Perceived Air Quality and Productivity in the Office Building

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Abstract. Problems of perceived quality of the environment find its reason especially when monitoring performance and productivity of work. Thus, verification of the degree of environmental quality impact on employee performance comes into consideration. The results of two independent studies involving 50 subjects, and using similar procedures and blind exposures have shown that increasing the air quality (by decreasing the pollution load or by increasing the ventilation rate, with otherwise constant indoor climate conditions) can improve the performance of simulated office work (text typing, addition and proof-reading). Performance testing was performed in the open space office of an office building at three air exchange intensities: \( n_1 = 0.5 \text{ h}^{-1} \), \( n_2 = 1.5 \text{ h}^{-1} \) and \( n_3 = 2.5 \text{ h}^{-1} \). Other physical environmental parameters that could have affected the assessors' performance were maintained in the range: indoor air temperature \( \theta_{ai} = 22 - 24 \degree \text{C} \), relative air humidity \( \phi_{ai} = 40 - 60\% \), air velocity \( v_{ai} \leq 0.25 \text{ m.s}^{-1} \), noise level load \( L = 40 - 50 \text{ dB (A)} \), daylight - diffuse radiation component. The present results document the productivity benefits of providing good indoor air quality and indicate that providing indoor air of a higher ventilation level will increase productivity.

1. Introduction
Indoor air quality significantly affects user productivity and performance [1]. In cases of inadequate indoor air quality, phenomena such as headache, fatigue, dry mucous membranes and the associated discomfort from the working environment are very common [2]. The unsuitable indoors is commonly associated with Sick Building Syndrome (SBS) [3]. The basic quality parameters are temperature, humidity and the presence of pollutants such as solid particles, oxides and volatile organic compounds. These factors distress by distracting attention. Carbon dioxide (CO2) concentration is very often an important indicator of indoor environment quality [4]. The human body has a natural ability to adapt to the surrounding conditions. The possibility of individual temperature control is an advantage in terms of thermal comfort. Air humidity is directly related to its temperature, in summer the air is naturally damp and there is no need to humidify the supply air. In winter the humidity can fall below 30%, which is the minimum recommended value. The amount of air ensures the reduction of pollutants and odor removal. According to legislative requirements, the minimum amount is 25 m³/h per person. A number of studies deal with indoor air quality in offices [5-7].

Sufficient information on indoor air quality and office performance as well as productivity in office buildings in the Czech Republic is not available. This paper presents a summary of the results from the perceived air quality in 10 randomly selected office buildings across the South Bohemia, including performance and productivity. Problems of perceived quality of the environment find its reason especially when monitoring performance and productivity of work. Thus, verification of the degree of environmental quality impact on employee performance comes into consideration.

2. Case study
The results of two independent experiments show that the performance of simulated office work improves when the air quality is increased. To simulate office work, text typing, proof-reading and
addition were used, all being typical office tasks requiring concentration. Air quality was altered either by increasing the outdoor air supply rate from 0.5, 1.5 and 2.5 h⁻¹ while the same pollution source was always present. The aim of the present paper is to determine the relationship between air quality and the performance of office tasks. They reflect the actual air quality levels when the performance of simulated office work was measured.

The procedure for assessing the impact of individual environmental factors in buildings or their combinations on the perceived environmental quality and user performance through a software tool consisted of six phases - A to F. In preparation phase A, the assessor explained how to complete questionnaires and how. Phase B represented the first round of sensory evaluation of perceived environmental quality through six subjective scales of evaluation. Subsequently, in phase C, the first round of performance testing was carried out. The performance was measured using a group of three different types of tasks. The performance of simulated office work including text typing, addition and proof-reading, was used to estimate productivity. An average number of characters typed per minute, an average number of correctly completed arithmetical calculations (units) per hour (i.e., excluding units with errors) and an average number of lines that were correctly proof-read per minute (i.e., excluding the lines with missed errors or false positives) were used for analysis after each had been individually normalized.

In phase D, a similar subjective sensory assessment of perceived environmental quality was repeated to assess the degree of reviewers' adaptation to the set environmental conditions as in phase B. re-sensitively evaluated the perceived state of the environment through scales of subjective evaluation. At the end of the whole evaluation process, the assessors identified SBS symptoms during their performance testing.

For all three air exchange intensities, there was a decrease in subjective performance between phases C and E. The highest subjective performance was perceived by the subjects of the test process at the highest air exchange rate (n₃), where it was rated as "0 - normal" in both phases. Similarly, respondents' subjective performance was perceived and evaluated during the assessment process at air exchange intensity n₂. The lowest subjective performance was recorded at the lowest air exchange rate (n₁). In both phases, employees were rated almost “-1 - slightly lower”, again with a decreasing tendency between the phases. The results of the subjective evaluation of performance versus air exchange intensity are shown in Figure 1.

