On the Indoor Environment Impact on Occupants' Comfort and Performance

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Abstract: *The paper presents a literature survey on the relation/linkage of the indoor environment with occupants' comfort, performance and health. The effect of the IAQ and the thermal conditions on the performance of adults and school children are reviewed.*

Key words: *Indoor Environment, Occupants' comfort, Occupants' Performance, Occupants' productivity*

INTRODUCTION

In today's highly technologically developed world, people spend most of their lifetime indoors. A reasonable question is what kind of air people are exposed to when staying in the office, at school, university or at home. This question concerns scientists since there have been numerous reports of adverse health effects related to indoor air quality and thermal comfort in the last decades. Many studies have been conducted and research on the relationship of IEQ (Indoor Environment Quality) to health symptoms has advanced considerably. Wider recognition of this problem has also produced concern that health problems from poor indoor environments may reduce the performance of occupants in buildings.

VOCs, CO_2, formaldehyde, fungi, mold, dust- these are a small fraction of all the pollutants that contaminate the air people breathe. In addition, the impact of high relative humidity, insufficient outdoor air supply, the high temperature also leads to health problems and impaired performance.

Ironically, modern buildings increase the likelihood of poor indoor air quality. The need to conserve energy led to almost airtight buildings and eliminates the possibility of air exchange between indoors and outdoors, thus dramatically increasing the concentration of pollutants indoors.

OBJECTIVES

The present work reviews and summarizes the research done on the relation between indoor environment parameters and the performance of office workers, students and pupils. No studies on the effect of light, noise and aesthetics itself on the occupants' performance are reviewed. Thus allows the reviewed papers to be divided into two main groups: studies which investigate the effects of indoor thermal conditions on the human subject's performance and studies which evaluate the impact of indoor air quality on occupants' performance. From other hand side the considered articles involve adults (mainly office workers and adult students) and school children (pupils) exposed to both laboratory and field conditions. Most of the papers included in the survey are peer-reviewed journal papers but some are presented in conference proceedings.

THE EFFECTS OF THERMAL CONDITIONS ON HUMAN SUBJECT'S PERFORMANCE

Research on the relation and impact of the indoor temperature on occupants' performance has started in early seventies of the last century with series of experiments conducted by Wyon who studied the effects of moderate heat stress of adult students in a chamber study [24], [25], [26]. Although the experiments show unclear results they state great basis in the field as well as the use of neurobehavioral tests to study performance.
In 2003 Seppanen et al. published a relation between temperature and performance which

shows no change of performance in the comfort temperatures range 21-25°C and 2% decrease in performance per each °C increase of the temperature interval of 25-32°C [11]. Based on previous research Seppanen et al. summarizes relevant studies on the topic (generally measuring performance of office work or simulated office work) and calculates percentage of performance change per degree increase in temperature which gives more precise analysis in the 21-24°C range [12].

Lan et al. reports a study performed in China on the thermal environment effects on office workers' well-being, workload and productivity [3]. They used subjective rating scales as well as computerized neurobehavioral tests simulating office work. Physiological measurements of heart rate variation and electroencephalography were made. The results are similar to the other studies listed, i.e. indoor temperatures outside the comfort range have negative impact on tested subjects' performance. The authors found that warmer conditions affect negatively the occupants' well-being and the workload (i.e. efforts needed to complete tasks) in uncomfortable indoor environment increased and as a result the subjects had lower motivation to work.

Another paper by Lan et al. shows quantitative relationship between thermal sensation and performance [4]. A comparison of the relationship developed and relationships reported in previous studies is made. It shows good agreement especially in the comfort zone range and deviation especially in warmer conditions which are explained by the laboratory character of the study.

In this paragraph refers a study performed in Bulgaria under controlled indoor environmental conditions [2], [15]. The tested subjects were university students in engineering who performed a set of simple neurobehavioral performance tests especially designed to be sensitive to intensive mental work (and to simulate engineering/office work)[13]. A temperature range of 19-28°C was studied and the results proved the findings listed above that the optimum indoor air temperature in a classroom has to be in the interval of 23-26°C [5].

THE EFFECTS OF INDOOR AIR QUALITY (IAQ) ON HUMAN SUBJECT'S PERFORMANCE

Indoor air quality (IAQ) is one of the most important areas of IEQ, particularly in terms of the impact of a building on the health of occupants. IAQ refers to the presence or absence of air pollutants in buildings. There are many different types of pollutants that can affect indoor air, and they come from a wide range of sources.

