On the Influence of Indoor Temperature on Occupant's Performance

Detelin Markov, Peter Stankov, Iskra Simova, Martin Ivanov,
Nushka Kehayova, Emanuil Georgiev

Abstract: *The paper presents results from a human subjects experiment in a field lab with controlled indoor environment parameters on the impact of indoor temperature on occupant's performance. Test subjects in the experiment are second and third year students in the Industrial Engineering Bachelor degree course at the English Language Faculty of Engineering in Technical University of Sofia. The results, obtained, show that indoor thermal environment has a significant impact on all studied elements of student's performance.*

Key words: *Indoor Environment, Human Subjects Experiment, Occupant's Performance.*

INTRODUCTION

Short term rare exposures, up to 2 hours once per week, to indoor environment with deteriorated quality have a negative impact only on occupant's performance and productivity. However, long term regular exposures, 8 hours/day 5 days/week, to such environment though initially are manifested as permanent decreased performance and productivity of the occupant's after a sufficiently long period of time may lead to health outcomes.

There is an intensive research on the influence of different indoor environment parameters on the occupant's performance and productivity over the last 35 years. Reviews of part of these results are presented by the authors in [2, 3, 4, 10, 11] and by other researchers in [9, 12, 13, 14]. Most of the papers reporting results for the influence of indoor temperature on occupant's performance don't take into account CO2 concentration indoors, which has a direct negative effect on human decision-making performance even at 1000 ppm, as it is shown by Satish et al. in [9].

The purpose of this paper is to present quantitative results from a human subjects experiment about the impact of indoor air temperature on student's arousal level, logical thinking and mental performance at one and the same IAQ, lighting and noise level.

METHODS

The experiments were carried out in the field lab of the "Center for human comfort energy and environment indoor" (CERDECEN) at the Technical University of Sofia with controlled indoor thermal environment and indoor air quality.

Test subjects in the experiment were second and third year students in the Industrial Engineering Bachelor degree course at the English Language Faculty of Engineering in Technical University of Sofia. Student's arousal level, logical thinking and mental performance were measured at the beginning and at the end of the exposure period following the protocols and procedures presented by the authors in [2, 4, 10]. Each exposure period of 105 minutes begins and ends with 10 minutes of performance tests. Between the two tests, for 85 minutes, second year students were involved in regular classes on Fluid Mechanics and third year students in regular classes on Thermodynamics and Heat Transfer.

Arousal level of the students was assessed by the Tsai-Partington test. They were asked to connect for 30 seconds with lines as much numbers in the range from 1 to 30 as possible. The numbers were randomly distributed on a sheet of paper. The lines had to be drawn between two numbers in ascending order and during the entire test the pen ha dto be in contact with paper.

The ability for logical thinking of the students was tested by mini-Sudoku (6x6) puzzles. Students were asked for 300 seconds to fill-in correctly as much empty cells as possible of 8 mini-Sudoku puzzles. Difficulty level of each mini-Sudoku puzzle was 2, i.e 19 empty cells in each puzzle and 152 in total for the task, but the most efficient solution algorithm for each group of 2 puzzles was different. It was assured that the most efficient solution algorithm for the matching groups of mini-Sudoku puzzles to be solved at the beginning and at the end of the exposure period is the same.

Mental performance of the subjects was measured by a math test. Students were asked for 120 seconds to solve correctly as many as possible math problems comprising addition of five 2-digit numbers, which are not divisible exactly by ten. Each problem requires 9 addition operations.

All tasks were completed on paper. The order of completing the tasks and the time for each task were controlled by the moderator of the experiment, who was responsible also for the evaluation of clothing value of every subject.

The result from each performance evaluation test under a case is assessed firstly at individual level, with respect to both productivity and quality, and then the group result is calculated by summing up the individual results.

The group result (GR) from each test under a case is evaluated in two ways: first, as the ratio of the GR at the end of the exposure period to the GR at the beginning of the exposure period, with respect to both productivity and quality; and second as the ratio of GR with respect to quality to GR with respect to productivity, at both the beginning and the end of the exposure period.

The individual result (IR) of every student from each test at the end of the exposure period is compared with the result from the beginning of the exposure period, with respect to both productivity and quality, and then is categorized as Better (result), Same (result), and Worse (result).

