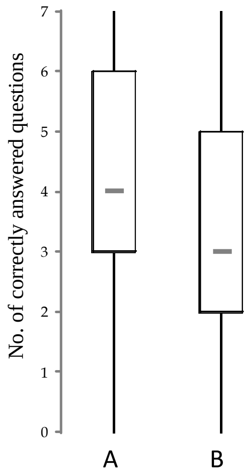

Figure 7: Boxplot of participants' test performance in cells A and B

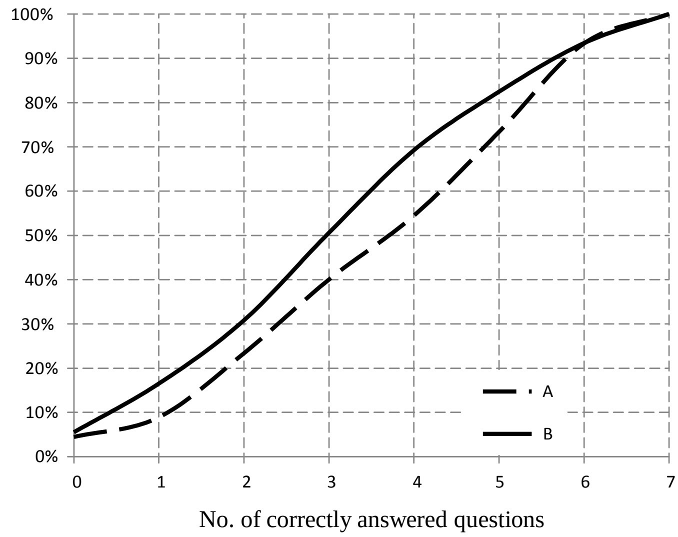

Figure 8: Cumulative distribution functions indicating the percentage of participants (in test cells A and B) who correctly answered less than a certain number of questions

Figures 9 and 10 show the mean test performance of participants as a function of the prevailing temperature and CO_2 concentrations respectively. The intended difference in the temperature regime in the two cells is clearly evident in Figure 9. However, ventilation rates could not be strictly controlled in the two rooms. Hence, both high and low CO_2 concentrations can be observed in both cells. To explore the potential impact of CO_2 concentration on the test performance, we grouped the data in terms of two categories, one with CO_2 concentration above 1300 ppm and the other with concentration below 1300 ppm. For these two data sets, the participants' test performance was recalculated (see Boxplot of Figure 11). This result implies that the observed better performance of participants in cell A cannot be explained based on the slightly lower CO_2 concentrations in this cell (see Figure 5). As Figure 11 demonstrates, the general test performance of participants exposed to CO_2 concentration levels above 1300 ppm was by no means inferior to those exposed to CO_2 concentration levels below 1300 ppm.

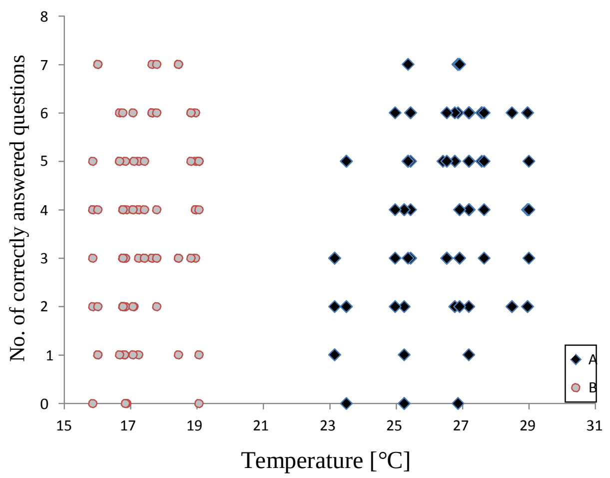

Figure 9: Test performance versus cell temperature.

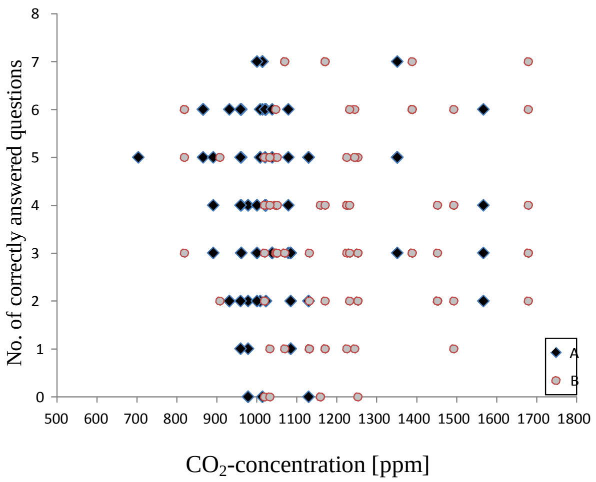

Figure 10: Test performance versus cell CO_2 concentration.

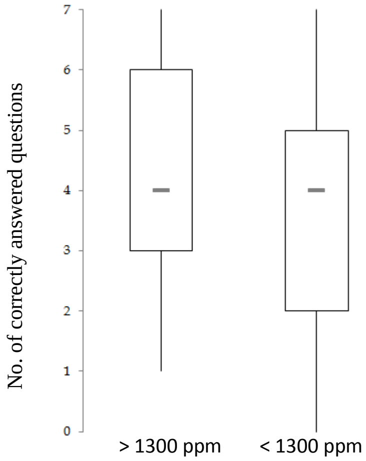

Figure 11: Boxplot of participants' test performance shown separately for two categories of CO_2 concentration

5 CONCLUSION

We examined the cognitive performance of a large group of participants via a test performed during a short-term occupancy in two differentially tempered mock-up office spaces. Thereby, participants in the warm room displayed a slightly better cognitive performance than those in the cold room. Even though the CO_2 concentration in the warmer room was slightly lower than in the colder room, it could not be identified as the main contributing factor to the difference in the cognitive performance: Further data analysis did not reveal a significant performance difference based on the categories high versus low CO_2 concentration. The results of this study are not meant to represent a general definitive judgment with regard to the effects of room temperature on cognitive performance of office workers. The inherent limitations of the study would render such generalization invalid (very short occupancy duration, unfamiliarity of the participants with the surroundings, the very specific nature of the test and its brevity, age range of the participants, disregard of outdoor climatic conditions, uncertainties in participants' activity levels and clothing, non-zero probability of differences in the cognitive preparation levels of participants in the two test cells). Nonetheless, the result do imply that certain prevailing statements in the literature regarding maximal permissible temperatures in office spaces must be taken *cum grano salis*.

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