An experimental laboratory study reported by Wargocki et al. links lower ventilation rates with reduced performance of office workers [19]. The results showed 1.7% rise in the overall productivity in every two-fold increase in the ventilation rates within the range of 3 to 30 l/s/person.

In 2002 Wargocki and Lagercrantz et al. published a comparison of two independent studies which investigates the effect of IAQ on office workers' productivity by decreasing the pollution load as simply removing a pollution source (20-year-old carpet) [16]. The presence of the carpet caused 6,5 % decrease in the typing speed and 18% increase in the typing errors. SBS complaints as headache, nose and throat irritation increased as well.

Another experimental study conducted in a field lab under controlled conditions and reported by Bako-Biro investigates the effects of 3-month-old computers' emissions on the performance of simulated office work. The presence of personal computers increased the percentage of dissatisfied and increased the time needed for text processing by 9% [1].

In 2006 Wargocki and Wyon summarized the available research done on this topic – both in laboratory and field experiments [27].

A direct effects of increased CO_2 (considered as an indoor air pollutant), within the range of indoor concentrations, on decision making are assessed and reported by Satish

et al. [9]. The authors found that relative to 600 ppm, at 1,000 ppm CO_2, moderate and statistically significant decrements appeared in six of nine scales of decision-making performance. Large and statistically significant reductions occurred in seven scales (of nine) of decision-making performance at 2,500 ppm, but at the same time performance on the focused activity scale increased.

Exposures on CO_2 in the range of 500 ppm to 3000 ppm with and without bio effluents are examined to be linked to cognitive performance in a Chinese study performed by Zhang et al. [29]. The results show that exposure to bio effluents reaching CO_2 concentration of 3000 ppm leads to significant decrease in addition speed but increase in speed of redirection task as well as increased number of errors in Tsai-Partington test which is the main task used to monitor the arousal level. Hence can be concluded the hypothesis of linking the CO_2 concentration with cognitive performance is correct.

THE EFFECTS OF THERMAL CONDITIONS AND IAQ ON PUPILS' PERFORMANCE

The indoor environment in schools has been much less studied than in other buildings such as offices, even though children, unlike adults, are much more vulnerable, must perform work that is not optional and is almost always new to them, and cannot make decisions concerning their school environment. Moreover school children are studying or working new tasks compared to the office workers for which their work is usually routine one and common which can make pupils' performance even more sensitive and affected by the indoor environmental factors.

In 2005 Mendell and Heath [6] publish a detailed review of the factors that may have impact on the school children performance. They found only few strongly designed and significant studies that assess links between indoor pollutants and thermal conditions in schools and pupils' attendance or performance. The most relevant to the present work are listed below.

Schoer and Shaffran [10] assessed the effect of the temperature on the pupils' performance in an experimental study performed in a pair of classrooms especially designed (laboratory conditions with one not cooled and one air-conditioned classroom) for the purpose. The studied temperature interval was 22°C to 26°C. About nineteen different tests with non-identical difficulty were applied to 10- to 12- year-old pupils for six to eight weeks. The results show that the students' performance in the cooled classroom was about 5.7% better compared to the performance of the students' exposed to the higher temperatures in the not cooled classroom.

Holmberg and Wyon [22], [23], and [26] have found much higher magnitude of the negative impact of the thermal conditions on school children's performance – often 30%. They conducted an experiment with children at the same age as in [10], which was exposed to three temperatures - 20°C, 27°C and 30°C. While children performance was tested by series of numerical and language-based tasks the authors observed and monitored their behaviour and attendance.

Correlations between pupils' health and performance and CO_2 concentrations in classrooms were determined by Myhrvold et al., [7]. He conducted physical measurements of CO_2 and other indoor air parameters, and distributed questionnaires to students in eight schools in Sweden. The majority of the complaints included headache, dizziness, tiredness, difficulty concentrating, i.e. increased prevalence of SBS symptoms. A graphical relation was proposed showing that decreasing ventilation levels, respectively increasing CO_2 concentrations are associated with reduced performance.