For the Tsai-Partington test the productivity is defined as the number of the lines drawn for 30 seconds, and the quality as the number of the correctly drawn lines. For the Logical thinking task the productivity is defined as the number of the filled-in empty cells of the mini-Sudoku puzzles for 300 seconds, and the quality as the number of the correctly filled-in empty cells. For the Mental performance task the productivity is defined as the number of the solved math problems for 120 second, and the quality as the number of correctly solved math problems.

The thermal environment in the field lab was assessed by point measurements at 4 space points following the procedure presented by Markov in [8], which fulfils the requirements of the international standards ISO 7730:2006 and ISO 7726:1998. The points were evenly distributed along the outer wall of the room and located at 1 m distance from it. During the exposure period at each of these points all physical parameters required for evaluation of the general thermal comfort indices (PMV-PPD and operative temperature) and local discomfort parameters (draught rate, vertical temperature difference, radiant asymmetry, and floor temperature) were measured three times with a time interval between two measurements of 30 minutes.

Assessment of the IAQ in the field lab is performed following the procedure presented by Markov in [7] and its categorization is done following the EN 15251:2007 standard. The quality of the indoor air is monitored continuously by a PS33 indoor air quality monitor, which collects data for atmospheric pressure, air temperature and relative humidity, as well as CO_2 volume fraction.

For characterization of both acoustic and visual environment in the lab point measurements were used. The sound pressure level in the room in dB(A) and the illumination level at a reference work place were measured with a time step of 10 minutes.

INVESTIGATED CASES

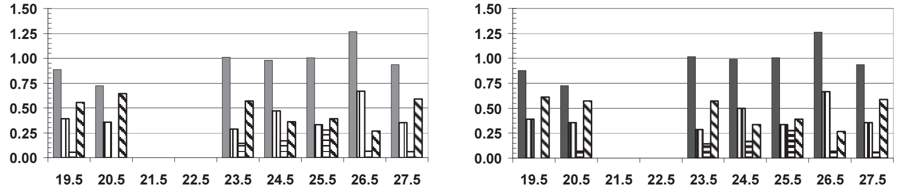
Students were exposed to indoor air temperatures in 7 intervals with length of 1 ^{o}C. All investigated intervals are situated outside the recommended by EN 15251-2007 standard interval of indoor air temperature for category I in classrooms, i.e [21, 23] ^{o}C. The investigated cases are identified with "IAT-" followed by the temperature in the middle of the interval. These intervals are IAT-19.5, IAT-20.5, IAT-23.5, IAT-24.5, IAT-25.5, IAT-26.5, and IAT-27.5.

The sound pressure level in the classroom was 63 dB(A) under all cases. According to EN 15251-2007 standard this value is outside the typical range for classrooms [30, 40] dB(A). For all cases illumination level at the reference work place was slightly higher than 300 lux, which fulfils the recommendations of EN 15251-2007 standard. For all cases maximum measured CO2 volume fraction in the room was 715 ppm, i.e 315 ppm above outdoors, which fulfils the criteria recommended by EN 15251-2007 standard for category I. For all case indoor air relative humidity was in the interval [25.9, 61.3] %, which fulfils the recommendations of EN 15251-2007 standard for category III.

RESULTS AND DISCUSSIONS

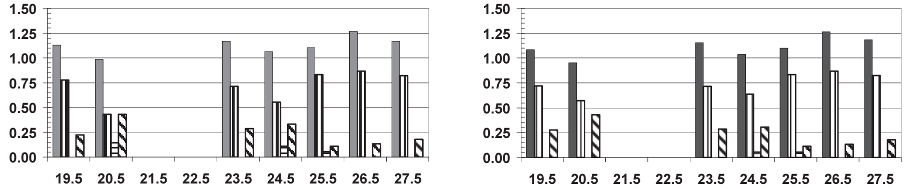
In total 58 subjects took part in the experiment. Second year students were 39 out of which 34 boys and 5 girls. Third year students were 19 out of which 17 boys and 2 girls.

Both GR and IR for the Arousal Level (AL) of the students under all cases are presented on Figure 1. The GR and IR about Logical Thinking (LT) and Mental Performance (MP) of the students under all cases are presented on Figure 2 and Figure 3, respectively. The Quality to Productivity ratio at the beginning and at the end of the exposure period for each test under all cases is presented on Figure 4.



