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# Experimental Study on the Indoor Environment Quality and Students' Performance in a Classroom

Iskra Simova, Detelin Markov, Nushka Kehayova, Radostina A. Angelova, Peter Stankov

***Abstract**: The present paper deals with the analysis of the results from a human subject experiment in a laboratory classroom with controlled microclimate. The goal of the experiment is to reveal if there is a relation between the indoor environment quality and occupants' performance. The results from the students' subjective votes about the acceptability of both indoor air quality and thermal environment in three indoor air temperature intervals are compared with their results from three tasks measuring objectively their performance, namely arousal level test, logical thinking test and mental performance test. The analysis of the results shows statistically significant improvement in the logical thinking in three of the studied temperature intervals.*

***Key words:** Indoor air quality, Thermal environment, Students' performance, Human Subject Experiment, Statistical analysis.*

## INTRODUCTION

Human comfort, performance and health problems related to the deteriorated indoor environment are widely and often reported within last decades. Basically, the effects of indoor environment on occupants may be divided into two branches: the influence of the *thermal environment* on human comfort, performance and health and the influence of *indoor air quality* on human comfort, performance, and health. Although many studies have researched this problem [7-16] there are still unanswered questions and unproven hypotheses. Most of the standards concerning indoor environment [1, 3, 4] are based on studies conducted in Scandinavian countries where the climate conditions and the occupants' thermal sensitivity differ from that in other, southern countries. The objective of the present paper is to present results from an experimental study on the impact of indoor environment on students' performance, performed in a laboratory classroom with a controlled indoor environment. Both thermal environment and indoor air quality are assessed subjectively, while subjects' performance is measured objectively

## METHODS

The experimental study was performed during the spring / summer semester in the laboratory classroom of the Centre for Research and Design in Human Comfort, Energy and Environment (CERDECEN) at the Technical University of Sofia. The thermal environment and the indoor air quality in the classroom are monitored and controlled.

Second and third year BSc students, following engineering education on English language, took part as volunteers in the study. All participants have signed informed consent following the requirements of the Helsinki Declaration.

At the beginning and at the end of the regular classes in Fluid Mechanics, for the second year students, and in Thermodynamics and Heat transfer, for the third year students, the performance of the participants was measured in terms of arousal level, logical thinking and mental performance via paper-based tests, described in [11]. The procedure of the experiment is presented in [5, 6]. At the end of the exposure period, students were asked to evaluate perceived thermal environment and air quality in the classroom by the subjective visual analogue scales (EN 15251:2007). The procedures for assessment of the thermal environment, visual environment, acoustic environment and IAQ in the classroom are described in [7].

Seven temperature intervals were studied, all being outside the recommended by EN 15251:2007 standard interval of indoor air temperature for category I in classrooms, i.e 21÷23 $^{o}$C. Some results from the objectively measured students' performance on each test

and for every temperature interval are summarized in [7].

Based on the subjective votes for the perceived IAQ in the classroom, both the Percentage of dissatisfied (PD, %) and Perceived air quality (PAQ, decipol) were calculated, following the procedure presented in [2]:

$$PD = \frac{100\exp(-0{,}18-5{,}28ACC)}{1+\exp(-0{,}18-5{,}28ACC)},\% \quad (1)$$

$$PAQ = 112\left[\ln(PD)-5{,}98\right]^{-4},\ decipol\ . \quad (2)$$

In eq. (1) ACC is the mean vote of acceptability the IAQ of the group of tested subjects.

Collected students' performance data at the beginning and at the end of each exposure period were analyzed for statistically significant difference in two steps:

- **Test for normality.** Shapiro-Wilk test was used to check the distribution of the results from the objectively measured students' performance. This test is appropriate for small sample sizes (<50) which makes it very suitable for the data obtained in the present experiment.
- **Test for statistical significance.** Based on the results from the normality test an appropriate test for finding statistically significant difference was applied.

For both normality and statistical significance tests the SPSS (acronym of Statistical Package for the Social Science) software package was used.

## RESULTS AND DISCUSSION

The present study was focused on the students' performance results, obtained for three indoor air temperature intervals. Table 1 summarizes the data about the boundaries of the temperature intervals, the number of tested subjects in each interval and the evaluation of PD and PAQ. On Fig. 1 is presented the individual acceptance vote of the test subjects about the thermal environment and the indoor air quality.