As a consequence of the findings published by Mendell and Heath, Wargocki and Wyon [17] designed and examined an independent field intervention experiments in school classrooms in late summer of 2004 and 2005. The need of such study was motivated by the lack of research in the field since the studies reported in [10] and [22],[23] published

several decades earlier as well as the need of more precise understanding of temperature interval found to be significant. The air temperature and the outdoor air supply rate were manipulated. Six to eight exercises exemplifying different aspects of schoolwork (numerical and language-based) were performed as part of normal lessons. Exercises included addition, multiplication, subtraction, comparison of numbers, logical thinking, reading and comprehension and proofreading. The performance of two numerical and two language-based tests was significantly improved when the temperature was reduced from 25°C to 20°C. When the outdoor air supply rate was increased from 5 to 10 L/s per person, their performance of four numerical exercises improved significantly, confirming the results of previously reported experiments in the same series. The above improvements were mainly in terms of the speed at which tasks were performed, with negligible effects on error rate.

Wargocki and Wyon [18] reported from an independent field intervention experiments carried out in mechanically ventilated classrooms (similar to [17]) receiving 100% outdoor air. Outdoor air supply rate and filter condition were manipulated to modify indoor air quality, and the performance of schoolwork was measured. Each week, in appropriate lessons, the children's usual teachers administered parallel versions of numerical and language-based performance tasks. They included addition, multiplication, subtraction, number comparison, logical thinking, acoustic proofreading, and reading and comprehension. The performance of two numerical and two language-based tests was significantly improved when the outdoor air supply rate was increased from 3 to 8.5 L/s per person. A significant effect of ventilation rate was observed in 70% of all the statistical tests for an effect on work rate, but there were no significant effects on errors.

DISCUSSION AND CONCLUSIONS

Even though the problem discussed in the present survey is object of scientific interest for several decades it is still actual and states more and more questions and unsolved aspects resulting from the modern world requirements.

The effects of IEQ on occupants' performance are found to be stronger in field studies compared to the controlled laboratory studies.

Most of the studies reviewed concerning the AIQ impact on human subject's performance recommend ensuring adequate ventilation and maintaining higher ventilation rates of the minimum listed in the standards as well as control on the indoor pollution sources.

As school children spend more time in schools than in other indoor environment except home, indoor environmental effects on pupils' learning, performance and attendance are of great importance because they could have direct or lifelong consequences not only for the children but for the society [6]. So that measures for developing of strong regulations on the schools indoor environmental quality are needed.

Small improvements in occupants' performance by improvements in indoor environmental quality may have significant economic benefit [11]. Cost-benefit calculations demonstrated that the net productivity gain reduced by improving indoor air quality could exceed the investment costs by a factor of 60 with a turnover period of no more than 2.1 years [21].

Future research on the topic is needed on how the signals of human perception are finally processed in the brain and how the human body finds the most proper reaction to the particular physical environment. A possible way is to monitor the human brain response via EEG (electroencephalography) as an objective assessment of indoor environmental impact on occupants' performance. Since the standard procedure for measuring the brain waves is hard, time consuming and needs trained personnel very limited research is done in this direction [4]. However modern technologies can provide good, cheaper and user friendly solutions [14].

References

[1] Bakó-Biró, Z., Wargocki, P., Weschler, C.J., and Fanger, P.O. (2004). “Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices” *Indoor Air* 14:178-187.

[2] Ivanov M., P. Stankov, D. Markov, I. Simova, N. Kehayova, E. Georgiev, (2014) 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

[3] Lan, L., Lian, Z.W., Pan,L., (2010),The effects of air temperature on office workers’ well-being, work load and productivity evaluated with subjective ratings, Applied Ergonomics 42, pp.29-36.

[4] Lan, L., Wargocki, P. and Lian, Z. W. (2011) Quantitative measurement of productivity loss due to thermal discomfort. Energy and Buildings, 43, 1057-1062.

[5] Markov D., P. Stankov, M. Ivanov, I. Simova, N. Kehayova, E. Georgiev, (2014), On the Influence of Indoor Temperature on Occupant’s Performance, Ruse University Science Works, October 2014, vol. 53, series 1.2, pp. 159 – 164.

[6] Mendell, M., G. A. Heath, (2005) Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance? A Critical Review of the Literature, Indoor Air Journal,15, 27-32

[7] Myhrvold, A.N., E. Olsen and Ø. Lauridsen. 1996. “Indoor environment in schools—Pupils’ health and performance in regard to CO2 concentration.” Proceedings of Indoor Air ’96 4:369 – 374.