Table 1 shows the results of the subjective evaluation of the individual environmental indoor factors in relation to the air exchange intensity.

At the air exchange intensities n₁ and n₂, the thermal state of the environment was perceived very similarly by the subjects, and in all three phases of sensory evaluation it was marked on the thermal
comfort scale close to the degree of "0 - neutral". At the highest air exchange rate (n₃), the thermal state of the environment was also felt "0 - neutral", but from the negative side of the rating scale.

The highest satisfaction with the perceived humidity conditions of the environment was recorded at the air exchange intensity n₂, when the respondents were marked on the perceived humidity scale close to the degree of “0 - neutral” during the whole testing process. At the lowest air exchange rate (n₁), the humidity of the environment during performance testing was felt by employees with a slightly decreasing tendency approaching the degree "-1 - slight drought". At the highest air exchange rate, the humidity level of the environment, similar to the air exchange rate n₁, was felt almost constant throughout the test process, with the result of the evaluation on the perceived humidity scale almost "0 - neutral".

The perception of noise at the start of performance testing at all three air exchange intensities was rated '2 - poor' by respondents on the noise load scale. Also in all three cases, there was an increasing tendency in the perception of this environmental component between the phases of sensory evaluation - the slightest increase in tendency was at the lowest intensity of air exchange rate (n₁). The strongest increase in tendency was recorded at the highest intensity of air exchange (n₃) - almost 3(acceptable).

The greatest dissatisfaction with the light conditions of the test room was observed at the lowest air exchange rate (n₁) and there was a decreasing tendency in perception of this indicator between the phases of sensory evaluation. In phase B, the perceived level of illumination was marked by the respondents as "0 - acceptable" and in the next two phases as closely to "-1 - low". At the other two air exchange intensities (n₂) and (n₃), the illumination rate was perceived by the subjects of the evaluation process almost constant and marked as close to 0 - acceptable' on the subjective evaluation scale during performance testing.

| Indoor factor | Air change | Phase B | Phase D | Phase F | Tendency |
|---------------|------------|---------|---------|---------|----------|
| Temperature   | n₁*        | 0.10    | 0.04    | 0.03    | ↔        |
|               | n₂         | 0.12    | 0.06    | 0.06    | ↔        |
|               | n₃         | -0.40   | -0.20   | -0.22   | ↔        |
| Humidity      | n₁         | -0.89   | -0.95   | -1.09   | ↓        |
|               | n₂         | -0.03   | 0.02    | 0.05    | ↔        |
|               | n₃         | -0.21   | -0.29   | -0.38   | ↑        |
| Noise         | n₁         | 2.09    | 2.17    | 2.29    | ↑        |
|               | n₂         | 2.11    | 2.34    | 2.51    | ↑        |
|               | n₃         | 2.13    | 2.66    | 2.88    | ↑        |
| Light         | n₁         | -0.08   | -0.83   | -0.96   | ↓        |
|               | n₂         | 0.04    | 0.02    | 0.06    | ↔        |
|               | n₃         | 0.08    | 0.07    | 0.09    | ↔        |

*  n₁ = 0, 5 h⁻¹, n₂ = 1, 5 h⁻¹, n₃ = 2, 5 h⁻¹

The evaluation of the perceived air quality during performance testing as a function of air exchange intensity using the odor intensity scale is shown in Figure 2. The highest satisfaction with the perceived air quality was achieved at the highest air exchange (n₃), when at the beginning of the testing process the abrasion intensity of 50% of the respondents was marked on the subjective scale of evaluation with the grade 0 - no odor and in the next two phases of sensory evaluation (D and F), this assessment has already been reported by an absolute majority of subjects. In performance testing under conditions with air exchange rate n₂, at the beginning of the evaluation process, the abrasion intensity was perceived by subjects as "1 - low odor" and at the end of the performance test as "0 - no odor". At the lowest air exchange (n₁), the intensity of the odor was indicated by the respondents in stage B on the subjective evaluation scale as “2 - moderate odor” and in the other two phases of sensory evaluation as “1 - poor odor”.