***Table 1. Studied temperature intervals***

| | Temperature interval | | |
|---|---|---|---|
| | **19 ÷ 20 °C** | **25 ÷ 26 °C** | **27 ÷ 28 °C** |
| **Test subjects** | 18 | 18 | 17 |
| **PD, %** | 19.21 | 14,69 | 14,31 |
| **PAQ, decipol** | 1.34 | 0,95 | 0,92 |

From both Table 1 and Fig. 1 it is obvious that the largest percentage of dissatisfied from the Indoor Air Quality (IAQ) among the test subjects is in the temperature interval 19÷20 °C, while for the other two intervals the results are almost equal. On Figure 1 is clearly seen that regardless of the temperature interval most of the test subjects vote the thermal environment as acceptable.

Focus of current paper is on the relation between the acceptance of the indoor thermal environment and indoor air quality by the test subjects and their performance. The results from all neurobehavioral tests, used for objective assessment of the performance, were evaluated once in terms of productivity (units/sec) and after that in terms of quality (number of errors).

The objectively measured performance in terms of arousal level (determined by Tsai-Partington test) was compared to the subjectively assessed Thermal environment in Fig. 2. It has to be mentioned that here the results of this test are represented only by the individual productivity change in lines/sec (i.e. the productivity of a subject at the end of the exposure period minus its productivity at the beginning of the period) as there were no

errors found for this test during the whole experimental study. The graphs show a decrement in the arousal for the temperature intervals 19÷20 ºC and 27÷28 ºC, as reported also by Wyon [14].

The comparison between the quality change and productivity change during the execution of the other two neurobehavioral tests are presented in Fig. 3 for the logical thinking (Sudoku puzzle) and Fig. 4 for the mental performance (math addition). Productivity change for all tests is estimated as for the Tsai-Partington test, in absolute units. The quality change for both tests is calculated in terms of ratios as follows: the quality to productivity ratio for each subject at the end of the exposure period minus its quality to productivity ratio at the beginning of the period.

The preliminary analysis of the data clouds on Fig. 3 shows improvement in the logical thinking productivity and quality in the studied temperature intervals, ascertained also in [7].

The results published in [7] for the mental performance as a group was proved by the graphs of the individual representation of the quality change vs. productivity change – Fig. 4. A significant decrement in both quality and productivity change is observed for the temperature interval 19÷20 ºC.

The next step in the analysis of the data, obtained by the experiment, was to find if the observed differences between the quality and productivity of the investigated psychological characteristics were statistically significant. Shapiro-Wilk test was used to test the normality of the data, collected for the three temperature intervals. The null hypothesis that the data were normally distributed, was rejected ($p<0,05$) and all the performance tests results are with non-Gaussian distribution. As a consequence, only non-parametric tests could be used to search for statistical significance.