[8] P. Wargocki, R. Djukanovic, Estimate of an economic benefit from investment in improved indoor air quality in an office building, in: Proceedings of Healthy Buildings Conference, Singapore, 2003, pp. 382–387

[9] Satish U., M. J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, W. J. Fisk, (2012) Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance, Environ Health Perspectives 120: 1671–167.

[10] Schoer, L., J Shaffran (1973) A combined evaluation of three separate research projects on the effects of thermal environment on learning performance, ASHRAE Transactions 79:97-108

[11] Seppänen,O., Fisk,W., Faulkner, D. (2003) Cost benefit analysis of the night-time ventilative cooling, Proceedings of the Healthy Buildings 2003 Conference, Singapore 2003, Vol 3:394-399.

[12] Seppänen,O., Fisk,W., Lei,Q.H., (2006) Room Temperature and Productivity in Office Work, Lawrence Berkeley National Laboratory, University of California, LBNL-60952.

[13] Simova I., D. Markov, P. Stankov, (2012), 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

[14] Simova I., D. Markov, N. Kehayova, P. Stankov, (2015), Battery for assessment of indoor environment impact on the performance of students, teachers and office workers, Proceedings of XXth Scientific conference FPEPM 2015, 13-16 September 2015, Vol. 2, pp. 39 – 47

[15] Stankov P., D. Markov, G. Pichurov, I. Simova, R.A. Angelova, S. Logofetova, M. Ivanov, S. Mijorski, (2012) 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

[16] Wargocki P, Lagercrantz L, Witterseh T, Sundell J, Wyon DP, Fanger PO (2002) "Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office" *Indoor Air.* 2002 Jun;12(2):74-80.
[17] Wargocki, P., D.P. Wyon (2007) "The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children", HVAC&R Research, Vol. 13(2), 193-220.
[18] Wargocki, P., D.P. Wyon (2007) "The effects of outdoor air supply rate and supply air filter condition in classrooms on the performance of schoolwork by children", HVAC&R Research, Vol. 13(2), 165-191.
[19] Wargocki, P., D.P. Wyon, J. Sundell, G. Clausen, and P.O. Fanger (2000) "The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity", *Indoor Air*, 10, 222–236.
[20] Wargocki, P., O. Seppänen, (2006) Indoor Climate and Productivity in Offices – how to Integrate Productivity in Life-cycle Cost Analysis of Building Services, REHVA Guidebook No.6, REHVA, Finland
[21] Wargocki,P., R. Djukanovic, Estimate of an economic benefit from investment in improved indoor air quality in an office building, in: Proceedings of Healthy Buildings Conference, Singapore, 2003, pp. 382–387
[22] Wyon D. P., (1969) The effects of moderate heat stress on the mental performance of children, Document D8/69, National Swedish Institute for Building Research. Stockholm: Building Research Council.
[23] Wyon D. P., I. Holmberg, (1972) Systematic observation of classroom behavior during moderate heat stress, Proceedings of the CIB (W45) Symposium "Thermal Comfort and Moderate Heat Stress", September 13-15, Garston, Watford, England.
[24] Wyon D., I. Andersen, G. Lundqvist, (1979) The effects of moderate heat stress on mental performance, Scandinavian Journal of Work Environment and Health, vol. 5, pp. 352 – 361
[25] Wyon, D.P. (1974) The effects of moderate heat stress on typewriting performance, Ergonomics, 17, 309–318.
[26] Wyon, D.P. (1975) The mental performance of subjects clothed for comfort at two different air temperatures, Ergonomics, 18, 359–374.
[27] Wyon, D.P., P. Wargocki (2006) "Indoor air quality effects on office work." In: Clements-Croome, D. (ed.) Creating the Productive Workplace, 2nd ed., 193–205, London: Taylor & Francis.
[28] Wyon, D.P., P. Wargocki (2006) "Room temperature effects on office work." In: Clements-Croome, D. (ed.) Creating the Productive Workplace, 2nd ed., 181–192. London: Taylor & Francis.
[29] Zhang, X., P. Wargocki, Z. Lian, Effects of Exposure to Carbon Dioxide and Human Bioeffluents on Cognitive Performance, Procedia Engineering, Volume 121, 2015, Pages 138-142, ISSN 1877-7058

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