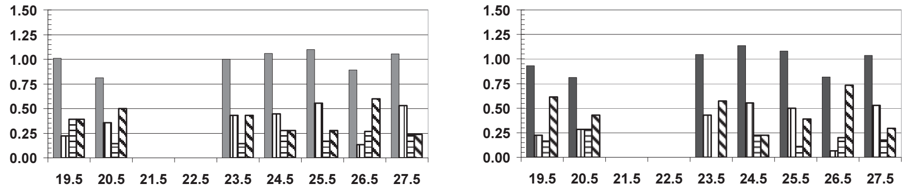
a) productivity b) quality

Figure 1: Variation of arousal level of students with indoor air temperature



a) productivity b) quality

Figure 2: Variation of logical thinking of students with indoor air temperature



a) productivity b) quality

Figure 3: Variation of mental performance of students with indoor air temperature

On each figure for every case, identified by the indoor air temperature at the middle of the interval, are presented four items: the dark bar represents the GR; the pale bar with vertical lines in it represents the ratio of the number of students with Better result at the end of the exposure period than the result at the beginning of the exposure period to the total number of students in the group; the pale bar with horizontal lines in it represents the ratio of the students with the Same result; the pale bar with inclined lines in it represents the ratio of the students with Worse result.

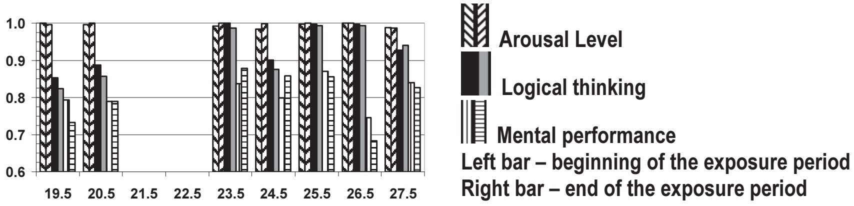


Figure 4: Variation of quality to productivity ratio of all tests with indoor air temperature

The indoor air temperature in the intervals [18, 20]°C and [27, 28]°C has negative impact on student's arousal level as a group. In the interval [22, 26]°C it causes no impact and in the interval [26, 27]°C it stimulates their arousal level. At individual level almost in all cases, except IAT-24.5 and IAT-26.5, at the end of the exposure period student's arousal level is lower than at the beginning of the period. However, the results from this test must be interpreted very carefully. The quality to productivity ratio for the Tsai-Partington test is closer to unity. Most probably this is an easy task for the tested subjects.

For all studied cases, except IAT-20.5, logical thinking ability of the students at the end of the exposure period is higher than the one at its beginning. Probably this is a result of the teaching process during the exposure period. In all cases, except IAT-27.5, the quality to productivity ratio for the logical thinking task of the group at the end of the exposure period is lower than that at its beginning. Most probably at the end of the exposure period the students are tired and absent-minded. Indoor air temperature stimulates the most students logical thinking in the interval [26, 27]°C.

The indoor air temperature in the intervals [20, 21]°C and [26, 27]°C has negative impact on student's mental performance as a group. In the interval [23, 24]°C it causes no impact and in the intervals [24, 26]°C and [27, 28]°C it stimulates their mental performance. The quality to productivity ratio for this task at the end of the exposure period is higher than the one at its beginning in the interval [23, 25]°C. For all other cases it is higher at the beginning of the period that at its end. The quality to productivity ratio for this task is the lowest among the three studied elements of student's performance. Most probably this is a result of the intensive use of computers and electronic calculators by the nowadays students for performing even simple calculation tasks.

CONCLUSIONS

The indoor air temperature in the interval [23, 26]°C has a slightly positive impact on students performance as a whole. It stimulates slightly their logical thinking and mental performance and has almost no impact on their arousal level.

Indoor air temperature in other intervals has significant and contradictory impact on the studied elements of student's performance. In the interval [26, 27]°C indoor air temperature stimulates both students arousal level and logical thinking and they have their maximum, but students mental performance is worsen significantly. In the interval [27, 28]°C indoor air temperature stimulates students logical thinking and mental performance but reduces their arousal level. The results from all tests decrease with the increase of the temperature in the interval [19, 21]^{o}C.