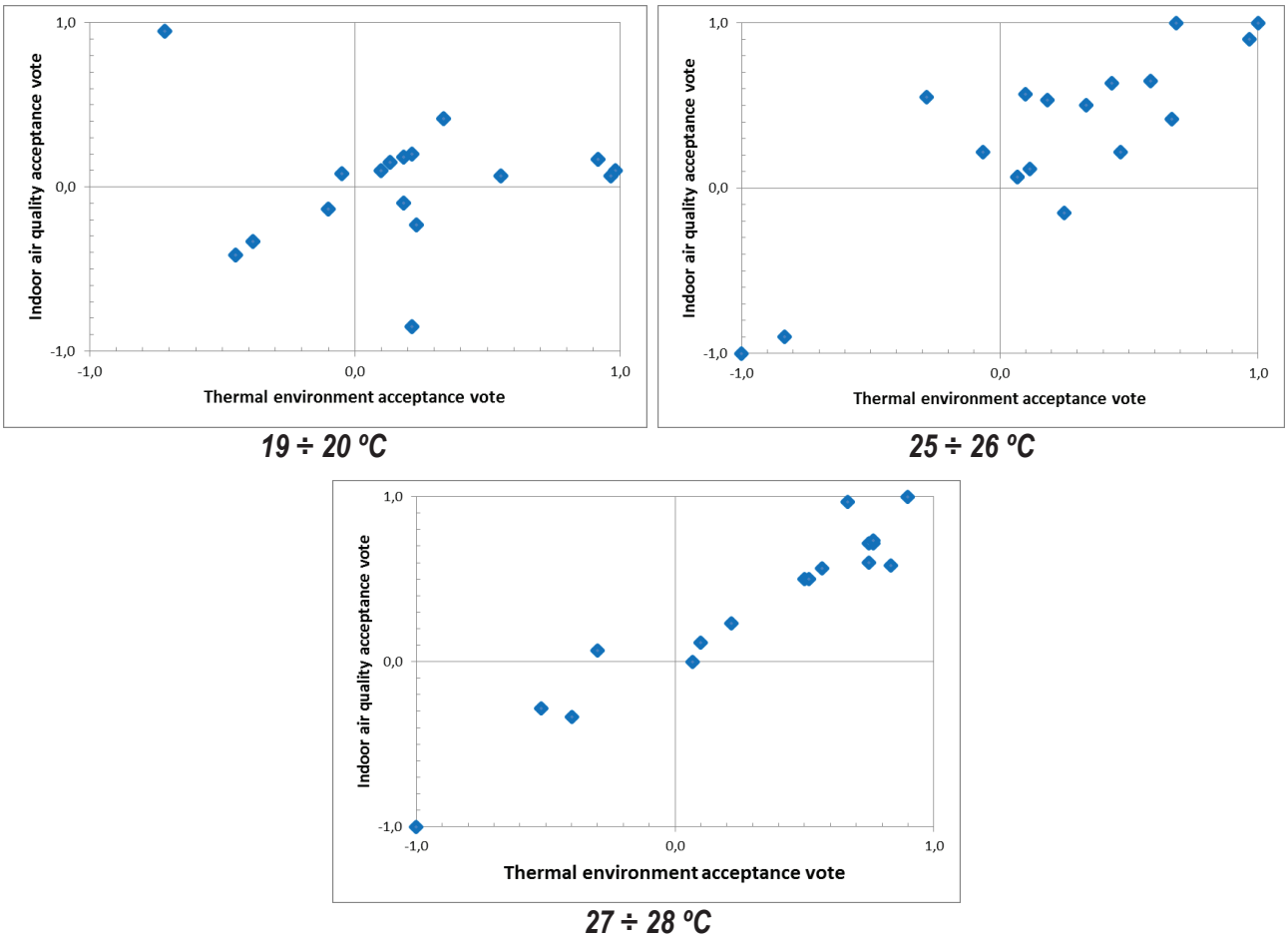
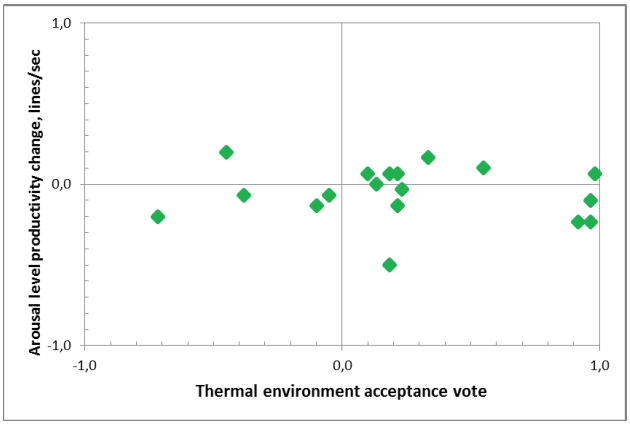
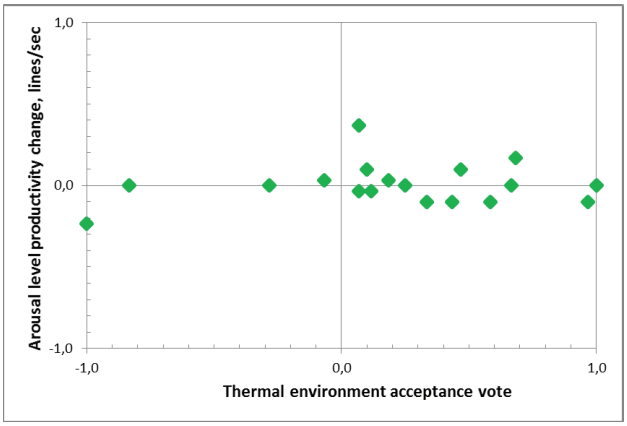