The perception of noise at the start of performance testing at all three air exchange intensities was rated '2 - poor' by respondents on the noise load scale. Also in all three cases, there was an increasing tendency in the perception of this environmental component between the phases of sensory evaluation - the slightest increase in tendency was at the lowest intensity of air exchange rate (n₁). The strongest increase in tendency was recorded at the highest intensity of air exchange (n₃) - almost 3(acceptable).
The assessment of the air acceptance during performance testing based on the air exchange intensity is shown in Figure 3. For all three air exchange intensities, air acceptance in all three phases of sensory evaluation of perceived environmental quality was always assessed by students on the negative side of the axis. In all three cases, the acceptability of air was assessed at the beginning of the testing process by respondents at a level of almost “0 - just unacceptable” with an increasing tendency between the various phases of sensory evaluation of perceived environmental quality. Respondents reported the lowest acceptance of air at the lowest air exchange rate ($n_1$), while the other two air exchange rates were very similar to the same.

Figure 2. Odor intensity by various levels of ventilation

Legend: no odor (0), slight odor (1), moderate odor (2), strong odor (3), very strong odor (4) and overwhelming odor (5).

Figure 3. Air acceptability by various levels of ventilation

Legend: clearly acceptable (+1) / just acceptable (0) and just unacceptable (0) / clearly unacceptable (-1).

The subjective performance evaluation was of a decreasing nature for all three air intensities between phases C and E. Almost equally, the subjective performance was perceived by the students during the evaluation processes performed at the air exchange intensity $n_2$ and $n_3$. 
No attention fluctuation was achieved in solving logical tasks for all three air exchange intensities (except for logical tasks in phase E). The highest fluctuation of attention was observed when solving the other two types of tasks, always with the lowest air exchange intensity (n1) (4, 5 - 10%). The highest inability to concentrate subjects was achieved when solving logical tasks at all three intensities of air exchange (about 3 to 6%). This indicator did not exceed the 1%% threshold for the other two types of tasks. A graphical solution of the average performance evaluation indicators for all three types of tasks depending on the air exchange intensity is shown in Figure 4 below.

**Figure 4. Performance and productivity by various levels of ventilation**

The highest overall performance was achieved in performance testing at the highest air exchange rate (n3), where the 98% threshold was exceeded in both test phases. Between phases C and E there was a slight decrease in overall performance (<0.5%). The success rate of the task ascertained by the overall performance at air exchange rate n2 was only 1% lower than the air exchange rate n3 in phase C and only 0.2% in phase E. In this case, the overall performance between the two phases of testing had a slightly increasing character (by 0.4%). Clearly, the lowest overall performance was achieved at the lowest air exchange rate (n1).

Correct performance at higher monitored air exchange intensities (n2 and n3) ranged from about 96 to 97.5%. In phase C, the correct performance was higher at the highest air exchange rate (n3) (97%), in phase E at the air exchange rate n2 (97, 5%). As with overall performance, the correct performance
was the lowest at the lowest air exchange rate \( (n_1) \), with a 93% success rate in Phase C. During the test process, the performance of air exchange \( n_1 \) and \( n_2 \) increased correctly (by about 2%) and at the rate of air exchange \( n_3 \), it decreased slightly (by 0.3%).

For the other two performance evaluation indicators, there were no large percentage differences (<0.7% -a) at air exchange intensities \( n_2 \) and \( n_3 \). The fluctuation of attention was almost three times higher when testing performance under the conditions of the lowest air exchange rate \( (n_1) \) compared to the other two air exchange rates (about 6.5%).

3. Conclusions
Increasing the intensity of the air exchange in all observed cases resulted in an increase in the objective and subjective performance of the respondents, an increase in their satisfaction with the perceived quality of the environment and a reduction in the incidence of SBS symptoms. The percentage differences in objective performance achieved at the air exchange rate \( n_2 \) 1.5 h\(^{-1}\) compared to the air exchange rate \( n_3 \) 2.5 h\(^{-1}\) were low (<1%), at the air exchange rate \( n_1 \) 0.5 h\(^{-1}\) compared to the air exchange rate \( n_2 \) 1.5 h\(^{-1}\), the objective performance was lower by about 3%. At the lowest air exchange rate \( (n_1) \), the lowest objective and subjective performance was achieved, almost always the lowest satisfaction with all components of perceived environmental quality.

Air quality affects productivity in offices. The performance of simulated office work is estimated to increase on average by 1.5% for every 10% decrease in the percentage of persons dissatisfied with the air quality. The overall performance of office tasks is estimated to increase by 1.9% for every two-fold increase in the ventilation rate at the constant pollution load or every two-fold decrease of the pollution load at a constant ventilation rate. The present data document, the economic benefits of providing indoor air of a higher quality, than the minimum prescribed by the present ventilation standards.

Although modern office buildings are equipped with an HVAC system, commercial and public buildings are still major sources of VOCs. What is more, the research has revealed that the levels of pollutants are much higher indoors than outdoors, in the vast atmospheric environment. When it comes to office buildings, factors such as working hours and the number of employees should be considered.

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