Based on the presented results, the optimum indoor air temperature in a classroom has to be in the interval [23, 26]^{o}C.

ACKNOWLEDGMENT

This study is part of the project "*Integrated study on the indoor environment impact on human performance, comfort and health and effective energy utilization"*, funded by Bulgarian Science Fund with The Ministry of Education Youth and Science under the ДДВУ-02-8/17.12.2010 grant agreement.

REFERENCES

[1] EN 15251-2007 standard, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

[2] Ivanov M., I. Simova, D. Markov, P. Stankov, Adjustment of the practical steps in the assessment of the indoor environment impact over occupant productivity and performance, Proceedings of XVIIth Scientific conference FPEPM 2012, 16-19 September 2012, Vol. 2, pp. 47-53.

[3] Ivanov M., P. Stankov, D. Markov, I. Simova, N. Kehayova, E. Georgiev, A study on performance assessment of students in controlled indoor environment conditions, Proc. of EENVIRO 2014 Conference - Sustainable Solutions for Energy and Environment, 5-6 June 2014, Bucharest, Romania

[4] Ivanov M., Stankov P., Markov D., Simova I., Modified procedures for assessment of the indoor environment impact over productivity and performance of students in laboratory conditions, Proceedings of the "XIX National scientific conference with international participation FPEPM 2014 – Sozopol, 14-17 September 2014", Vol. II, pp. 35-41, ISNN 1314-5371, 2014

[5] ISO 7726-1998 standard, Ergonomics of the thermal environment – Instruments for measuring physical quantities

[6] ISO 7730-2006 standard, Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

[7] Markov D., Methodology for indoor air quality (IAQ) assessment in practice, in P.Stankov (editor) Summer school on build environment, Proceedings of SEE-ERA-NET summer school on build environment, 7 – 12 June 2008, Pamporovo, Bulgaria, pp 164 – 167, ISBN 978-954-91681-9-8

[8] Markov D., Thermal environment assessment in practice, in P.Stankov (editor) Summer school on build environment, Proceedings of SEE-ERA-NET summer school on build environment, 7 – 12 June 2008, Pamporovo, Bulgaria, pp 168 – 173, ISBN 978-954-91681-9-8

[9] Satish U., 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 Perspectives 120: 1671–1677 http://dx.doi.org/10.1289/ehp.1104789, (2012).

[10] Simova I., D. Markov, P. Stankov, Battery for assessment of indoor environment impact on the performance of students, teachers and office workers, Proceedings of XVIIth Scientific conference FPEPM 2012, 16-19 September 2012, Vol. 2, pp. 64 – 72

[11] Stankov P., D. Markov, G. Pichurov, I. Simova, R.A. Angelova, S. Logofetova, M. Ivanov, S. Mijorski, Integrated Study on Indoor Environment Impact on Human Performance, Comfort and Health, and Effective Energy Utilization, Advances in Bulgarian Science 2012, National Centre for Information and Documentation, pp. 19

– 28, ISSN 1312-6164

[12] Toftum, J, Wyon, D, Svanekjær, H & Lantner, A 2005, 'Remote Performance Measurement (RPM) – A new, internet-based method for the measurement of occupant performance in office buildings'. in *Proc. of Indoor Air 2005.* vol. 1, China, pp. 357-361.

[13] Wyon D., I. Andersen, G. Lundqvist, The effects of moderate heat stress on mental performance, Scandinavian Journal of Work Environment and Health, vol. 5, 1979, pp. 352 – 361

[14] Zhang H., E. Arens, D. E. Kim, E. Buchberger, F. Bauman, C. Huizenga (2010) "Comfort, perceived air quality, and work performance in a low-power task–ambient conditioning system" *Building and Environment,* 45(1), pp. 29-39.

ABOUT THE AUTHORS

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

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

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

Assistant Prof. Martin Ivanov, PhD, MSc, Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, Phone: +359 2 965 3305, E-mail: martin_ronita@yahoo.com.

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

Emanuil Georgiev, MSc, Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, Phone: +359 2 965 3305, E-mail: ev1l@abv.bg.

This paper has been reviewed.