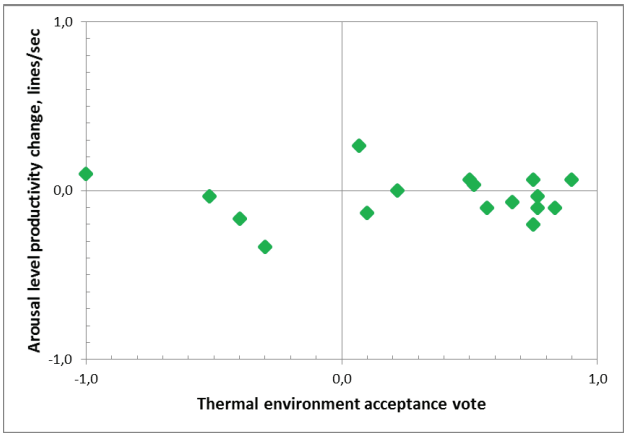

*Fig. 1 Subjective assessment of the indoor thermal environment and IAQ*




*19 ÷ 20 ºC*



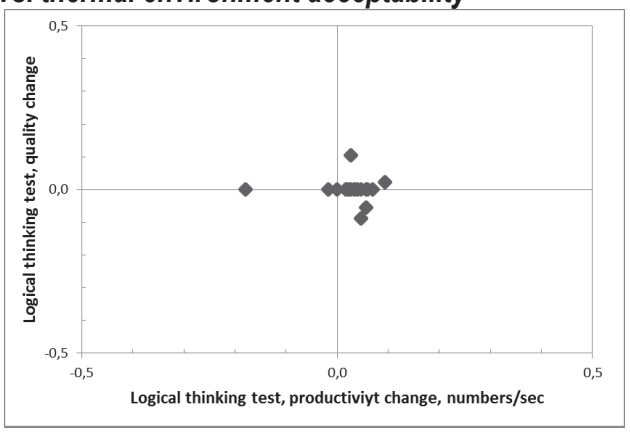

*25 ÷ 26 ºC*



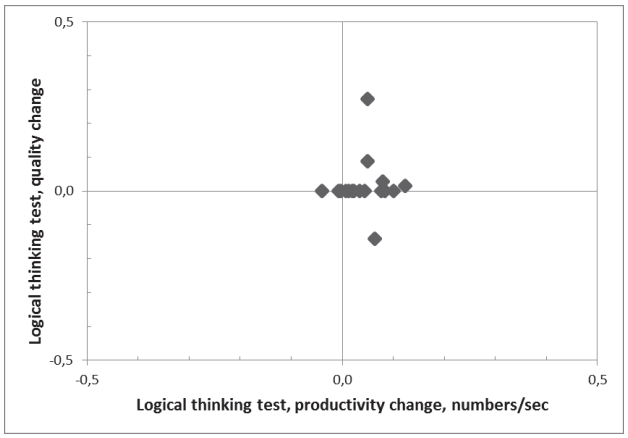

*27 ÷ 28 ºC*

***Fig. 2 Arousal level productivity change vs. thermal environment acceptability***


*19 ÷ 20 ºC*




*25 ÷ 26 ºC*




*27 ÷ 28 ºC*

***Fig. 3 Logical thinking quality change vs. logical thinking productivity change***

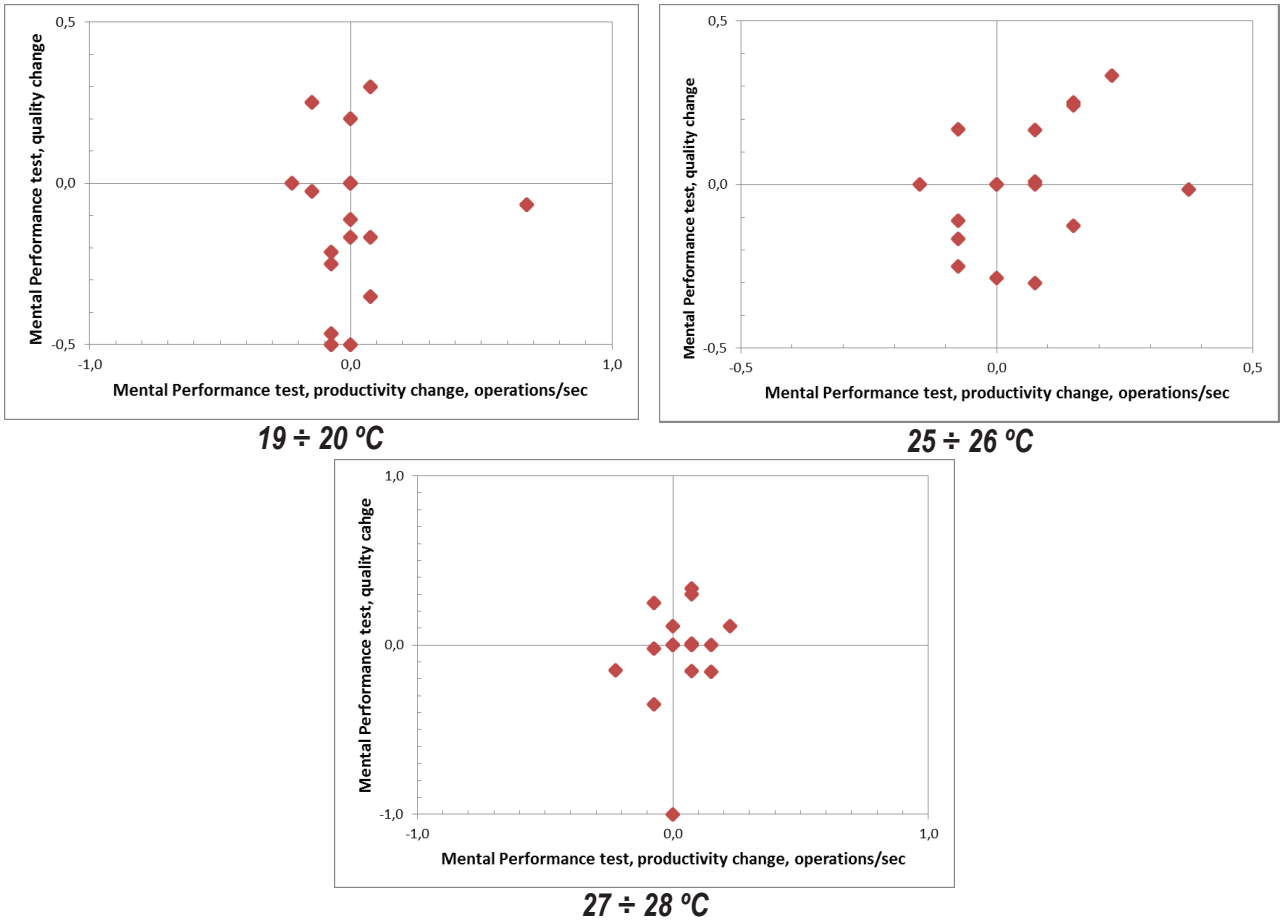



*Fig. 4 Mental performance quality change vs. mental performance productivity change*

Two questions were tested by Wilcoxon sign ranked test which is the non-parametric alternative to the t-test for independent samples with normal distribution:

1. Does the group *productivity* of the subjects at the end of the exposure period differ statistically significant from the one at its beginning?
2. Does the *quality* result for the whole group at the end of the exposure period differ statistically significant from the one at its beginning?

The results from the statistical test proved that there is a statistically significant improvement in the productivity of the logical thinking for the three temperature intervals. Concerning the quality, the significant improvement of the subjects' logical thinking at temperature intervals 25÷26 °C and 27÷28 °C was statistically proven. The other tested performance parameters showed a change tendency, but without statistical evidence. Summary of the results is presented in Table 2.

***Table 2. Statistically significant results***

| Temperature interval | Statistically significant change for Logical thinking | |
|---|---|---|
| | Productivity | Quality |
| **19 ÷ 20 °C** | Improvement, p=0,015 | |
| **25 ÷ 26 °C** | Improvement, p=0,006 | Improvement, p=0,006 |
| **27 ÷ 28 °C** | Improvement, p=0,002 | Improvement, p=0,002 |

## CONCLUSION

Indoor air temperature in the interval 19÷20℃ impacts negatively the arousal level

and the mental performance of the tested subjects and statistically significant improves the productivity of logical thinking.

There is evidence that the mental performance is improved but the arousal level is reduced at temperatures of 27÷28 ℃. At the same temperature interval statistically significant improvement in both quality and productivity in the logical thinking is found.

The temperature interval 25÷26 ℃ stimulates the logical thinking of the students in productivity and quality and this change is statistically significant, while there is no clear evidence for the other two performance parameters monitored – arousal level and mental performance.

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**Contact information:**

Assist. Prof. Iskra Simova, MSc, Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, Phone: +359 2 965 3305, E-mail: iskrasimova@gmail.com ;

Assoc. Prof. Detelin Markov, PhD, Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, Phone: +359 2 965 3305, E-mail: detmar@tu-sofia.bg;

Nushka Kehayova, MSc, Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, Phone: +359 2 965 3305, E-mail: n.kehayova@abv.bg;

Assoc. Prof. Radostina A. Angelova, PhD, DSc, Department of Textiles, Technical University of Sofia, Phone: +359 2 965 2902, E-mail: joy_angels@abv.bg ;

Prof. Peter Stankov, PhD, DSc, Center for Research and Design in Human Comfort Energy and Environment, CERDECEN, Phone: +359 2 965 2326, E-mail: peter.stankov@abv.bg.

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***This paper has been reviewed.***